Utilization of the multicriteria decision-making methods for the needs of mining industry

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The area of Slovakia has the assumptions for the development of mining, metallurgy and other related science disciplines since time immemorial, thanks to its mineral wealth. The production of waste and its subsequent location troubles many of the mining towns. This article focuses on the decision-making process in the field of selection of an appropriate location for the storage of waste which is produced by mines that would fit all the conditions and requirements laid down in the laws of the State. For a good selection of solutions, it is necessary to have a number of truthful information and usability of the software product (e-MDM – electronic Multi-criteria Decision Making), which enables easier and faster choice based on multicriterial methods, where all the relevant data and their essential characteristics are an important element in terms of decision-making, or ranking and are judged according to certain selected evaluation criteria.

Keywords: *multicriteria methods, decision-making process, allocation, mining production, waste*

Introduction

The mining industry produces large quantities of material ranging from raw materials to materials that make up the waste which burdens environment. The ore mining itself and improper disposal of waste is serious danger for nature. The nature cannot help itself from such a waste because most of it is hardly decomposable substances which remain in the wild as a contaminant. Often, we come across a solution which proposes movement of scrap heap to other location, which, of course, does not solve a problem! And so began a sharp increase in the volume of the transferred waste rock and mine dumps substrates from an environment with compatible components to an environment where they are suddenly exposed to the atmosphere [1].

This is related to an issue of appropriate selection of waste storage that meets the requirements defined in the laws of the states and the European Union, economic and environmental standards, technical requirements as well as requirements for environmental protection. Therefore, the problem of allocating the location of the materials forming the unwanted waste is multi objective- problem requiring considerable attention. Since the methodology for multi-criteria decision-making involves many different methods and solution approaches, it is necessary to develop a system based on programming resources which would offer solutions at the level of pseudo-expert system [2].

While traveling and exploring the beauty of Slovakia, piles of waste are often seen in places where they should not be at all. Illegal dumps are updated daily with new heap of mining waste substrates and diversity of waste in its neighbourhood is always rich. This was also a reason for creating a software product based on software solutions for distribution problems with a proposal and selection of the optimal solution when necessary criteria are defined [3].

It is assumed that if there is no attempt to reclaim mining areas in Slovakia, to remove the piles of mining waste from places where they are not supposed to be, or if an appropriate technology for the recovery of waste affected areas is not developed, there exists a serious threat to the ecological balance in country [4].

Analytical review

Allocation of manufacturing processes is one of the strategic decisions not only for logistics of production but all systems which activity is building on the production [5]. Allocation depends on many factors so we can think about multicriteria decision making. „The allocation can be defined as a process, which result is a determined particular position to the location of a warehouse, a company, a machine, a manufacture process, people, animals, things and other activities in a particular area, respectively in area that best suits for the defined

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conditions and restrictions on such requirements e.g. supplies, production, distribution or trade, strategy and tactics. [6]" To solve any allocation problem we can choose from two approaches [2] [6]:

1. First approach is based on multicriteria decision-making – it is used mainly while thinking about suitable locality when there are a couple of locality options. The ideal would be to transfer that problem to „multifactorial cost criteria function", but it is quite tricky to transform some factors like availability of raw materials or necessity of manpower to the costs. Hence multifactorial evaluation and its transformation to single criteria decision-making are used in most cases [2].

2. Second approach is based on geometrical interpretation of the allocation problem and its transformation to transport problem where we consider the necessary criterion as a cost optimization for transportation of inputs to the manufacturing process as well as products distribution to purchasers [2].

Multicriteria decision-making methods

Multicriteria decision-making is used mainly when allocation of manufacturing process, distribution or operation centre is depending on many factors, some of which can be economically evaluated and some not [6] [7].

Multicriteria decision-making tasks can be solved using the following steps [2] [6]:

- Defining the criteria by which every variant will be evaluated.
- Determining the importance (weight) for each criterion (nonstandard form k_i or standardized form α_i, W_i).
- Calculation of the total usefulness for each variant.
- Determining the optimal variant and variant effectiveness.

Direct methods – the subject decides about both input parameters and their relationships [2]:

- Metfesell allocation,
- The method of criteria classification to groups,
- The method of assigning the points to criteria from specified point scale,
- Method of preferential sort order of the criteria,
- Grading scale.

