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SLOBODAN VUJIĆ*, MARJAN HUDEJ**, IGOR MILJANOVIĆ***

RESULTS OF THE PROMETHEE METHOD APPLICATION IN SELECTING THE TECHNOLOGICAL SYSTEM AT THE MAJDAN III OPEN PIT MINE

WYNIKI ZASTOSOWANIA METODY PROMETHEE DO WYBORU SYSTEMU TECHNOLOGICZNEGO W KOPALNI ODKRYWKOWEJ MAJDAN III

This paper discusses the application of the PROMETHEE model and the results achieved in practice, following the example of the multi-criteria selection of the technological system at the Majdan III clay mineral raw material open pit mine of the Potisje Company, Republic of Serbia. After the introduction comments, reasons are explained for selecting the new technological system, conditions and limitations for the seven alternative solutions considered are described, mathematical foundation for the PROMETHEE method and a multi-criteria model of the problem in question are presented. The solution with the following structure was ranked first and accepted by the Company management as the best: Bucket chain excavator – Conveyor belts – Spreader (ECS), alongside a decision is made on the acquisition of machinery and system construction. The system was put into operation in 2000. The experience and the data accumulated in the previous twelve years confirm that the decision made on the application of the ECS technology was just, and the conclusion lists the benefits achieved.

Keywords: multi-variate analysis, promethee method, decision making support, technological system selection, Majdan III open pit mine

W artykule omówiono zastosowanie modelu Promethee i przedyskutowano uzyskane w ten sposób wyniki na przykładzie wielokryterialnego wyboru systemu technologicznego do zastosowania w kopalni odkrywkowej minerałów ilastych Majdan III, należącej do przedsiębiorstwa górniczego Potisje (Republika Serbii). Po uwagach wprowadzających przedstawiono powody wyboru nowego ciągu technologicznego, omówiono warunki oraz ograniczenia dla siedmiu alternatywnych rozwiązań, podstawy matematyczne metody Promethee oraz wielokryterialny model zagadnienia. Rozwiązanie uznane za najlepsze i zaaprobowane przez zarząd przedsiębiorstwa zakłada zastosowanie następującego ciągu technologicznego: koparka łancuchowa jednonaczyniowa – przenośniki taśmowe – rozkładarka(system ECS). Podjęto także decyzje odnośnie zakupu sprzętu i instalacji systemu, który uruchomiony został w 2000 roku. Doświadczenia i dane

* MINING INSTITUTE, BELGRADE, SERBIA, E-Mail: slobodan.sujic@open.telekom.rs
** MINING AND CONSTRUCTION COMPANY, VELENJE, SLOVENIA
*** FACULTY OF MINING AND FEOLOGY, UNIVERSITY OF BELGRADE, SERBIA

zebrane z przeciągu ostatnich dwunastu lat potwierdzają zasadność wyboru systemu technologicznego. W podsumowaniu zestawiono listę uzyskanych korzyści.

Słowa kluczowe: analiza obejmująca wiele zmiennych, metoda Promethee, wspomaganie procesów decyzyjnych, wybór ciągu technologicznego, kopalnia odkrywkowa Majdan III

1. Introduction

Generally, decision making in solving technical or technological problems in mining means generating possible solutions and selecting the most suitable ones. Solution generation depends on creativity, ideas, expertise, experience, motivation and the attitude of experts towards the risk. The selection of solutions is a procedure where one of the considered alternatives is selected, by using a certain methodology (Azimi, 2012). The quality of the decision relies on the quality of alternatives offered, criteria applied, and, to some extent, on the method of selection. Two tasks hold the key importance in decision making (Batanovic, 2011):

