FORTY YEARS WITH AVALANCHE DETECTION SYSTEMS IN NORWAY

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ABSTRACT: As part of public strategies for the protection of Norwegian roads against avalanches, automatic avalanche monitoring for spontaneous road closure and opening has become an increasingly important and well-known method. During 1980s, analogue geophone systems were put into use. These resulted in effective closure of a handful of roads if avalanches released in order to evacuate before a potential accident. There was, however, no online connection to the facilities, and the roads could remain closed for several hours, even if the avalanches did not reach down to the road. Moreover, manual visits were necessary to verify whether avalanches had hit the roads. From the mid-2010s, however, major changes took place. The geo-phone systems faced competition from doppler radar, infrasonic measurements, and ground-based radar in-terferometry. The systems also became digitally available through user-friendly dashboard login. It was now possible to connect to camera systems for verification and to log in via remote access to inspect road traffic, avalanche crowns and run-out zones. Manual visits became less necessary.

In recent years, automatic reopening after avalanche events has been introduced. This can happen both if avalanches have too short run-out lengths to pose any threat to roads, and if automatic post-processing of an event reveals that the detection was a false alarm (e.g. weather events). Experiments are also currently being carried out with the use of distributed acoustic sensing (DAS) in fiber optic cables on the roadside.

This article attempts to summarize the experiences from more than 40 years with detection systems in Norway.

KEYWORDS: avalanche detection, monitoring, geophones, radar, Norway

1. INTRODUCTION

Ever since the Norwegian road construction gained momentum in the mid-20th century, the public road network has been exposed to avalanches and other natural hazards. Traditionally, protection against avalanches has been carried out with the help of tunnels and terrain measures (e.g. breaking mounds and deflection dams), as well as physical protection structures such as avalanche galleries, corrugated steel pipes and retaining fences.

However, already from 1974 work has been done to find alternative protection methods against avalanches. The Snow Committee was then established within the Norwegian Public Roads Administration (hereafter abbreviated NPRA). This committee was effective until 1982 (Norem, 1984). Their task was, among other things, to change the road authorities' strategy to a more proactive approach. From now on, research on how the avalanche danger developed from day to day was requested. The focus increased on how to take care of the safety of both road users and road contractors. Consequently, NPRA wanted to develop decision criteria for when it was necessary to close roads preventively and when it was safe enough to clear and open roads after avalanche cycles. This new strategy led to the introduction of both preventive release of snow avalanches using explosives and testing of avalanche detection using geophones (Norem, 1984).

From that time and until today, the technology that has been used to monitor avalanches, avalanche danger and avalanche impact on Norwegian roads mainly consists of geophones (from 1981), doppler radar (from 2014), infrasound sensors (from 2014), ground based InSAR (from 2016), live visual monitoring with the help of online camera systems (from 2017) and distributed acoustic sensing (from 2021). It is fair to mention that in addition to avalanches, some detection systems also take care of debris floods, landslides and rockfalls. However, the avalanche detection is in focus in this article.

This article attempts to summarize the experiences from more than 40 years with detection systems in Norway. This comprises more than 50 contracts with less than ten providers of avalanche monitoring systems at 23 locations (26 if we include rockfalls and landslides and 29 if we include projects that will start within next season). Find the most relevant locations in Figure 1). The different detection concepts tried

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out over the years will refer different parts of a flowchart in the appendix (Figure *6*).

