An avalanche index for roads

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ABSTRACT
Several methods have been introduced through the years to evaluate avalanche risk along road sections. In 1988, Peter Schaerer introduced Avalanche Hazard Index, a numerical expression of damage and loss as the result of an interaction between snow avalanches and vehicles on a road. Later works by different authors have developed the methodology for risk management and winter road opening of high alpine pass roads.

This project is a spin-off of a project conducted by ORION Consulting for the Icelandic Road Authority. This project describes a simple method to evaluate possible consequences of an avalanche hitting a passing vehicle on a road section. Besides the size, intensity and frequency of avalanches, the severity of the consequences is related to several environmental factors such as the distance from the road body to potentially dangerous terrain features. Such factors may include cliffs and steep banks along fjords, as well as steep slopes above the road. In addition, the consequences of an encounter between a vehicle and an avalanche may depend on the probability of a speedy rescue.

The factors used are quantified on a scale from 0–5, where the lower values are given the worse case and higher values the more favourable.

Test results show that this procedure gives other results than a preliminary assessment suggests in some cases. At a specific avalanche threatened stretch of road site in northern Iceland, a different avalanche path received a higher index value than the one that initially was considered the worst.

1. INTRODUCTION
At present, neither guidelines nor other instructions are available for the road authority in Iceland to evaluate the avalanche threat to the road traffic or to prioritize necessary measures. In 2000, the Ministry of Environment published regulations for populated areas. The safety requirements are related to individual risk, defined as the probability of a fatal injury of an individual living (with occupancy of 75% of the time) in an un-reinforced house. The actual risk can be estimated by considering the probability of an individual staying at home, the avalanche frequency and intensity, and the strength of the building.

Risk-based methods based on encounter probability and average values for mortality have been used before, *i.e.* in the Avalanche Index Method (Schaerer, 1989). However it is possible to extend these methods by introducing several environmental factors that can affect the survival of avalanche victims. For instance, a small avalanche that hits a car in an unfavourable or a remote area can have disastrous consequences for those in the car. On the other hand, if conditions were more favourable the travellers might do well. Thus, the encounter probability alone does not always show the whole risk picture.

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The endeavour of this paper is to point out some factors, that may affect the survivability of victims that are hit by an avalanche on a road and to introduce a simple tool for prioritizing protective measures.

2. PROBLEM APPROACH AND LIMITATIONS
The avalanche threat to a road section is limited in time. Also, in Iceland, the annual variability can be great, from no avalanche cycles at all to several weeks. Different roads also have different traffic or traffic characteristics. Some avalanche-prone roads may be the only road connection to villages while other villages have a second access road. School buses may travel the road every day and busses full of tourists may travel the road in case of some events in the villages in the wintertime.

3. THE INDEXING METHOD
The method is based on assigning values to various factors that are related to avalanches, avalanche paths, the surroundings *etc.* Those factors can be the recurrence of avalanches, the slope inclination of distal side, the distance to life threatening object on distal side and distance to the nearest rescue station, *etc.* The factors could as well be the probable effect of protective measures, aspect of the starting zone. The alternative detours, the length and the susceptibility of these to hazards can also be considered. The scale ranges from 0–5. Every factor is then weighted from 0–1.0 and the sum of all the weighted numbers is called the index for the avalanche path. The lower the index is the more urgent it is to protect the traffic, either by moving the road or by protecting it.

4. DATA COLLECTION

4.1 Avalanche history and frequency
The Icelandic Road Authority (IRA) logs every avalanche that hits the road system and files them into their database. IRA also reports all avalanches to the Icelandic Meteorological Office (IMO), where they are stored in their central avalanche database.

The frequency of known avalanches that hit the road is estimated from the current data set. It is of interest to consider different size classes of avalanches, but the 10–20 year avalanches are here considered to be the "normal" design avalanches for roads. From this frequency estimate based on the data set, a maximum value is set to 0 and minimum value set to 5.

4.2 Inclination of distal side of the road
Cars are often thrown or pushed off the road, down the distal side when hit by an avalanche. The approach here is to relate the severity of such an incident to the inclination of the distal side; the steeper the slope, the more severe the accident. The first 50 m of the distal side, from the road, is considered to be the most important one. Inclination is divided into 5° steps, ranging from 0 to 25° or larger. It is rated from 5 to 0, see Table 1.

Table 1. The Inclination of the distal side of the road.

Inclination	Scale
>25°	0
20°-25°	1
15°-20°	2
10°-15°	3
5°-10°	4
0°-5°	5

Table 2. The distance to a cliff or a life-threatening object.

Distance at distal side	Scale
0-25 m	0
25-150 m	1
50-75 m	2
75-100 m	2
100-125 m	4
>125 m	5

Table 3. The width of the avalanche track at roadside.

The width	Scale
>125 m	0
100-125 m	1
75-100 m	2
50-75 m	3
25-50 m	4
0-25 m	5

4.3 Distance to a cliff or a life threatening object

Many avalanche-prone road sections are on coastal areas in Iceland; the sea is on one side and the mountain on the other side. This is similar to many Norwegian road sections, but different from the typical Alpine road sections.