The first task relates to the selection of the criteria and the criteria valuation of the alternatives proposed. When solving the practical problems in mining, most often there are circumstances with more criteria, sometimes conflicting (Bakhtavar, 2009). The criteria can be presented both in a *quantitative* and *qualitative* manner. The quantitative criteria are presented in a numerical form, e.g. values for: profit, costs, productivity, production scope, mine capacity, energy consumption, ore metal contents, calorific value of the coal, etc. The qualitative criteria are presented in a linguistic form, e.g. good, better, poor, weak, insufficient, satisfactory, etc. (Abath, 2009). In selecting the criteria and the criteria valuation of alternatives, the key responsibility lies upon the decision maker for its subjectivity, which cannot be completely dismissed (Brans, 1986, 2005). In order to completely remove or obscure the subjectivity of decision maker, the team work is recommended in selection of the criteria as well as the criteria valuation of the alternatives.

The second task relates to the selection of the suitable mathematical-model approach for decision-making support. Which mathematical model will be used depends on the type of the problem, its structure and the proficiency of decision makers in the decision support methods (Doumpos, 2010), particularly in the operations research methods (Beynon, 2011). In general, this is the easier operational task with less subjective influences.

The short retrospective on the main phases of decision making process is synthetizing the essence of the subject of this paper, which is the application and an assessment of the PROMETHEE method application in multi-criteria selection of the technological system of the Majdan III open pit mine. We will discuss here the reasoning behind the introduction of a new technology in this open pit mine.

The open pit mine Majdan III is owned by the company Potisje from Kanjiza, situated at the northeast of the Republic of Serbia. The company was established in 1903, and it is one of the leading manufacturers of high quality tiles and bricks in the Southeastern Europe. The Company owns three tile factories, a brick factory, the decorative ceramics factory and the Majdan III open pit mine. With annual capacity of 400,000 tons of clay, Majdan III provides the production of 140,000,000 pieces of tiles, bricks and ceramics. Since 2003, the Company is a part of the Tondach Group.

The consumption level of clay raw material reserves at the Majdan II open pit mine influenced the company management decision on opening the new open pit mine Majdan III. This decision was followed by the decision to replace the technological system applied at the Majdan

II open pit mine for the purpose of low productivity and production unreliability with the new system having better production performances. The first step was to produce the Mining project of the Majdan III open pit mine, alongside with the research study for the selection of the new technology. Seven technological alternatives, applicable at the Majdan III open pit mine were analyzed. The multi-criteria analysis by PROMETHEE method ranked the continual system with four bucket chain excavators for the clay excavation, six rubber conveyor belts for the transport of clay to the spreader at the storage place in the factory grounds as the best. Hereinafter, an acronym ECS for this system (from Excavator (bucket chain) – Conveyor – Spreader).

The production at the Majdan III open pit mine commenced in 1996. Due to the lack of investments, the acquisition of the ECS system was postponed and the combined technology with bucket chain excavators at excavation, loader at loading and trucks at clay transport from the open pit mine to the storage place at the factory grounds was used as the transient – temporary solution.

Upon ensuring the investments, the Company acquired the machinery and equipment and commenced the construction of the ECS system in 1999. The system test runs took place in 2000. Figure 1 shows the spatial disposition of the ECS system machinery and facilities of the Potisje Company, while the figure 2 shows the detail with bucket chain excavators working at the Majdan III open pit mine.