Indirect methods – the values of importance (weight) are determined by mutual comparisons between each of the criteria [2]:

- Fuller's triangle – pair comparison,
- Saaty method.

Saaty´s method was developed in 1980 by Thomas L. Saaty, who was a professor in the University of Pittsburgh, USA. Decision-making problem is expressed as a hierarchical structure where the highest level is the objective of decision-making, respectively the lowest alternatives to be evaluated. Saaty's method requires the assignment of criteria for a pair of variations for each criterion using the Saaty scale [8].

Steps of Saaty method [2] [5] [6]:

1. First of all, the matrix of criteria is completed where the first row and first column will be written out with determined criteria – the number of criteria is not limited and is dependent on the evaluator.
2. The role of the evaluator is to write down the values into the fields of upper triangle part which corresponds to the criterion comparison in the row with the criterion in the column. Lower triangle part of the matrix is filled out with inverted value *1/x*. While creating a pairs to be compared $S = (s_{ij}),\ \ i, j = 1,2,3...k,$ there *i* used a scale of 1, 3, 5, 7, 9. Values 2, 4, 6, 8 are called as an interstages and the values is interpreted as follows (Tab. 1):

Tab. 1. The value of the corresponding comparison criteria according to Saaty [2].

Intensity	Definition	Explanation
1	Same importance	Two elements are equally involved in the intervention of the target
3	The importance of one element is less than the other	The experience and views of the gently prefer one attribute over the other
5	Substantial or strong importance	Experiences and opinions strongly prefer one over the other.
7	Demonstartive importance	One attribute is the preferred and its dominance is demonstrated in practice.
9	Absolute importance	Preference for one attribute over another is at the highest possible level of expression.
2, 4, 6, 8	Mean values between two adjacent assessments.	If a compromise is needed due to the ambiguity of the associations referred to definitions of importance.

3. Sum up the values of each column in the Saaty´s matrix.
4. Subsequently, the amount of the value in cell is divided by the sum of corresponding column.
5. And finally, sum up the values in each row and divide by the total sum of the values in the matrix, and with those obtained information we get the standardized value of the weights of the criteria.

In program e-MDM is this method registered with the following source code [3][9]:

```
...    for(int i=0;i<PK;i++)
       {
        SaatySumaStlpca[i] = 0;
        for(int j=0;j<PK;j++)
         SaatySumaStlpca[i] = SaatySumaStlpca[i] + MATICA[i][j];
       }     ...
```

The Weighted Sum Method (WSM, Proportionally Indexed Method-PIM) is mainly used when we need to concentrate all the criteria to on one specific decision, all into one of the basic indicator, taking care that the criteria [10][11]:

- They have a different character, both in terms of quantification, but also randomness.
- They are from different areas (such as trade, manufacturing, distribution, etc.).
- They have different importance in view of the objective of the target of analysis.
- The method generally expresses the relation (1) [2][5][6]:

$$U_m = \sum_{i=1}^{n} \alpha_i \, u_{im} \tag{1}$$

where: m – the amount of elements to be evaluated,
n – the amount of defined criteria,
u_{im} – the usefulness of the m-th element in the i-th criterion,
U_m – the overall usefulness of the evaluation points (called stability index),
α_i– the weight of the i-th criterion shows the relation (2).

$$\sum_{i=1}^{n} \alpha_i = 1 \tag{2}$$

In the program e-MDM is this method registered with the following source code [3][12]:

```
ZVUV->XStringGrid1->Cells[1][1] = "Ai" for(int i=0;i<PK;i++)
 ZVUV->XStringGrid1->Cells[1][i+2] = (int)(Vi[i]*10000)/(float)10000;
 for(int i=0;i<this->PocetPobociek;i++)
   {
 ZVUV->XStringGrid1->Cells[2+(i*2)][1] = "Ui" + (String)(i+1) + "
<1,10>";
      ZVUV->XStringGrid1->Cells[3+(i*2)][1] = "Ai x Ui" + (String)(i+1);
....
```

The Method of Multiplying the Awards (MMA) is identical to the procedure in the previous method, but generally method is possible to write the relation (3) [2][5][6]:

$$U_m = \prod_{i=1}^{n} \alpha_i \, u_{im} \tag{3}$$

where m – the amount of elements to be evaluated,
n – the amount of defined criteria,
α_i – the weight of the i-th criterion, crucial to the person,
u_{im} – the usefulness of the m-th element in the i-th evaluation criteria,
U_m – the overall usefulness of the evaluated place (stability index).