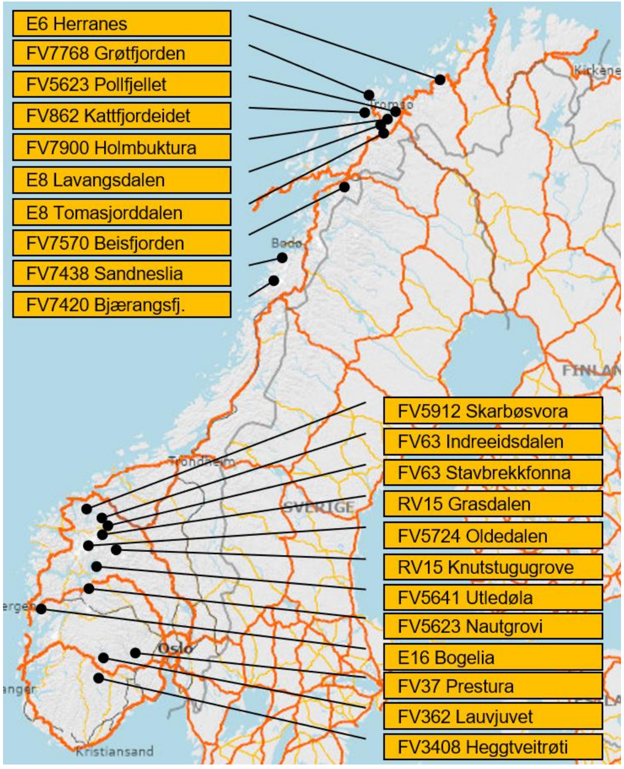

Figure 1: The most relevant locations described in this article. 'FV', 'RV' and 'E' stand for county roads (*fylkesveg*), national roads (*riksveg*) and European roads, respectively.

2. DEVELOPMENT STEPS

2.1 *Automated road closures using geohones*

The first detection system that was established in Norway monitored the *Lauvjuvet* avalanche path on county road FV362 in Vinje (see Figure *1*). This was established in 1981 after design by Norem (pers. comm., 2024) and manufactured in collaboration with Eidsvold Electronics AS (EIDEL) and the Norwegian Geotechnical Institute (NGI). The system was chosen after inspiration from geophone testing in Rogers Pass, Canada, a few years earlier (see Salway 1978; Shearer and Salway 1980).

This first-generation detection system aimed to close the road automatically when the geophones detected ground vibrations that exceeded a certain threshold value. This requested for careful tuning of the sensitivity of the geophones. At this time, there was no ambition to let the system take care of the re-opening of the roads.

The system had a local set-up, and detected signals were sent through cables to a local traffic signal system that ensured automatic road closure. The system would not know if the avalanche reached the road. The regional traffic control center was notified, and a contractor was sent to the site for inspection and manual resetting of the system (Figure *2*). There was no camera monitoring or remote access that could facilitate decision making from afar. Still, the system worked well according to the expectations of that time. Several similar installations were therefore installed over the next twenty years (Håland, 2013) in the avalanche paths of *Skarbøsvora* in 1985, *Knutstugugrove* in 1993, *Fossåna* in 1994, *Heggtveitrøti* and Prestura in 1995, *Sandneslia* in 1996, *Tomasjorddalen* in 2000 and *Herranes* in 2001.

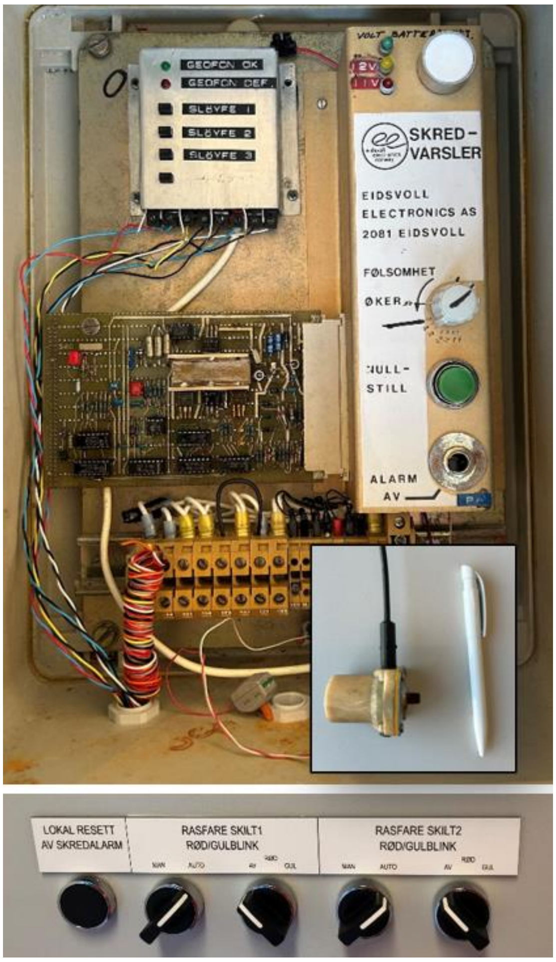

Figure 2: Example of technical cabinet for geophones used in Lauvjuvet (1981-2017, upper panel) and local reset panel used in Heggtveitrøti (1995-2022, lower panel). Photo: Audun Langelid.