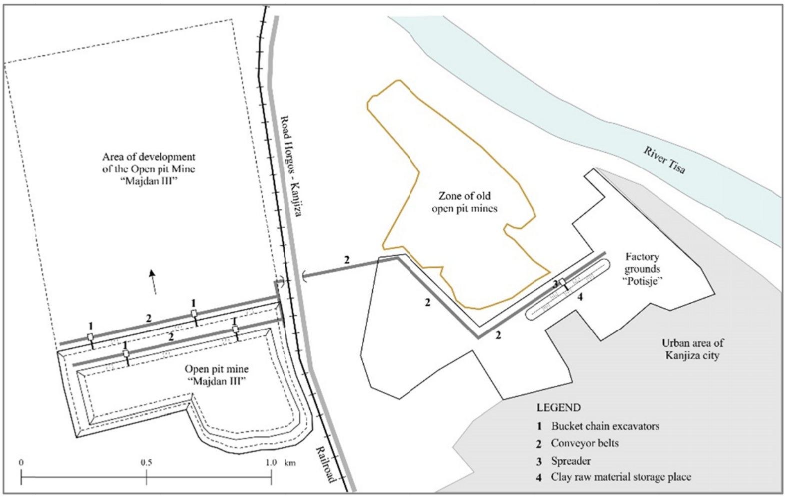

Fig. 1. Schematic presentation of the spatial disposition of the ECS system machinery and facilities of the Potisje Company

For the purpose of establishing the efficient remote control and management of the ECS system, a computer monitoring and management system with GPS telemetry was built in. Majdan III open pit mine is the first clay open pit mine with the real time satellite supported monitoring of the ECS system operation worldwide. The data collected during twelve years of operation, provided valid foundation for the objective analysis, valuation and the assessment of the reliability of PROMETHEE model application in decision making process. The problem of the Majdan III technological system selection is unique, enabling the reasoned review of the validity of the solution that was recommended by the PROMETHEE analysis and put in practice. Figure 3 shows a detail from the command post of the Majdan III open pit mine monitoring-management system.

The short review of the opening of the Majdan III open pit mine and the construction of the ECS system given here is helpful in understanding the problem, and confirms the rule of mining engineering that the path from the task and an idea to the project solution and realization is not straightforward.

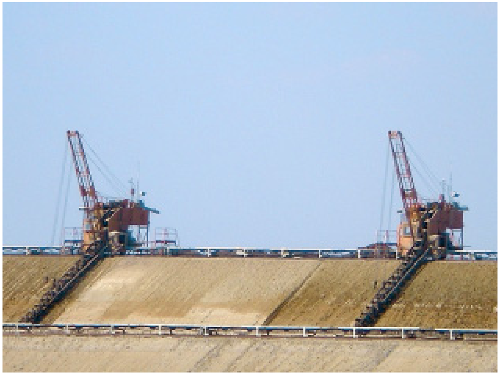

Fig. 2. A detail from the Majdan III open pit mine, showing bucket chain excavators and conveyor belts of the ECS system

Fig. 3. A detail from the command post of the Majdan III open pit mine showing ECS control system

2. Mine conditions and limitations

At the Majdan III open pit mine, clay is excavated in a shallow layered-sedimentary deposit of a swamp-alluvial-loess type. The annual production amounts at 450,000 tons of clay. The excavation is performed in two layers, the higher layer 1000 m long and 7 m high, and the lower 850 m long and 6 m high. According to its capacity and mining grasp, Majdan III open pit mine is a large open pit mine of its class.

During the problem-solving in mining as well as design, the starting point is always in certain conditions and limitations that influence the solution selection decisively. In selecting the Majdan III technological system, the following limitations are considered to be the most important:

1. Materials comprising the working environment of the Majdan III open pit mine have poorer physical-mechanical properties, and in the presence of water (underground water, rainfall, snow), these properties are becoming even poorer. This limitation have a significant impact the selection of the excavation, loading and transport machinery and it must be adequately taken into account in the technological system selection analysis.
2. Tile and brick production is not highly profitable, therefore maximum caution in planning and generation of all costs, ranging from the investment to production is necessary. There is high importance of the cost in the technological system selection analysis.
3. Environmental protection demands and the establishing of the balanced relation between the environment and mining operations at the open pit mine are correlating with the ex-

cavation technology applied. Majdan III open pit mine is located in an agricultural area, in the immediate vicinity of the town of Kanjiza and the spa-recreational-tourist center. Because of its significant influence in selecting all portions of the technological system, limitations such as this should be built in as attributes into the analytical model.

