COMBINING THE CONCEPTUAL MODEL OF AVALANCHE HAZARD WITH THE BAVARIAN MATRIX

Karsten Müller[1]*, Christoph Mitterer[2], Rune Engeset[1], Ragnar Ekker[1] and Solveig Ø. Kosberg[1]

[1]Norwegian Water Resources and Energy Directorate, Oslo, Norway
[2] Bavarian Avalanche Warning Service, Munich, Germany now at ALPsolut S.r.l., Livigno, Italy

ABSTRACT: The European Avalanche Danger Scale provides definitions for each of the five danger levels. However, some terms used in the scale are not fully defined, which might lead to inconsistent assessments and communication of avalanche danger among different forecasting services, but also within the same team of forecasters. Already in 2005, the European Avalanche Warning Services (EAWS) introduced the Bavarian Matrix (BM) as an auxiliary tool to overcome these inconsistencies. However, some of the cells of the matrix are still not fully accepted and discussed within the EAWS. Discussions among forecasters revealed that the ambiguous definitions of the terms applied within the BM are the main reason for the debate on these cells. In 2010, the North American avalanche community implemented a revised version of the avalanche danger scale and declared its first and foremost purpose is public risk communication. The Conceptual Model of Avalanche Hazard (CMAH) was developed as part of the revision process in North America. It describes the process of avalanche danger assessment in a comprehensive manner. The strength of the CMAH is its streamlined structure and definition of the individual terms used and its integration of avalanche problems. Although all applied terms map directly to the North American Avalanche Danger Scale, the CMAH fails to provide a danger level at the end of the assessment process, which again might lead to different assessments. Therefore, we propose a merge of the two concepts, CMAH and BM. Our merge resulted in the Avalanche Danger Assessment Matrix (ADAM), which consists of a likelihood-matrix and a danger-matrix based on the NA definitions. We also provide a link to the terms used within the EAWS.

KEYWORDS: Avalanche forecasting, Bavarian Matrix, Conceptual model of avalanche hazard, EAWS.

1. INTRODUCTION

In 1993, the European Avalanche Warning Services (EAWS) agreed on a common 5-level danger scale (SLF, 1993). The European Avalanche Danger Scale (EDS) defines each danger level by the expected snowpack stability and the avalanche triggering probability. The spatial distribution of hazardous spots is inherent in both columns. In addition, the column on avalanche triggering probability specifies the expected avalanche size with regard to natural triggering. Besides minor changes in 1994 (SLF, 1994), this danger scale is still in use in Europe today. However, some limitations and ambiguities in the scale were identified. In order to harmonize the assessment among avalanche forecaster for the cases/scenarios on smaller increments, the EAWS adopted the Bavarian Matrix (BM) in 2005 (EAWS, 2016a).

* *Corresponding author address:*
Karsten Müller, Norwegian Water Resources and Energy Directorate, Middelthunsgt. 29, 0301 Oslo, Norway;
tel: +47-2295-9096;
email: kmu@nve.no

1.1 The Bavarian Matrix

The EDS describes an increase in at least two of the three factors: snowpack stability, spatial distribution, and destructive size with each danger level. The BM disaggregates the factors spatial distribution and probability of avalanche release of the EDS and provides thereby a more differentiated description of each danger level (Fig. 1).

Bavarian Matrix (auxiliary matrix for preparing the avalanche bulletin)

Distribution of hazards sites \ Probability of avalanche release	generally only with high additional loads	particularly with high additional loads (possibly also with low additional loads)	already with low additional loads possible	with low additional loads probable	OR	spontaneous release of small-sized avalanches possible	spontaneous release of medium-sized, in some cases large-sized avalanches possible	spontaneous release of many medium-sized, in several cases large-sized avalanches probable	spontaneous release of numerous large-sized, often large-sized avalanches probable
single hazard sites (specificable in the AR*)	1	2	2	2		1	2		
hazard sites on some steep slopes (specificable in the AR*)	2	2	3	3		2	3	3	
hazard sites on many/most steep slopes (specificable in the AR*)	2	2	3	4		2	3	4	4
hazard sites on many/most steep slopes (not definable in the AR*)	2	3	4	4		3	4	4	5
hazard sites also in moderately steep slopes				5			4	5	5

Effective 2011-09-01

Fig. 1: The EAWS adopted the Bavarian Matrix as an auxiliary tool in 2005. It provides the working basics for the generation of the avalanche bulletins (EAWS, 2016a). The grey fields are not finally approved yet.

