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Method of Selecting Opening Cut Location Using Multi-Criteria Analysis of Decision Variant Mapping

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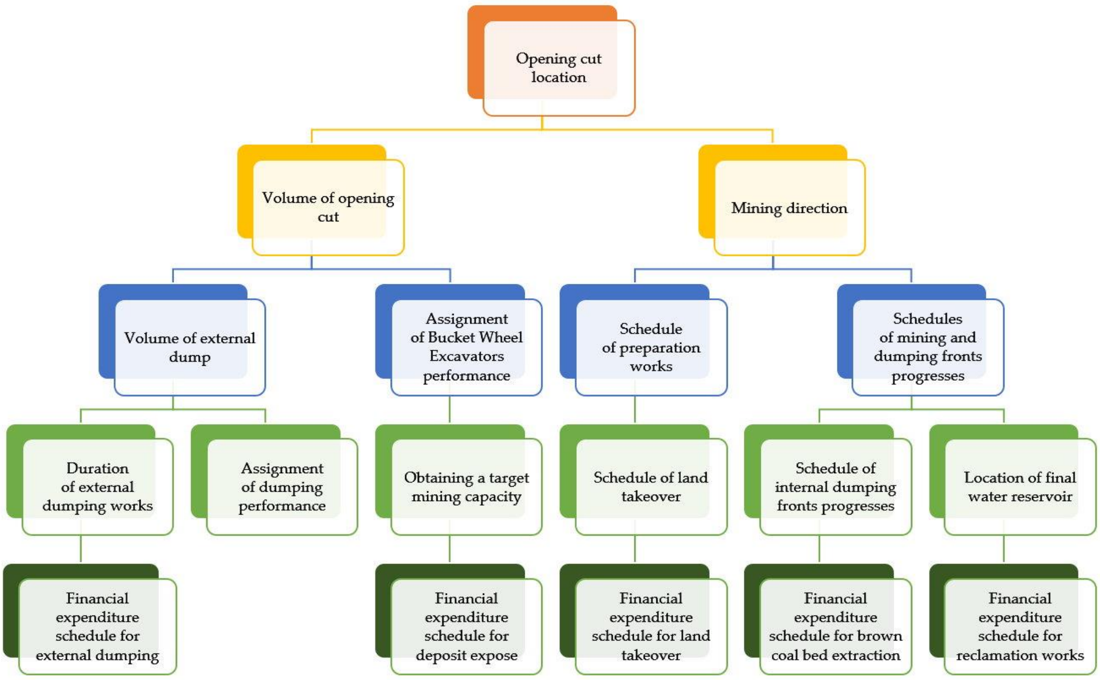
Abstract: The aim of the article is to present a solution to the research problem that addresses the selection of the opening cut location in the surface mining method. Selecting the opening cut location is a strategic mine planning matter and has a key impact on the overall processes occurring during mining operations. This choice is a complex, and at the same time, mathematically ill-defined issue. The selection procedure should take into account many, often opposing, perspectives of the interveners, who represent the criteria laid down by the technical and organisational, economic, as well as social and environmental groups. In order to be able to compare criteria of a different nature, the authors implemented a multi-criteria method as a solution, derived from operational research. The mathematical tool best suited to the characteristics of the issue of selecting the opening cut location is a method from the ELECTRE family, which was used to create the final solution ranking. The main achievement of the method presented is the specification of a complementary group of assessment criteria and the application of a method allowing a solution to be created, which results in the selection of the most favourable decision variant. The developed method supports decision-makers responsible for making investment decisions in the implementation of mining projects.

Keywords: surface mining; rational mineral deposit management; opening cut; multi-criteria decision analysis; strategic mine planning

1. Introduction

Selecting the opening cut location is a strategic decision taken in the process of designing surface mines. The location of a deposit has a key impact on most of the processes associated with surface mining, not only during the construction phase of a mine, but throughout the entire mining project cycle. This selection has a direct or indirect impact on subsequent processes, and the effects of the decision can be compared to a chain reaction effect. This situation is illustrated by Scheme 1.



Scheme 1. Impact of opening cut location selection on subsequent processes during surface mining (own study).

The entity interested in the exploitation of a deposit must specify the location where the deposit is to be made available already during the application process for the extraction concession. Reference shall be made in the first formal and internal documentation of the entrepreneur. The documentation includes: a preliminary feasibility study, feasibility study, project information sheet, environmental impact report, deposit development project and finally, detailed technical and economic assumptions.

In the practice to date, during the construction of surface mines, designers have adopted the principle that the most advantageous opening cut location is in the shallowest area of the deposit. Such a solution guarantees the smallest volume of external dump, the quickest access to the deposit and the shortest time needed to reach the target output. Taking into account that the cost of moving overburden masses is the main component of the cost of making the deposit available, the final result is most often also the lowest cost of constructing the opening cut.

Such an approach, however, does not take into account important environmental aspects and factors related to public participation in environmental protection and environmental impact assessments. The community has the right to have an input into the future of areas where industrial investments are planned, with particular emphasis on the commitment to environment care and sustainable development [1–3].

The authors of the article, in view of numerous factors affecting the process of the implementation of a mining investment consisting in the surface mining of deposits, assumed that in order to select the location of the opening cut, it is necessary to solve a multi-criteria decision-making problem in terms of technical and organisational, economic, as well as social and environmental factors [3]. The optimisation of the economic effectiveness of a mining project, which is the most important criterion from the perspective of the mining entrepreneur, is currently insufficient, and the solution thus determined may result in a serious impediment in the phase of conducting mining operations and, in extreme cases, even make it impossible to obtain a concession to extract the mineral from the deposit [4–6].

