MANAGING MOUNTAIN PASSES EXPOSED TO AVALANCHES

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ABSTRACT

Managing mountain passes exposed to avalanches is of great concern both for the Norwegian Public Roads Administration (NPRA) and the contractors in mountainous areas. One of the main transport corridors in Norway along the E136 trunk road in Romsdalen is an example of a road that is subject to road closures every winter due to avalanches that are already triggered, or due to the risk of avalanches being considered too high to let the traffic pass through.

This paper presents the occurrences in Romsdalen in March 2010 during what is referred to as the "avalanche week". Many avalanches were triggered during this week, and in addition there were large landslides that caused extensive closures on the road network in the county. The E136 was closed to traffic for four consecutive nights. On the morning of the fifth day the situation was considered to be have sufficiently normalized for the closure restrictions to be lifted.

The experience from the "avalanche week" raises several issues. Every night the road closure resulted in an accumulation of approximately 120 trailer trucks on each side of the road blocks and in addition many passenger cars were affected. The company's economic losses are large during such events and represent a sum of traffic impacts consisting of several components. The paper addresses the different consequences and discusses strategies for avalanche control.

1. INTRODUCTION

Managing mountain passes exposed to avalanches is a great concern both for the Norwegian Public Roads Administration (NPRA) and the contractors in mountainous areas. One of the main transport corridors in Norway, which passes through the area along the E136 trunk road in Romsdalen, is an example of a road exposed to road closures every winter due to avalanches that are already triggered or due to the risk of avalanches being considered too high to let the traffic pass through. A weather incident on 15–19 March 2010 in the western part of mid-Norway illustrates different aspects of managing mountain passes exposed to avalanches.

The period 15–19 March 2010 is referred to as the "avalanche week". An avalanche occurs when weaker snowpack layers cannot support the layers of snow above, and the snow conditions were of that nature over a wide area that particular week. Many avalanches were triggered, and in addition there was a substantial risk of avalanches that caused extensive closures on the road network in the county. The E136 was closed to traffic on four consecutive nights. On the morning of the fifth day the situation was considered to be sufficiently normalized for the closure restrictions to be lifted.

The experience from the “avalanche week” raises several issues. Every night the road closure resulted in an accumulation of approximately 120 trailer trucks on each side of the road blocks and in addition many passenger cars were affected. The company's economic losses are large and represent a sum of traffic impacts consisting of several components. The paper addresses the different consequences and discusses strategies for avalanche control in light of experience from Norway and of routines used for avalanche control in the USA.

2. CASE: AVALANCHE WEEK

2.1. Information strategy

The storm event in the “avalanche week” was forecast by the Meteorological Institute and a meeting was held on 12 March to review the routines and responsibilities for all parties involved.

The meeting also concluded on an information strategy. The strategy was to inform often and with simple messages using local radio stations. Possible night closures were advised before 1 p.m. each day.

Representatives of the road owner were available to the media almost around the clock.

2.2. Description of the incident

14–19 March 2010 was a period of severe weather in Møre og Romsdal, and the weather incidents that hit most of the county caused this period to be named the "avalanche week". There were many avalanches during this particular week of March, and in addition the substantial avalanche risk in a wide area resulted in extensive closures on the road network in the county. Both trunk roads and minor roads were affected.

Based on the weather situation on Monday 15 March the road owner, in consultation with geological experts and the contractor decided that it was necessary to initiate closure of the following sections of trunk roads in the county, see Figure 1:

