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Remarks to the risk assessment for abandoned mine sites

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Poznámky k odhadu rizika opustenej bane

The authors give some remarks to the term risk *regarding its use for the assessment of abandoned mine sites. These remarks are based on the recommendation* Geotechnical Investigation and Evaluation of Abandoned Mine Sites *developed by the working committee* Abandoned Mining *of the German Society for Geotechnical Engineering (DGGT) and the German Society for Mine Surveying (DMV), published in 2004.*

By this recommendation, the risk *is defined as a product of the occurrence probability and the extent of damage of an unwanted event. The occurrence probability for each unwanted event is described by the linguistic terms* in all probability, probable, less probable *or* practically impossible. *The extent of damage for each unwanted event is described by the linguistic terms* insignificant, small, high *or* very high. *A matrix out of these terms is used to define schematically an explicit limiting risk for each unwanted event.*

The authors point out that a schematic determination of limiting risk should be supported by an unique and comprehensible evaluation of all significant risk factors and parameters influencing the extent of damage. Fuzzy sets can be used instead of a discreet classification leading to more plausible results. The processing of linguistic terms by a fuzzy logic system is demonstrated.

Keywords*: abandoned mine sites, risk assessment*

Introduction

The opencast and in-situ mining were done in Germany since mid age. These mining activities lead to thousands of near to surface cavities. The stability of mining excavations is affected continuously by anthropogenic and natural effects. Possible damages contain more or less a potential of risk for peoples and objects. A systematic investigation and assessment of abandoned mine sites and occurred damages as well as a determination of the potential of risk are essential for an effective safeguard and sustainable clean-up. Therefore, systematic and unique criteria of treating the measurements are necessary for acting experts from mining authorities and consultants.

These criteria are a part of recommendations developed and published by the common working committee *Abandoned Mining* of the German Society for Geotechnical Engineering (DGGT) and the German Society for Mine Surveying (DMV). These recommendations contain definitions important for regulating the responsibility and the liability (Meier et al. 2004). The term *Abandoned Mining* means the entirety of mining excavations and drillings as well as open casts, dumps, tips and residual holes, which are no longer used for mining activities. Other mined excavations which were never used for mining purposes, like e.g. beer or wine cellars, antiaircraft-galleries and tunnels, should be treated like mining excavations. The *area of influence* due to abandoned mine sites means an area whose characteristics or functions are influenced negatively by abandoned mining or a future influence can not be excluded. The borderline of this area has to be determined under a consideration of the former mining situation, the geotechnical and tectonic conditions as well as the soil and rock mechanical characteristics of the overlying strata.

Abandoned mine sites in Germany are related to several kinds of former mining, e.g. ore mining, uranium mining, copper mining, hard coal mining, lignite mining, pit and quarry industry, potash mining as well as salt mining. The extent of potential hazard areas is different, depending on the kind and intensity of the former mining. E.g., probably 75 % of the urban area of Saxony is affected by the abandoned mining, 2.300 notifications of damage are registered for the former uranium mining, 3000-4000 shafts for the copper mining are notified in the area of 200 km² around the cities of Mansfeld and Sangershausen and within the Ruhr Basin 60.000 hazard areas are notified mostly related to the hard coal mining (Busch et al., 2005b).

Recommendations of the Treatment

The development and allocation of a state-of-the-art guideline for the geotechnical investigation and assessment of roof stability of mining excavations and stability of strata in the surrounding of old mining openings were a main target of the recommendation. The geotechnical investigation and assessment means an interdisciplinary analysis of the available information about the abandoned mine site, the geological

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and hydrological conditions, including the textual and graphic documentation of results. The area of influence has to be determined. Sub areas with increased degasification or inflow of water have to be analyzed additionally. The sustainable water drainage function of galleries has to be considered. The geotechnical investigation and assessment ends with a risk analysis and assessment.

Finally, the guideline should provide the risk assessment by a differentiated investigation and evaluation methods including the actual land use. The results of the investigation and assessment establish a basis for the planning of land use, if necessary, of further investigations as well as of necessary safeguard and clean-up measurements.

Use of the term risk

The term *risk* is of particular importance within the assessment of possible influences onto the surface. In technological context, the term *risk* is defined by the product of the occurrence probability and the extent of damage of an unwanted event. By definition, an area of influence is safe if all possible risks are below a specific value, named the limiting risk.

