AUTOMATED AVALANCHE RISK RATING OF BACKCOUNTRY SKI ROUTES

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ABSTRACT: Avalanche accidents are often due to the fact, that many backcountry trips take place at locations with high avalanche risk at the time. A new web platform (http://www.skitourenguru.ch), introduced 2015 in Switzerland, addresses this problem. The platform evaluates twice a day the avalanche risk on 625 popular backcountry routes in Switzerland. The resulting risk indicator is a decimal value in the range [0..3] and can be split into three basic risk categories: "low", "elevated" and "high risk". The risk indicators are calculated by combining terrain characteristics with up-to-date avalanche forecasting data. The algorithm is essentially based on the well-known Graphical Reduction Method (see Fig. 6). Terrain analysis embraces slope angle evaluation, ridge and forest detection. The avalanche forecasting data from the "Swiss Snow and Avalanche Research Institute" includes regional information about danger level, critical elevations and critical aspects. On the web platform backcountry skiers can select routes depending on distance from home, start altitude, difference in altitude, difficulty and risk category. The platform turned out to be very popular. The hit statistic shows, that most users select routes with "low risk". A poll evaluation proves, that the quality of the risk indicators is as high as a group of experienced backcountry skiers would rate the routes. Even though the web presentation of the content is challenging, the approach has the potential to direct the users to routes with low avalanche risk. Such redirection can make an important contribution to the avalanche accident prevention. In the present article the underlying risk assessment methodology is introduced in more detail. The accuracy of the corresponding risk indicator and its value for the personal risk based decision making of individual backcountry skiers is discussed.

KEYWORDS: Avalanche Risk, Platform, Graphical Reduction Method, Risk rating

1. INTRODUCTION

Avalanches on backcountry recreation routes are the product of the three factors **terrain**, **snow conditions** and avalanche triggering **humans**. When Munter (1997) introduced the method 3x3 he specified the required procedure for three phases. Special importance got attached to the first phase, the **planning phase**.

All trip planning must start with a list of selected feasible routes. A new platform, introduced 2015 in Switzerland, supports backcountry skiers during the trip planning phase by providing an initial list of feasible routes. Based on the available information during the planning phase (avalanche forecasting and terrain model), the platform calculates risk indicators for 625 popular backcountry routes in Switzerland. With a set of extended filters the users can produce an individual list of routes. All further trip planning and accomplishment still follows the method 3x3. It's important to understand, that the platform doesn't predict the avalanche risk for routes or for single terrain points in absolute terms. The risk indicator does represent an estimate of the nominal magnitude of the anticipated avalanche risk.

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The platform first and foremost wants to contribute to a rational decision taking under conditions characterized by uncertainty. It's the nature of decisions that they have to be taken in any case. Independent of the quality or quantity of available information, it's recommendable to process all useful information during the decision making process.

The idea to produce risk information from avalanche forecasting data and from Digital Elevation Models (DEM) dates back to the 90ths. In order to provide easy to understand avalanche forecasting information Leuthold & Allgöwer (1996) used a GIS to combine avalanche forecasting data with terrain data. Eisenhut & Utelli (2012) made a further step by integrating an enhanced terrain analysis into a discrete model based on the Graphical Reduction Method (GRM). Not only they could produce first dynamic discrete risk maps, but they calculated as well discrete risk indicators for a set of manually digitized routes. Reudenbach (2012), Streit (2013) and Siegmann & Heller

(2015) implemented similar approaches, always based on a **reduction method** and implemented within a GIS. Buzaid (2014) suggested an algorithm, able to calculate a dynamic risk map from sunlight, temperature, slope, precipitation and wind. So far all approaches remained on the level of feasibility studies. The first web platform to introduce dynamic risk indicators for a set of routes was http://www.skitours-paradise.com. Based on manually established route ratings, the approach still renounces to an automatized, reproducible terrain analysis.