- E136, Bjorli - Sogge bridge
- E136, Måndalen - Våge
- E39, Ørskogfjellet

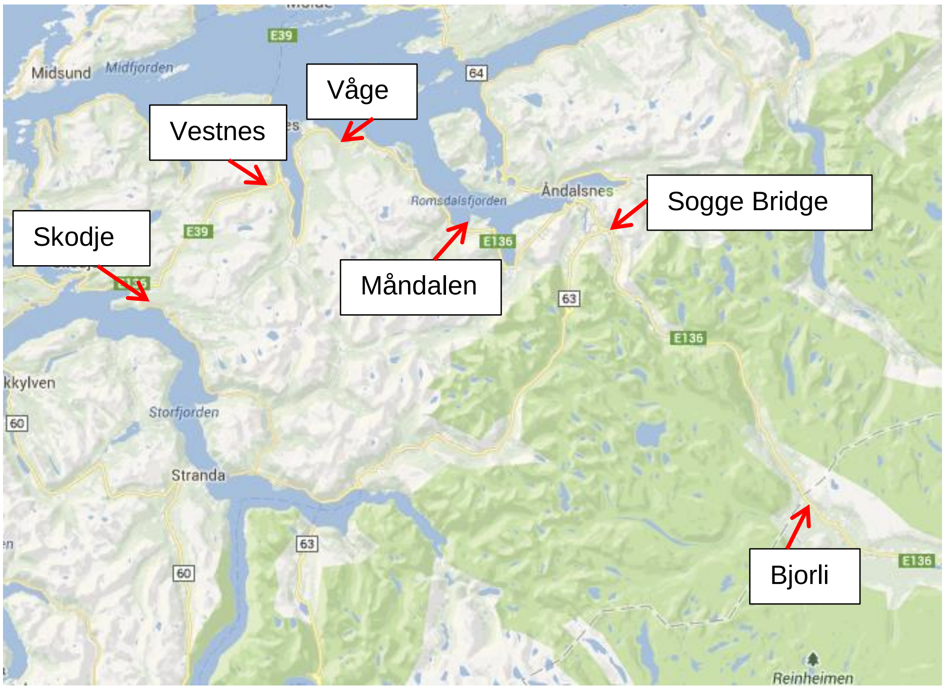

Figure 1 – Road closures on E136/E39 due to risk of avalanches

The E136 was closed to traffic at around 8 p.m. on Monday 15 March, following an assessment that the danger of avalanches in Romsdalen was so great that it was considered unacceptable to allow traffic to proceed as normal. The closure was effectuated by closing the road at Bjorli, Sogge Bridge, Måndalen, Våge, Vestnes and Skodje. Notice of the road closures in Romsdal was through activation of road signs at Dombås and Bjorli from the east, see Figure 2 and Figure 3, and from the west by Sogge Bridge.

Figure 2 – E136 closed in Romsdalen

Figure 3 – Road closure on E136 at Bjorli

Figure 4 – Manually operated closure at Bjorli

The closures at Bjorli (540 metres above sea level) and Sogge bridge (50 metres above sea level) were manually operated, see Figure 1. The other closures were implemented using only signs as shown in Figure 5. The picture in Figure 5 is from Måndalen, indicating that the road is closed and a trailer can be seen waiting. One of the challenges of using only signs is to maintain respect for the signs during a long period of closure, and some road users ignored the signs.

Figure 5 – Road closure on E136 at Måndalen – “Road closed 200 metres ahead”

The local people on road sections affected by the road closures had to make their own assessments of the risk of driving between locations on closed sections.

The closure resulted in an accumulation of trailers and by 10 a.m. on 16 March it had reached a number of about 120 trailer trucks on each side of the road blocks: see an example from the parking lot at Bjorli in Figure 6. The picture is taken on the evening of Tuesday 16 March.

Figure 6 – Some of the trailer trucks waiting at Bjorli

Although the weather and snow situation still indicated that there was a danger of avalanches, it was decided early in the afternoon of 16 March to allow the vehicles that were waiting to pass through the valley. This was done by sending a vehicle every minute in one direction at a time. Personnel were placed as observation posts at strategic points to survey the situation and in case of avalanche to warn the personnel responsible for the "convoy".

After releasing the halted vehicles, the road was blocked again, and it was decided to make a new assessment of the situation on the morning of Wednesday 17 March. Overall, the night closure lasted for four days and only on the morning of 19 March was the situation considered to be sufficiently normalized for the closure restrictions to be lifted.