The BM is basically a look-up-table, which should facilitate a harmonized determination of the avalanche danger level. It was originally introduced to assure uniformity between avalanche forecaster within an organization, but also with neighboring avalanche forecasting services. The BM is split into a human-triggered part (left) and a part dealing with spontaneous avalanches (right). The vertical axis depicts the distribution of hazardous spots increasing from top to bottom. On the horizontal axis release probability for human-triggered avalanches and/or release probability and number of possible spontaneous avalanches are depicted. The BM neglects the avalanche size on the human-triggered part, but having evaluated all factors, the forecaster can clearly find a commonly defined level of danger.

A workgroup of the EAWS is currently working towards an improved BM (Müller et al., 2016) and method described in our paper is a result of this process.

1.2 The Conceptual Model of Avalanche Hazard

The North American avalanche community first adopted the EDS in 1994, but released a revised version in 2010 (Statham et al., 2010). At the beginning of the revision process, North American avalanche experts stated that "*initial explorations to define the problem resulted in more questions and uncovered an almost complete absence of formal underpinnings for the danger scale*" (Statham et al., 2010).

The responsible work group developed the conceptual model of avalanche hazard (CMAH) during the revision of the danger scale. The CMAH describes the workflow of an avalanche forecaster to assess the avalanche hazard as illustrated in Fig. 2.

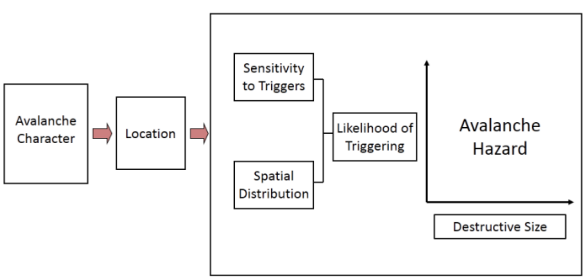

Fig. 2: The process of assessing avalanche hazard as described by the CMAH (Canadian Avalanche Association, 2016a).

Following this workflow the forecaster first identifies the avalanche character, its spatial distribution and its sensitivity to triggers. The latter two factors lead to the likelihood of triggering. Finally, an expected destructive size has to be given. The avalanche hazard chart (Fig. 3) concludes the assessment process.

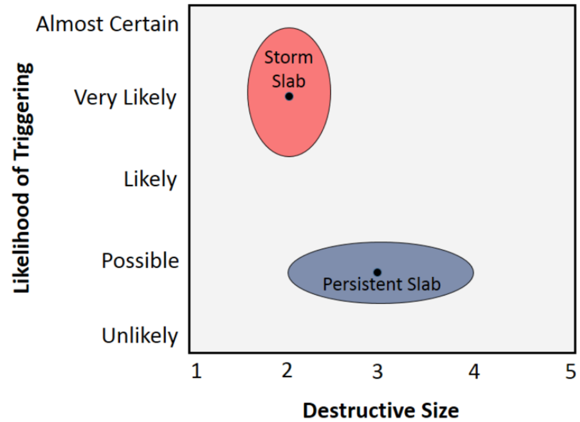

Fig. 3: An example of the avalanche hazard chart (Canadian Avalanche Association, 2016a).

The chart indicates the ranges of likelihood of triggering and destructive sizes for relevant avalanche problems as an ellipsis. The size of each ellipsis indicates the uncertainty related to the avalanche problem (Canadian Avalanche Association, 2016a). The lower left corner of the hazard chart indicates low avalanche danger, while the upper right corner indicates high/extreme avalanche danger. The CMAH does not provide a danger level.

1.3 Advantages and disadvantages of the two concepts

The BM suggests a danger level for most combinations of spatial distribution and avalanche release probability. The BM (in its current state) does not incorporate avalanche size with regard to human-triggered avalanches. E.g. in a situation where it is possible to trigger an avalanche by low additional load on some slopes, danger level 3-considerable is suggested, independent of the expected size. Thus, leaving room for interpretation of the danger level among forecasters.

The terms used in the BM and EDS are ambiguous and overlap in their relevance for the avalanche danger level. E.g. the relation between the snowpack stability, the necessary additional load and the probability of avalanche release are not well defined.