Gipfel	Gipfelhöhe	Start	Starthöhe	Höhendifferenz	Anreisedistanz	Schwierigkeit	Risiko
13 / 625	m		> 1000 m	> 1200 m	< 40 km	< ZS	Alle
Fil da Rueun	2346	Valsins	1138	1209	28	L	0.42
Piz Titschal	2534	St. Martin	1344	1201	23	L	0.70
Piz Dadens	2764	Brigels	1285	1502	21	WS	0.89
Chrüzlistock	2703	Rueras	1447	1256	12	WS+	0.93
Piz Val Gronda	2813	Giraniga	1268	1545	23	WS+	0.95
Piz Pazzola	2576	Platta	1373	1204	7	WS	0.99
Oberalpstock	3317	Sedrun	1441	1876	9	ZS-	1.05
Piz Maler	2784	Sedrun	1400	1471	10	WS+	1.42
Piz Giuv	3081	Dieni	1455	1627	12	ZS-	1.45
Winterhorn	2656	Hospental	1452	1204	35	WS	1.61
Piz Ravetsch	2997	Oberalppass	2032	1234	21	WS-	1.94
Piz Maler	2784	Rueras	1397	1408	11	ZS-	1.97
Piz Cristallina	3116	Fuorns	1455	1687	9	ZS-	2.68

Fig. 1: Resulting individual list of feasible routes.

2. INTERFACE AND FUNCTIONALITY

The platform http://www.skitourenguru.ch evaluates twice a day the avalanche risk on 625 popular backcountry routes in Switzerland. The resulting risk indicator is a decimal value in the range [0..3] and can be split into three basic risk categories as proposed by the GRM (see Fig. 6):

- Low risk [0..1]: green color
- Elevated risk [1..2]: orange color
- High risk [2..3]: red color

Trip planning requires the answer to two questions: 1. Where do I go? 2. Where on the planned route are my avalanche hazard cruxes? The platform supports users in finding answers to both questions.

The identification of a list of feasible routes can be done either by a search mask or by browsing on a map. In order to provide an individual list of feasible routes, it's a recommended practice to use the search mask. Routes can be filtered by **distance from home**, **start altitude**, **difference in altitude**, **difficulty** and **risk category**. By default, only routes below a specific difficulty grade and only routes with "low risk" are displayed. In Fig. 1 you find the example of a resulting individual list of feasible routes.

Subsequently the users can inspect the details (see Fig. 2) for any route on the list. On the left hand side, meta data related to the selected route are provided together with the full information (including texts) of the avalanche forecasting service. On the right hand side, the route is shown on a topographic map. All route sections are colored according to their risk category. At a glance the user can understand, where potential avalanche hazard cruxes may be encountered on the route.

It must be mentioned, that the platform doesn't want to substitute a self-responsible trip planning according to the method 3x3. As soon as the user made his choice, he is invoked to plan and accomplish the trip as learned during avalanche education courses. Accordingly, the platform is explicitly not directed to novices.

3. METHODOLOGY

In order to calculate risk indicators for single points and for routes, the following data is fed into the model:

- Digital Elevation Model: SwissAlti3D raster data-set with a resolution of 10 m.
- Forestation: The SwissTLM3D vector data-set distinguishes between closed and open forests.
- A set of 625 popular backcountry routes, manually digitized.
- The currently valid avalanche forecasting data from the Swiss Snow and Avalanche Research Institute (SLF). The following elements get extracted from the service: Danger regions, danger levels and the core zone information (critical elevations

and critical aspects). The avalanche texts are used to fine-tune the danger level. In all zones outside the core zones the danger level is decremented (so called 1-level rule). In order to avoid danger level jumps, the algorithm works horizontally and vertically with continuous transitions between zones of different danger levels.

- A manually maintained data-set of "Safe Locations".

Fig. 3 shows the applied data flow model.

Core of the model is the Graphical Reduction Method (GRM). For details refer to Fig. 6. In Switzerland the GRM is part of the recommended avalanche doctrine, defined by the “Kernausbildungsteam Lawinenprävention Schneesport” (2014). According to Harvey & Nigg (2009) the GRM is one of the main decision tools for backcountry activities in avalanche terrain, nevertheless its significance decreases from the planning phase to the individual slope in the method 3x3.

