AVALANCHE OPERATION FOR ROAD PROTECTION IN GRØTFJORD, TROMSØ

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ABSTRACT: The Troms County Council (TCC) oversees a 2915 km road network, which includes measures to mitigate avalanches on exposed routes. Approximately 100 locations across the county are mapped where avalanches frequently impact roads. One of these locations is along County Road 7768 adjacent to the fjord Grøtfjord, where avalanches historically hit the road 1-2 times every year. Statistically, 78 % of these avalanches occurred when the road was open to traffic. The road is the only access route to Tromvik, a village with 144 inhabitants.

The road is threatened by several avalanche paths on the east face of Nonstinden, rising 700 m above the road. Following the county's cost-effective strategy for avalanche mitigation, 10 RACS towers, a PTZ and thermal camera, and a Doppler radar were installed, all operational since the winter season 2022/2023. These instruments, alongside daily avalanche forecasts, constitute the avalanche operation in Grøtfjord which is one of its kind for avalanche mitigation in Norway.

The avalanche forecast follows a structured workflow, resulting in assessments categorized as low, medium, or high mitigation levels. Medium and high levels prompt potential avalanche control missions and road closures, respectively.

The radar and cameras have been essential for studying snow cover, avalanche activity, and snow drift. Video footage of each avalanche provides experience and knowledge into avalanche paths and triggering conditions. During the polar night, these tools are crucial for registering avalanches and verifying control mission results. The Arctic Ocean's proximity brings polar lows, causing unpredictable heavy snow showers and strong winds, which are difficult to forecast. To meet this challenge, a dynamic approach is taken. When needed, forecasts can be issued both in the morning and in the afternoon, and occasionally control missions must be undertaken on short notice.

The two most important goals for the operation have been: no naturally released avalanches on open road and to ensure consistent road access, minimizing closures to only during control missions. Following two seasons of operation, no avalanches have hit the road while open.

KEYWORDS: Avalanche operation, RACS, Avalanche detection, Doppler radar, Avalanche forecasting.

INTRODUCTION

The Troms County Council manages a 2915 km road network, including measures to mitigate avalanches on exposed routes. County Road 7768 adjacent to the fjord *Grøtfjord* is one location where avalanches historically hit the road 1-2 times annually. In 2022, a mitigation operation was put in place, consisting of site specific avalanche forecast, RACS towers and surveillance. This article seeks to assess the performance over the past two seasons, with a particular focus on the benefits of integrating RACS towers with radar and PTZ camera.

1.1 Situation

Grøtfjord is a 4.5 km long fjord on Kvaløya, approx. 20 km from Tromsø city. County Road 7786 runs along the shoreline through the fjord, thus providing access from one side to the other. On each side of the fjord there are steep slopes where avalanches occur, most frequently at the west side where the road passes under a north-south orientated ridge up to 700 masl named Nonstind. The avalanche exposed part of the road is approximately 1.2 km long (see figure 1).

The road is the only access to Tromvik, a village with around 140 inhabitants, where fishing industry is the main livelihood. With the local school closed, pupils take a bus through the avalanche area to attend school. Grøtfjord is popular for outdoor sports and northern lights viewing, increasing tourist activity in recent years. The average daily traffic (ADT) is 300 (2023), with 12 % being heavy commercial vehicles (NPRA, 2024). Winter road reliability is crucial for the fishing industry and the safety of residents.

Grøtfjord is located at 70 degrees latitude, resulting in a polar night from November 28 to January 14.

1.2 Avalanche characteristics

There are several known avalanche paths on both sides of Grøtfjord. The west side has the highest avalanche frequency of impacting the road, making it the focus of mitigation efforts. In this area there are 5-6 known avalanche paths with release areas up to 650 masl. According to the *Norwegian national road database (*NVDB), these paths have a recurrence interval of 1.5, meaning avalanches hit the road 1-2 times annually (NPRA, 2024). The avalanche paths *Storraset* and *Nordst* (see figure 1) have the highest frequencies (0.26 and 1, respectively). Storraset, with a 400 m wide flank as release area, typically produces avalanches from crossloading events with S and SE winds. The release area of Nordst is a bowl where the whole bowl potentially can release at once, but more commonly avalanches occur in single chutes beneath and around rock outcrops. The lower part of the slope is vegetated with sparse forest (only 1-3 m high trees) up to about 150 masl, thus having an insignificant effect on stopping avalanches.

Statistically, 78 % of avalanches between 2016 and 2022 hit the road while it was open (NVDB). During the same period, the road was closed for an average of 43.5 hours each year due to the risk of avalanches or avalanche deposits on the road.