The risk assessment is divided into four steps, each for a single unwanted event. First, the identification of the unwanted event, then the determination of its occurrence probability, then the determination of the possible extent of damage and, as a last step, the determination and assessment of risk for this specific unwanted event. (Meier et al. 2004)

Identification of all relevant unwanted events

Typical unwanted events due to the abandoned mining are the collapses of shafts, drillings or opening holes, the appearance of subsidence or cracks, damages caused by mine water as well as degasification. Because of the century long experience with damages caused by mining, the identification is mostly without problems. Problems may occur if several unwanted events cause the same area of influence and their impacts are superposed. Another problem may occur if an affected object within the influence area had had already existing structural damages.

Determination of occurrence probability for each unwanted event

In most cases ones has to manage a lack of geotechnical parameters. Therefore, an exact determination of the occurrence probability is hardly possible. To estimate the geotechnical parameters by an extrapolation of experience from neighboring locations or similar districts seems very difficult, because of different mining characteristics, complexity of geotechnical parameters as well as inhomogeneous and discontinuous overlaying strata. Therefore, the determination of the occurrence probability should take place by linguistic terms like e.g. *in all probability*, *probable*, *less probable* as well as *practically impossible*. Using linguistic terms one has to be sure that the terms are standardized by a unique and explicit definition, referring to the kind of unwanted event.

Determination of the extent of damage for each unwanted event

In consequence to the fuzzy determination of occurrence probability described before, an exact determination of the extent of damage is difficult as well. The determination of the extent of damage has account on one hand the kind of possible influence at the surface (e.g. sinkhole, crack), on the other hand the use at the surface (e.g. cropland, public traffic) as well as the kind of a possible damage (personal injury, damage to property, environmental damage). Therefore the determination of the extent of damage should be done by linguistic terms like e.g. *very high*, *high*, *small* as well as *insignificant*. Once more, these linguistic terms should be standardized by an unique and explicit definition, referring to the kind of unwanted event, the kind of influence as well as the kind of possible damage.

Determination and assessment of risk for each unwanted event

As mentioned before, the term *risk* is defined as a product of the occurrence probability and the extent of damage of an unwanted event. This product has to be calculated for each identified unwanted event. Tab. 1 shows a matrix containing possible results. The fields below the thick line, defining the limiting risk, are representing the result *safe* (class IV). The fields above the thick line, are representing the result *unsafe* (classes I, II, III). If each risk for all unwanted events is below the limiting risk, the situation at the surface can be assessed as safe. If only one single risk is above the limiting risk, the situation at the surface should be assessed as unsafe.

The term *limiting risk* is of slightly different use because of different applications and regulations as well as a varying number of parameters to consider. However, this matrix is easy to use, accepted by several technical disciplines and therefore a kind of standard.

Tab. 1. Determination and assessment of risk for an unwanted event, according to Meier et al. (2004).
Tab. 1. Určenie a odhad rizika pre neočakávanú udalosť podľa Meiera a kol. (2004).

occurrence probability ↑					
	in all probability	IV	III	II	I
	probable	IV	IV	III	II
	less probable	IV	IV	IV	III
	practically impossible	IV	IV	IV	IV
		insignificant	small	high	very high
		extent of damage →			

limiting risk

More complicated is the determination of the classes *occurrence probability* and the classes *extent of damage*. At first, the relevant geotechnical information for the determination of occurrence probability should be collected completely. An example is shown in Table 2.

Tab. 2. Information sheet for an occurrence probability (example).
Tab. 2. Informačný list pre pravdepodobnosť príhody (príklad).

specification	criteria											
	geotechnical parameters					water related parameters					former damages	…
	1		…	n		1		…	n			
	spec	temporal change		spec	temporal change	spec	temporal change		spec	temporal change		
mining excavation	good, medium, bad	neg, unknown, pos	…	good, medium, bad	neg, unknown, pos							
inflow/efflux of water						good, medium, bad	neg, unknown, pos	…	good, medium, bad	neg, unknown, pos		
existence of former damages											yes, unknown, no	
…												…

The rows in Tab. 2 show specifications of the object of investigation, relevant for the occurrence probability of one single unwanted event. These are mostly geometrical, mining, geotechnical or hydrogeological specifications. If several unwanted events are present (e.g. overlaying openings of different depth) such a table has to be made for each one. The columns show the criteria of each specification assessed by linguistic terms like *good, medium, bad* or *negative, unknown, positive* or *yes, unknown, no*. Because the linguistic terms are already specified, the description is simple, clear, traceable as well as comparable. A further advantage is that the information is processible by a later rule based system.