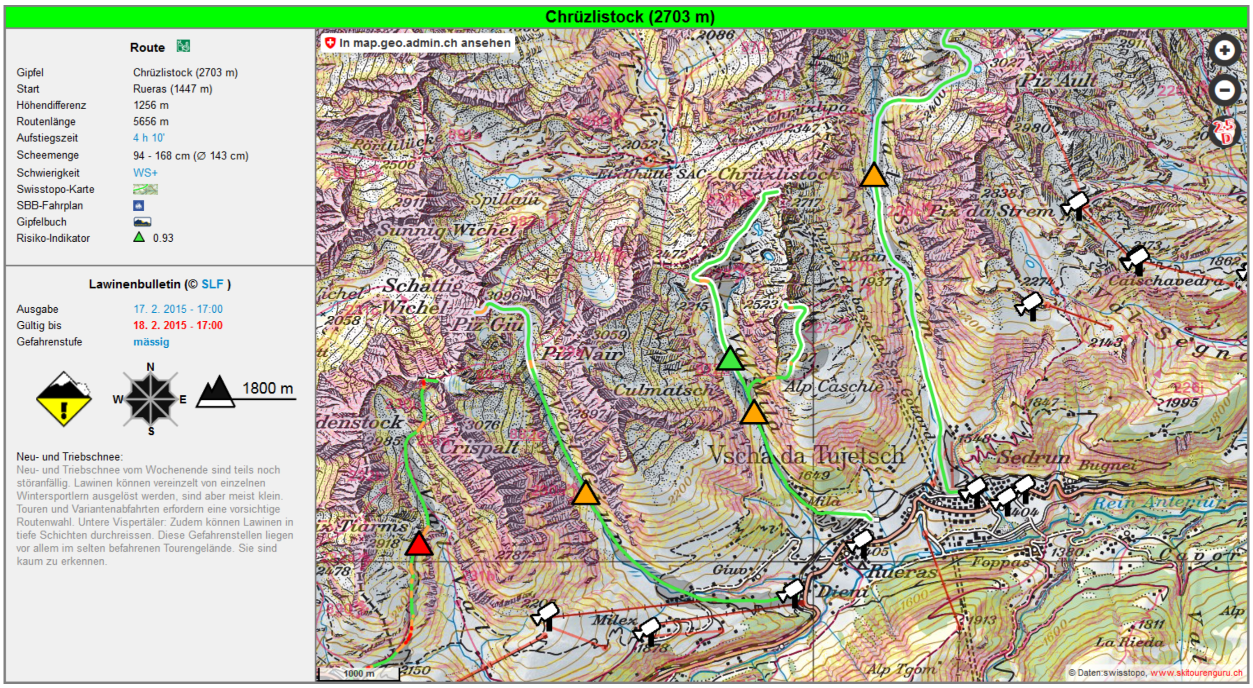

Fig. 2: Detail information of the route to the Chrüzlistock.

The GRM reflects the idea, that an elevated avalanche danger level can be compensated by renouncing to steep terrain. Consequently, the GRM allows the deduction of a risk category from the **slope angle** and the **avalanche danger level**. The GRM prescribes, that the terrain point, where the slope angle has to be recorded, depends on the avalanche danger level:

- Low (1): Steepest point must be searched on the track.
- Moderate (2): Steepest point must be searched within a distance of 20 m from the track.
- Considerable (3): Steepest point must be searched on the “entire slope”.
- High (4): Steepest point must be searched on the “entire slope including the deposition zone”.

Hereby, the exact definition of the “whole slope” is not straightforward and requires assumptions and simplifications. The implemented algorithm resolves the problem by calculating gradient lines and near gradient lines. All zones from where the current point of the skier can be reached by these lines are taken into account (see Fig. 4).

Danger moderation got implemented for forested areas (closed forests) and for ridges. Ridges got extracted by a **multi-scale planar curvature** algorithm. Closed forests are deduced from the highly precise SwissTLM3D terrain model.

It turned out, that the algorithm overrates the risk on secured roads or within secured settlements. Such rating errors get handled by a manually maintained safe location data-set.