The distance to the shoreline, a cliff or any other dangerous obstacle at the distal side is important when the survivability of a driver and/or passengers is considered. The grouping is done in 25 m steps from 0 m to 125 m. If the distance is greater than 125 m it is considered a "good" site and is graded 5. The classification is shown in Table 2.

4.4 The width of the avalanche

The encounter probability is dependent on avalanche width and the probability of a vehicle being present. The speed of the vehicle can be considered constant. The avalanche width depends on the avalanche size. When historical data exist they are used; is cases where no data exist, an assessment has to be made. If an avalanche width from an "unknown"[1] avalanche path is used in combination with the known width of avalanches it can be considered to grade it higher[2] by one step to compensate for the uncertainty. When new road alignment is planned, the width of all avalanches is estimated so it is not necessary to grade them higher. Each step is 25 m, ranging from 0 to 125 or more, see Table 3. The speed of a vehicle is considered constant.

4.5 Rescue operation

ICAR (The International Commission on Alpine Rescue) has kept records[3] of avalanche victims over the last years. Their records, from winter 2004/2005 to the winter 2006/2007, show

[1]Avalanches that hit the road have not been reported but calculation and site investigation indicate that avalanches can hit the road.
[2] If no avalanches are observed it would be inappropriate to grade it the same as known avalanche. Lower grade means more severity.
[3] Backcountry skiing or snowboarding, free ride (off piste), on ski runs, alpinists, on roads, in buildings, on snow mobiles, and others.

that 1631 persons have been caught by an avalanche; of those, 949 were rescued alive or about 60%. In a Swiss study (Margreth and others, 2003), the probability of death of an individual in a vehicle caught by an avalanche is found to be 18%. In a Norwegian report, Kristensen and others (2003) estimate that the risk is somewhat higher in a remote area in Norway, about 40%. The reason for higher number is thought to be linked to adverse high mountain conditions, topographic characteristics and longer rescue time. The authors do not know it if any research on survival chances in vehicles has been carried out in Iceland. Avalanches hitting vehicles are very few, significantly less than a one per year on average. There are, however, many similarities between Iceland and Norway; the climate, remote areas and terrain features. Therefore, it seems reasonable to assume similar numbers as the Norwegians do; here we propose slightly a lower survival chance or 30–40%, mainly because of harsher weather.

Falk and Brugger (1994) have studied the survival chance of avalanche victims in the backcountry. Their result show that the survival chance drops to about 65% in 20 minutes and to 35% after 30 minutes. The importance of short distances (and quick responses) for rescue personnel or police to reach the avalanche site is therefore important. In Iceland, as well as in Norway, the voluntary avalanche rescue groups are the main resources in avalanche accidents. For an organized voluntary rescue team a response time of 15–20 minutes is quite normal, *i.e.* to prepare for the mission at the rescue station. The travel time to the avalanche site is a variable, depending on the distance, travel speed, conditions of the road surface (snow or ice) and the weather. Here we assume that the travel speed is 50 km/h. This speed might seem to be relatively low but taking into account that most of avalanches in Iceland occur in bad weather, higher speed does not seem to be reasonable and not advisable for a rescue group.

When comparing avalanche paths, the distance from the rescue centre to the path is important. Comparison can be performed between paths at two or three different sites like north, east and west Iceland. Only the distance counts. The longest distance will have the lowest (0) while the shortest distance the highest (5).

If an avalanche hits a vehicle it is most likely that the nearest voluntary rescue team will be asked for help. It can take voluntary teams 15–20 minutes to be ready at their rescue station and several minutes to drive to the avalanche site. For an avalanche prone road section, where avalanche tracks are in close proximity, the time difference between tracks is not that important but if different road sections are compared the respond and travel time might be important. The longest time to reach the avalanche site is here rated 5 and shorter distances are rated correspondingly.

4.6 Traffic volume

Traffic volume (WDT[4]) is one of the important factors when comparing two different road sections. WDT has no effect when comparing paths at the same road sections. Here a logarithmic scale is used to grade the traffic volume (5-log(WDT)). This method can be questioned for very low traffic volume but can be considered to be reasonable for larger volumes, WDT >10 vehicle/day.

[4] Winter Daly Traffic.

5. APPLICATION OF THE METHOD

The indexing system has been tested on few of the avalanche paths in an avalanche prone area in northern Iceland between Dalvík village and Ólafsfjörður village. At the moment only few categories have been tested, more will be done later.

Table 4 The table shows an example of how this method can be applied. Few of the paths are compared here for the road section.