In the same way to each selected factor, criteria a specific weight is assigned and it is necessary to follow the principle that the sums of the weights are equal to 1. The greater the attributed weight factor is, has a greater importance in the selection of the optimal location, in case the maximum tasks. The weights between themselves express the ratio of the importance of the factor.

In program e-MDM is this method registered with the following source code [3][9]:

```
...
ZVUV->XStringGrid1->Cells[3+(i*2)][j+2] = ZVUV->XStringGrid1->Cells[2+(i*2)][j+2].ToDouble() * ZVUV->XStringGrid1->Cells[1][j+2].ToDouble();
        ZVUV->XStringGrid1->Cells[3+(i*2)][PK+2] = ZVUV->XStringGrid1->Cells[3+(i*2)][PK+2].ToDouble() * ZVUV->XStringGrid1->Cells[3+(i*2)][j+2].ToDouble();
...
```

The Method of Quadratic Graph (MQG) is based on the principle of approaching the values of partial usefulness so optimal values, and the relation is designed so that the resulting solution is always the lowest value, i.e. value nearest to zero.

For the selected assessment point it is necessary to choose the weighting factors, criteria. For each selected factor is defined an optimal value of the evaluation criteria, ui optimal in the range of cardiac rate for example < 1.10 >. The more the evaluation criteria fill in the selected criteria, the more is the result close to zero, as in maximized and minimized evaluation.

In general, it is possible to write a method in the following relationship (4) [2][5][6]:

$$U_m = \sum_{i=1}^{n} \left[\frac{u_{i,m} - u_{i,optim}}{u_{i,optim}}\right]^2 \tag{4}$$

where m – the amount of elements to be evaluated,
n – the amount of defined criteria,
$u_{i,optim}$ – the optimal value of the usefulness of the *i*-th evaluation criteria,
u_{im} – the usefulness of the *m*-th element in the *i*-th evaluation criteria,
U_m – the overall usefulness of the evaluated place (stability index).

In the program e-MDM is this method registered with the following source code [3]:

```
...   ZVUV->Edit2->Text = " - ";
 ZVUV->XStringGrid1->Cells[1][1] = "Uiopt";
     for(int i=0;i<PK;i++)
      ZVUV->XStringGrid1->Cells[1][i+2] = "10";
      for(int i=0;i<this->PocetPobociek;i++)
      {
       ZVUV->XStringGrid1->Cells[2+(i*2)][1] = "Ui" + (String)(i+1) + " <1,10>";
...
```

Software application e-MDM (electronic - Multicriteria Decision Making)

The program e-MDM was created on the initiative of the head of the author at work of Logistics Institute of Industry and transport (ULPaD) for the purpose of Distribution logistics in the field of Industrial logistics, which calculates the accuracy and appropriateness of the allocation from different areas based on Analytic Hierarchy Process (AHP) methods (method of weighted sums - PIM, multiplication of awards, quadratic graph, Saaty).

The program is a software product that is created in the programming language of Borland C Builder 5.0, which is helpful when dealing with multicriterial decision designed only for the needs of distribution logistics and decision making from view of allocation, but also in the effective solutions to any problems raised, where decision in different areas depends on more criteria not only on one decision.

The Program has been utilized for solving the fictional problem to suitably choose the right location of storage for mining waste, which significantly threatens the environment around Horná Nitra, where are three mines producing lignite coal with sites (Figure 1):

- HBP a.s. Baňa Nováky, branch plant - extraction of brown coal and lignite, extraction of coal by abyssal way by use of modern techniques,
- Hornonitrianske mines Prievidza, a.s., HBP, a.s. – production of brown coal,
- Mine Handlová – branch of brown coal.