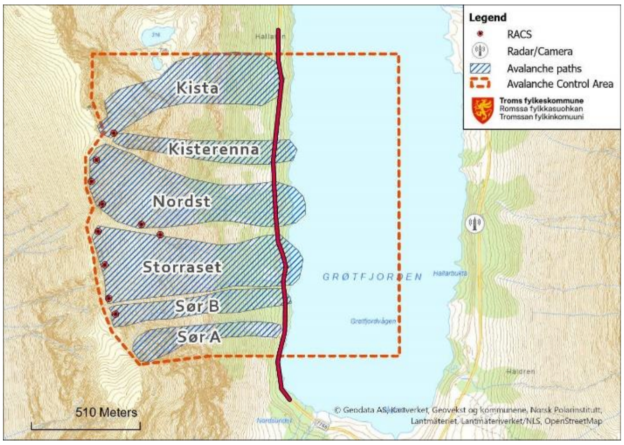

Figure 1: Map showing the Avalanche Control Area.

1.3 Mitigation history and strategy

Until 2022, mitigation efforts relied on observations and road closure recommendations from the contractor responsible for ploughing. Based on these recommendations, the department within the TCC takes the formal decision to close the road. Typically, the department has little or no local experience for each avalanche exposed road section and relies fully on the local contractor. This method is standard for avalanche-prone roads in Norway without additional mitigation measures. Consequently, the level of safety and regularity heavily depends on the individual skills, interest, and experience of each contractor, since there are no criteria concerning avalanche education in the contracts.

The County's Transportation Plan (RTP) outlines a 12-year avalanche mitigation program (2022-2033) using cost-effective measures like RACS, avalanche forecasting, and support structures. This strategy aims to secure more meters of avalanche exposed road than with other methods (tunnels, bridges, sheds) within the budget. Structural measures such as tunnels, bridges and sheds have been the traditional way of securing avalanche exposed roads in Norway. Initially, a 300 million NOK bridge (price estimated in 2015) over the fjord was planned for Grøtfjord, but it was replaced by RACS towers, cameras, and radar, operational by winter 22/23.

2. THE AVALANCHE OPERATION IN GRØTFJORD

The Grøtfjord avalanche operation is unique in Norway, combining RACS towers with radar and cameras. Internationally, it is notable for operating in Arctic conditions at 69 degrees latitude, with extended winter darkness.

2.1 Goals

Before the first winter with RACS towers, radar, and cameras, the following goals were set for the operation in this specific order:

- No natural avalanches on the open road
- Maintain road regularity with closures only during control missions
- Ensure that control-triggered avalanches don't damage the road and deposits can be cleared quickly
- Announce control missions at least 12 hours in advance to the public for predictability

2.2 RACS, radar and camera

Ten Wyssen towers are strategically placed on the mountainside to cover six avalanche paths (see chapter 2.2). Two of these towers are equipped with weather stations that record temperature and wind. These are powered with solar and wind electricity. One of the towers in *Nordst* is equipped with a camera showing parts of the release area.

The Doppler radar, located across the fjord about 1700 meters from the release areas (see figure 1), detects avalanches in real time and sends alarms via email and SMS. It registers avalanches from the uppermost release areas to the fjord, providing the following data in the data portal:

- Heatmap with start/stop location and outline (precision +/- 50 m horizontally and vertically)
- Estimated avalanche size (EAWS standard)
- Total run time [mm:ss]
- Maximum velocity along the radar's visibility line [m/s]
- Detonation from towers

The radar also detects vehicles entering and exiting the control area, and the number of vehicles inside the control area is displayed.

Two cameras are installed at the radar location: one PTZ (pan-tilt-zoom) camera and one thermal camera. These cameras can move between pre-set positions (e.g., release areas for each avalanche path) or be directed via PC control. The thermal camera records avalanches in the dark or under challenging light or weather conditions. Both cameras capture video footage of detected avalanches and take snapshots every three seconds during the avalanche runtime. A second PTZ camera was installed last season in order to manually direct one camera without disturbing the automatic video footage recorded by the other during control mission.