4. The Potisje Company, with hundred years of tradition in clay exploitation, has vast technological experience, established organizational, technical-technological and work discipline and qualified workforce with developed habits. Abandoning one and transiting to another technology means not only the acquisition of new machinery and equipment but the training and coaching and adapting the workers for the operation, maintenance and repairs of the new machinery. The transition of the new technology can lead to the changes in workforce employed. All this is exposed as the expenditure influencing the selection of the technological system and it should be built in the analytical model.
5. In selecting the transport machinery, the transport route, road construction costs, transport costs, environmental influence etc., are taken as the limiting factors.

The level of technological system adjustment to the real environment is in correlation with the conditions set, and the better level of system adjustment means that the system is better suited for the operation in the given environment (Vujic, 2004). The finding that more conditions and influence the selection of the technological system shows that this is a *multi-criteria or a multi-attribute problem* (Cancer, 2004). This is the engineering task, where the limitations and conditions are to be reviewed, alternative technological solutions, applicable at the Majdan III open pit mine to be defined, and the best solution to be selected, according to the criteria adopted.

3. Selection of alternative solutions and criteria

Upon request from the Potisje Company management, respecting the specifics of the Majdan III open pit mine, possible technological solutions were analyzed, and seven alternatives were recognized. The possibility to perform the transport by trucks and scrapers by using one of two transport routes (RR1 and RR2, see Table 1 comment), is separated into two alternatives for the purpose of this analysis (Vujić, 1995). The technological solution applied at Majdan II, the old open pit mine, which was to be replaced with the more advanced solution because of its low productivity and unreliability, is included in the analysis for the purpose of comparison with the new technological solutions as the seventh alternative. Table 1 shows the review of the technological solutions included in the analysis.

As a preparation for the multi-criteria analysis, all seven alternative technological systems are processed in the same manner, consisting of: defining the machinery structure of the system, calculation of capacity and the necessary number of machines in the system, assembly of the equipment and machinery, necessary civil construction works, norms for material, required work force, and cost calculation. The detailed description of the processing would burden the text with irrelevant details; therefore we will give only some of the important comments.

The specificity and the suitability of the scraping technique (alternatives A1 and A2) are reflected in the fact that one machine is performing all the technological operations: excavation, loading, transport and the deposition of material at the storage place. Application of this technology at the Majdan III open pit mine can be troublesome with rainfalls or snowy periods. Scraper operation is rendered difficult or impossible due to the sodden soil. The alternatives A1 and A2 are technologically equivalent, differing in transport conditions and the transport road routes construction conditions (RR1 and RR2).

TABLE 1

Review of the possible alternative solutions for the Majdan III open pit mine technological solution

No.	Technology	Technological system machinery structure	Alternative
1.	Cyclical – scraping (road route RR1)	Automotive elevating scrapers ↔	A1
2.	Cyclical – scraping (road route RR2)	Automotive elevating scrapers ↔	A2
3.	Cyclical – conveyor belts and trucks (road route RR1)	Bucket chain excavators → conveyor belts → loaders → trucks ↔	B1
4.	Cyclical – conveyor belts and trucks (road route RR2)	Bucket chain excavators → conveyor belts → loaders → trucks ↔	B2
5.	Continuous technology (ECS system)	Bucket chain excavators → conveyor belts → spreader	C
6.	Combined	Bucket chain excavators → conveyor belts → loader → railroad transport ↔	D
7.	Cyclical (OPM Majdan II, to be abandoned)	Bucket chain excavators → railroad transport ↔	E

Comment: RR1 – Road route 1,440 m long; RR2 – Road route 1,395 m long

In a technological sense, there are no differences between the alternatives B1 and B2, consisting of the selective excavation of clay on two benches by bucket chain excavators, transport by rubber conveyor belts to the transfer storage place on the east side of the open pit mine. The clay is loaded into the trucks at the transfer storage place and transported to the storage place within the factory grounds by trucks. The particular thing about this solution is the combined transport (by rubber conveyor belts and trucks), and a transfer storage place. With this solution, trucks aren't moving on the soft soil within the open pit mine, which is particularly important during rainy season, when the truck movement is either difficult or impossible. Similar to the alternatives with scraping technologies, alternatives B1 and B2 differ only by transport road routes lengths, and construction conditions (RR1 and RR2).