The CMAH provides a clear guidance for the avalanche danger assessment process. The concluding avalanche hazard chart provides visual guidance to which danger level might be appropriate and its accompanying uncertainty. However, it does not suggest a danger level and little aid is provided in situations that are in-between two danger levels.

Another potential ambiguity in the CMAH is that it does not describe the link between the factors: sensitivity to triggers, spatial distribution, and the likelihood of triggering. It only states that the likelihood of triggering depends on the spatial distribution and the sensitivity to triggers.

Compared to the terminology used in the BM the terms used in the CMAH are clearly separated and individually defined. We compared the terminologies of the two concepts to identify similarities and differences.

Both concepts should aid the forecaster in his/her avalanche danger assessment process. Both concepts have advantages and disadvantages and it seems that these are antipodal to each other. We therefore attempt to combine the two concepts to remove their soft spots.

2. COMPARISION OF TERMS

We compared the terms used in the BM and the CMAH to establish a link between them before we try to merge the two. In North America the term avalanche hazard is frequently used, while in Europe avalanche danger is more common. We treat these two terms as equal in this study. We further treat the terms “natural release” and “natural triggered” as equal in this study. Tables 1-4 show a comparison of terms used in the BM and the CMAH, as well as the danger scales NADS and EDS.

2.1 Additional loading vs. sensitivity to triggers

At first, the largest difference between the BM and CMAH is the classification of the necessary triggers/loading.

The BM separates between low additional load (defined as “*individual skier/snowboarder, riding softly, not falling*”) and high additional load (defines as e.g. “*single hiker / climber*”) (EAWS, 2016c). The EDS terms “high” and “low” additional load are used as a substitution to indicate lower or higher probability of human-triggered avalanches. The CMAH seems to combine these two terms as human-triggering, but we could not find a clear definition of human-triggering as part of the CMAH. E.g. is a group of skiers riding closely together considered human-triggering? The exact definition will have an impact on the likelihood terms used in combination with these triggers and the relation to the terms in the BM. Tbl. 1 shows our interpretation.

Tbl. 1: Comparison of terms related to human triggering used in the BM and CMAH. The last column also suggests a link to the snowpack stability terms used in the EDS.

Triggering by additional load (BM)	*Sensitivity to (human) triggers (CMAH)*	*Snowpack stability (EDS)*
With low additional load probable	Touchy (Triggering almost certain)	Poorly bonded
Already with low additional loads possible	Reactive (Easy to trigger with ski cut)	Moderately to poorly bonded
Particularly with high additional load	Stubborn (Difficult to trigger)	Moderately well bonded
Generally, only with high additional loads	Unreactive (No avalanches)	Well bonded

Snowpack stability is an integral part of the EDS. However, it is not used in the BM. We see the EDS terms *snowpack stability* and *avalanche triggering probability* as inversely related and redundant. Meaning the column *snowpack stability* could be removed from the EDS. The CMAH replaces these two terms by the term *sensitivity to triggers* (Tbl. 1).

Tbl. 2: Comparison of terms related to natural avalanche release used in the BM and CMAH. The BM uses number of avalanches while the CMAH expresses likelihood of natural avalanches.

Number of avalanches (BM)	*Sensitivity to (natural) triggers (CMAH)*	*Likelihood of natural avalanches (NADS)*
Numerous	Touchy (numerous)	Very likely / almost certain
Often / “in some cases numerous”	Reactive (several)	Likely
In some cases	Stubborn (few)	Possible
Unlikely / “in isolated cases” / “only small avalanches are possible”	Unreactive (No avalanches)	Unlikely

Tbl. 2 shows the link between the terms used for naturally triggered avalanches. The right hand side of the BM expresses increasing danger by an increasing number/amount of avalanches, while the CMAH uses the same four sensitivity terms as in Tbl. 1, but providing a slightly different explanation (Canadian Avalanche Association, 2016a). In the NADS, the likelihood for human- and natural triggered avalanches is described by the four likelihood terms in the last column of Tbl. 2.

2.2 Destructive size

The destructive size of an avalanche is divided into five classes, both in Europe and North America (Canadian Avalanche Association, 2002; EAWS, 2016c). The numbering and description of the destructive potential is almost identical (Tbl. 3). Differences exists in the naming conventions for each class.

