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MULTICRITERIA ANALYSIS OF PREVENTIVE MEASURES IN ORDER TO REDUCE THE RISK OF ACCIDENTS IN MINES WITH SURFACE OPERATIONS

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Abstract: Accident risk management in mining facilities includes measures to eliminate the possibility of accidents, which ensures that the risk of hazardous activities and hazardous substances is acceptable. Accident risk reduction takes place through accident prevention phases that are elaborated in detail separately for each mine and for each type of mining activity. In this paper, a multi–criteria analysis of the most important prevention measures is done in order to reduce the risk of accidents in mines with surface exploitation. The analysis was performed by AHP method. The results are used to develop an optimal plan for mine prevention from accidents, and the most important measures are the selection of those technologies and techniques that pollute the environment less and the determination of endangered zones and adequate spatial planning for new facilities, settlements and excavation dynamics.
Keywords: mine, risk, accident, AHP

1. INTRODUCTION

Mines with surface exploitation must take into account the risks of accidents that may arise due to the natural disasters or some breakdowns in the process. They can cause damage both in the mine itself and in the environment – on private objects, land, water, air, flora and fauna, etc. For this reason, mines are obliged to make up annual plans for the occupation of land, the purchase or dislocation of buildings and the expansion of the sanitary protection zone around the mine where, in the event of a mine accident, environmental endangerment appears [1]. Along with the given plans, plans are being made for the recultivation of degraded land in and around the mine, too.

Also, a detailed analysis of the impact on the environment is made for open–pit mines. This analysis assesses the impact and determines measures of prevention, preparedness and response to accidents that would be caused by both natural disasters and malfunctions in the work process. The most risky accidents are related to objects containing dangerous substances (fuel and lubricant storages, tanks, landfills, mining slopes and machines in the production process). During an accident, these objects can be damaged, and this can lead to endangerment of the ecological factors of the environment, as well as the mine's facilities, including the employees [2].

Prevention includes a set of measures and procedures that are undertaken at the potential site of an accident at a surface mine. The aim of prevention is to prevent and reduce the probability of an accident and its possible consequences. Prevention measures and procedures are determined based on the risk assessment, with the probability of their effectiveness being adequate to the probability of an accident occurring. Also, prevention measures and procedures must take into account the specifics of each mine related to the applied technology, the type of mineral raw material, the size of the surface mine, the number of employees, etc. [3, 4].

2. MATERIAL AND METHODS

The appropriate work methodology is defined in order to obtain optimal results. An accident at a mine can cause significant problems, so prevention measures aimed at minimizing the risk of an accident are discussed here.

The unique work methodology, defined by the author, is shown in Figure 1.

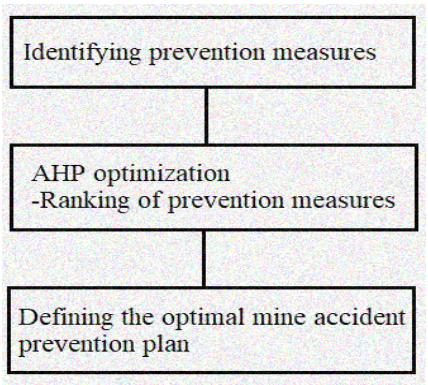

Figure 1. Schematic presentation of the work methodology

Figure 1 shows that research begins with the process of identifying prevention measures. The measures were identified on the basis of existing regulations in the field of mining, as well as on the basis of interviews with managers and experts of mining companies in our country. The questions are designed in such a way as to obtain the necessary data based on experiences and prevention measures that should be applied with the aim of optimal functioning of surface mines.

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After the interviews, the author defined the final list of prevention measures with company managers. In doing so, it was concluded that the application of all identified measures is necessary, because this is the only way to reach an optimal prevention plan and reduce the risk of accidents in surface mines.
In the next phase, the prevention measures from the list were ranked in order to prioritize their implementation. The AHP method was used for the ranking, where the ratings were given by the group decision–making method (author with managers and experts from open surface mines).
After obtaining the ranking results, the optimal mine prevention plan was defined with the aim of minimizing the risk of accidents. Consequently, the plan contains the optimal sequence of defined prevention measures that are applied based on the defined priority.

3. AHP METHOD

AHP is a well–known quantitative method for ranking alternatives and it decomposes a complex decision problem into a multidimensional hierarchical structure consisting of objectives, criteria and alternatives. Using the AHP method, the influence of criteria is determined, alternatives are compared in relation to each criteria, and alternatives are finally ranked [5].