2.3. Traffic impact

The traffic impact consisted of several components:

- Loss of traffic
- Delays
- Detour via longer routes

Bypasses or detours will often be a consideration the driver has to assess in relation to the duration of the closure. Detours can be a complicating factor where the driver must find an appropriate alternative, and may also have a negative traffic safety impact if the new route is longer and perhaps of a poorer standard.

Traffic counts on the E136 show that as many as 130 foreign trailer trucks drive through Romsdalen on weekdays. This corresponds to 30 per cent of heavy traffic. It is difficult to impart information to foreign drivers through the media, and foreign drivers in general will be insufficiently informed about road closures and will make up a large proportion of those who are stationary waiting for the road to be opened. In addition to the delays, the situation is not satisfactory for the drivers from a service point of view since the closure points are not normally provided with the necessary facilities.

Figure 7 and Figure **8** show the variation in total traffic volume and the number of trailer trucks at Horgheim between Bjorli and Sogge Bridge from 15–19 March.

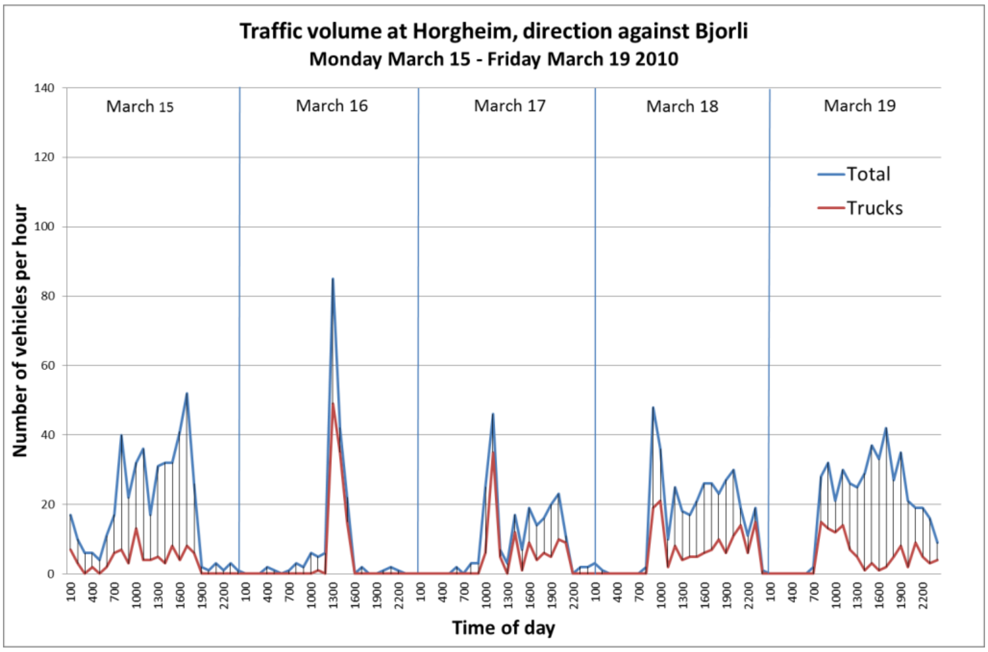

Figure 7 – Traffic volume at Horgheim, direction towards Bjorli, Monday 15 March – Friday 19 March 2010