Tbl. 3: Comparison of the avalanche size naming conventions in the EDS and North American Danger scale (NADS).

Destructive size (BM & CMAH)	*BM/EDS new convention*	*NADS*	*BM/EDS old convention*
1	Small	Small	Sluff
2	Medium		Small
3	Large	Large	Medium
4	Very large		Large
5	Extreme	Very large	Very large

The recent adoption of new names for the avalanche sizes in Europe is more in line with naming used in North America.

2.3 Spatial distribution

The spatial distribution describes the extent of potentially unstable slopes within the forecasting area. The terminology for the spatial distribution of hazardous spots is similar, with the exception that the BM uses three different terms for the class that the CMAH generally summarizes as "*widespread*" (Tbl. 4). However, neither the BM nor the CMAH state which extent should be considered. EAWS states that a danger level can be issued for areas of more than 100 km^2, but no upper limit is given. Around the world, forecasting services operate in areas of thousands or even tenth of thousands of km^2. The CMAH states that uncertainty is connected to scale (Canadian Avalanche Association, 2016b) indicating that larger regions need to be treated different than smaller regions.

Tbl. 4: Comparison of terms used to describe the spatial distribution in the BM and CMAH.

Spatial distribution of hazardous sites (BM)	*Spatial distribution (CMAH)*
Single / isolated	Isolated
Some / indicated	Specific
Many	Widespread / many
Most	
Also in moderately steep terrain	

3. AVALANCHE DANGER ASSESSMENT MATRIX

We merged the concepts behind the BM and CMAH into the Avalanche Danger Assessment Matrix (ADAM). ADAM combines the workflow of the CMAH with the visual design and the link to the danger levels that the BM provides (Fig. 4 & 5). ADAM has two components, a Likelihood Matrix and a Danger Matrix. The Likelihood Matrix establishes the relation between the sensitivity to triggers on its vertical axis and the spatial distribution on its horizontal axis. The Danger Matrix combines the resulting likelihood of triggering on its vertical axis with the destructive size on its horizontal axis to suggest a danger level. It is designed to be an objective assessment tool for the forecasters, but may also be used to communicate the basis for the danger rating to advanced users. Fig. 4 shows ADAM using the CMAH terminology and Fig. 5 using the BM terminology. The relations between these terms are as stated in Tbl. 1-4.

ADAM follows the assessment process described by the CMAH. We first evaluate the sensitivity to triggers (or snowpack stability), e.g. "*reactive*", and the spatial distribution of the current or expected avalanche conditions, e.g. "*specific*". We could start at the top left corner of the likelihood-matrix and ask ourselves "*are touchy conditions widespread?*" If not, we continue to the next combination "*are touchy conditions present on specific terrain features?*" and so forth until we match our current/expected conditions. Then we transfer the yielded likelihood of triggering ("*possible*" in our example) over to the danger.

We then move along the corresponding likelihood-row in the danger matrix to the typical avalanche size for the current or expected conditions (e.g. "*size 3*"), providing us with the corresponding danger level ("*3-considerable*" in our example).