2.2 *Digitalization and new methods to close roads*

From the mid-2010s major changes took place. Several test projects started in collaboration with new companies and institutes (see details in section for acknowledgement). Modern industrial field laptops, new sensors, connection to Internet and digitalized data flow allowed for running advanced onsite analyze software, accessing data remotely and verifying events using live digital PTZ cameras and event recording, with both optical and thermal video.

In fact, most results an even raw data, photos and videos could be analyzed together with detection data when logging on to the provider's user-friendly dashboards. Both avalanche crowns and run-out zones could be studied as well as the traffic situation on the road, if the visibility was good. Manual on-site visits thus became less necessary. This way, one could with some luck, from the office decide if the detection was caused by a real avalanche and if it had hit the road or not.

In the same period, geophone systems established between 1981 and 2001 faced competition from doppler radars: The first ones were first installed in *Knutstugugrove* and *Utledøla* in 2014 (see Figure *3*). In the following years, new radars were in installed in *Sandneslia*, *Holmbuktura* and *Bogelia* in 2017.

Figure 3: Radar installed at Utledøla (2014-2021). Photo: Vegard Bondevik Lie, NPRA. The road is from 2020 administrated by Vestland county.

Even the old analogue geophone systems changed at this time, as wireless communication and digitalized data flow replaced old and vulnerable cable transmission (Kvistedal, 2016). This technology was first introduced in *Sandeslia* in 2015, and again in *Lauvjuvet* in 2017, *Prestura* in 2018 and in *Nautgrovi* in 2020.

In the flowchart in the appendix (Figure 6), all systems that aimed to close roads but not re-open them (as described in section 2.1 and 2.2) are schematically presented under monitoring 'avalanche release detection' (box A2).

2.3 Automated alerts based on danger signs

In addition to monitoring avalanches with the purpose of automatically closing roads, some projects were started solely to monitor avalanche activity and other danger signs to enhance site specific avalanche evaluation, not to close roads.

For instance, infrasound detection of avalanches was tested and later operationalized in *Grasdalen* and *Indreeidsdalen* from 2014, in *Kattfjordeidet* from 2016 and in *Lavangsdalen* from 2018. Data from these sites have been used to automatically notify forecasting services and road operators about ongoing avalanche cycles, increasing their awareness about the danger at their interest area. The methodology and its results are further described by Humstad et al. (2016 and 2021) and Steinkogler et al. (2018).

At the winter-closed road under the avalanche path *Stavbrekkfonna*, ground based InSAR detection has been used to monitor the glide acceleration of wet snow prior to glide avalanches in springtime. Road operators are notified if the acceleration exceeds a threshold value where the avalanche is expected to be released at any time. Here, automatic closure is not a relevant issue since summer-opening is waiting for the avalanches to release first. But the monitoring allows the road operators to start preparing the road for opening, when the acceleration is low, several weeks before they could before this warning system was operationalized in 2019 (and tested from 2016). This method is further described by Skrede et al. (2016) and evaluated by Humstad et al. (2018).

In recent years distributed acoustic sensing (DAS) with the help of fiber optic cables and interrogators have been tested to see if they could detect avalanche runouts on roads or close to roads, for instance in *Holmbuktura* from 2021 (Krogh et al., 2024) and *Grasdalen* from 2022.Other applications of DAS are described in section 2.7.

In the flowchart in the appendix (Figure 6), the application of danger sign detection is represented by box A1.

2.4 Automated re-opening of roads

When doppler radar was introduced as an avalanche detection method in 2014 and the results became accessible in online dashboards and video recordings, this question quickly arose: Since we can follow an avalanche from start to stop in near real-time, why should we not introduce automatic road re-opening when an avalanche is detected to have stopped in safe distance to the road? Hence the road authorities started a dialog with relevant radar providers and introduced a concept for regions of interest (ROI) and danger zones (DZ), see example in Figure *4*.

If avalanches start within the ROI and stop above the DZ, one could accept automatic re-opening. If avalanches on the other hand enter the DZ, they are believed to stop on the road or dangerously close to the road. Then automated re-opening is out of the question and manual inspection is necessary before opening is acceptable.