Table 1. Decision-making elements comparison scale

Dominance	
Description	Mark
Equal	1
Weak dominance	3
Strong dominance	5
Very strong dominance	7
Absolute dominance	9
2, 4, 6, 8 are intermediate values	

The comparison matrix is the basis for mutual comparison of criteria and comparison of alternatives in relation to criteria. The aim of the comparison is to obtain the size of the impact of the criteria on the ranking result, as well as the "strength" of each alternative. These quantities are called the weight coefficient. They are determined by means of appropriate grades that evaluate the criteria and alternatives. In doing so, the degree of consistency is also calculated and its value must be less than 10% (0.1) in order for the ranking result to be accepted. Comparison of criteria and alternatives is done using a scale with grades from 1 to 9 – Tab. 1.
Determination of the final ranking of alternatives is done by synthesizing the results obtained at all levels.

4. RESULTS AND DISCUSSION

— Identification of prevention measures

Since the research was based on the results of interviews with managers and experts of mining companies, a list of accident prevention measures was obtained based on their assessment and existing regulations related to mining. When a list of all the proposed measures was obtained, an analysis of the given measures was carried out and a final list containing essential accident prevention measures at mining companies was made. This list includes the following measures:

- Selection of those technologies and techniques that pollute the environment less and provide a higher degree of protection (M1). This measure implies the selection of more modern available technologies and techniques that have a higher degree of reliability in operation and less pollute the environment and provide a higher degree of protection. This measure significantly reduces the risk of accidents in mines, but requires large investments. The solution is in a phased investment in the improvement of technologies and techniques.
- Maintenance of work technology discipline at the required level (M2). This measure implies the development and implementation of internal instructions for the operation and maintenance of devices based on the law and regulations given on technical norms and occupational safety during the surface exploitation of solid mineral raw materials and valid domestic and international standards. This measure is applied in all mining companies. The goal is to maintain work technology discipline at an appropriate level and ensure proper operation and handling of equipment by workers, as well as proper maintenance of equipment and proper maintenance of all roads and passages to and from dangerous installations, which can significantly reduce the risk of accidents at the mine.
- Application of technical means and equipment for detection and protection (automatic detection and extinguishing of fires, dilators for measuring the movement of the slope of the mine or tailings dump, etc.) (M3). This represents a set of measures aimed at timely detection of the danger of accidents in the mine, as well as the elimination of certain dangers. The specified set of measures implies the installation of appropriate measuring stations and other devices in and around the surface excavation.
- Control and supervision of monitoring in the security system, especially for the spread of chemical hazards (dust and gases in the environment, dangerous shocks, noise, etc.) (M4). This is a set of measures that experts say are gaining more and more importance due to increasing public pressure to

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protect the environment. Surface mines are a major source of environmental pollution, partly because the above measures have not been applied to a significant extent.

- Timely elimination of all observed technical and technological deficiencies (M5). The aforementioned preventive measures aim at constant control and elimination of all defects that may occur in the production process. In this way, many potential risks of accidents in surface mines can be avoided, because any deficiency can lead to a chain failure in the operation of many systems.
- Determining the zones of environmental threat (I, II, III) and adequate spatial planning for the construction of new buildings, settlements and excavation dynamics (M6). These preventive measures have the task of protecting and timely preparing the environment around the surface mine for future exploitation. The emphasis is primarily on the protection of buildings, settlements and the area around the mine, the purchase and relocation of buildings, the construction of the necessary mine buildings and facilities in accordance with the expected dynamics of mine development.
- Timely information and involvement of the public in decision–making on all issues important for the safety of the population (M7). The mining sector must create an effective system of communication with the public. The public, especially the population around surface mines, must be included in the decision–making process related to their safety, environmental protection, etc. In this way, good cooperation between all stakeholders can be achieved, which can significantly reduce the risks of accidents for them.

— AHP optimization

After identifying all preventive measures aimed at reducing the risk of accidents at mining companies, the given measures are ranked using the AHP method. As it was said, the aim of the ranking is the prioritization of preventive measures against accidents, which will enable the development of an optimal mine accident prevention plan.

The ranking of the measures was carried out by managers and experts, as mentioned above – Tab. 2.

Table 2. Comparison marks of accident prevention measures

	M1	M2	M3	M4	M5	M6	M7
M1	1	2	3	4	3	1	3
M2		1	2	1	1	1/2	1
M3			1	1	1/3	1/3	1/2
M4				1	1/3	1/4	1/2
M5					1	1/2	1
M6						1	1
M7							1