As mentioned before, there are three groups of possible damages: damages to properties, environmental damages as well as personal injuries. Tab. 3 shows exemplary objects of investigation for each group and their criteria. Every object within the area of influence should be investigated. Similar to Tab. 2, every row shows the criteria to assess each specification by linguistic terms like *positive, medium, negative* as well as *no, unknown, yes*. The reasons for the use of linguistic terms are the same as for Tab. 2.

An important criterion is the temporal change of a specification. For the occurrence probability, there are mostly changes with a negative impact, e.g. the progress of disaggregation or the permanent impact of water. For the extent of damage the temporal change is mostly given by the change in use at the surface. The criterion of temporal change can help to determine the tendency of future risk and the period of time till the next investigation and should be considered particularly within Tab. 1.

Tab. 3. Information sheet for extent of damage (example).
Tab. 3. Informačný list pre rozsah škody (príklad).

kind of damage	**specification**	**criteria**						
		construction parameters			ecological parameters			possible danger to life
		1	…	n	1	…	n	
damages of property	construction	pos, medium, neg	**...**	pos, medium, neg				
	traffic routes	pos, medium, neg	**...**	pos, medium, neg				
	...	pos, medium, neg	**...**	pos, medium, neg				
environmental damages	natural reserve				pos, medium, neg	**...**	pos, medium, neg	
	groundwater				pos, medium, neg	**...**	pos, medium, neg	
	receiving water				pos, medium, neg	**...**	pos, medium, neg	
	...				pos, medium, neg	**...**	pos, medium, neg	
personal injuries	habitants							no, unknown, yes
	public place							no, unknown, yes

Fuzzy sets and fuzzy rules

In consequence to the strategy to use linguistic terms for the assessment of geotechnical specifications and the extent of damage, the processing should be done with fuzzy variables and fuzzy rules pertaining to a fuzzy logic system. One main reason is the possibility to assess the criteria by a very fine graduation, to model existing relationships between distinct criteria and compute the results by knowledge based rules. The basic concept of a fuzzy logic system is the combination of fuzzification, inference and defuzzyfication (Fig. 1).

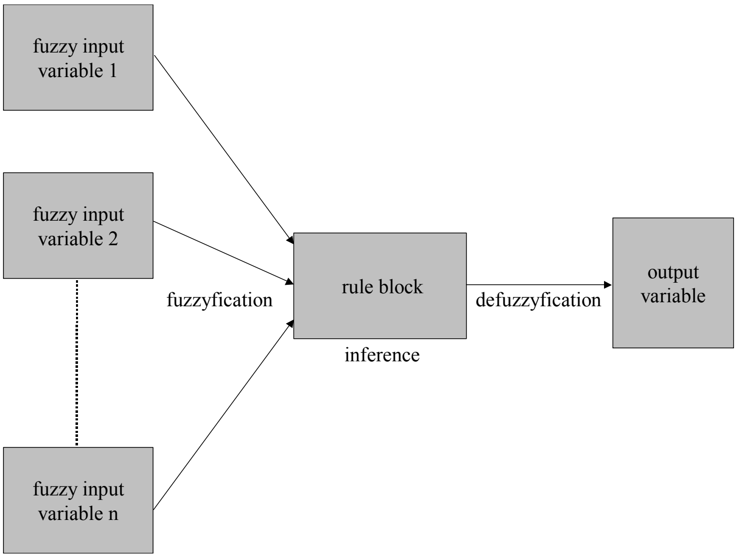


Fig. 1. Structure of a fuzzy logic system.
Obr. 1. Štruktúra konfúzneho logického systému.

The structure of a fuzzy logic system is shown in Fig. 1. On the left side, the several fuzzy input variables are describing e.g. geotechnical specifications. This process is named fuzzification. This group of fuzzy input variables belongis to a rule block. This rule block contains an expert knowledge in the form of rules between every possible combination of the grouped fuzzy input variables. This process is named inference. The result of the rule block is an output variable describing the behaviour of the specification according to the chosen fuzzy input variables. Processing the output variable into a non-fuzzy and plausible value is called defuzzyfication. The following fuzzy based exemplary computing was done with the fuzzyTECH 5.31 g software. (N.N. 2006)

Fuzzification

Fuzzyfication contains the determination of the degree of performance of distinct membership functions describing the behaviour of input variables within a specific process. Normally, the degree varies between 0 and 1. The kind of membership functions can be adapted individually (Fig. 2). Because of limited computing capacity, linear gradients of the membership functions are recommended.