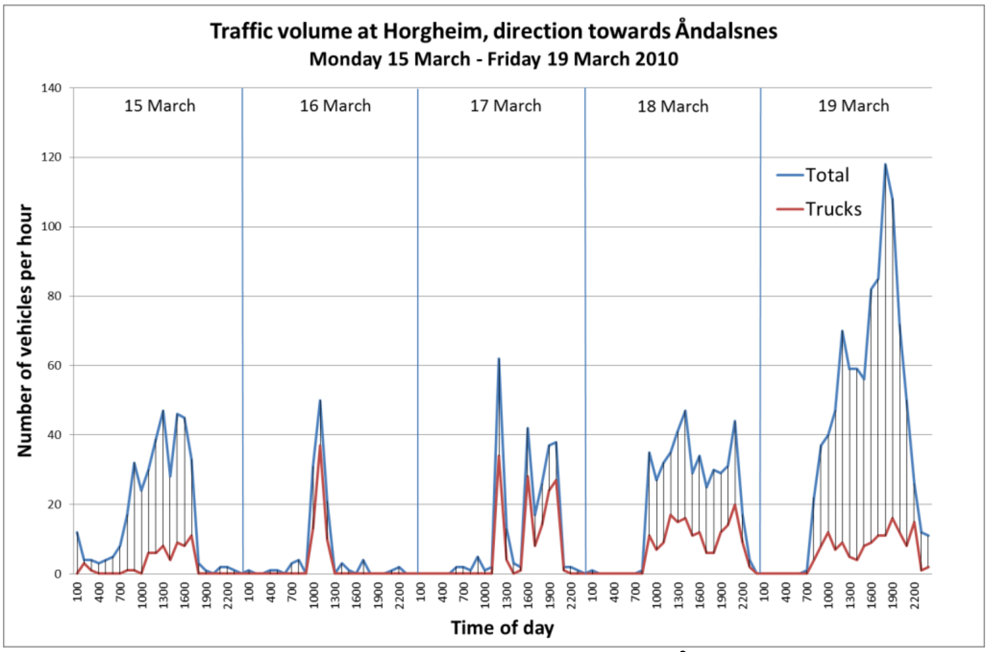

Figure 8 – Traffic volume at Horgheim, direction towards Åndalsnes, Monday 15 March – Friday 19 March 2010

It can be seen that the most stringent restrictions were implemented on Tuesday 16 March, allowing for traffic only between noon and 3 p.m. Romsdalen was closed to traffic again on the night of Wednesday 17, Thursday 18 and Friday 19 March with slightly varying opening hours in daytime.

Figure 9 shows the daily traffic volume in the avalanche week compared to the previous week, which was categorized as an “ordinary week”. Table 1 shows the daily change in traffic and for the avalanche week as a total.

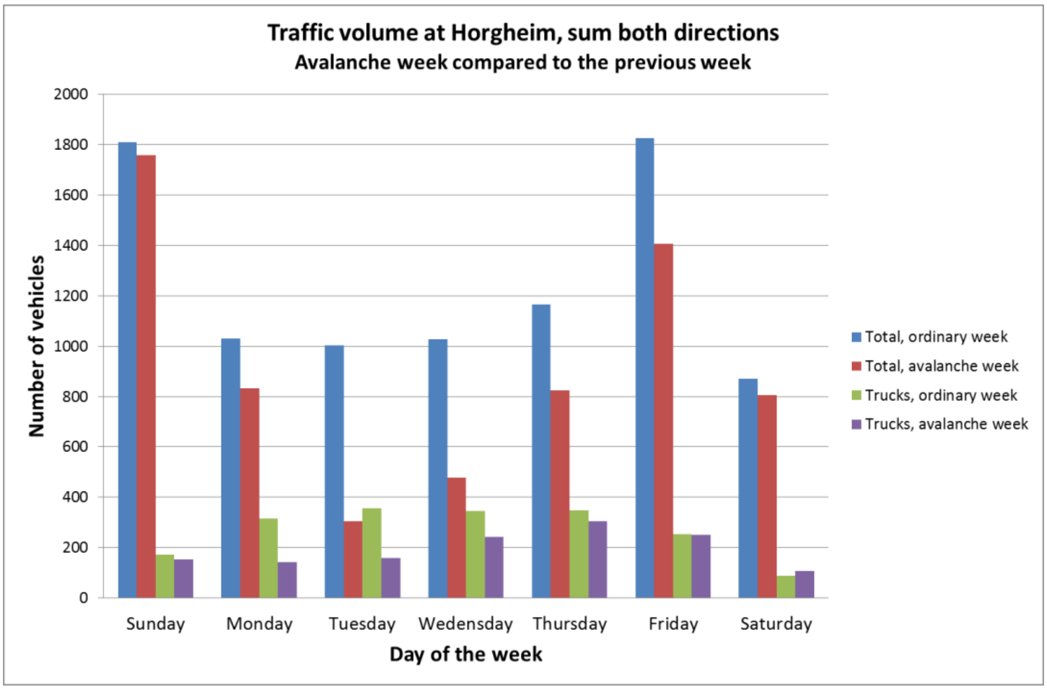

Figure 9 – Traffic volume at Horgheim, sum both directions, avalanche week compared to the previous week