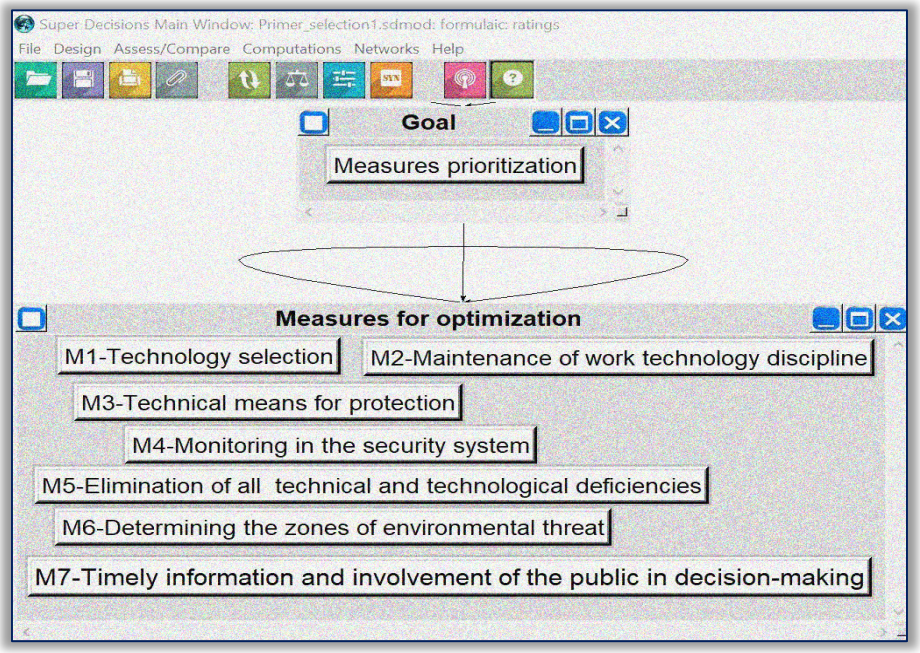

Figure 2. Multidimensional hierarchical structures of goals and measures

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After comparing the preventive measures, the Super Decisions software was used to obtain the results of the ranking of the measures. In doing so, a multidimensional hierarchical structure of goals and measures was determined – Figure 2, and after that the weighting coefficients of the proposed measures were determined (the results are shown in Figure 3).

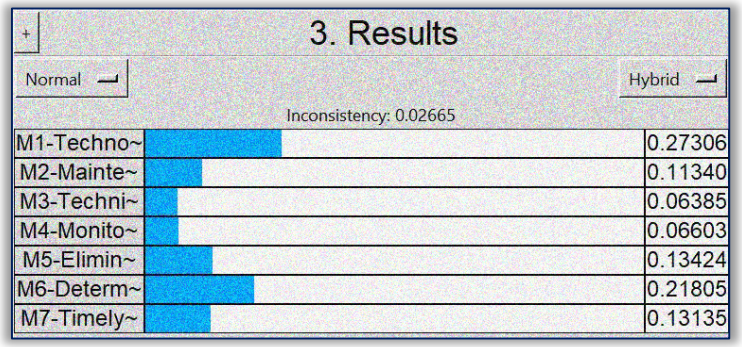

Figure 3. Results of optimization

The degree of inconsistency is 0.02665, which is less than 0.1, so the results are consistent.

— Defining the optimal mine accident prevention plan

The obtained results (Tab. 3) can be seen as very important guidelines for mines in terms of the priority in which the defined preventive measures should be applied when creating an optimal mine accident prevention plan.

Table 3. Ranking result with weight coefficients

No.	Proposed measures	Result
1.	M1 (Selection of those technologies and techniques that pollute the environment less and provide a higher degree of protection)	0,27306
2.	M6 (Determining the zones of environmental danger (I, II, III) and adequate spatial planning for the construction of new buildings, settlements and excavation dynamics)	0,21805
3.	M5 (Timely removal of all observed technical–technological deficiencies)	0,13424
4.	M7 (Timely informing and involving the public in decision–making on all issues important for the safety of the population)	0,13135
5.	M2 (Maintaining labor and technological discipline at the required level)	0,11340
6.	M4 (Control and supervision of monitoring in the security system, especially for the spread of chemical hazards)	0,06603
7.	M3 (Application of technical means and equipment for detection and protection)	0,06385

The results show that it is possible to divide preventive measures into three groups in terms of the priority of their application. The first group includes measures M1 (Selection of those technologies and techniques that pollute the environment less and provide a higher degree of protection) and M6 (Determining the zones of environmental danger (I, II, III) and adequate spatial planning for the construction of new buildings, settlements and excavation dynamics). Their weight coefficients are the highest. In general, these are preventive measures that have the long–term task of reducing the risk of accidents. The choice of those technologies and techniques that less pollute the environment and ensure a greater degree of protection and the determination of environmental risk zones and adequate spatial planning for the construction of new buildings, settlements and the dynamics of excavation represent a long–term solution both for surface mines and for the local community that exists in the immediate vicinity of mine. Therefore, these preventive measures must be a priority during the development of a mine accident prevention plan. The disadvantage of these measures is that they require a large initial investment of the mine, but later obtain much better financial results with a large reduction in the risk of accidents.