The environment is at risk because of the nearby coal-fired power plant Nováky producing waste and emissions of harmful gases, and also close are the chemical plants Nováky, threatening the environment by harmful chemicals [3][13].

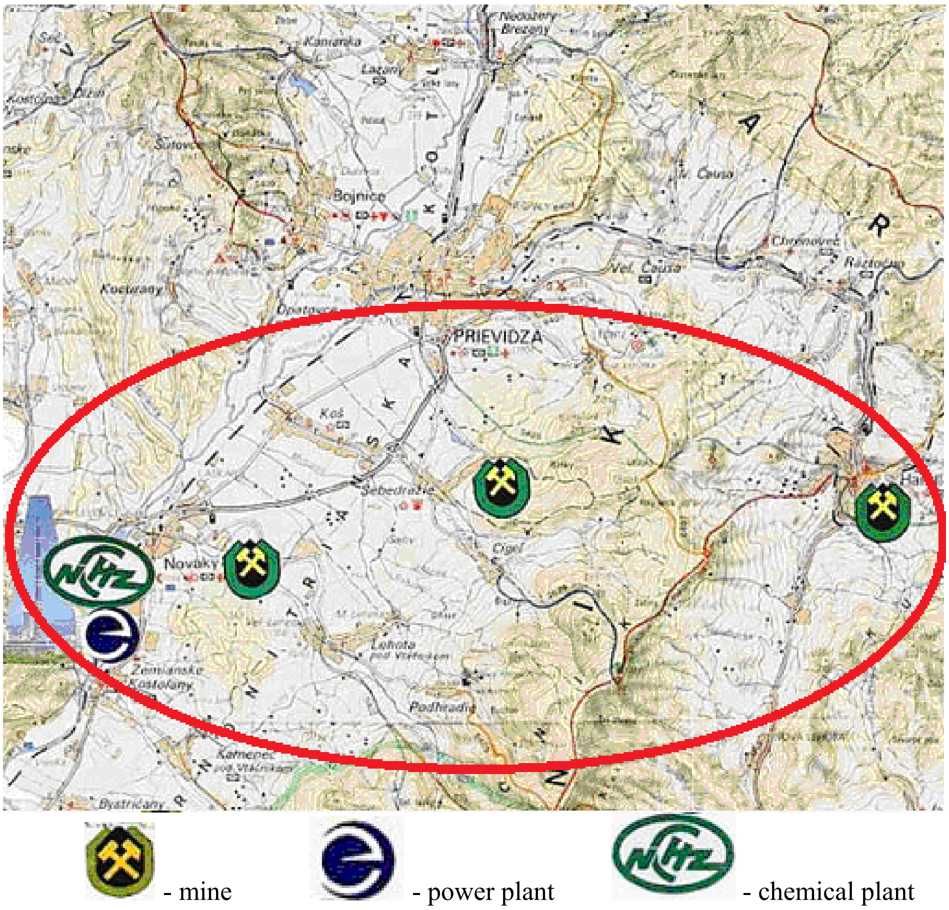


Fig. 1. Mines in region of Horná Nitra [3].

The site of location of the central stock over this mines, the plant and the chemical plant is not suitable from point of highly visited nearby Bojnica castle and Turcianske spa therefore we proposed to allocate the stock, which will be controlled and under constant supervision in the southern region from these places [3][14][15]. We suggest to evaluate three places-Prašice, Klatova Nová Ves and Prochot, while around these sites is a big enough area to build a central stock of waste, where there is no overflowing river or other protected area nearby.

For a better evaluation we use a program e-MDM (Figure, 2, 3, 4, 5, 6, 7) with the selected proportionately index method, with five defined criteria and calculation of the weights of the criteria according to the Saaty's method.

Criteria for evaluation [2][3][11]:

1. Advantage of location as a part of allocation,
2. Technical difficulty of solution,
3. Distance from the source,
4. Available infrastructure,
5. Ecology party of the project.

