AVALANCHES ON THE ROADS: OPERATIONAL AND RESEARCH ASPECTS FOR THE MANAGEMENT OF RISK WITHIN THE PROJECT ALCOTRA N. 144 "MAP3"

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ABSTRACT: The avalanche risk management on roads is a complex issue that concerns several aspects: social, economic and political. In particular, the problem is worsened in mountain areas, strongly anthropized, whose access is often possible only by a single road. Generally, at the head of the valley, ski resorts are present, which represent important tourism resources.
In this work, we aim at describing a specific case of high avalanche risk on a road. During winter 2013-2014, the road n. 44 along the Gressoney valley in Aosta Region (NW of Italy) was precautionarily closed from the afternoon of March 1st to the evening of March 2nd after a heavy snowfall. Stopping traffic in the valley and the partial closure of a ski resort generated an economic loss of more than €200.000 altogether. Were the closure and its duration adequate? Would a shorter road closure with a resulting lower economic damage have been safe enough ? Or should the road have been closed for longer and can we only put it down to luck that there were no serious consequences to public safety? To try to answer these important questions, we are developing several activities aiming at the definition of risk scenarios: monitoring, modeling, program management, reporting and cataloging activities, all enriched by the support of research through the development of European projects, including the project MAP[3].
We think this is a good example of how research can support the administrations in the issue of avalanche risk management.

KEYWORDS: roads, avalanche hazard management, ski resort

1 INTRODUCTION

The region of the Aosta Valley (RAVA) is situated in the far north-western part of Italy. Set between the Graie Alps and the Pennine Alps, the Aosta Valley is surrounded by the highest mountains in Europe, culminating in the ranges of the Monte Bianco (4807m), Monte Rosa (4634m) and Gran Paradiso (4061m). It is a completely mountainous region (3263sqkm) with 60% of its territory at altitudes above 2000 m a.s.l..12 lateral valleys flow into the main valley in herring bone formation, each one separated from the other by high mountains with steep slopes. Access by road has been much improved by the opening of the Gran San Bernardo Tunnel (1964) and the Mont Blanc Tunnel (1965), as well as the completion of the A5 Torino – Aosta Highway.
This was extended to the Mont Blanc Tunnel in 2006. These roads and tunnels brought to an end, the Region's centuries – old winter isolation. Connections with Switzerland and France used to rely on the seasonal opening of the Gran San Bernardo and Piccolo San Bernardo Cols. Furthermore, the main roads along the lateral valleys have also been made passable all the year round by the construction of numerous avalanche tunnels (despite these shelters, in the past six years, 71 avalanches reached or obstructed the regional roads) [Segor V. et al., 2010-2012].
The Aosta Valley is therefore an original destination, easily reached even for a short break. Its high mountains are an ideal playground for Alpine skiing, free riding, free style snowboarding, cross-country skiing, skiing excursions, ski mountaineering, telemark, skiing, heliskiing, kite surfing. The Aosta Valley has hundreds of cableways covering over 700 km of downhill slopes, about 400 km of cross-country pistes,

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facilities for acrobatic snow surfing and more than 1,200 ski instructors and 200 mountain guides. The most important ski areas are the international ones of Breuil–Cervinia (lying between Italy and Switzerland) and La Thuile (lying between Italy and France) and the three all –Italian Monterosa Ski Valleys. The range of ski resorts in the Aosta Valley is distributed among 28 large and small centres. Nearly three quarters of the regional workforce is employed in the service sector with tourism and its connected activities as its heart.
The winter season of 2013-2014 (from December to April) is an example. The number of tourists present came to nearly 1,5 M people.
Of these, 16,46 % were in the MonteRosa Ski Area (Ayas, Gressoney and Alagna Valleys). The area is an asset to be developed both in operational and cultural terms, while taking into account the management of traffic mobility and the hazards of avalanches.
In this context, here's an interesting observation extracted from the Gressoney Valley Local Avalanche Committee (CLV) 2013-2014 report:
"A *serious traffic inefficiency problem has been noted in several cases. Critical avalanche or snowfall events have not only congested the mobility for obvious reasons but have been the cause of dangerous traffic jams in the direction of traditionally dangerous avalanches...omissis... a problem not to be overlooked seeing the many dozens of bumper to bumper cars in a queue under high-risk avalanche slopes."*