As soon as the continuous risk indicators got calculated for each segment of the route, the final route risk indicator can be deduced from the risk values along the route. Therefore, the algorithm searches the riskiest n (n=250 m) meters along the route. The identified riskiest route segments can be scattered over the route or attached to each other. The route risk indicator is finally calculated by averaging the risk indicator over these segments.

The value n is a highly sensitive configuration parameter. A low value n will lead to higher risk indicators, a high value n will lead to lower risk indicators. The value n is configured in such a way, that the risk indicators have a reasonable safety margin (see chapter 5).

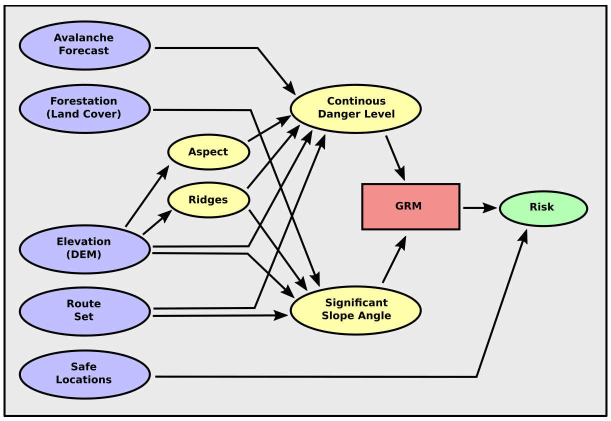

Fig. 3: Data flow model.

4. UNCERTAINTY

It's a common consensus that the occurrence of avalanches can't be predicted, but depending on time and location active avalanche releases are more or less likely. This likelihood should be expressed in probabilistic terms, i.e. as a probability of occurrence. However, experience shows that this is difficult, especially due to the large epistemic uncertainties that accompany any prediction. For that reason, it is common practice to express the probability of avalanche occurrence indirectly by a nominal risk indicator.

Although the risk indicator does not directly relate to probability, it is of importance that the epistemic uncertainties in the estimation of the indicator are considered consistently. The epistemic uncertainties relate to a) the data that is used to estimate the indicator, and, b) the algorithm where the data is combined.

Referring to a) it is noted that the data used for estimation of the risk indicator is different in terms of the spatial and temporal level of detail and measurement accuracy:

- DEM: With a resolution of 10 m and a precision between 1-2 m SwissALTI3D is an extremely accurate data-set.
- Forestation: SwissTLM3D vector data-set may not be always up-to-date but with a precision better than 10 m the best available data source.
- Routes: The routes are manually digitized on the best available topographic maps (scales up to 1:5'000). Different sets of GPS tracks supported the digitization process. Route drawing on topographic maps can follow a well-defined best practice; nevertheless, it's not possible to draw an optimal route unless you are in the terrain. A risk rating along a route on a map raises the issue of "route sensitivity".
- Avalanche forecasting service: The data provided by the avalanche forecasters has a high degree of abstraction (generalization level) and each data element carries a level of uncertainty difficult to quantify.

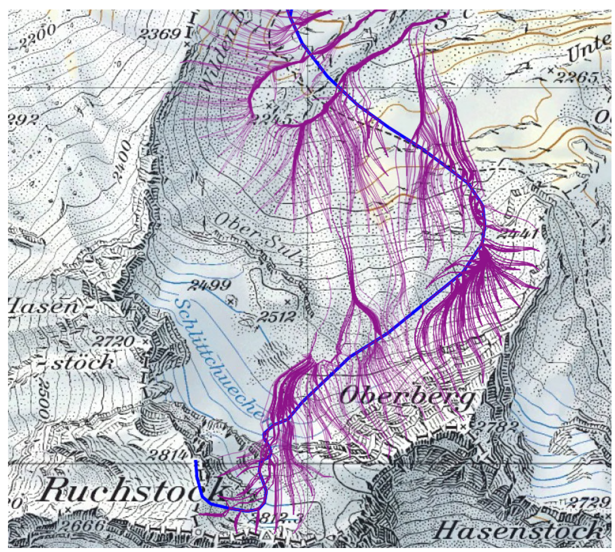

Fig. 4: Gradient lines (Base map: Swisstopo).