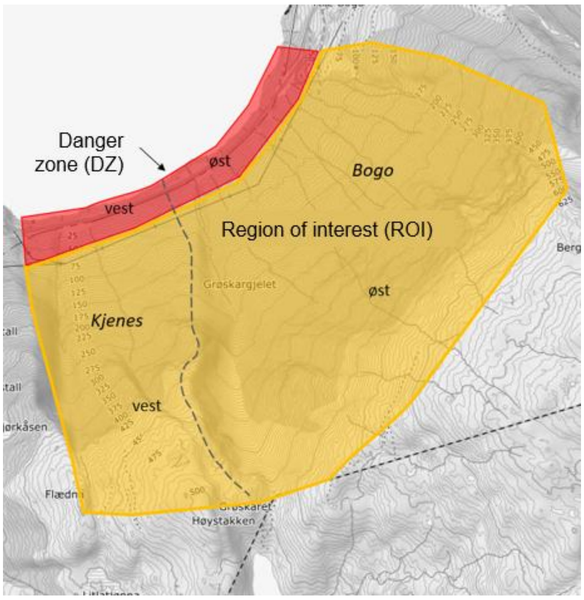

Figure 4: Example of region of interest (ROI) and danger sone (DZ) in Bogelia (from Humstad and Frekhaug, 2022)

This kind of approach was introduced in *Holmbuktura* from 2019, in *Knutstugugrove* from 2020, in *Bjærangsfjorden* from 2021, in *Utledøla* from 2022 and in *Bogelia* from 2023. In 2020, the road administration responsibility in Norway was split between NPRA and new-established county road administrations, and several counties took part in this new step.

Before this re-opening approach was introduced, even small avalanches that stopped 200 m or so from the road could close the road for more than two hours, even in good visibility, because of uncertainty and overcommitment from personnel involved (Humstad and Frekhaug, 2022). From now on, the same event would give a closure time of less than a few minutes.

In the flowchart in the appendix (Figure 6), all systems that aims to close roads and also re-open them if acceptable are schematically presented under monitoring 'avalanche release detection' (box A2) combined with 'avalanche run-out detection (box A3).

2.5 Detection to support avalanche control

Detection systems could also be used to support active avalanche control through detection of both naturally released avalanches and avalanches released by explosives. This has been done in *Grøtfjorden* from 2021 (Krogh et al., 2024).

2.6 False alarm re-interpretation

Prior to a new procurement process for *Bogelia*, studies of both Bogelia and other locations showed that a great proportion of radar detections (often more than 50 %) was caused by weather events and not avalanches (Humstad and Frekhaug, 2022). This could happen if for instance a cloud of precipitation particles with a certain extent and speed moved towards the radar, similar to suspended particles in an avalanche powder cloud. A dialog was again initiated between the road owners and the industry, to see if it was possible to start automated re-interpretations of already detected events. The aim was to find out if an event that first was interpreted as a large avalanche in realty could not be an avalanche, because of properties such as too long duration, too large height above the ground or unrealistic lateral propagation.

A functionality that carries out this re-interpretation and sends a re-opening signal, if a detected avalanche proves to be a false alarm caused by weather, was introduced in *Bogelia* from 2023 and in *Oldedalen* from 2024. A weather event will still close the road, but instead of 15 to 60 minutes closure and manual evaluation, a road will now be reopened after one to five minutes (Humstad and Frekhaug, 2022).