The second group includes measures M5 (Timely removal of all observed technical–technological deficiencies), M7 (Timely informing and involving the public in decision–making on all issues important for the safety of the population) and M2 (Maintaining labor and technological discipline at the required level). These preventive measures have lower weight coefficients compared to measures from the first group. The reason for this is because the mentioned measures refer to medium–term tasks aimed at reducing risk and they represent a supplement to the preventive measures from the first group.

The third group includes measures M4 (Control and supervision of monitoring in the security system, especially for the spread of chemical hazards) and M3 (Application of technical means and equipment for detection and protection). These preventive measures have the lowest weight coefficients. Preventive measures of the third group refer to operational tasks in the daily performance of work in order to collect

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data and apply certain means for detecting the risk of accidents. These measures play a significant role in risk reduction and they also complement the preventive measures from the first and second groups.
Based on the obtained ranking results, the optimal mine accident prevention plan should rely on defined preventive measures, which are ranked by importance. As can be seen from Figure 4, at the top are the most important, long–term measures that are systemic and as such reduce the risk of accidents at surface mines to the greatest extent. These are the measures from the first group – M1 (Selection of those technologies and techniques that pollute the environment less and provide a higher degree of protection) and M6 (Determining the zones of environmental threat (I, II, III) and adequate spatial planning of the construction of new buildings, settlements and dynamics excavations). Below are the measures from the second group (medium–term measures) – M5 (Timely removal of all observed technical and technological deficiencies), M7 (Timely informing and involving the public in decision–making on all issues important for the safety of the population) and M2 (Maintaining labor and technological discipline at the required level). At the bottom are measures from the third group (operational measures) – M4 (Control and supervision of monitoring in the security system, especially for the spread of chemical hazards) and M3 (Application of technical means and equipment for detection and protection). The lines connecting these measures indicate the need to supplement and combine them during application, because this is the only way to achieve their maximum effect – minimizing the risk of accidents.

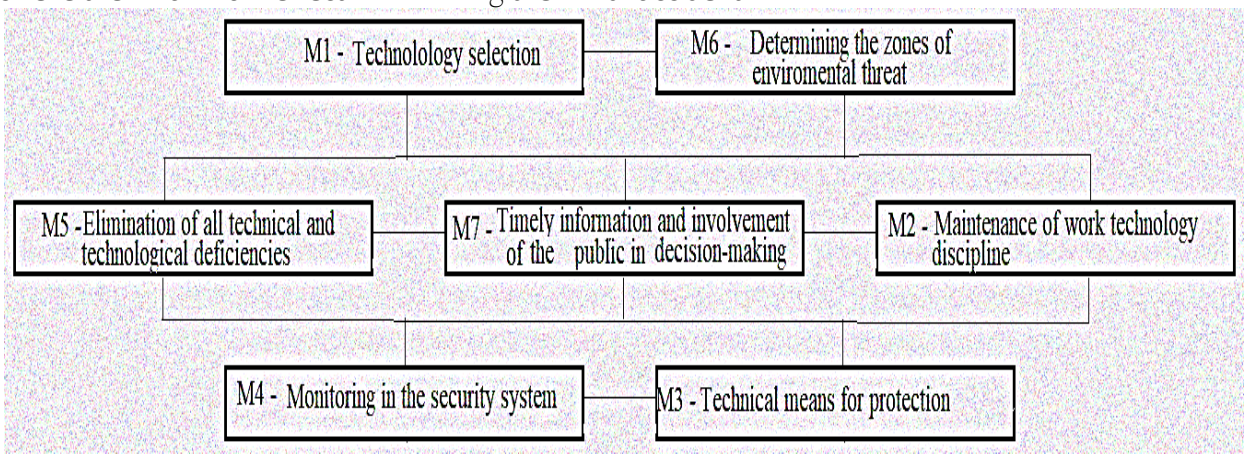

Figure 4. Scheme of measures for creating an optimal mine accident prevention plan

5. CONCLUSION

In this paper, the AHP method was applied to rank the necessary preventive measures with the aim of creating an optimal plan for the prevention of accidents in surface mines. Seven measures were considered – M1 (choosing those technologies and techniques that less pollute the environment and provide a higher degree of protection), M2 (maintenance of labor and technological discipline at the required level), M3 (application of technical means and equipment for detection and protection), M4 (control and supervision of monitoring in the safety system, especially for the spread of chemical hazards), M5 (timely elimination of all observed technical and technological deficiencies), M6 (determination of environmental danger zones (I, II, III) and adequate spatial planning of the construction of new buildings, settlements and dynamics excavations) and M7 (timely information and involvement of the public in decision–making on all issues important for the safety of the population).
Based on the results obtained using the AHP method, prevention measures can be divided into three groups – the first group represents long–term measures (M1 and M6), the second group represents medium–term measures (M5, M7 and M2) and the third group represents operational (short–term) measures (M4 and M3).
The optimal mine accident prevention plan must implement all measures, with the priority of the given measures defined by the results of the AHP ranking.

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