Data about the terrain and data from avalanche forecasting have a fundamentally different character. Where the terrain data has a resolution of 10 m and is extremely accurate, the avalanche forecasting data at best has a resolution of many kilometers and is highly uncertain. However, both data contain important information that is considered for the estimation of the risk indicator.

Every trip planning activity that takes into account the avalanche forecasting data implicitly or explicitly combines these fundamentally different data types. It's important to understand, that the output can't provide an accurate analytic single slope forecast. Nevertheless, the output can support an optimal strategic decision process by maximizing the mobility and minimizing risks.

Referring to b) some further limits are due to the applied model:

- The GRM has a weak scientific base. Pfeifer (2008) provided one of the few proposals to validate Munter's Reduction Method. Particularly the parametrization (search distances, separation of risk categories) of the GRM remain questionable.
- The GRM focuses on slope angles, excluding other terrain features like **slope size**, **slope form**, **slope roughness** or **distance to ridges**. Schmudlach & Köhler (2016) propose a terrain classification scheme, that encompasses more than just the slope angle.
- The GRM acknowledges only quantifiable information from the avalanche forecasting service and dismisses all qualitative information.
- The GRM can only take into account current snow conditions if they are represented by the quantifiable information of the avalanche forecasting data. This applies especially to the **drift snow** and **wet snow** pattern.

All mentioned limits can weigh on the coherence of the resulting risk indicators.