The basic feature of the alternative C is the machine structure of the technological system, achieved by joining the bucket chain excavators with rubber conveyor belts for the transport to the spreader at a storage location within the factory grounds. Advantages of such technological approach are: negligible sensitivity to climate variations and the rain, insignificant environmental influence because machines are moved by electric motors, there are no exhaust gases and no dust caused by trucks and scraper movements, and the noise and vibration are insignificant.

The specifics of the alternative D are the transport of clay by rubber conveyor belts from the open pit mine to the transfer storage place, and by locomotive-hauled wagons from the transfer storage place to the clay storage place within the factory grounds. There are two advantages with this solution. The first is the investment savings achieved by using the wagons and locomotives already owned by the Company, and the other is the avoidance of the complex movement of railroad tracks at the open pit mine, achieved by replacing the railroad transport with the rubber conveyor belts.

The alternative E is the applied technical solution used at the Majdan II open pit mine that is abandoned. The most prominent feature of this technological system is the railroad transport from the bucket chain excavator to the storage place within the factory grounds. In order to ensure maneuvering and movement of the compositions, bypass loops are constructed on the benches, and to move these loops periodically, together with other railroad tracks, means lowering the effective operational time, influencing the production and work productivity to decrease, and demanding permanent involvement of significant number of employees for the railroad track maintenance, etc.

The definition of the criteria and their weights is of key importance for the multi-criteria analysis. In solving the problem in question, particular attention was paid to this. To avoid or minimize subjectivity and errors that may be generated by it, the professional team was formed with 2 project team engineers and 2 engineers from the Potisje Company. All team members were experienced professionals, with more than 20 years of working experience and with significant knowledge of opencast mining technologies, mineral-raw materials and conditions at the Majdan III open pit mine. The team had two tasks: to check the validity of the proposed technological alternatives, and the second to define the criteria and their weights for the multi-criteria selection of the best technological solution. The mechanism of team synergetic cooperation was established as a panel-discussion with equal treatment of each individual attitude and opinion. The final, collective standpoint, was formed after a argumentative discussion and consensus-reaching process. The team suggestions were presented to the management of the Company, as the final decision maker. The key joined conclusion was six criteria is sufficient to encompass all technical, technological, ecological, engineering-geological and other parameters relevant for the multi-criteria analysis of the Majdan III open pit mine technological system selection. Table 2 presents a review of the criteria suggested, two of them quantitative and four qualitative.

TABLE 2

A review of the best technological solution selection criteria

No.	Criteria	Mark	Measurement	Goal	Weight
1.	Value of investments in the technological system	C1	Quantitative	C1 → min	0.30
2.	Specific costs of technological system production	C2	Quantitative	C2 → min	0.30
3.	Ecological suitability of the technological system	C3	Qualitative	C3 → max	0.10
4.	Suitability of the technological system (environmental influence)	C4	Qualitative	C4 → max	0.10
5.	Transport route suitability	C5	Qualitative	C5 → max	0.15
6.	Level of training of the employees for operating the system and its maintenance	C6	Qualitative	C6 → max	0.05

The quantitative criteria C1 and C2 are presented by numerical currency value and approaching to the minimum, and functionally are connected with the second condition in the *Mine conditions and limitations* section. The qualitative criteria C3, C4, C5 and C5 are approaching the maximum, and they are expressed through grades: poor (equivalent 1), sufficient (equivalent 2), good (equivalent 3), very good (equivalent 4) and excellent (equivalent 5). The criterion C3 is functionally connected with the third condition, criterion C4 with the first condition, criterion C5 with the fifth, and criterion C6 with the fourth condition.