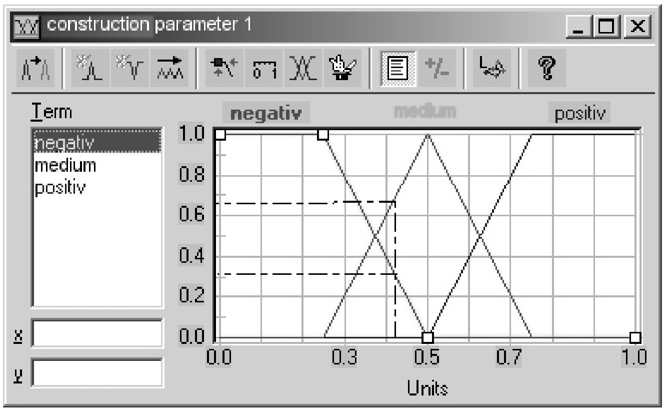


Fig. 2. Membership functions (fuzzy TECH 5.31 g).
Obr. 2. Funkčné parametre (konfúzny TECH 5.31 g).

Fig. 2. shows an example (in the left box) of the linguistic terms *negative, medium, positive* to describe e.g. the condition of a specific construction parameter. The terms are grouped to a so called fuzzy set. Usually, one has to chose one of this terms. The evaluations like *rather negative* or *rather positive* are not possible. Fuzzy sets are working differently. They have to assess the specification by a value between e.g. 0 and 1. If the value is chosen near to 0, the assessment is extremely negative. A value near to 1 means the assessment is extremely positive. Every grade between is possible and enables a fine graded evaluation. The example shows a chosen value of around 0.42. This value is a member of the function *negative* (with a degree of performance of around 0.31) as well as of the function *medium* (with a degree of performance of around 0.66). This multi membership will be considered calculative by the later fuzzy ruling and enables a continuous, simple, more realistic and therefore an objective assessment. If needed, the membership function for each fuzzy variable can be fitted separately.

Inference

Inference means a knowledge based processing of fuzzy sets in two steps. The first step is called aggregation. This can be done e.g. by the commonly used *Max-Min Operator*

$$\mu = (1-\lambda)\min_{i=1..n}(\mu_i) + \lambda\max_{i=1..n}(\mu_i) \qquad (1)$$

where μ is the degree of performance for the entirety of all connected fuzzy input variables. μ_i is the degree of performance for each single fuzzy input variable. λ is the balancing factor between the different degrees of performance. If λ is set to 0, the aggregation is of the same effect like a logical AND (2, fig. 3). If λ is set to 1 the aggregation is of the same effect like a logical OR (3, fig. 4). Every value for λ between 0 and 1 is possible.

Logical AND by Min-Operator:

$$\mu = \min\{\mu_1, \mu_2 .... \mu_n\} \qquad (2)$$

Logical OR by Max-Min Operator:

$$\mu = \max\{\min\{\mu_1\}, \min\{\mu_2\} ..... \min\{\mu_n\}\} \qquad (3)$$

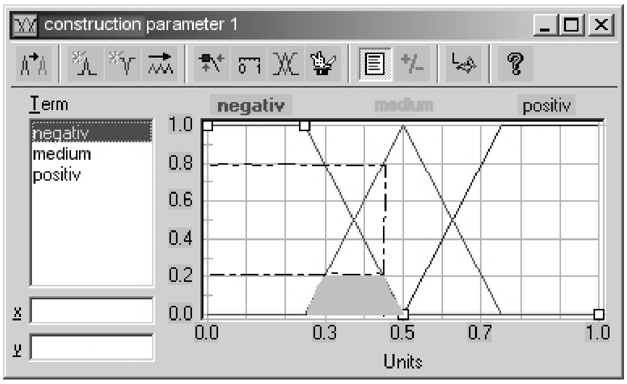


Fig. 3. Fuzzy result (grey shaded) for an input value of 0.42 and λ=0 (logical AND) (fuzzy TECH 5.31 g).
Obr. 3. Konfúzny výsledok (sivé tieňované) pre vstupnú veličinu 0.42 a λ=0 (logický AND) (fuzzy TECH 5.31 g).