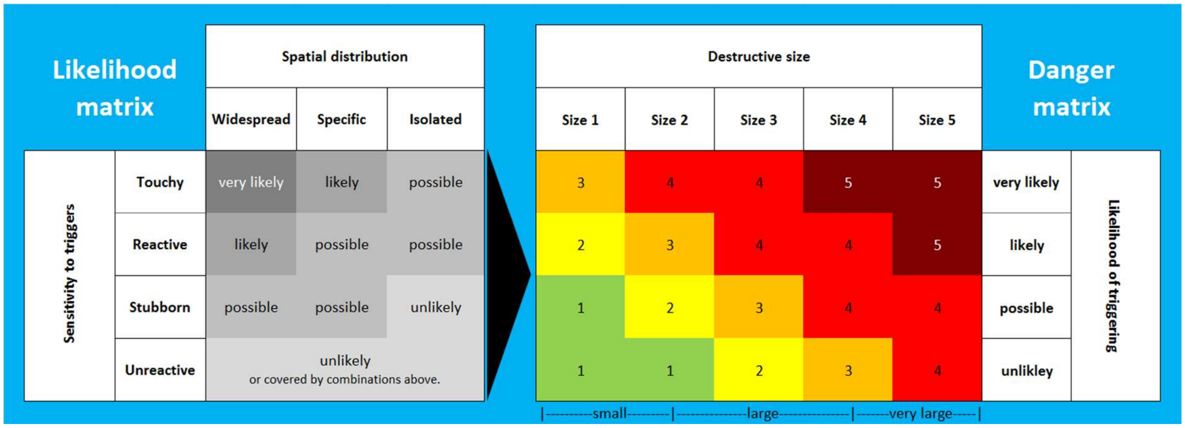

Fig. 4: Avalanche Danger Assessment Matrix (ADAM) using the CMAH terminology. The Likelihood Matrix on the left-hand side defines the likelihood term based on the assessed spatial distribution and the sensitivity to triggers. The Danger Matrix on the right hand side, provides the guideline for the appropriate avalanche danger level by combining the resulting likelihood of triggering with the expected destructive avalanche size. The last row "unreactive" will generally be covered by other combinations, e.g. if many slopes are unreactive, isolated might still be reactive or stubborn and therefore define the corresponding likelihood.

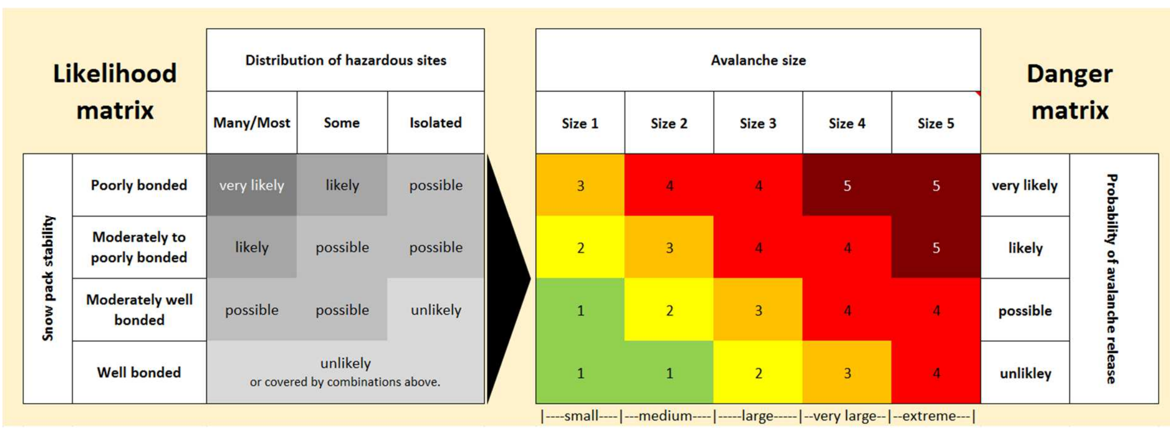

Fig. 5: ADAM with terms used in the BM. The axis of "snowpack stability" could be exchanged with "triggering by additional loading" as stated in Tbl. 1.

Fig. 6 & 7 show two examples of the use of ADAM using forecasts from www.varsom.no, in order to illustrate two typical situations. In Fig. 6, CMAH terminology is used, and BM terminology is used in Fig 7. The system of selecting and displaying selected cells in the matrices is easy to implement and use in forecasting software, both for producing bulletins and for presentation to end users. It is easy to understand the logic behind the forecast, which factors produce the danger level for the different avalanche problems and what is required to tilt the danger level up or down.

Since the Danger Matrix closely resembles the "*avalanche hazard chart*" of the CMAH, it could be used in a similar manner. Avalanche problems and there uncertainty can be drawn on the danger matrix. However, we recommend to use rectangles instead of ellipsis. In case of uncertainty, both in the destructive size and the likelihood of triggering of more than one class, one danger level will always have the majority inside the rectangle and should be chosen. If the uncertainty stretches over more than two classes of one/both factors in the danger matrix, and cannot be reduced, this high level of uncertainty needs to be clearly communicated to the user.