For criteria weights, the range from 0.05 to 1 was adopted. It was assessed that C1 and C2 criteria hold the heaviest weight of 0.3, criterion C5 follows with 0.15, then criteria C3 and C4 with 0.10 and C6 with the weight of 0.05. The review of criteria and their weights is given in Table 2.

4. The mathematical-modelling approach

In selecting the method for solving the practical problem of multi-criteria decision making (MCDM), it is appropriate to consult some of MCDM methods classification. In this case, it was assessed that the most suitable is the classification "according to the problem solving manner", with two groups of methods:

- The first group consist of methods where multi-criteria problems are brought down to the problems solvable with one of the known mathematical programming methods;
- The second group consists of methods where problems are solved by analysis and ranking of alternatives. It is assumed that all the alternatives are criteria valued in the same manner. The procedure of assigning values is one of the following: mathematical calculation, experimental measurements, heuristic valuation or subjective assigning of grades (Vujić, 2004).

Features of the problem in question, reflected in:

- More decision making criteria;
- More alternatives (solutions) for the selection; and
- Selection of a single, final solution,

are directing towards the second group of methods, with PROMETHEE, ELECTRA and AHP being the most prominent. There are two reasons for selecting the PROMETHEE model as a tool for the analysis of the technological solution at the Majdan III open pit mine. The first is our positive experience with this method in solving some of the previous problems, and the other is that PROMETHEE model is using six generalized criteria for expressing preferences of the decision maker regarding the actual criteria for the problem in question, which is somewhat diminishing the influence of subjectivity on the assessment (Halouani, 2009; Behzadian, 2010).

The family of Preference Ranking Optimization Methods for Enrichment Evaluation methods with the acronym PROMETHEE is made of four methods named I, II, III and IV. PROMETHEE I gives partial ranking of elements or alternatives, PROMETHEE II is determining the complete rank, PROMETHEE III the interval ranking of elements, while PROMETHEE IV, as the extended version of PROMETHEE III considers an uninterrupted array of alternatives. Main features of this family of methods still under the development are:

- The built-in generalized criteria for expressing preferences of the decision maker regarding the actual criteria for the problem that is solved;
- The user is allowed to introduce new types of the generalized criteria for the problem in question and to express its preferences regarding certain criteria (Parreiras, 2007).
- Introduction of weights is enabled for certain criteria.

The mathematical model PROMETHEE is presented in many operations research references. Therefore the authors believe, for the purpose of rationality, that omitting the mathematical model is reasonable and that it has no influence on the quality of the papers' message. Opposed to this, the presentation of the mathematical model in the paper would only unnecessary contribute to the increase in the number of pages.

5. Problem solution

The multi-criteria analysis of the process of selecting the best solution for the technological system at the Majdan III open pit mine was performed by PROMETHEE II method, using the Promcalc software. The matrix model of the problem, Table 3, is formed according to the program procedure, based on the parameters defined in the *Selection of alternative solutions and criteria* section, with seven alternatives and six criteria. For the purpose of continuity and better understanding, for alternatives and criteria, the same notation is used in tables 1, 2 and 3.

Values of investments in the technological systems (column C1 in the Table 3) and the specific costs of technological system production (column C2) are given in real currency amounts. Because of currency values updating, and in order to avoid possible dilemmas, the currency values for C1 and C2 are not given in the local currency, but in a monetary equivalent called currency unit (c.u.). This has no influence on the calculation procedure and the outcome. The assessment of the ecological suitability of technological systems (column C3 in the Table 3), the suitability of the technological system for operation in the open pit mine conditions (column C4), suitability of the construction of the transport route (column C5) and the training level of workers for operation and system maintenance (column C6) were defined by the professional team, as described in the section 3. The same accounts for the weights. For the generalized preferences, the regular function (Type 1) was used for all criteria. The following are the outcomes of the problem processing by PROMETHEE II method, using the Promcalc software.