2.3 <u>Avalanche forecast</u>

Daily site-specific avalanche forecasts for Grøtfjord west are produced from November 15th to May 15th. The forecasting tool adheres to ISO9001 standards for risk mitigation (Langeland and Steinkogler, 2023) and incorporates recommendations for Site Specific Avalanche Warning published by EAWS. Each forecast follows a structured workflow, including:

- Weather observations from the two RACS towers and the Stor-Kjølen weather station (790 masl and 13 km east of Grøtfjord), all recording wind and temperature.
- New snow amount in Grøtfjord and precipitation measured at Tromsø Meteorological station (100 masl and 21 km southeast of Grøtfjord).
- Avalanche observations, typically visually confirmed radar detections.
- Snow cover observations using PTZ camera.
- Snow observations by a forecaster from nearby slopes with similar aspects and elevation.
- Snow profiles, weather, and avalanche data from the regional forecast service observation database RegObs.
- Information from local ploughtruck driver.
- The regional bulletin from varsom.no.
- Weather forecast for Nonstind (700 masl).

The forecaster evaluates the likelihood of avalanches ranging from sizes 1 to 5 for current avalanche problems. This assessment results in an OSARM matrix (Langeland et. Al 2018) with three mitigation levels; low, medium or high (see table 1). Control missions are considered at the medium level. High level means closed road, and control missions are executed. The mitigation levels in the matrix are tailored to the avalanche paths in Grøtfjord, where avalanche of sizes 3 and larger are expected to reach the road. For the case of size two avalanches, mitigation measures are also considered at higher likelihoods. This gives a wider margin of error in the operation. Furthermore, it captures the need to flush out persistent weak layers when stability is low, thus avoiding that these layers produce larger avalanches and more difficult mitigation later in the season.

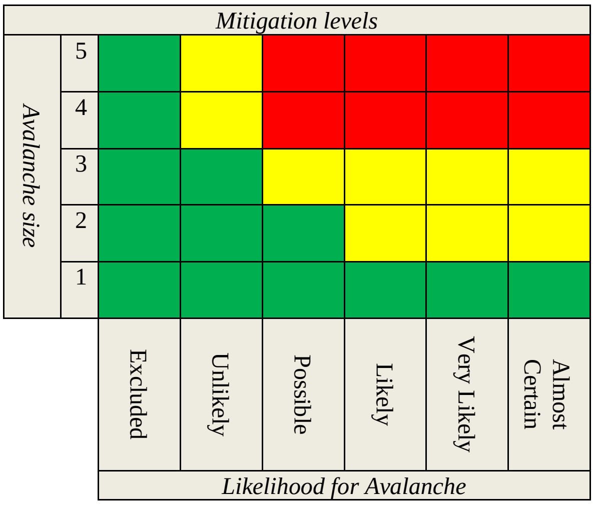

Figure 2: Matrix used in the forecast to determine mitigation level. Green, yellow and red colors mean low, medium and high mitigation levels, respectively.

3. RESULTS AFTER TWO YEARS OF OPERATION

Table 1 summarizes the results of control missions, avalanches and road closures over the two operational seasons.

Table 1: Results of control missions for two seasons

	Season 22/23	*Season 23/24*
Control missions	10	9
Detonations	89	80
RACS triggered avalanches [total/on road]	52/12	42/0
Naturally triggered avalanches [total/on road]	6/0	4/0
Road closure [hh:mm]	22:51*	5:35
Increased measure level [medium/high]	9/1	9/1

**Including 10 hours on March 31st, when the road was closed due to avalanche hazard at "Grøtfjordfjellet" (not a part of the controlled area).*

The data above show that the first three goals outlined in Chapter 3.1 were successfully achieved during the initial two seasons of operation. The last goal "Announce control missions at least 12 hours in advance for predictability" has not been achieved. In both seasons, there were several occasions where control missions and road closures were announced only 2-3 hours in advance.

4. OPERATIONAL LEARNINGS

4.1 <u>The tools</u>

The radar has been a valuable tool for verifying the results of control missions, especially in low-visibility conditions, such as darkness, fog or snowstorms. It detects small natural released slabs during snowstorms, which is important information for forecasters and in some cases used for timing control missions. The avalanche outline and heatmap together with video footage enhance documentation. It also serves as a precautionary measure to ensure the area is free for audience/animals before missions, in addition to a manual check by driving through the area. However, there have been some challenges with false alarms when the radar mistakenly identify sleet or snow showers as avalanches.

Video recordings of avalanches have significantly enhanced our comprehension of the avalanche site, including its paths and outflows. The cameras allow us to distinguish between solid debris and dust clouds, and in some cases ensure no deposits remain on the road after avalanches (both natural and RACS triggered). The zoom capability has proven invaluable for monitoring the snow cover's surface, helping us determine, for example, if the snow is loose or settled. For wet snow problems, we can observe small rolling snowballs. By taking daily snapshots in the same positions, we can compare snow cover and the size of cornices at the ridge over time.