2 ANALYSIS AND ACTIVITIES OF MONTEROSA SKI BETWEEN MARCH 1ST AND 16TH 2014

On March 1st there was a snowfall of 50-80cm at 2.000m (with peaks of 100cm) in mid Gressoney Valley and Val d'Ayas. These snowfalls, associated with moderate winds, formed new drifts at altitudes above 2.000m, further overloading the slopes. The Regional Snow and Avalanche Bulletin for Saturday March 1st and Sunday March 2nd was issued quoting a high danger level of 4 for the Gressoney, Ayas and Champorcher valleys and for the high parts of Valtournenche. On March 1st, the Regional Gressoney Valley road was closed and on March 2nd three avalanches fell. During the night between March 3rd and March 4th, a further 70 cm of fresh snow fell in the lower part of the valley. On March 4th, at the end of the period of perturbed weather, and for the first time during last winter, the temperature began to rise progressively and steadily and this continued throughout the following days. In particular, the maximum temperatures at 2.300m from March 8th till the 16th, went over the 5°C mark. (Fig. 1).
According to the temperature diagram from the automated weather station near Gressoney La Trinité at an altitude of 1.993m, a trend of decisively increasing temperatures was inferred from the beginning of March, with maximum temperatures of over 20°C on the second. (RAVDA, in press; AINEVA, 2014).

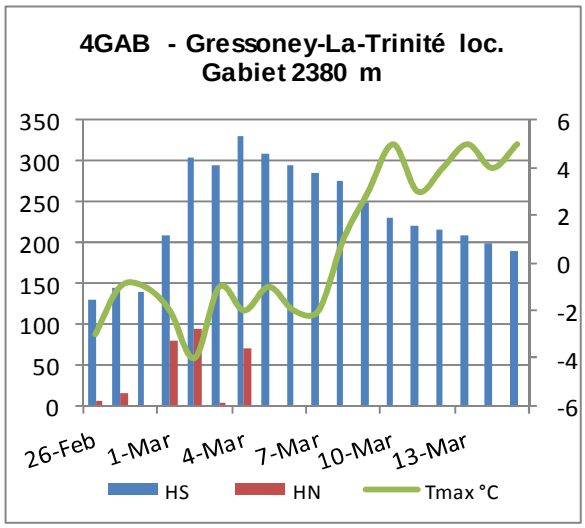

Fig. 1: Snow level data and maximum temperatures from February 26th to March 15th from the fixed snow camp Mod 1 – AINEVA 4 GAB in Gressoney Valley

As a consequence of the rising temperatures, there were numerous avalanches, among which the Val Nera di Mezzo (Fig.2) which will be analyzed in this article. This avalanche triggered itself at about 2.600m a.s.l. and was of weak cohesion with a density of 340kg/m3. The avalanche eroded part of the snow cover (with a density of 220kg/m3) and split at an altitude of about 2.100m a.s.l.
The right-hand branch, which crept into a torrent bed, carried a wooden bridge downstream for about 150 meters. The left-hand branch caused a further detachment of the snowpack, ground level, at 1.950m a.s.l.