The rank of alternatives obtained by this analysis is given in table 5, while table 6 gives the review of the weights stability intervals, which, as the elements of the sensitivity of solution, show the variation boundaries for the criteria weights where no alternative rank will occur.

TABLE 3

Matrix model of the problem

		Criterion					
		C1	**C2**	**C3**	**C4**	**C5**	**C6**
Min / Max:		min	min	max	Max	max	Max
Type:		1	1	1	1	1	1
Weight:		0.30	0.30	0.10	0.10	0.15	0.05
Alternative	A1	17.06	45.72	3,00	4.00	0.00	2.00
	A2	19.52	48.05	3,00	4.00	0.00	2.00
	B1	15.34	52.79	3.00	4.00	3.00	3.50
	B2	17.79	55.14	3,00	4.00	3.00	3.50
	C	17.67	34.16	5,00	5.00	5.00	2.00
	D	10.57	49.77	4.50	5.00	4.00	3.00
	E	6.69	55.68	4.00	5.00	4.50	5.00

Comment: The real value in c.u. for C1 is obtained when the table value is multiplied by 10^6.

For the purpose of clear understanding of the alternatives ranking, based on the Table 5, Table 7 was formed, where technological alternatives with machinery structures are ordered by their ranking.

TABLE 4

Evaluations and flows

Alternative	C1	C2	C3	C4	C5	C6	Phi +	Phi –	Phi
	min	min	max	max	max	Max			
A1	17.06	45.72	3.00	4.00	0.00	2.00	0.43	0.42	0.01
A2	19.52	48.05	3.00	4.00	0.00	2.00	0.23	0.62	-0.39
B1	15.34	52.79	3.00	4.00	3.00	3.50	0.36	0.51	-0,15
B2	17.79	55.14	3.00	4.00	3.00	3.50	0.16	0.71	-0,55
C	17.67	**34.16**	**5.00**	**5.00**	**5.00**	2.00	0.75	0.20	0,55
D	10.57	49.77	4.50	**5.00**	4.00	3.00	0.67	0.29	0,38
E	**6.69**	55.68	4.00	**5.00**	4.50	**5.00**	0.56	0.41	0,15

TABLE 5

Promethee flows

Alternative	Phi+	Rank	Phi-	Rank	Phi	Rank
A1	0.433	4.0	0.425	4.0	0,08	4.0
A2	0.233	6.0	0.625	6.0	-0,392	6.0
B1	0.358	5.0	0.508	5.0	-0,150	5.0
B2	0.158	7.0	0.708	7.0	-0,550	7.0
C	0.750	1.0	0.200	1.0	0,550	1.0
D	0.675	2.0	0.292	2.0	0,383	2.0
E	0.558	3.0	0.408	3.0	0,150	3.0

TABLE 6

Weights stability intervals

Criterion	Weight	Interval		%	% Interval	
C1	0.30	0.28	0.39	30.0	28.41	35.66
C2	0.30	0.23	0.31	30.0	24.49	30.91
C3	0.10	0.00	0.12	10.0	0.00	11.72
C4	0.10	0.00	0.00	10.0	0.00	100.00
C5	0.15	1.13	0.31	15.0	13.31	26.85
C6	0.05	0.04	0.12	5.0	4.38	10.99

TABLE 7

Promethee II complete ranking

Rank	Alternative	Phi	The alternative
1.	C	0.550	Bucket chain excavators → conveyor belts → spreader (ECS system)
2.	D	0.383	Bucket chain excavators → conveyor belts → loader → railroad transport ↔
3.	E	0.150	Bucket chain excavators → railroad transport ↔
4.	A1	0.080	Automotive elevating scrapers (the alternative with road route RR1) ↔
5.	B1	-0.150	Bucket chain excavators → conveyor belts → loaders → trucks (the alternative with road route RR1) ↔
6.	A2	-0.392	Automotive elevating scrapers (the alternative with road route RR2) ↔
7.	B2	-0.550	Bucket chain excavators → conveyor belts → loaders → trucks (the alternative with road route RR2) ↔

According to the PROMETHEE analysis, the highest rank is held by the alternative C, or the technological system with the following machinery structure: 4 bucket chain excavators, 2 bench conveyor belts, 4 stationary conveyor belts and a spreader.