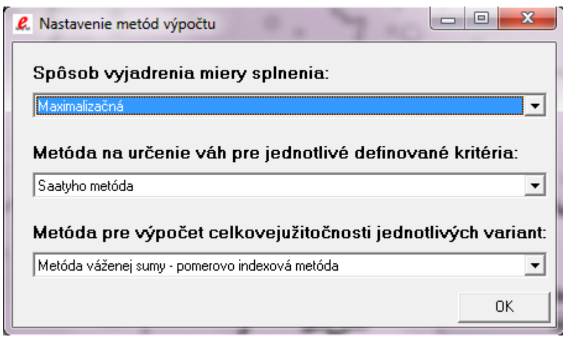
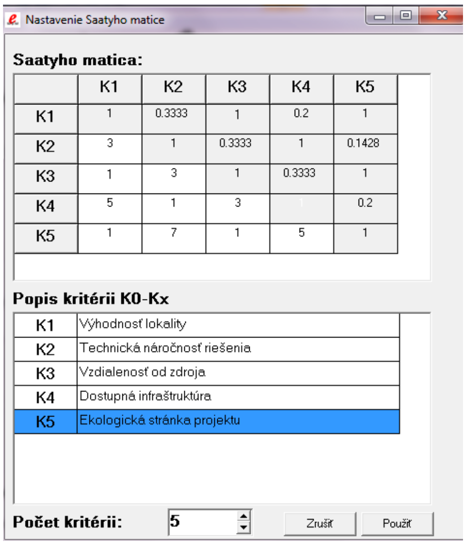


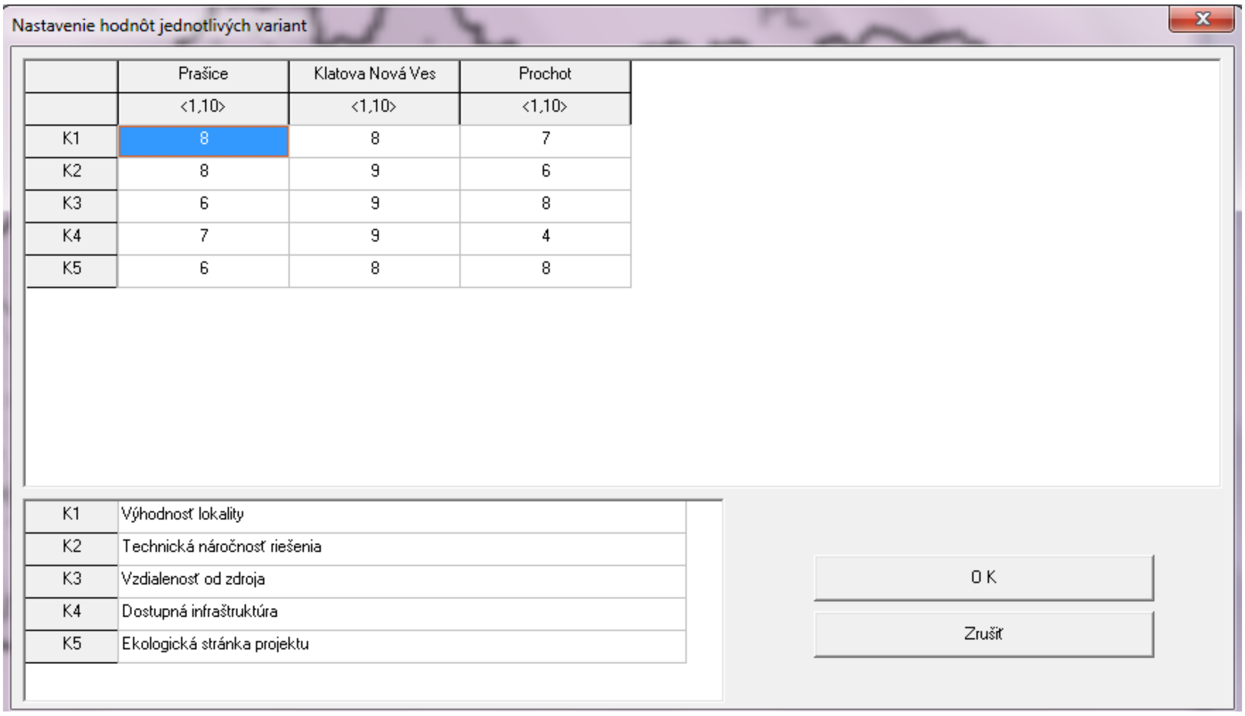
Fig. 2. Set up of calculation methods [3].