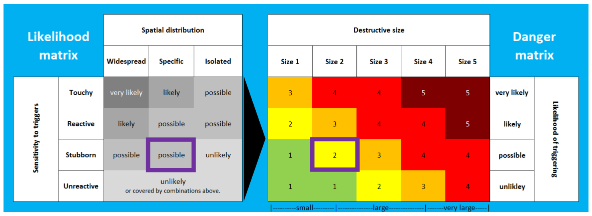

Fig. 6: The first example illustrates a situation with expected snow precipitation (1-15 cm, showers) and strong winds, creating a wind slab problem on top of a generally stable snow cover (Varsom, 2016a). The problem is limited to specific slopes. Triggering is expected to be difficult and danger level 2-moderate was issued.

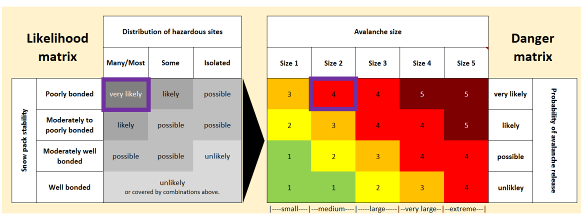

Fig. 7: In the second example, heavy snow precipitation (30-50 cm) and strong winds are forecasted (Varsom, 2016b). This comes on top of another 20-40 cm of new snow from the previous day. Thus, a storm slab problem and a loose dry problem are expected. The problems are widespread, the snow pack is poorly bonded and triggering easy. Danger level 4-high was issued.

4. DISCUSSION

ADAM links the results in the avalanche hazard chart to the avalanche danger levels. By analyzing the BM we found that rather the avalanche size than the difference between human- and natural triggered avalanches influences an increase in danger level. By introducing the avalanche size, we were able to remove this separation inherent in the BM. ADAM does not explicitly differentiate between human-triggered or naturally-triggered avalanches. This information is inherent in the sensitivity to triggers and assessed there. However, this important information needs to be conveyed to the user through the avalanche bulletin.

While the danger scale only describes a change in danger level when two or more of the three main factors change, ADAM defines each incremental change. The BM does the same, but is lacking the avalanche size as an individual factor. Ideally, the classes for each factor contributing to the avalanche danger should be chosen such that an increase/decrease in each of them has an equal impact on the danger level suggested. E.g. an increase of the expected avalanche size class should have an equal impact on the danger level as a step up in the spatial distribution classification.

Haegeli et al. (2012) tried to establish a link between the danger rating and the CMAH by analyzing the assessments of Canadian and U.S. avalanche forecasters over three years. We did a similar, however less quantitative analysis, for Norway. An originally ambiguous definition can lead to subjective biases in the statistical analysis. This was also observed by Haegeli et al. (2012) who stated: "*While forecast regions did not have a significant effect on the selection of danger ratings, significant differences were identified among avalanche forecasters.*" It is therefore important to define each factor influencing the assessment process in an unambiguous manner.

We find the terms used in the EDS and the BM ambiguous and partially redundant. The different languages in Europe pose certain challenges while identifying common terms. A literal translation of one term into another language sometimes is accompanied by a slight change in meaning or common perception of this term. This potential change in perception of one term could lead to a different perception in the avalanche danger assessment. A translation should aim at adhering to the definition rather than being literally correct. This will require a careful translation process.

We suggest to establish links between the terms used internationally as illustrated in Tbl. 1-4 to reduce subjective and/or ambiguous use among forecasters and to ease communication with the users. In the future, it might be helpful to establish internationally accepted terms in one language from which the national (language-specific) terms are derived.

4.1 Improving definitions

The Likelihood Matrix of ADAM provides a relation between the sensitivity to triggers (snowpack stability), the spatial distribution and the likelihood of triggering. However, a subjective bias might still be present in the definitions of these terms. Based on our experience, we see the biggest challenge in the definition of the terms "likelihood of triggering" and "spatial distribution".

Spatial distribution in terms of *isolated*, *specific widespread* or *some* and *many* etc. does not yet have a common definition with regard to the size of the forecasting region at hand. The CMAH defines it with regard to how easy it is to find evidence for an instability and how this evidence is distributed. In Europe, definitions vary from service to service or are not defined at all. A suggestion, that came up in context with introducing the BM in 2003 is shown in Tbl .5 (T. Stucki, pers. comm.).

Tbl. 5. Possible definition for the spatial distribution of unstable slopes within a region.