Figure 9 illustrates that the greatest total traffic reduction was on Tuesday 16 March with the most extensive restrictions. It can also be seen that the variation in total traffic differs from the variation for trucks. The heavy traffic was affected earlier but also normalized earlier than the total traffic.

Table 1 – Daily change in traffic volume in the avalanche week compared to the previous week

	Difference between avalanche week and the previous week	
Day of week	Total traffic	Trucks
Sunday	-3%	-10%
Monday	-19%	-55%
Tuesday	-70%	-55%
Wednesday	-53%	-30%
Thursday	-29%	-12%
Friday	-23%	-1%
Saturday	-8%	21%
Total for the week	-27%	-27%

From Table 1 it can be seen that the reduction in both total traffic and trailer trucks was 27% in the avalanche week compared to the previous week. From these figures it can be concluded that in addition to the delays, there was a loss of traffic and detours to other routes. However, it is not possible from available data to conclude on the split between those two options.

3. EXPERIENCE FROM THE AVALANCHE WEEK IN ROMSDALEN

3.1. Operational issues

The observations that were made during the period 16–19 March 2010 clearly illustrated what appears to be the most important issue in terms of maintaining the traffic capacity on roads during challenging weather conditions. The avalanche situation that occurred during the snowstorm and the fact of dealing with this situation overshadowed the effort to keep the road open in technical terms. Keeping the road open will mainly be a question of having enough snow removal equipment to put into operation. While the road was closed one could also possibly envisage that due to safety concerns for the operating personnel it might be necessary to stop snow-clearing on the most exposed avalanche areas. Reopening of the road would then conditionally require access to a snow blower.

It was clearly demonstrated that it was appropriate to implement closure measures, but one of the major uncertainties was related to the assessment of the real avalanche risk. There were a total of 16 avalanches in the "avalanche week" both on known avalanche paths and partly in "new" avalanche zones. At the same time, snowdrifts that are normally triggered under the conditions that prevailed were not released since the amount of snow locally was not sufficiently great to trigger an avalanche. An example of this is Sæterbøfonna in Romsdalen towards Horgheim, see Figure 10, which was the main reason for closure of Romsdalen, but this glacier remained stationary during the avalanche week.

Figure 10 – Sæterbø glacier can be seen in the upper right part of the picture

The concern for the safety of the maintenance truck personnel can be illustrated by the fact that on 15 March there was an avalanche in Romsdalen which stopped just before the snow reached the road. The snowplough driver who was in the path of the avalanche right at that moment lost visibility in the whirling snow and experienced powerful air pressure that almost pushed the truck off the road.

A few catchment basins have been built, but this is not considered to be a sufficient safety measure to prevent serious incidents caused by avalanches.

3.2. Economic impact

There will obviously be a great economic impact both for businesses and for individuals from extensive road closures such as those in the avalanche week. The main cost components for businesses will be:

- Extra cost for the transport provider
- Extra cost for the goods owner
- Extra labour costs if there is a halt in production
- Extra cost for the customer if production is affected

The consequences in the form of detours to alternative routes will depend on the length of the detour route in relation to the shortest way. The greatest impact will be if the trip is not completed at all.

3.3. Other consequences

Under such extensive road closures as those that occurred in the avalanche week, societal functions stop almost totally, affecting important community services such as accessibility for emergency vehicles. There will also be social impacts on people prevented from pursuing their daily routines.