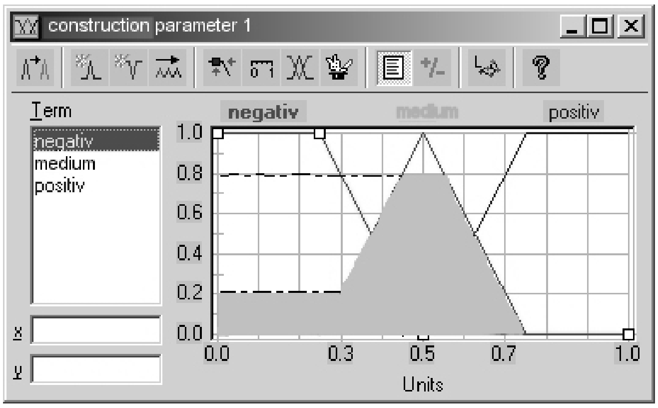


Fig. 4. Fuzzy result (grey shaded) for an input value of 0.42 and λ=1 (logical OR) (fuzzy TECH 5.31 g).
Obr. 4. Konfúzny výsledok (sivé tieňované) pre vstupnú veličinu 0.42 a λ=1 (logický OR) (fuzzy TECH 5.31 g).

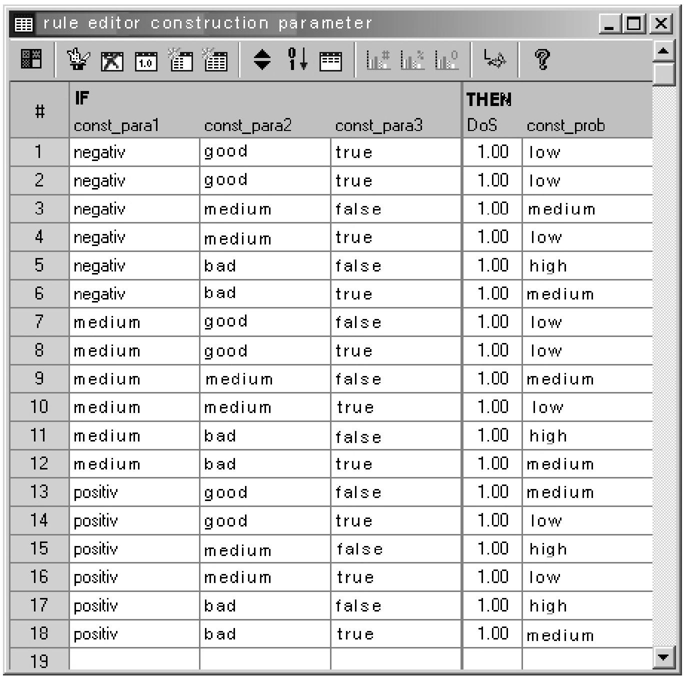
The second step is called composition. If different rules are processing the same membership function of an output variable, one has to determine the level of influence off all rules. This can be realized e.g. by the common used Max-Operator, what means that the rule with a higher degree of performance will be dominant.

Defuzzyfication

The inference produces a fuzzy variable as the output, understandable like a surface volume below a function (see Fig. 3 and 4). Out of this set, one has to determine the most plausible *sharp* result. This step is called defuzzyfication. A common used algorithm is given by the *Center-of-Maximum Method*. By this method, the sharp result is calculated by the weighted average of the maxima of all involved membership functions. The weights are given by the results of the inference. The degree of performance as well as the kind of membership function for the output variable can be adapted individually.

Application of a fuzzy logic system to the risk assessment

The knowledge can be implemented into a fuzzy logic system by different ways. One opportunity is a table with a list of all possible combinations of the grouped fuzzy sets. Fig. 5 shows an example concerning the extent of damage with three fuzzy input variables. Each variable is defined by multi membership functions. The columns from the left show a distinct number of fuzzy input variables *construction parameter 1..n* (e.g. location within the influence area, monetary worth, existence of safety measures). These terms are a part of the IF-condition of each rule. The right column shows the result for each rule. This column has to be fulfilled by an expert representing the knowledge. The column titled DoS (degree of support) is a weight for each singe rule, in this example all set to 1. This value has to be determined by the expert as well. It is easy to understand that the number of rules is limited by the expert capacity. In the shown example, three specifications with three or two different membership functions lead to $3 \cdot 3 \cdot 2 = 18$ rules, what is quite good to handle. But, e.g. eight fuzzy input variables with three membership functions leads to $3^8 = 6561$ rules, what is practically not manageable.