We have observed overlapping coverage areas of some towers, particularly those located at Storraset and Nordst (6 towers). At the start of the first season, we frequently used all ten towers to ensure sufficient loading of the snowpack. However, we have since found that using groups or individual towers can be enough. Despite having three towers at Storraset, typically only one or two are necessary, with the choice depending on wind direction. The Kista tower has proven its effectiveness by frequently triggering avalanches in three gulleys with a single detonation. Darkness and little (turbulent) wind have caused power supply issues for weather stations and the camera on the RACS towers. These systems were occasionally put into a low-power state, especially during the first season. Operational experience has gradually decreased this problem over time.

4.2 Site knowledge and examples

Our experience from Grøtfjord shows that it takes time developing local knowledge about avalanche characteristics in specific paths. Here are some examples from Grøtfjord:

- Critical situations typically arise from cross-loading from SE to SW. Consequently, most naturally released avalanches occur nearest to the fetch. The avalanche paths *Sør A* and *Sør B* have most frequent avalanches, both naturally and artificially released (see figure 1). These avalanche paths rarely reach the road, and when they do, it's typically just the powder cloud. *Storraset*, however, releases less frequently but has a larger release area and a higher likelihood of reaching the road.
- Wind measurements show significant variations in both in direction and strength between Stor-Kjølen and the weather stations on the towers, with Stor-Kjølen generally experiencing stronger winds. The presence of the fjord and the steep topography create turbulent wind systems along the mountainside, making it challenging to predict wind loading into release areas.
- The Arctic Ocean's proximity brings polar low pressures. These cause unpredictable heavy snow showers and strong winds, which are difficult to forecast. Night to December 24th in 2022, an unexpected polar low hit Grøtfjord. The forecasted mitigation level was originally set to low, meaning no measures were planned. However, the radar unexpectedly started registering many small avalanches that night. The expected zero mm precipitation with a gentle breeze turned into 20 mm precipitation accompanied by gale-force winds. Consequently, a control mission was performed at short notice the next day (Christmas Eve), releasing six avalanches, none with terminus to the road.

4.3 Experience with forecasting

Using a structured workflow forecast for an avalanche operation aimed at avalanche risk mitigation for a road has not been standard practice in Norway. One of the main advantages of this approach is that it reduces subjectivity in decision-making.

In our opinion, local experience is crucial for successful avalanche forecasting. It is not an academic exercise, as creating a checklist that covers every potential scenario and outcome is impractical. Nevertheless, by documenting all avalanches and forecasts for the site, this local expertise can be transferred and potentially integrated into the forecast structure, including elements like threshold values.

The Christmas Eve example, among others, has demonstrated the benefits of issuing forecasts with shorter validity periods than the standard 24 hours. During the 23/24 season, a more dynamic approach was tested, where the validity of the forecast was determined individually. In uncertain weather conditions, the forecast validity was reduced to 12 hours or even less. This resulted in more frequent and accurate forecasts, reducing the number of control missions while maintaining road safety. This approach also minimized or eliminated the need for ad hoc assessments and/or cancelled avalanche controls, providing better predictability for both the operational organization and road users.

During periods of stable weather or shoulder season, the dynamic approach is reversed by extending forecasts up to 4 days. This allows for resource allocation to be focused on critical times, while still maintaining a baseline understanding of snowpack conditions.

5. CONCLUSION AND OUTLOOK

Over two years of operation, no avalanches have hit the road while it was open. Closure times decreased by 47 % in the first season and 87 % in the second season. Road closure announcements were typically made the day before, though there were occasions of sudden closures. We believe that continuing with the dynamic approach can further minimize the sudden road closures in the upcoming seasons. Additionally, the forecasting team's experience level is increasing with each season.

The operation in Grøtfjord has demonstrated that securing roads with unconventional methods, particularly in a Norwegian context, is both feasible and effective even in the far north. We believe that the investment in radar and camera technology in addition to RACS towers is justified given the unique site conditions in Grøtfjord. These tools provide valuable data on avalanche characteristics, snowpack, and area monitoring. However, it remains essential to venture into the terrain to assess snow conditions and stability firsthand, ensuring that theoretical models align with practical observations.

Until now, the forecaster has overseen control missions on-site. Next season, we will trial procedures for remote avalanche control missions, with the contractor assuming primary on-site responsibility. The forecaster will supervise the operation remotely using the cameras, radar, and telephone.

TCC have plans of establishing similar operations for several other avalanche exposed road sections in the future. This summer and autumn (2024) a system consisting of 24 RACS towers (O'bellx+), two Doppler radars and four cameras (two PTZ and two thermal) are being installed at Arnøya, an avalanche exposed island north in the county. This system will be operational with avalanche forecasting for the upcoming season.

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