3.4. What can be done better

People involved in the management of the situations that occurred during the avalanche week have highlighted several action points that can help in minimizing the consequences of road closures:

- Simplify and use more correct names for closure locations
- Greater involvement of the ferry crew in all matters concerning ferry connections
- The emergency preparedness crew should be organized with a fixed meeting point to improve the information flow
- The emergency preparedness crew should also be more involved in the decision processes
- More use of the Traffic Management Centres
- It may also be possible to expand the use of the “convoy” in traffic management
- Meetings after the weather incident with the most affected municipalities

3.5. Other aspects

- All avalanche zones should be included in the avalanche protection plans
- It is important that the action plans, regulations and procedures are simple and easy to understand
- There is a challenge with respect to a change of contractor and fewer people with local knowledge

In the Avalanche week the road owner and the contractor were in contact with people with local knowledge. This was a challenging position and responsibility was determined in a tangible way, but it was also revealed that there is a need to improve practices and routines in several areas. First and foremost, procedures should be established in order to better support local knowledge through actual observations/records of snow conditions and danger of avalanche. This can be done by combining instrumentation and inspections by helicopter. It is also recommended that controlled release of avalanches be attempted using an air cannon such as the Daisy Bell. It is recommended that equipment of this type, see Figure 11, should be stationed within such a radius that it can be available within a few hours.

Figure 11 – Preparing Daisy Bell for operation

Since manned helicopters rely on relatively good visibility to take off, it is also necessary to conduct experiments using unmanned helicopters. Experience from Washington State of using unmanned helicopters is good, and it is appropriate to look at the technique that has been developed in the United States, see Chapter 4.5.

When such large areas are affected as was the case during the avalanche week, there will be a need for continuous updates on weather conditions, traffic conditions and road closures. It may be difficult for the Traffic Management Centre to have full control at all times, and a separate system should be established that collects all the relevant information.

Another important point is that of road user information on road closures and alternative routes. There will also be a need to set up variable message signs at strategic locations to reduce the need for manual traffic control.

Other important aspects are preparedness and routines with regard to public information during severe weather events. The road was kept free from snow in the period of closure to be prepared for quick reopening if the situation allowed for it. This strategy put the drivers of the maintenance vehicles at risk and one of the major uncertainties was the assessment made about the real risk of avalanches.

4. US STRATEGIES FOR AVALANCHE CONTROL

4.1. In general

This chapter refers to the strategies for avalanche control in Washington State (WSDOT) and Colorado (CDOT), USA. The main difference from Norwegian practice as demonstrated by the handling of the avalanche week in Romsdalen, is the common use of explosives in the USA to actively control the triggering of avalanches.

4.2. Snow slide situation in Washington State and Colorado

Snow slides are a fact of life in the Cascade Mountains in Washington State [1]. Avalanche control is a winter-long activity on two primary travel corridors, I-90 Snoqualmie Pass (3,022 feet equivalent to 921 metres) and US 2 Stevens Pass (4,061 feet equivalent to 1238 metres). Snoqualmie Pass is the only Interstate in Washington through the Cascades. It averages nearly 450 inches (equivalent to 11.4 metres) of snowfall each winter and typical traffic volume is more than 32,000 vehicles per day including 8,000 trucks.

Each winter, WSDOT stations specially trained avalanche control teams at Hyak, near the I-90 Snoqualmie Pass summit and at Berne Camp, near the US 2 Stevens Pass summit. The teams work to reduce the avalanche hazard as well as the number and duration of highway closures.

WSDOT uses both active and passive measures in their avalanche control strategy and closes some passes during the winter if the avalanche control work becomes too hazardous.

CDOT regularly monitors and/or controls some 278 of the 522 known avalanche paths in Colorado to help prevent avalanches from impacting Colorado highways [2]. During the 2011-2012 winter season, CDOT triggered 516 avalanches with explosives and handled 83 natural occurrences, all of which impacted Colorado highways. CDOT experienced 332 hours of road closures due to avalanche control, resulting in a total of 13,221 feet (equivalent to 4000 metres) of snow covering the centreline of the roadway. The roads were closed a total of 370 hours for avalanche hazard mitigation - there were no injuries, fatalities or equipment damage.