	K1	K2	K3	K4	K5
K1	1	0.3333	1	0.2	1
K2	3	1	0.3333	1	0.1428
K3	1	3	1	0.3333	1
K4	5	1	3		0.2
K5	1	7	1	5	1

K1	Výhodnosť lokality
K2	Technická náročnosť riešenia
K3	Vzdialenosť od zdroja
K4	Dostupná infraštruktúra
K5	Ekologická stránka projektu

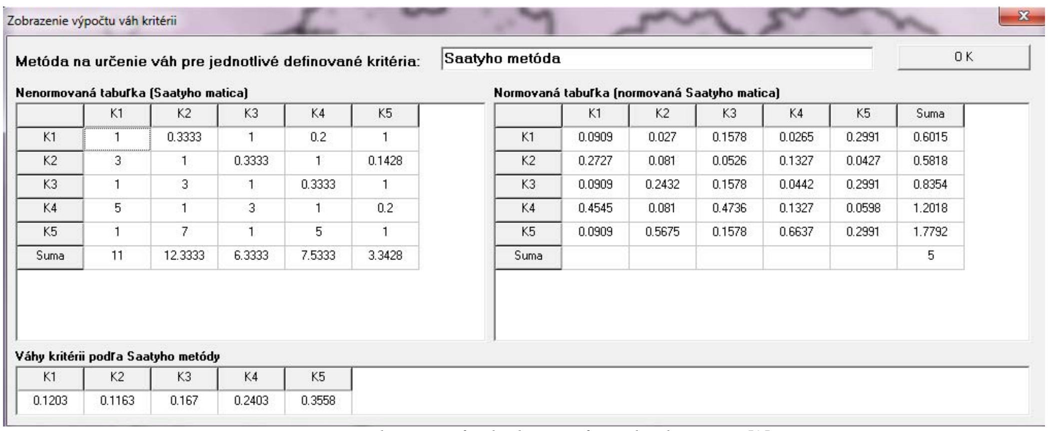
Fig. 3. Set-up of Saaty matrix and description of the criteria [3].



	Prašice	Klatova Nová Ves	Prochot
	<1,10>	<1,10>	<1,10>
K1	8	8	7
K2	8	9	6
K3	6	9	8
K4	7	9	4
K5	6	8	8

K1	Výhodnosť lokality
K2	Technická náročnosť riešenia
K3	Vzdialenosť od zdroja
K4	Dostupná infraštruktúra
K5	Ekologická stránka projektu

Fig. 4. Set the values for each option [3].



Nenormovaná tabuľka (Saatyho matica)

	K1	K2	K3	K4	K5
K1	1	0.3333	1	0.2	1
K2	3	1	0.3333	1	0.1428
K3	1	3	1	0.3333	1
K4	5	1	3	1	0.2
K5	1	7	1	5	1
Suma	11	12.3333	6.3333	7.5333	3.3428

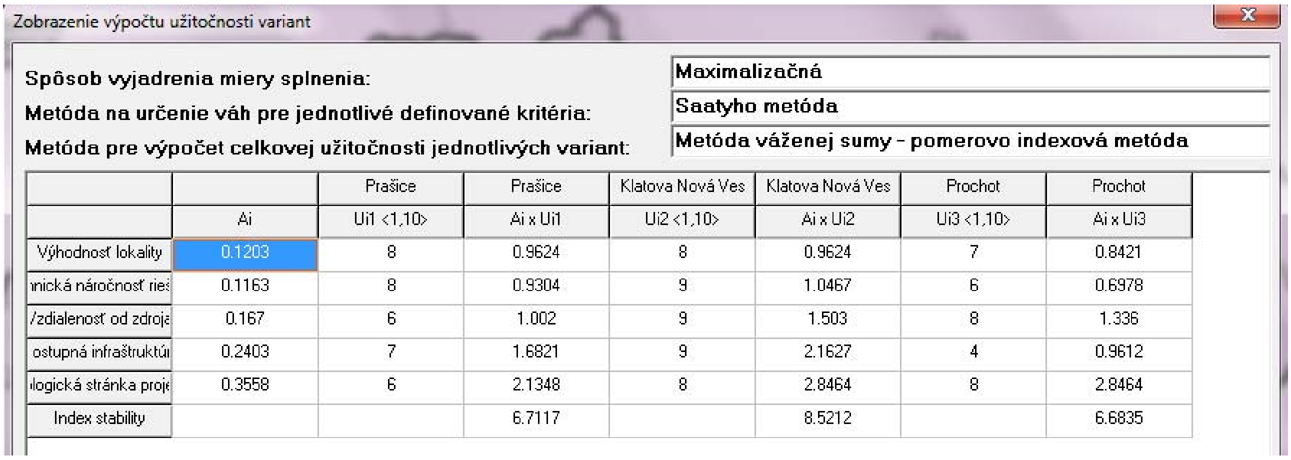
Normovaná tabuľka (normovaná Saatyho matica)