Fig. 2: Val Nera di Mezzo: the event of March 10th, 2014. In the foreground, the sediments of the right-hand branch which destroyed a wooden bridge. In the background, the sediment caused by the left-hand branch

2.1 Gressoney CLV activities

Extract from the CLV minutes:

"...*Seeing the critical state regarding the heavy snowfall, on March 1st 2014, we proceeded to carry out a mere surveillance of the territory until 6.30a.m. The layer of snow which has fallen varies between 40 and 80cm with the highest peak concentrated in a spot called Pont del Trenta in the municipality of Gaby. The persistence of heavy snow falls is confirmed.*

At 11.30 a.m. there was the notification of the discharge of the avalanche known as 'Testa Grigia' , situated in the district of Gressoney –La – Trinité. The powder cloud from the discharge, reached the bends on the regional road, from a place called Orsia towards the hamlet of Gofèr, whitening the house walls. At the same time, we were notified of some secondary discharges at Selbsteg and one of these partially buried a car parked at the 'Piccolo Résidence'. In consequence of the above-mentioned events, the Mayors decided to issue a decree to close the Regional road from the municipality of Gaby to the municipality of Gressoney.

On March 2nd 2014, at 5 o'clock in the morning, the commander of Gaby's Forestry Post is told that an avalanche (Toppo Schluecht 01-044) had fallen at Trino (Gressoney –Saint- Jean). With a width of 80m and a depth of 1.50m, it was occupying and completely obstructing the Regional Road.

From 5.30a.m. a survey of the avalanche is carried out in order to supply information on the clearing of the avalanche snow from the Regional Road, this being subject to checks on the safety of the site. In the meantime, the Piste Manager for the Monterosa Ski area was contacted. They were carrying out artificial triggering with the use of an helicopter, and he referred that it had set off vast artificial avalanches."

2.2 Economic analysis of the ski area – how much does an avalanche cost?

The Regional Road, n. 44, of the Lys Valley (Gressoney) was closed from 3 p.m. on Saturday March 1st until 5 p.m. on Sunday March 2nd 2014. On Sunday March 2nd, in the Monterosa ski area (Fig.3) a global presence (excluding Alagna Valsesia) of 6.849 skiers was recorded (776 entering the resort in the Gressoney Valley - these were either local inhabitants or people residing above the road block – and 6.073 recorded in the Ayas Valley). On the takings side the total amount was of € 121.165 (€12.587 for the Gressoney Valley and €108.578 for the Ayas Valley).

During that day, the skiing connection between Ayas and Gressoney was provided, as usual, by the Bettaforca Col, which remained open.

These figures have been compared to the average values recorded on the same Sunday in the years from 2005 till 2013. When we say 'the same Sunday, we mean the Sunday before Carnival (Mardi Gras).

Average attendance for the ski resort has been of 8.219 skiers (3.316 on the Gressoney side and 4.913 on the Ayas side). Analyzing the average takings we reach € 278.400 (€123.000 Gressoney and €155.400 Ayas).

Fig. 3: The study area in the Monterosa ski resort - Gressoney Valley (Gressoney La Trinité, Gressoney Saint Jean) and Ayas Valley (Champoluc, Antagnod, Brusson)

If you abstract from the particular Sunday preceding the Carnival and you analyze the days

when there were the most people (taking an average of the 5 best days in a period between 2005 and 2013) you get the following results: an average of 13.837 skiers - with a peak of 14.685 – (5.313 for the Gressoney Valley and and 8.524 for the Ayas valley) and an average of € 315.266 in takings (€137.127 Gressoney € 178.139 Ayas). The best daily takings, on the other hand, are over € 400.000 (€150.000 for Gressoney and €250.000 for Ayas).
By analyzing this data, we can understand that on that day, with one valley not accessible by road, the ski resort lost about €157.000 if we compare it to the same holiday period. If the same situation occurred in the "best" day the amount lost could have achieved close to € 280.000.
Beware that direct confrontation between n° of skiers and takings can't be made because n° of skiers includes those having seasonal or multi-day tickets (bought in advance) and daily passes.
Estimates for general social costs and spillovers could be further examined in depth.