Spatial distribution term	*Suggested percentage of unstable avalanche terrain within a region*
Isolated	<10%
Some	10-30%
Many	30-66%
Most	>66%

A study at SLF showed that at danger level 2-moderate about 25% of the randomly picked slopes are unstable, while at 3-considerable 50% of the slopes were unstable (Harvey et al., 2012). If we match these values with the description in the danger scale(s) for these levels the terms “some/specific” would correspond to 25% and “many” to 50% unstable slopes within a region. Thus, falling in the ranges provided by Tbl. 5.

Defining likelihood for a rare event such as triggering an avalanche is challenging. As forecasters, we want to make people aware of a potentially dangerous situation. We tell them “today, it is likely that you trigger an avalanche”. If we look up various definitions for “likely” we end up with values of more than 50% or even 66% percent (EAWS, 2016c; Mastrandrea et al., 2010). However, sending out 1000 skiers on 1000 avalanche slopes at considerable avalanche danger, would luckily not result in 500 or more accidents.

The Likelihood Matrix of ADAM defines likelihood as a product of sensitivity to triggers (or snowpack stability) and the spatial distribution. To find correct percentages for our likelihood we have to assign percentages to the individual factors.

If we use the suggestion in Tbl. 5 and assume we have a poorly bonded snowpack on some slopes (~20%) in our forecasting area. We further define a poorly bonded (or touchy) snowpack as a 50% chance for a human to trigger an avalanche on one of these slopes (or another more reasonable value). According to the likelihood matrix we consider the likelihood of triggering as “likely”. In numbers (0.2 x 0.5 = 0.1), it would correspond to a 10% chance of triggering an avalanche in our forecasting area. 10% is a very low likelihood compared to other definitions, e.g. Mastrandrea et al. (2010) call such an event “very unlikely”. However, since triggering an avalanche is already a very rare event, a ten percent chance is very high in that respect. Since using “very unlikely” would not work in our communication to the public, we have to apply terms such as “likely”, but with a definition that works in our context.

4.2 User communication

The main goal of a regional danger rating is to communicate the danger to the public. It should therefore be an integral part of the assessment process to evaluate the message the danger rating sends to the user.

Simple phrases for each danger level geared towards specific user groups can be easily derived from ADAM. For recreational backcountry travelers avalanches of size 2 pose a serious threat. A short phrase for each danger level can be derived from the column “size 2” of the Danger Matrix in Fig. 4 (Tbl. 6).

Tbl. 6: Short and intuitive description for each danger level would ease communication with media and end-users.

Danger level	*Compact description*
1 – low	Avalanches are unlikely or small.
2 – moderate	Avalanches are possible, but mainly small.
3 – considerable	Avalanches are likely and may be large.
4 – high	Avalanches are very likely and may be large.
5 – very high / extreme	Avalanches are certain and may be very large.

5. CONCLUSION

We presented a merge of two avalanche assessment approaches, Bavarian Matrix and Conceptual Model of Avalanche Hazard. The intention was to combine the strength of each concept. The result is the Avalanche Danger Assessment Matrix (ADAM). ADAM is used to assess the avalanche danger from the three factors avalanche size, sensitivity to triggers (snowpack stability) and spatial distribution. It is based on the CMAH, the Bavarian Matrix and the European and North American Danger Scales. ADAM has two components, a

Likelihood Matrix and a Danger Matrix. It is designed to be an objective assessment tool for the forecasters, but may also be used to communicate the basis for the danger rating to advanced users.

We established a relation between the factors "*sensitivity to triggers*", "*spatial distribution*", and the "*likelihood of triggering*", which is ambiguous in the CMAH. We added the factor "*destructive size*" to the concept of the BM, while simultaneously reducing its complexity.

We compared the terms used in North America and Europe to describe the three major factors of avalanche hazard assessment. We found that the terms used in one system have equivalents in the other system. In our opinion, the terms in the CMAH are less ambiguous than in the BM. Establishing a clear translation/relation between the terms commonly used will ease the understanding and communication between different avalanche forecasting services and the subjective bias between forecasters. We also believe that such a merge could provide the basis for a framework that could find international acceptance. The danger scale itself does not necessary need to contain the full definitions if its main purpose is (ease of) communication with the public. ADAM combined with the CMAH or similar concepts should provide the full definition and be the basis for the professional avalanche forecaster and advanced users.