4.3. Forecasting avalanches

WSDOT evaluates avalanche hazards using a variety of tools, including weather observations, forecasts, snow analysis and historical records [1]. Crews also analyse daily observations of new snow, wind speed and direction, air temperature, sky conditions and other factors. Remote automated weather stations relay information by phone, radio or satellite. This provides technicians with conditions at the tops of often-inaccessible avalanche starting zones.

CDOT teams up with the Colorado Avalanche Information Center to help predict avalanche conditions and the necessity for avalanche control. Factors that are considered to increase the risk of avalanche danger are large quantities of new snow, high winds and drastic changes in temperature.

4.4. Performing avalanche control

When an avalanche hazard develops, WSDOT uses artillery or explosives to trigger the avalanche. These are various methods of delivery depending on the topography and accessibility to the avalanche path. Explosives are placed by hand, cable-pulley bomb trams, or with surplus military weapons.

In addition to active avalanche control, WSDOT also uses passive control methods to control snow slides. These include snow sheds over the highway; elevated roadways so avalanches pass under them, or with catchment basins to stop the avalanche before snow reaches the highway. WSDOT also uses diversion dams to keep the snow off the highway.

When there is a high risk of avalanche danger, CDOT will close highways at the location of the avalanche path in order to conduct avalanche control. Once all the unstable snow has been brought down, CDOT crews have to clear all of the snow and debris from the roadway before reopening the highway to traffic. Since it is impossible to predict how much snow will be brought down during a control mission, it is difficult to estimate how long a highway closure will be in place. CDOT will open the highway as soon as it is safe for the travelling public.

Any time CDOT conducts avalanche control, messages will be posted on electronic signs in order to inform motorists of the road closure. In addition, motorists can visit the web at www.cotrip.org or call 511 for current road and weather information and updates on avalanche control work. Motorists can also sign up for e-mail and text message alerts.

4.5. New technology

WSDOT Avalanche Teams has been testing new technologies that could be incorporated into their control programme, and WSDOT views the use of unmanned aircraft systems (UASs) as having the potential to provide direct operational advantages. Small UASs, which are commercially available, are able to be launched off a vehicle or from a road, can carry small payloads and high resolution cameras and sensors, and are able to use Global Positioning Systems (GPS) to fly pre-set flight plans autonomously.

As an example, WSDOT has evaluated the use of (UASs) under severe mountain weather conditions in cooperation with the University of Washington (UW) [3]. Two small UASs have been tested, a fixed wing and a rotary wing (helicopter), see Figure 12, to evaluate their advantages for avalanche control.

Figure 12 - The rotary wing RMAX

The project found that unmanned aircraft hold considerable promise for WSDOT's avalanche control operations. This was especially true for rotary wing aircraft. One of the main benefits of this technology is the ability to provide real-time aerial surveillance of snow conditions and avalanche terrain. UASs also could potentially be used to deliver control explosives in pre-selected, inaccessible avalanche paths. With enhanced optical or non-optical sensor technology such as LiDAR, UASs might also be used to detect people in areas that are targeted for the release of avalanche control explosives or to effectively assess snowpack properties.

5. RECOMMENDATIONS FOR AVALANCHE CONTROL

Below are listed different elements of a system for avalanche control based partly on experience from the avalanche week in Romsdalen and partly on the US strategy for avalanche control in Washington State and Colorado.

- Mapping of avalanche-prone areas
- Passive protection by use of snow sheds, catchment basins etc.
- Organizational clarifications of roles and responsibilities
- Instrumentation and recording of snow conditions
- Warning systems and information strategy
- Development of traffic management routines varying between preventive measures and more urgent actions
- Road weather information system and system for forecasting avalanche risk
- Team (emergency preparedness crew) with operational tasks
- New technology for surveillance of avalanche areas
- Techniques for active avalanche control

- Calculation tools for socioeconomic calculations and evaluation of avalanche incidents

The importance of giving priority to avalanche control is expected to increase in the years to come, with more extreme weather incidents as a result of climate change. It is therefore also important to exchange experience within this field between countries with mountain passes and avalanche-prone areas.

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