2.3 *Statistical analysis*

Following an analysis regarding the data of presences (not all of them skiers) in the Gressoney Valley and in the entire Aosta Valley Region, the results are the following: in the municipalities situated at the top of the valley, which could not be reached as the result of the closure of the regional road (Gressoney Saint Jean and Gressoney La Trinité) 5.474 presences were recorded. Compared to the annual average recorded since 2005, this corresponds to a decrease of 356 people (6.1%), a figure which is higher than the general decrease of only 1.4% recorded in the entire Aosta Valley Region.
It is necessary however to point out that the high economic loss recorded in the ski resort (see paragraph 2.2) should not so much be attributed to fewer presences owing to the road closure as to the fact that, during the days of Saturday March 1st and Sunday March 2nd most of the ski resort was closed and the snow was still falling. In effect, 356 fewer people than during the seasonal average would have resulted in an economic loss of only €15,000. This figure is reached by calculating the cost of a daily skipass.
The number of presences lower than the yearly average are mainly ascribable to adverse weather conditions and, particularly, to ongoing snowfalls. It would seem, therefore, that the closure of the regional road did not have a critical bearing on the economy of the upper part of the Gressoney Valley.
It must be pointed out, however, that the closure of the road took place on the day after the usual arrival date for weekend skiers (Friday).
If the road closure had happened between Friday and Saturday, and with a favourable weather forecast, the decrease in presences would have been higher and the damage, as quantified in paragraph 2.2, would have been ascribable only to the closure of the same road.
Through the analysis carried out, it would seem that the principal cause of the possible decrease in presences is to be attributed to the poor weather conditions observed and/or the adverse meteorological forecasts.
At a managerial level, therefore, the closure of a regional road at the same time as there is bad weather and the closure of the system can be carried out with greater peace of mind in that it does not entail serious economic repercussions.
Vice versa, one must take into consideration the case of large numbers of tourists, in good weather conditions, associated with a rise in temperature which would bring about an increase in avalanche events. What would the cost be of an avalanche that involved the road system, crushing the road users?

3 REGIONAL ADMINISTRATION AND RESEARCH PROJECTS

How much of this decision is attributable to luck or to experience? And how much to prudence and Responsibility? How hard is it to manage communications and understand the critical issues? These are some of the questions that still have no answers.
In an attempt to answer the above questions and to improve the managerial aspect of roads in regard to avalanche hazard, the Autonomous Region of the Aosta Valley, has for several years been collaborating with the most important research centers, both Italian and international, by participating in projects financed by the European Union. In particular, the Region's working with the MAP3 Project –P.O. Territorial European Cooperation for France/ Italy (Alps) 2007- 2013, which finances research activity aimed at the operational management of avalanche risk.
Shown below, are the main activities carried out by the Regional Administration in the area of operational management of avalanche hazard in various research projects.

3.1 *Area of pre-criticality forecasting*

It would be useful to improve the forecasting abilities both in terms of use and availability of the forecasting models and in the terms of spatialization of snow-weather data, wind study and wind movement. It is also necessary to increase and perfect the data obtained from the automated weather stations.
Having observed the increase in wet-snow avalanche events, even in out-of spring months with the resulting set of problems of forecasting and management, the Regional Avalanche Bureau together with research bodies and the Monterosa Ski Resort have launched a study in order to individuate the snow-weather factors which trigger off these dangerous situations (Frigo et al., 2014).