ACKNOWLEDGEMENTS

We like to thank Thomas Stucki, Patrick Nairz, Grant Statham, Karl Birkeland, Markus Landrø, Hans Konetschney, Thomas Feistl, Bernd Zenke, Igor Chiambretti, Flavio Berbenni, Samuel Morin and Jürg Schweizer for valuable discussions on the Bavarian matrix, the CMAH and avalanche danger assessment.

REFERENCES

Canadian Avalanche Association, 2016a: Conceptual Model of Avalanche Hazard. Accessed 17. August 2016 [Available online at http://infoexhelp.avalancheassociation.ca/images/8/8e/Conceptual_Model_of_Avalanche_Hazard_Final.pdf]

Canadian Avalanche Association, 2016b. Technical Aspects of Snow Avalanche Risk Management - Resources and Guidelines for Avalanche Practitioners in Canada (C. Campbell, S. Conger, B. Gould, P. Haegeli, B. Jamieson, and G. Statham Eds.). Revelstoke, BC, Canada

Canadian Avalanche Association, 2002. Observation Guidelines and Recording Standards for Weather, Snowpack, and Avalanches. Revelstoke, BC.

EAWS, 2016a: Avalanche danger scale. Accessed 17 August 2016 [Available online at http://www.avalanches.org/eaws/en/main_layer.php?layer=basics&id=2]

EAWS, 2016b: Bavarian matrix. Accessed 17 August 2016 [Available online at http://www.avalanches.org/eaws/en/main_layer.php?layer=basics&id=4]

EAWS, 2016c: Glossary. Accessed 17 August 2016 [Available online at http://www.avalanches.org/eaws/en/includes/glossary/glossary_en_all.html]

Haegeli, P., Falk, M., Klassen, K., 2012. Linking Avalanche Problems to Avalanche Danger – A First Statistical Examination of the Conceptual Model of Avalanche Hazard. Proceedings of the International Snow Science Workshop in Anchorage, Alaska

Harvey S., Rhyner H., Schweizer J., 2012. *Lawinenkunde*. Bruckmann Verlag GmbH, München, ISBN 978-3-7654-5779-1, 192 p.

Mastrandea, M.D., Field C.B., Stocker T.F., Edenhofer O., Ebi K.L., Frame D.J., Held H., Kriegler E., March K.J., Matschoss P.R., Plattner G.K., Yohe G.W., Zwiers F.W. 2010, Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on the Consistent Treatment of Uncertainties. Intergovernmental Panel on Climate Change. Accessed 17 August 2016 [Available online at http://www.ipcc.ch]

Müller, K., Stucki, T., Feistl, T., Konetschny, H., Coleou, C., Nairz, P., Berbenni, F. and Mitterer, C. 2016. Towards an improved European auxiliary matrix for assessing avalanche danger levels. Proceedings of the *International Snow Science Workshop* Breckenridge 2016.

Staham, G.,Haegeli, P.,Birkeland, K. W., Greene, E., Israelson, C., Tremper, B., Stethem, C., McMahon, B., White, B., Kelly, J., 2010a: The North American Public Danger Scale. Proceedings of the *International Snow Science Workshop, Lake Tahoe, CA*

Statham, G., Haegeli, P., Birkeland, K. W., Greene, E., Israelson, C., Tremper, B., et al., 2010b. A conceptual model of avalanche hazard. Paper presented at the International Snow Science Workshop, Lake Tahoe, CA.

SLF Institut für Schnee und Lawinenforschung (ed) 1993: Interpretationshilfe zum nationalen Lawinenbulletin des Eidgenössischen Institutes für Schnee und Lawinenforschung SLF, Davos, 2. Aufl. Mitt. Eidgenöss. Inst. Schnee- Lawinenforschung.

SLF Institut für Schnee und Lawinenforschung (ed) 1994: Interpretationshilfe zum nationalen Lawinenbulletin des Eidgenössischen Institutes für Schnee und Lawinenforschung SLF, Davos, 3. Aufl. Mitt. Eidgenöss. Inst. Schnee- Lawinenforschung.

Varsom, 2016a. Avalanche bulletin for Romsdal 22 February 2016 [Available online at www.varsom.no/en/Snow-avalanche/Romsdal/?date=2/22/2016]

Varsom, 2016b. Avalanche bulletin for Romsdal 25 February 2016 [Available online at www.varsom.no/en/Snow-avalanche/Romsdal/?date=2/25/2016]