#	IF const_para1	const_para2	const_para3	THEN DoS	const_prob
1	negativ	good	true	1.00	low
2	negativ	good	true	1.00	low
3	negativ	medium	false	1.00	medium
4	negativ	medium	true	1.00	low
5	negativ	bad	false	1.00	high
6	negativ	bad	true	1.00	medium
7	medium	good	false	1.00	low
8	medium	good	true	1.00	low
9	medium	medium	false	1.00	medium
10	medium	medium	true	1.00	low
11	medium	bad	false	1.00	high
12	medium	bad	true	1.00	medium
13	positiv	good	false	1.00	medium
14	positiv	good	true	1.00	low
15	positiv	medium	false	1.00	high
16	positiv	medium	true	1.00	low
17	positiv	bad	false	1.00	high
18	positiv	bad	true	1.00	medium
19					

Fig. 5. Knowledge based ruling (fuzzy TECH 5.31 g).
Obr. 5. Poznatky k rozhodnutiu (konfúzny TECH 5.31 g).

Fig. 6 shows an example of fuzzy based risk assessment with a minimum of complexity. The upper three rule blocks determine the occurrence probability processing input variables according to Table 2. Each of these upper three rule blocks leads to an output variable describing the occurrence possibility for the three groups of fuzzy input variables. These three output variables are fuzzy input variables for the next rule block determining the absolute occurrence probability for this example.

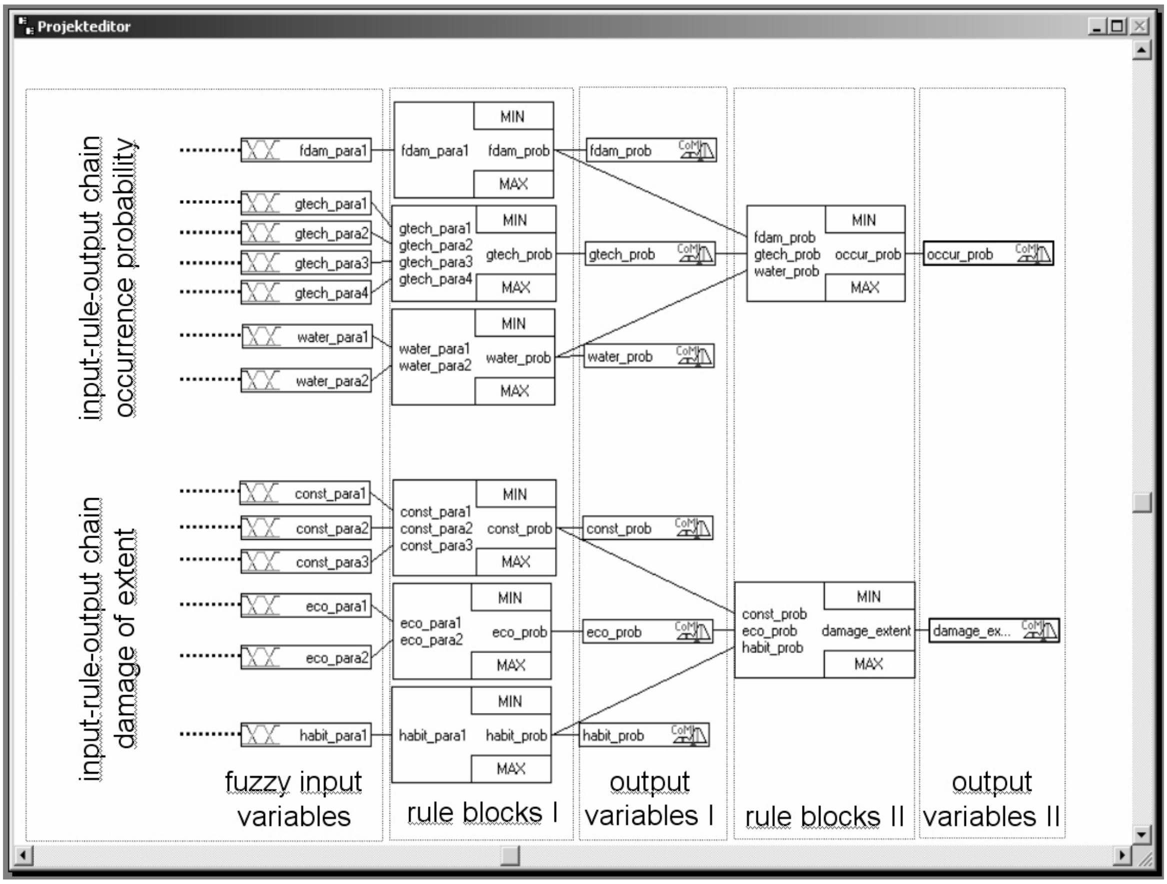
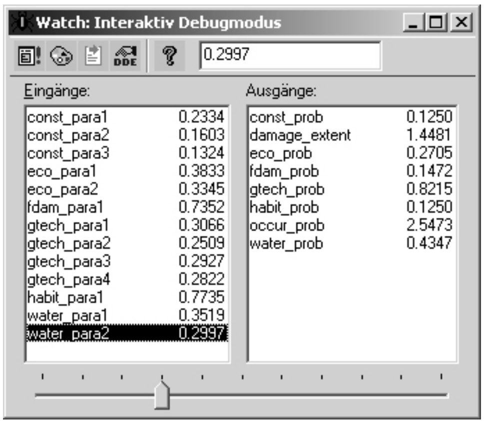