3.2 *Area of management during criticality stage*

The management of avalanche hazard during criticality is one of the crucial and most complex points during which a perfect technical management must imperatively be associated with logistical management, together with both social and communication management.
In order to improve these aspects, RAVA has implemented various applied research projects with the objective of supplying innovative, trustworthy and state-of-the-art instruments for the purpose of giving support to the technicians operating in critical cases.
Among the many examples put into effect in the last few years, one can mention the online census in real-time (detection) of avalanches even in cases of poor visibility or darkness thanks to the pioneering IAN Infrasonic Array Network. So far this covers 1/6 of the regional territory. As well as providing support in real-time, this instrument has revealed itself as useful and innovative, thanks to the gathering of data on 'non-conventional' avalanches and also for a more comprehensive understanding of the events themselves. It's no accident that in an ordinary way, thanks to the easy acquisition of information regarding the weather and the process of locating where the avalanches releases, and by crossing the relative data with the local snow-weather conditions, one can understand the causes which set off the event.
An example of the development of advanced technologies in support of operational technicians in a case of criticality is the development of the web-platform for the CLV - Local Avalanche Commisions [Segor et al. 2014]. Created as a decisional support in the field of managing avalanche risk in municipal territory, they have the task of supporting the municipalities in forecasting activities and of estimating the snow weather conditions and the condition of stability of the snowpack, of surveillance, of pre-warning and intervening in risk situations and of managing the emergency, in order to ensure, at local level, the control of dangerous situations in their relevant territories, all on the basis of uniform methodologies.
For the very purpose of supplying the CLVs with an operational support instrument to manage avalanche danger at a local level, RAVA in collaboration with CELVA – Consortium of Local Bodies in the Aosta Valley – and on the basis of Austrian colleagues' experience, gave the green light to the implementation of the web platform. This is an easily used technical instrument which visualizes and files data relevant to snow measurement, weather, avalanches, transcribing manual measurements and evaluations, as well as the traceability and the records of any operations carried out and what measures were advised.
Another example of technological innovation and harmonious cooperation between the Regional Administration and the technicians in the sector is the development of research applied by RAVA and the ski areas of MonteRosa and Cervinia on the effectiveness and efficiency of artificial triggering systems both with explosives and with gas in order to also make the systems usable in high security for the management of avalanche hazard on regional roads.

3.3 *Area of creating scenarios of avalanche hazard*

A useful tool to analyze snow an avalanche data in order to create different scenarios of avalanche hazard situation is the software RAMMS. RAMMS is a 2d avalanche dynamics program developed by the researchers of the WSL_SLF of Davos (Switzerland) which models the flow behaviour. Thanks to the introduction of random kinetic energy (RKE) associated with granule velocity fluctuations, of the cohesion and of the snowcover erosion (Christen et al. 2010; Bartelt et al. 2012) one is able to determine in a more realistic way the speed and the pressures during the flow, as well as ever more accurate shapes and volumes of the deposit. By means of research projects, the Region is supporting the implementation of a tool which will automatically determine the area of release, depending on the "roughness" of the slope and the amount of snow on the ground (Veitinger et al., 2012).

Futhermore, in these projects the role performed by temperature in the propagation of avalanches is investigated (Valero et al., 2012; Steinkogler et al., 2014). In order to find out the thermal situation of a slope we are working in the light of localizing, by means of Alpine 3D, accurate data of the condition of the snowcover as supplied by Snowpack.
As pertains to the altitude of the detachment, a technique is being developed which would allow one to calculate it starting from calibrated photographs. This procedure is part of the AdHoc4Map3 methodology (Bornaz et al., 2013). This method was born to support Forecasters and Cartographers for the rapid measurement and drawing of avalanche limits, especially on the deposition zone. The tool manages digital calibrated photographs of the avalanche events integrated with a digital terrain model and orthophotomaps creating a "solid" geo-referenced image showed in 3D-GIS environment.
We should emphasize how gathering data for the avalanche land register has also proved itself useful as a support for avalanche hazard map-making.
In particular, the model RAMMS RKE with the erosion module was applied to the 10th March 2014 Val Nera di Mezzo avalanche, using the real data as input data (area and volume of detachment, density, cohesion).
The results obtained from these few data produce fairly realistic stopping distances (Fig. 4). The avalanche split into two branches generating two separate deposit areas. It is interesting to note that throughout history the avalanche had never channelled itself into a right-hand branch, whereas the RAMMS simulations reproduced this very situation. This emphasizes the potentiality of RAMMS to reproduce scenarios of avalanche activity which are useful for the management of avalanche hazard.
The right-hand branch channelled itself into the creek, a situation that was clearly reproduced thanks to the high definition of DEM (2m). Moreover, the depth of the deposit found was compatible with the actual one.
If the models of dynamics are already well calibrated for extreme avalanches, their application for small to medium sized avalanches is the course of being validated.
Small avalanches are less destructive than extreme events but can nonetheless create serious problems for tourism in ski resorts or road-safety operations, as they are difficult to predict and more frequent. For this purpose, events of small/medium size such as at P.ta Seehore of being simulated (Bovet et al. 2013, 2014, Maggioni et al. 2012, 2013b).