	K1	K2	K3	K4	K5	Suma
K1	0.0909	0.027	0.1578	0.0265	0.2991	0.6015
K2	0.2727	0.081	0.0526	0.1327	0.0427	0.5818
K3	0.0909	0.2432	0.1578	0.0442	0.2991	0.8354
K4	0.4545	0.081	0.4736	0.1327	0.0598	1.2018
K5	0.0909	0.5675	0.1578	0.6637	0.2991	1.7792
Suma						5

Váhy kritérii podľa Saatyho metódy

K1	K2	K3	K4	K5
0.1203	0.1163	0.167	0.2403	0.3558

Fig. 5. Visualisation of calculation of weighted criteria [3].


Zobrazenie výpočtu užitočnosti variant

Spôsob vyjadrenia miery splnenia:	Maximalizačná
Metóda na určenie váh pre jednotlivé definované kritéria:	Saatyho metóda
Metóda pre výpočet celkovej užitočnosti jednotlivých variant:	Metóda váženej sumy - pomerovo indexová metóda

		Prašice	Prašice	Klatova Nová Ves	Klatova Nová Ves	Prochot	Prochot
	Ai	Ui1 <1,10>	Ai x Ui1	Ui2 <1,10>	Ai x Ui2	Ui3 <1,10>	Ai x Ui3
Výhodnosť lokality	0.1203	8	0.9624	8	0.9624	7	0.8421
ınická náročnosť ries	0.1163	8	0.9304	9	1.0467	6	0.6978
/zdialenosť od zdroja	0.167	6	1.002	9	1.503	8	1.336
ostupná infraštruktúı	0.2403	7	1.6821	9	2.1627	4	0.9612
ılogická stránka proje	0.3558	6	2.1348	8	2.8464	8	2.8464
Index stability			6.7117		8.5212		6.6835

Fig. 6. Visualisation of calculation of weighted criteria [3].