Path#	Distance to rescue base			Inclination of distal side	Distance to an obstacle or a cliff	Width of path		Number of avalanches			WDT 2008		Sum Index	Rank
								Frequency 25						
	Weight#		0,2	0,15	0,2		0,1			0,2		0,15	1,00	
	[Km]	[Min.]	Grade	Grade	Grade	[m]	Grade	[n/25Year]	[t]	Grade	[veh/day]	Grade		
05BF01	6,0	22,0	2,3	2,0	5,0	170		15	0,6	2,9	480	2,3	2,7	10
05BF02	6,1	22,0	2,3	3,0	5,0	170		15	0,6	2,9	480	2,3	2,8	12
05BF03	6,2	22,1	2,2	3,0	5,0	0	5,0	0	0,0	5,0	480	2,3	3,7	16
05BF04	6,3	22,1	2,2	2,0	5,0	0	5,0	0	0,0	5,0	480	2,3	3,6	15
05BF05	6,4	22,1	2,1	2,0	2,0	70	3,0	21	0,8	2,1	480	2,3	2,2	6
05BF06	6,4	22,1	2,1	2,0	2,0	70	3,0	21	0,8	2,1	480	2,3	2,2	6
05BF07	6,5	22,2	2,1	2,0	3,0	70	3,0	35	1,4		480	2,3	2,0	4
05BF08	6,8	22,3	1,9	2,0	3,0	70	3,0	36	1,4		480	2,3	1,9	2
05BF09	6,8	22,3	1,9	2,0	3,0	70	3,0	36	1,4		480	2,3	1,9	2
05BF10	6,9	22,3	1,9	3,0	3,0	50	2,0	9	0,4	3,8	480	2,3	2,7	11
05BF11	7,0	22,3	1,8	4,0	2,0	50	2,0	9	0,4	3,8	480	2,3	2,7	9
05DF02	9,5	23,2				70	3,0	9	0,4	3,8	480	2,3	1,9	1
05EF01	10,5	23,5		4,0	5,0	80	3,0	8	0,3	3,9	480	2,3	3,1	13
05EF02	10,9	23,6		2,0	5,0	0	5,0	0	0,0	5,0	480	2,3	3,2	14
05EF03	11,1	23,7		2,0	3,0	130		9	0,4	3,8	480	2,3	2,0	5
05EF04	11,1	23,7		4,0	4,0	130		9	0,4	3,8	480	2,3	2,5	8

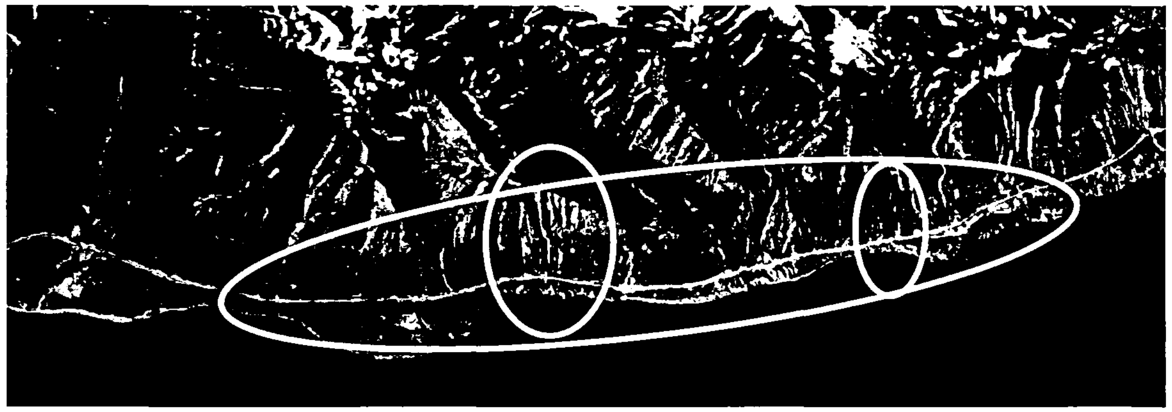

Figure 1. This aerial photo shows the observation area, inside the large ellipse, on the Ólafsfjarðarvegur road stretch between Dalvík and Ólafsfjörður villages north of Akureyri, Iceland. The vertical ellipse on the left depicts the initially "worst" site and the one on the right depicts the "new worst" site. Aerial photo: Iceland Geodetic Survey.

6. RESULTS AND DISCUSSION

This method was tested in one project carried out by ORION Consulting for the Icelandic Road Authority. The avalanche site is along the main highway from the village Dalvik to the village Ólafsfjörður in northern Iceland. Avalanches hit the road quite frequently; see report by ORION (Jónsson, 2007). The report describes the frequency of avalanches at known and "unknown" tracks and the individual risk for road users as a result of an avalanche encounter.

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It also describes the worst avalanche track according to the method used in the report. After applying this indexing method a different avalanche track was considered to be the worst and the former worst was considered to be the second worst. The reason for this is that even though avalanches are not that frequent the consequences were not taken into account. This "new" worst site is only within 25 m from a cliff and the sea but the former worst is around 100 m from a cliff.

This method is in its early stage, further discussion and comments are welcome.

7. CONCLUSION

Limited tools are available for the road authorities to quantify the severity of an avalanche accident on the road network. The proposed avalanche indexing method for roads aims first of all to help the road authorities to be able to quantify the need for measures in small or large avalanche areas. It is a simple method but it gives good information on avalanche paths on the road network that need to be protected from avalanches.

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