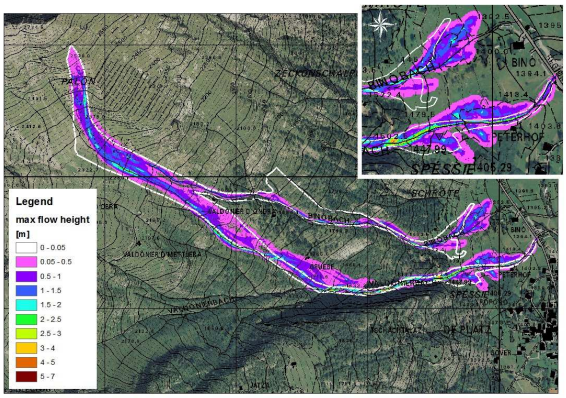

Fig. 4: Comparison between the highest depth of the flow as simulated in RAMMS and the perimeter survey of the actual event of the Val Nera di Mezzo avalanche. In the box a zoom of the avalanche deposit area.

In effect for the events recorded at the experimental site of P.ta Seehore (Barbero et al. 2013, Maggioni et al. 2013), there is further information: force data, temperature, speeds recorded from an instrumented obstacle, speed of the avalanche front, pre and post- event laser scan measurements, which together with the straw/pipe test (Bovet et al. 2012, 2013) supply data on the snow erosion and deposit. The data recorded by the obstacle allows one to improve our knowledge regarding the impacts of avalanche flows on structures and infrastructures (AAVV 2012) and therefore to provide rules of pressure which are useful for sizing, in view of more effective prevention. It is to be noted that the obstacle system activates itself automatically and is therefore able to record natural events, which often have different characteristics to those set off artificially.

4 CONCLUSIONS

Were the closure and its duration adequate? Would a shorter road closure with a resulting lower economic loss been safe enough? Or should the road have been closed for longer or can we only put it down to luck that there were no serious consequences to public safety?
The closure of the Gressoney Valley Regional road, on the 1st and 2nd March 2014, in conjunction with heavy snowfalls, turned out to be adequate and appropriate in a timely manner. The hazard in this case, proved by the events, was high and the

economic loss was relatively limited. It is not known how far the threshold of a socially acceptable risk was overstepped on the night of March 3rd/4th. On the other hand, the risk that was run from March 8th, with a clear increase in temperature, was underestimated. In this case, as there were no signs of snowfall, mechanisms of difficult management are activated, both because of the social perception of the danger and because the competence in assessment is lacking. To be absolutely rigorous, the CLVs should have closed the road from the 8th onwards until the most important events had taken place, given that the temperature did not fall until March 16th. In retrospect, one could have reasonably considered a closure of at least three days (Saturday 8th, Sunday 9th, and Monday 10th) but in this case, the economic loss would have been the aforementioned one in paragraph 2.2.

Two possible actions could be proposed: (i) the first one at a management/communication level in order to improve information about accessibility of ski areas in real time, in terms of road conditions. This could be easily solved – because of the particular orographical configuration of the Aosta Valley – with information panel boards situated on the three principal access roads linking the region with France, Switzerland and Piemonte. The second proposal (ii) is at a technical/ management level with the improvement of local forecasting by means of event scenarios so as to attempt to limit the avalanche hazard to a socially acceptable threshold. This second proposal also has to go through the activities carried out within the research projects, with actions aimed at the fine-tuning of operational management at ground level.

From the experience acquired, collaboration between the various players involved is of fundamental importance: regional administration, road system management, local bodies, ski areas, tour operators and research institutes.

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