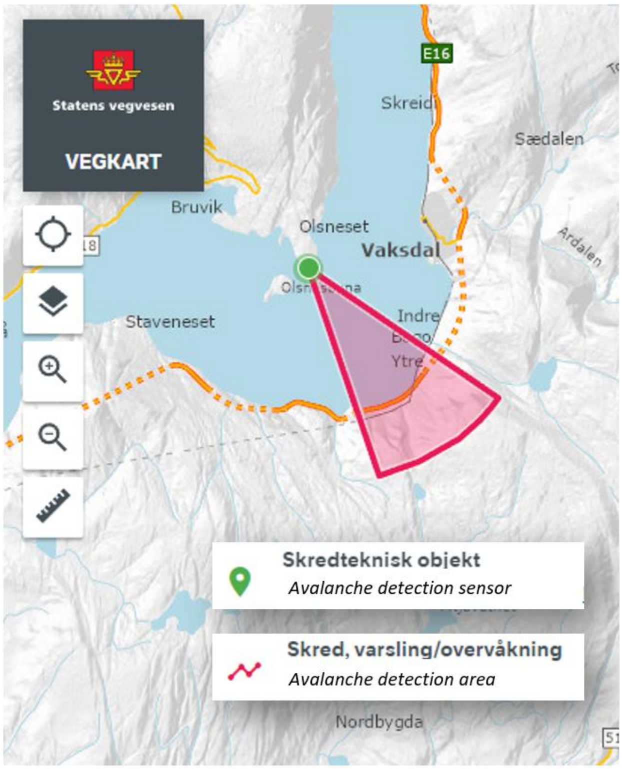

Figure 5: Map presentation of the Bogelia avalanche area above road E16, ripped from vegkart.no, showing the radar position and the radar coverage area. You could find all active detection systems at this website, using the search phrases on the figure.

In the flowchart in the appendix (Figure 6), the systems that aims to close roads, re-open them if acceptable and in addition run this false alarm analysis, are schematically presented under box A2 combined with both box A3 and A4.

2.7 Traffic detection

We also want to mention that different types of traffic detection are used to enhance the whole decision process after avalanches on roads. In *Holmbuktura* there are three different technologies in use, namely inductive-loop traffic detectors, detection algorithms on the avalanche radar dataset and DAS technology using fiber optic cables (Turquet et al., 2024).

In *Grøtfjorden*, from 2021, radar data is used to detect vehicles. In new projects on Arnøya (*Singla* and *Oterelvane*) from which are planned to start 2024/2025, the county plans to use the avalanche radar to detect both vehicles on the road and vessels on the fjord below the slope.

3. EXTENDED OBJECTIVE

During planning of the second radar project for *Bogelia*, NPRA realized that they had to extend their objective for the avalanche detection systems. Traditionally, the focus had been to prevent avalanches to *hit vehicles* on the road, and to prevent vehicles from *driving into avalanche debris* on the road. Through studies of the first project period (2017-2023) and planning of the next phase (2023-2035), Humstad and Frekhaug (2022) pointed out the following challenges: There were too many false alarms because of weather events, and too many unnecessary callouts and with too many people involved to inspect even trivial and harmless events. One could almost say, that in some cases, it would be better not to know about all the events since they should not require much action. Also, there were too many occasions where the road user did not respect the red blinking traffic signals that were lit because of detected avalanches. In fact, this led to illegal driving on temporary closed roads. This problem is also unveiled by Jenssen and Moscoso (2021). They describe that some road users misinterpret a red blinking stop-light to indicate that there is an error on the signal system itself.

To work systematically to meet these challenges, a new set of objectives for avalanche detections in NPRA was formulated and used from 2023:

1. Prevent road users and vehicles from being hit by avalanches.
2. Prevent vehicles from driving into avalanche deposits on the road.
3. Prevent illegal driving on closed roads.
4. Establish a known pattern of action for all involved in the event of an avalanche.
5. Facilitate quality control and development in the operational phase.
6. Share avalanche-related information with emergency services and forecasting services through varsom.no.

4. DISCUSSION

Based on experiences from all the detection systems used for more than 40 years, and from the new objectives, several discussions and research projects could be initiated.

Examples on questions that should be asked are: How precise is the detection? How could the number of false alarms be further reduced? In which avalanche paths should detection system be a preferred solution? How is the cost-benefit picture? How many systems could an organization manage to organize and operate? How is the environmental footprint compared to traditional methods? How could the road users' respect for signals that closes roads be increased? Would it help with more specific information on digital message signs informing them about the event and the expected waiting time? And does the procurement process and contract form facilitate innovation and technical advances?

Moreover, the increasing number of active systems collects many well documented avalanches in terms of timing, speed, volume, and run-out length. Could all these data be used in research to learn more about the avalanche dynamics on the site?

5. CONCLUSION

This article indicates that a variety of detection systems has proved to be useful to protect road traffic for many years. Modern technology has facilitated gradual and stepwise advances in the monitoring strategies.

These methods do comprise a relevant alternative for avalanche mitigation in some areas, and it is a strength that they often cost less than large protection structures.

Some weaknesses that must be addressed are the number of false alarms that still is not neglectable, which also influence the publics' confidence to the systems. In addition, avalanches will still block the roads.