Other alternatives are ordered in the following manner: D, E, A1, B1, A2, and B2. Interesting is the third position, held by the alternative E, namely the technology applied at the Majdan II open pit mine that was abandoned. Higher rank of this technology than the scraper or truck based technologies (alternatives A1, B1, A2 and B2) is explained by lower investments (C1 criterion) and relatively better performances in relation to the criteria C3, C4, C5 and C6.

Company management accepted the results of this study analysis, with the ECS system as the best technological solution for the Majdan III open pit mine.

6. Conclusion and the final assessment

The designers' proposition, based on the complex study analysis of the technological alternatives applicable in the conditions of the Majdan III open pit mine, and the multi-criteria comparative analysis by the PROMETHEE model was accepted by the management of the Potisje Company, opting for establishing the ECS system at the Majdan III open pit mine. As it was stated at the beginning of the paper, the acquisition of the machinery and equipment for the ECS system was delayed by three years for financial reasons. The construction of the ECS system commenced in 1999, and the system was put into operation in 2000.

Twelve years of experience in operating the ECS system, without any additional construction or other design changes, together with the contemporary computer system of ECS system remote control, recording all events in the system and the effects on production are enabling the ground rule for the argumentative and objective review of the effects, results and the benefits achieved.

By following this approach in the technological system selection, numerous benefits and savings were accomplished, to name only the most important: transport costs of the ECS system were lowered by 4 times compared to the technological system previously used at the Majdan II open pit mine. Monthly oil consumption was lowered by 50,000 liters; the electric energy consumption increased, but consumption of oil decreased, and the monthly savings in energetic resources consumption reached 23,750 €; number of workers is lowered by 18, with monthly savings approximately at 40,000 €; the effective operational time at the open pit mine increased by 792 hours per year; reliability and safety of the system operation is high in all weather conditions; maximum efficiency of clay excavation, homogenization and selective deposition is achieved; negative influences on the environment are avoided; there are no exhaust gases or dust, the noise is minimized, etc.

The problem of technology selection is one of the fundamental mining problems, where the financial effects of mining, operational safety, production reliability, ecological safety, etc., depend on its solving. The approach presented here can be instructive and educative for solving similar problems in other mines, thus overcoming the importance of a single open pit mine. Our multi-decade experience shows that any other mine could be taken as an example, supporting the opinion that the PROMETHEE model is an efficient tool in completing analyses, selection, assessments, decision making and solving numerous multi-criteria problems in mining.

The assumptions regarding the successful approach in solving practical problems by means of multi-criteria optimization are surely the correct selection and the setting up an adequate multi-criteria model. In a procedural sense, depending on the complexity of a real problem, the expertise, interest, motivation and the caution of decision-makers, the multi-criteria models are less or more successful approximations of the real life situations. In the process of building the multi-criteria model, the unavoidable and undesirable subjectivity of the decision-makers, is playing a major role in linguistic valuation of the criteria, e.g. good, poor, small, medium, large, etc. Which criteria should be applied and how to conduct the criteria valuation of alternatives are the key questions the answers of which are deciding the multi-criteria analysis outcome.

If a judgment can be made based on the results achieved with the ECS system at the Majdan III open pit mine, during the phase of analysis, an adequate selection of technological alternatives and criteria was accomplished and an appropriate ratio of criteria weights and the selection of the working multi-criteria model.

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