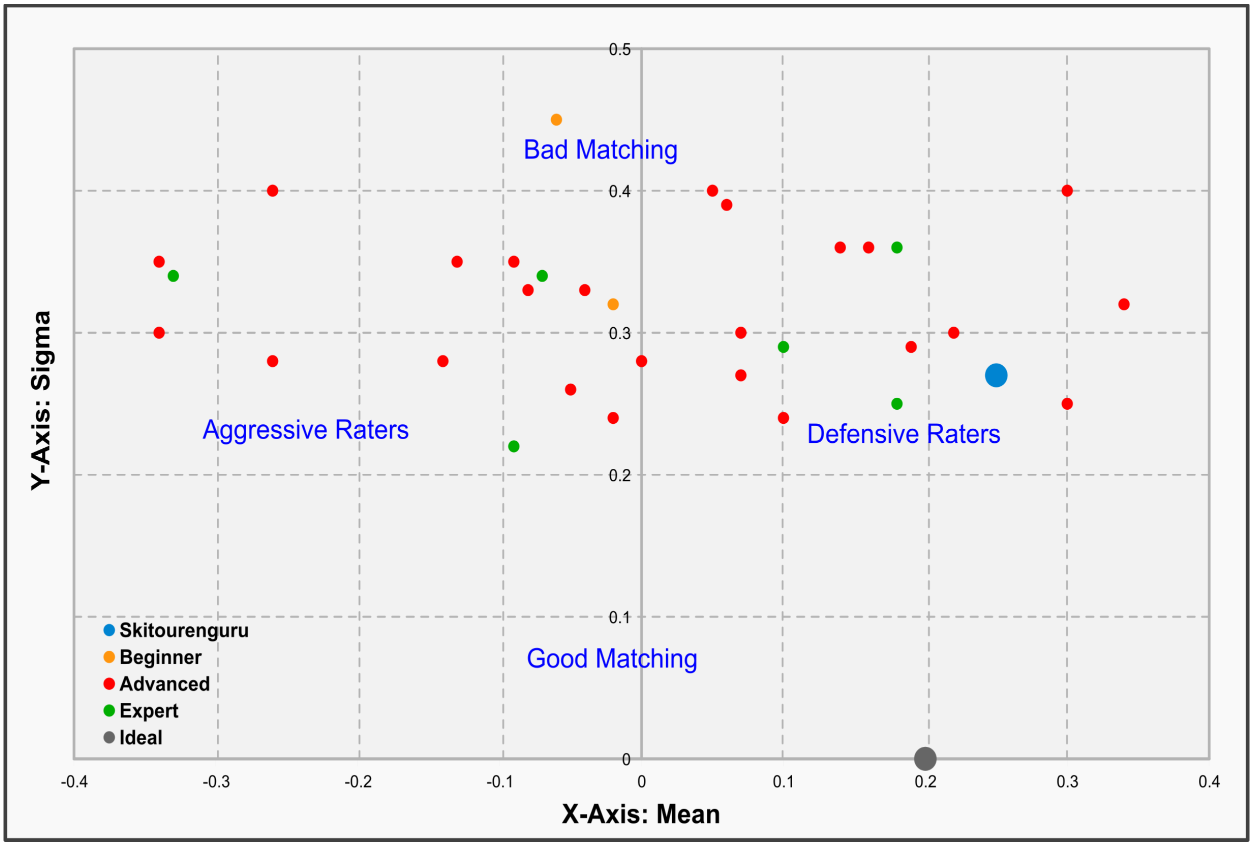

Fig. 5: Mean/Sigma Scatter Diagram for all 32+1 poll participants.

5. VALIDATION

Reduction Methods can be verified by combining avalanche accident data with data about the movement pattern of the recreation community. The movement pattern of the recreation community basically remains unknown. Accident data are known to have a bias towards accidents with serious consequences. Due to these difficulties in this approach we validate the algorithm by comparing the results to a **reference rating**. The reference rating, was deduced from a poll performed in the winter 2015/16. Every poll participant had to rate a set of 30 popular backcountry routes for 3 well defined typical avalanche bulletins. Accordingly the participant had to fill out a table consisting of 90 (30x3) risk indicators in the range [0..3].

The reference rating got calculated by averaging over all 32 **participant ratings**. Depending on the skill level of the participant, different weights got attributed: 4 (expert), 2 (advanced) or 1 (novice).

Results: The 99%-confidence interval remains for all 90 risk indicators under ±0.16. These unexpectedly sharp confidence intervals are due to a relatively high level of agreement among the participants.

Subsequently it was possible to compare every individual participant rating to the reference rating. Comparison was done by calculating mean and standard deviation (sigma) over all 90 **error values**. The error values can be calculated by subtracting the reference rating from a participant rating. Fig. 5 shows a mean/sigma scatter diagram for all 32 participants plus the automatically generated rating (Skitourenguru). The x-axis (mean) gives us a measure, whether the participant rates routes more defensively or aggressively then the reference rating. The y-axis (sigma) gives us a measure how well the participant matched the relative rating pattern.

The automatically generated rating (Skitourenguru) has a low sigma value (0.27) and a high mean value (0.25). A low sigma value means a "good matching" of the relative rating pattern. Skitourenguru is among the best 20 % of all participants. A high mean value means "defensive rating". The value can be interpreted as a relatively high safety margin.

Some principal shortcomings of the poll suggest we shouldn't over interpret the results:

- Even though a part of the participants are personally known to the authors, their skill levels basically remain unknown.
- It's unknown, whether the participants got a common understanding of the task to be executed. This problem specifically applies to the mental calibration of the risk scale [0..3].
- From a statistical point of view, averaging over an ordinal numeral is not approved.

Nevertheless, the poll points in the same direction as a statement from Harvey & Dürr (2016) that a user must have a very good knowledge to top the ratings of the presented algorithm.