Fig. 6. Example of a fuzzy logic system (fuzzy TECH 5.31 g).
Obr. 6. Príklad konfúzneho logického systému (konfúzny TECH 5.31 g).

The lower three rule blocks determine the possible extent of damage for this example processing input variables according to Table 3. Again, the rule block has three output variables describing the single extent of damage. Theses three output variables are fuzzy input variables for the rule block determining the total extent of damage.

This example contains 13 fuzzy input variables, (left column in Fig. 6) and 123 rules to define. If adequate information is available, more input variables can be defined or an input variable can be substituted by a separated input-rule-output chain.

Fig. 7 shows on the left side the 13 fuzzy input variables each with a value between 0 and one 1 defined e.g. by a slider or typing. Simultaneously, the values for the output variables are calculated considering all multi membership functions defined for each variables. The output variables are defined as fuzzy input variable for the subsequent rule blocks. Therefore, the last two output variables *occurrence probability* and *damage extent* (both grey shaded) will be calculated simultaneously as well. The four similar triangle membership functions represent the four classes of occurrence probability or the extent of damage for the given example. So, the output variable canbe directly taken for determining the total risk using the risk matrix. In this example, the value for the occurrence probability is 2.5473 and the value for the damage extent is 1.4481.



0.2997

Eingänge:

const_para1	0.2334
const_para2	0.1603
const_para3	0.1324
eco_para1	0.3833
eco_para2	0.3345
fdam_para1	0.7352
gtech_para1	0.3066
gtech_para2	0.2509
gtech_para3	0.2927
gtech_para4	0.2822
habit_para1	0.7735
water_para1	0.3519
water_para2	0.2997

Ausgänge:

const_prob	0.1250
damage_extent	1.4481
eco_prob	0.2705
fdam_prob	0.1472
gtech_prob	0.8215
habit_prob	0.1250
occur_prob	2.5473
water_prob	0.4347

Fig. 7. Example of a debugged fuzzy system (fuzzy TECH 5.31 g).
Obr. 7. Príklad ladenia konfúzneho systému (konfúzny TECH 5.31 g).

Using the results of the fuzzy logic system, the risk matrix described in the chapter 3.4 must be adapted slightly. Instead of the step function representing the limiting risk, a linear function can be used (see Fig. 8). In addition to the discrete classes for the occurrence probability and the extent of damage, the axes of coordinates from 0 to 4 are integrated. The results from the example are plotted along the ordinate or the abscissa leading to a point of intersection near to the limiting risk. Now, in contrast to the limiting risk designed by a step function, a more detailed conclusion about risk is possible.