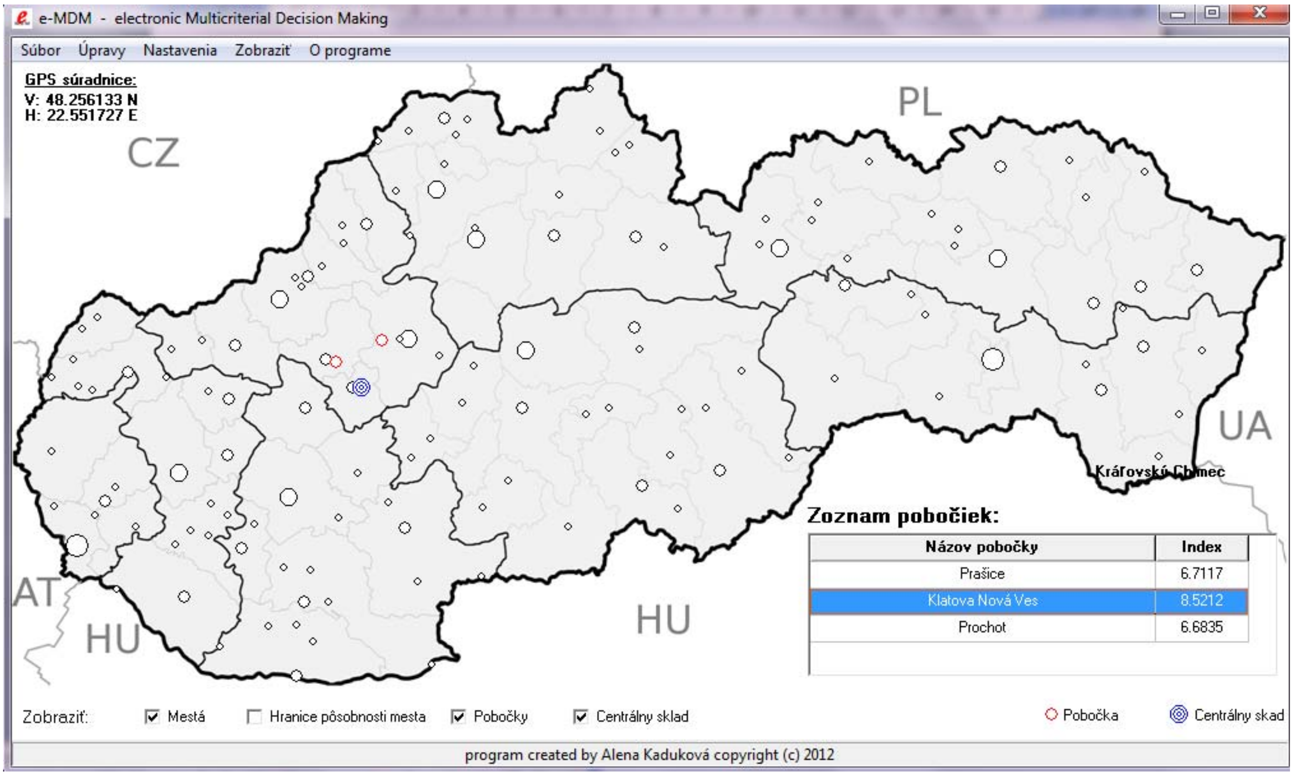


Fig. 7. Visualisation of calculation of weighted criteria [3].

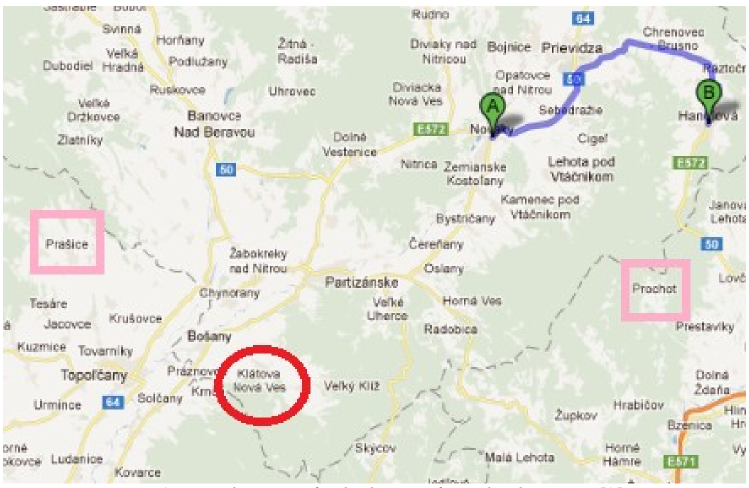


Fig. 8. Visualisation of calculation of weighted criteria [3].

Among the three selected location and using the program e-MDM we assume that the most appropriate place for allocation of the stock for needs of three defined mines, power plants and chemical plants is area of the village of Klatova Nová Ves (Fig. 8).

Conclusion

Implementation of the programme e-MDM to the issue of stock for waste threatening the environment in the area of the upper Nitra showed the solution of the issue by the introduction and establishment of the stock of these wastes at the location near the village of Klatova Nová Ves, as this area is not a protected territory, in addition there is no overflowing river, as a source of potable water, and is the most appropriate solution to this problem in defining the five criteria mentioned above. The use of the program has been beneficial in terms of time and scientific as well.

The advantages of the program:

- it is not necessary to know the methods completely into the details,
- reports are also the result,
- eliminating the human errors (from calculations position),
- fast, flexible, reliable, easy to understand,
- the ability to define an unlimited number of criteria and points for consideration.

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