All the detections made over the years add up to thousands of incidents that could teach us something about avalanches and effects of avalanche protection, both locally in each avalanche path and as a general academic and professional topic.

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APPENDIX: AVALANCHE MONITORING CONCEPTS

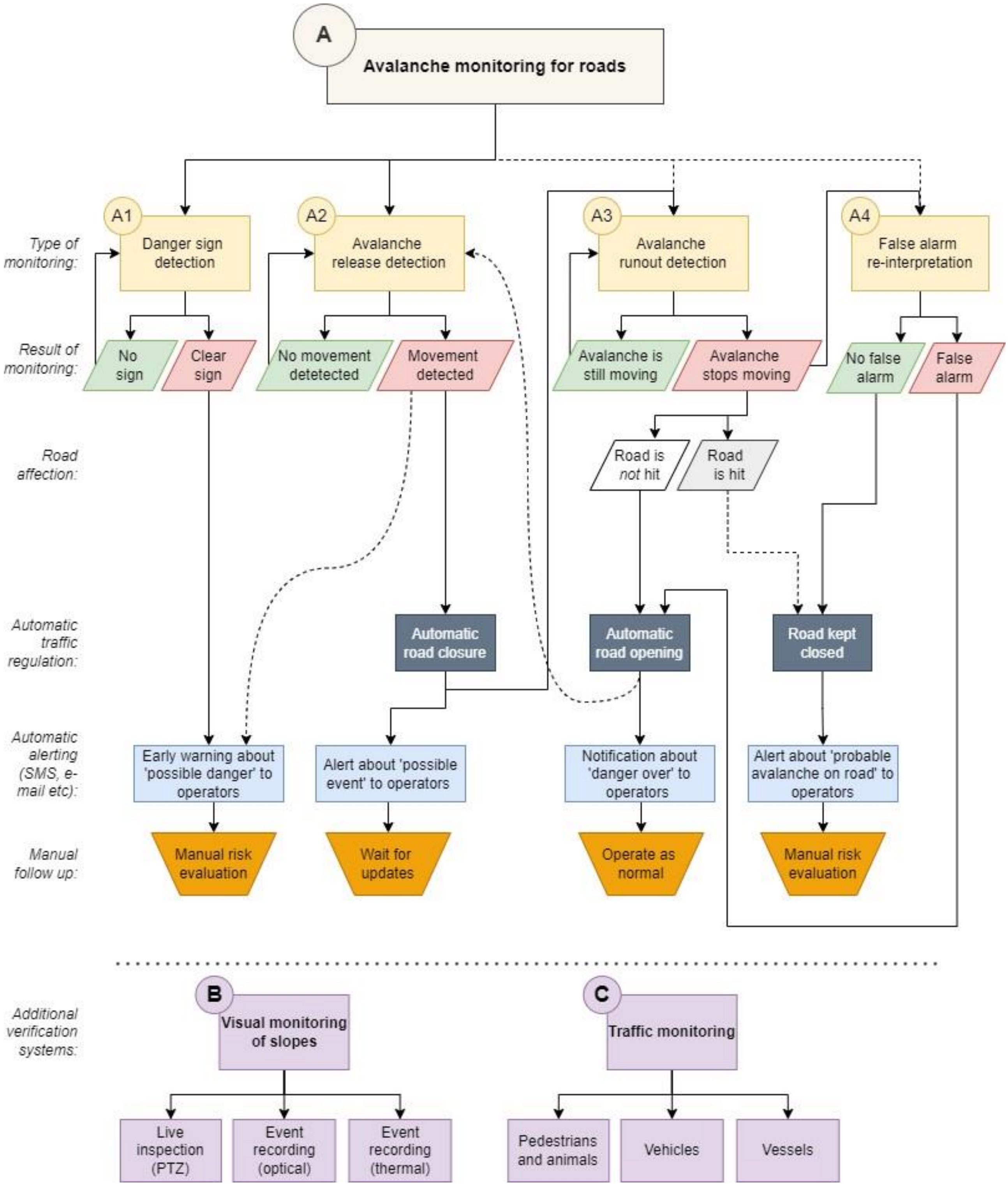

Figure 6: Flowchart describing different detection concepts. As examples, systems with automated road closures correspond to box A2, whereas automated re-opening happens if box A3 is added. Systems with automated false alarm re-interpretation are represented by box A4.