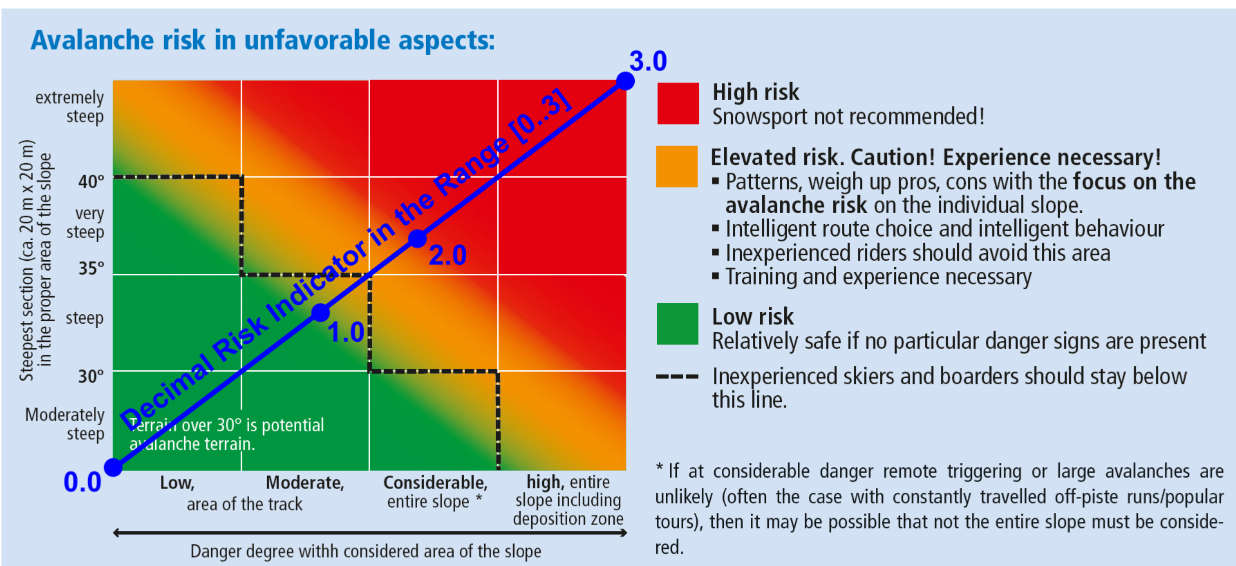

Fig. 6: Graphical Reduction Method (GRM).

6. CONCLUSIONS

There is a principal agreement among avalanche experts, that a relevant part of accidents could be prevented by a strict application of a risk reduction method. Walter & Brügger (2012) confirm that for a total of 441 avalanche accidents in Switzerland between 1999 and 2009, the GRM would have signalized in 64 % of the cases a "high risk" and in further 27 % of the cases an "elevated risk". McCammon & Hägeli (2004) report for the US **prevention values** between 65 and 82 %. Even though the reported numbers were questioned by Uttl et al. (2012), the principal capability of reduction methods to prevent avalanche accidents was never negated. If the presented platform has the ability to direct the users to places with lower avalanche risk, it can make an important contribution to the avalanche accident prevention. Munter (1997) notices that every tool based on selective abstinence must work by definition. An algorithm that penalizes steep slopes oriented to the north and danger zones with the danger level “considerable” obviously can propagate selective abstinence.

Even for advanced users it is a challenging task to apply a risk reduction method. As the related process exhibits a considerable interpretation space, human beings can easily be trapped by emotions, beliefs, and motivations as described in Kanheman (2012). A standardized algorithm able to calculate reproducible risk ratings for a huge amount of routes can direct the attention of the users towards routes with a low a priori risk level. Finally, a platform that provides a real added value to users, has an enormous potential to link users to up-to-date avalanche knowledge.

Nevertheless, it’s important to remember that risk reduction methods deploy their value first and foremost during the planning phase. The assessment of the alpine winter terrain requires a complex set of skills. A platform that provides dynamic risk indicators for routes involve a certain risk that novices get attracted to a terrain they are not able to handle. Partly the issue can be faced by adequate user communication and guidance, but the risk to attract novices can’t be discarded totally. At least a click statistic from the winter 2015/16 clearly shows, that the focus of the users is on routes with low risk level. The limits presented in chapter 4 implicate that the calculated risk indicators can be incoherent. Misleading risk indicators are a problem, but the high levels of uncertainty in the avalanche domain suggest we must abandon the concept of absolute correctness and absolute safety.

The major challenge is the development of best practice tools, that support an optimal decision making process. Automatic algorithms can make an important contribution, as they are not affected by human biases. Kahneman (2012) notices: “*Statistical algorithms greatly outdo humans in noisy environments for two reasons: they are more likely than human judges to detect weakly valid cues and much more likely to maintain a modest level of accuracy by using such cues consistently*”.

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