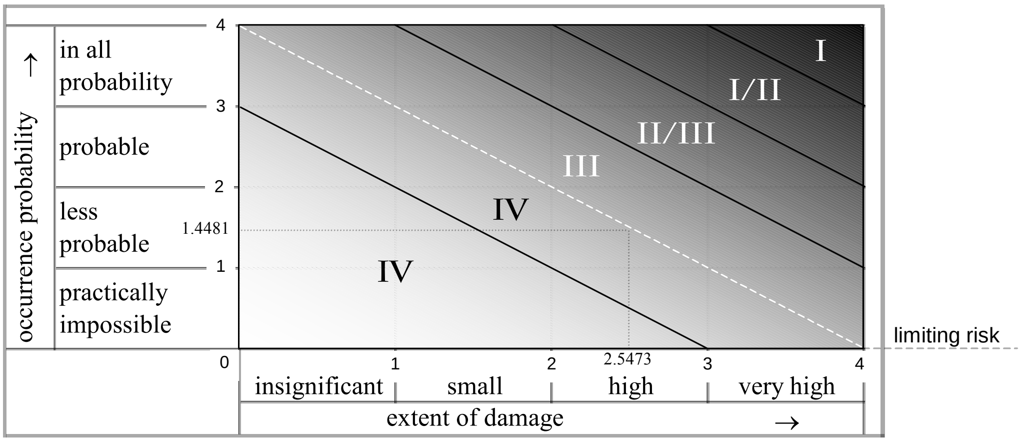


Fig. 8. Modified risk matrix.
Obr. 8. Modifikovaná rízska matica.

Results and outlook

None fuzzy logic based systems, as described before, is not able to substitute his risk assessment regarding the objectiveness, traceability, comparability, resolution as well as the plausibility.

The objectiveness is given if the model of inference, describing the entirety of fuzzy input variables and the rules between, them is used as a standard. Then, the subjective assessment concentrates on the fuzzy determination of a distinct number of input variables. The algorithms behind are already defined and the computing will run automatically. As an additional effect, the occurrence of gross or logical errors is minimized. The traceability and the comparability mean that the assessment of the same object can be done several times, using the same model as well as the same algorithm and computing steps. Assessments e.g. by different consultants can be compared directly. The resolution means that the risk assessment is finally not pressed into a relatively coarse 4x4 matrix subdivided by a step function. More decimal places can help to decide between safe and unsafe in critical cases. The plausibility means that the system is not a black box and the definition of rules and algorithms can be controlled easily.

To apply a fuzzy logic system in a daily work of geotechnical risk assessment, the model of inference has to be developed in a more detail. This can be done by adapting and calibrating the system based on the results of a number of real showcases.

References

Busch, W., Maas, K., Meier, G., Sroka, A., Klapperich, H., Tondera, D. (eds.): Proceedings of the 2nd Abandoned Mining Colloquium, 7th-9th November 2002, *Clausthal University of Technology, Germany. Verlag Papierflieger, Clausthal-Zellerfeld 2002. ISBN 3-00-010468-2*.

Busch, W., Maas, K., Meier, G., Sroka, A., Löbel, K. H., Klapperich, H., Tondera, D. (eds.): Proceedings of the 5th Abandoned Mining Colloquium, 3th-5th November 2005, *Clausthal University of Technology, Germany. Verlag Glückauf, Essen 2005*.

Busch, W., Maas, K.: Actual Situation of Abandoned Mine Sites in Germany and Recommendations for Treatment. *Paper presented at the Commission No. 3 and 5 Meeting (Mining and Environment, Geodesy), International Society for Mine Surveying (ISM), Prague, Czech Republic, November 8, 2005, published on CD*.

Klapperich, H., Meier, G., Sroka, A., Tondera, D., Busch, W. (eds.): Proceedings of the 1st Abandoned Mining Colloquium, 8th-9th November 2001, *Technical University Bergakademie Freiberg, Germany. Verlag Glückauf, Essen 2001. ISBN 3-7739-5972-9*.

Meier, G., Sroka, A., Löbel, K.H., Klapperich, H., Tondera, D., Busch, W., Wagner, H., Randjbar, B. (eds.): Proceedings of the 4th Abandoned Mining Colloquium, 4th-6th November 2004, *Montanuniversität Leoben, Austria. Verlag Glückauf, Essen 2004. ISBN 3-7739-5999-0*.

http://www.fuzzytech.com/, *N.N. (2006)*

Petry, F. E., Robinson, V. B., Cobb, M. A. (Eds.): Fuzzy Modeling with Spatial Information for Geographic Problems. *Springer, Berlin 2005.*

Sroka, A., Löbel, K.H., Klapperich, H., Tondera, D., Meier, G., Busch, W. (eds.): Proceedings of the 3rd Abandoned Mining Colloquium, 6th-8th November 2003, *Technical University Bergakademie Freiberg, Germany. Verlag Glückauf, Essen 2003. ISBN 3-7739-5989-3*.