The proposed method for selecting the opening cut location comprehensively takes into account the requirements for the entrepreneur planning the implementation of a mining project. The implementation of a new algorithm of behaviour allows the selection of the most advantageous solution proposed, facilitating the process of making strategic investment decisions regarding opening cut location.

2. Rationale behind the Literature Review

Selecting the opening cut location can be considered as a topic related to mine planning. However, when looking at this issue from a broader perspective, it should be included in the concept referred to as strategic mine planning. Strategic planning is the first phase of mine planning, which defines the economic and technical direction of the project [7]. The phase of strategic planning is decisive in the context of the success of the mining project [8,9]. The basis for creating a proper strategic plan is to define objectives, e.g., maximising NPV (Net Present Value), minimising negative impact on the environment, minimising investment outlays and many others. As part of strategic planning, many optimisation methods are used to maximise the selected objectives. In the design of surface mines, the work of [10] by authors Jurdziak and Kawalec can be pointed out, who, using optimisation tools based on the Lerchs–Grossmann algorithm, and depending on the value of coal prices, can optimise variants of target excavations to maximise resource utilisation or maximise NPV values. Zajączkowski et al. in the paper [11], using heuristic algorithms, indicated the location of the external waste heap with the lowest cost of external disposal.

Optimisation tools are widely used in surface mining. In the area of strategic planning, these applications play a very important role, but the compilation of multi-dimensional optimisations is a more complex issue. The prime concern is that the optimisation of each chosen objective takes place while infringing other objectives. Schroder claims that the best mining planner is one who is aware of the complexity of the encountered problems and is able to catalogue and manage knowledge from various fields [12,13]. A model of a holistic approach to planning mining projects was proposed by Roumpos [9,10]. He states that long-term design should be based on an integrated approach, taking into account the latest technical, environmental, economic and social data. To make the strategic planning model of the mine achieve objectives in the most sustainable way, he proposed the division of the main model into sub-models that include: a geological, hydrogeological and geotechnical model, mine construction and development model, mine environmental impact model and financial project model. Multi-criteria methods have already been used in surface mining. Examples can be the paper of Zajączkowski et al. [14] in which the MCDA method was used to select the method of mechanical rock mining, or the work of Bodziony et al. [15,16], in which the MCDA method was used in the problem of the selection of technological dump trucks in surface mines.

Selecting the opening cut location is part of strategic mine planning. Under the binding legislation, mining designers are forced to consider multi-attribute objectives closely related to the operational objectives of the mining project. Reviewing literature, the authors did not find studies that allow a comprehensive assessment of the mining investment, taking into account the multi-faceted nature of this issue.

3. Selection of a Multi-Criteria Tool and Definition of the Method of Selecting Opening Cut Location

The purpose of the elaborated method is to create a ranking of solutions among competing variants of opening-cut location. Due to the nature of the coherent evaluation criteria family selected to solve the decision problem, it is impossible to use traditional methods from the group of multi-attribute expected utility hypothesis, which require the criteria to be aggregated into a single synthesis criterion (global criterion). This approach does not take into account the incomparability of variants and forces the analyst to present the criteria by using a common scale according to which each criterion can be assessed.

The issue of selecting the opening cut location is a typical multi-criteria decision problem with a heterogeneous structure, the essence of which is to find a compromise between many, often opposing perspectives. The definition of the issue allowed it to be assigned to a group of multi-criteria mapping methods, and to select the ELECTRE III tool to solve it.

The ELECTRE III method [17–20] is a multi-criteria mapping method of a finite set of variants, assessed using a set of criteria. The calculation algorithm of the ELECTRE III method includes three basic phases [21]:

Phase I—design of the assessment matrix and definition of the decision-maker's preference model.

Phase II—design of the ranking relation.

Phase III—implementation of the ranking relation.

Phase I begins with determining a set of A variants and defining a coherent family of F criteria. For all variants, the values of particular f_j criterion functions are determined. Subsequently, using the thresholds of equivalence q_j, preference p_j and veto v_j, as well as importance coefficients w_j, a decision-maker's preference model is defined for each criterion j. The rule is that $q_j < p_j < v_j$ [21].

In Phase II, for each pair of variants (a, b), the following are successively determined [21]:

Concordance coefficients c_j (a, b) that determine the extent to which, according to criterion j, "variant a is at least as good as b".

$$c_j(a,b) = \begin{cases} 1 \text{ if } f_j(a) + q_j\big(f_j(a)\big) \geq f_j(b), \\ 0 \text{ if } f_j(a) + p_j\big(f_j(a)\big) \leq f_j(b), \\ \text{a linear function with a value between 0 and 1} \end{cases} \tag{1}$$

- Concordance index that forms the so-called concordance matrix:

$$C(a,b) = \frac{1}{W}\sum_{j=1}^{n} w_j c_j(a,b), \text{ where : } W = \sum_{j=1}^{n} w_j \tag{2}$$

- Ratio of findings D_j(a, b):

$$D_j(a,b) = \begin{cases} 0 \text{ jezeli } f_j(b) \leq f_j(a) + p_j\big(f_j(a)\big), \\ 1 \text{ jezeli } f_j(b) \geq f_j(a) + v_j\big(f_j(a)\big), \\ \text{a linear function with a value between 0 i 1} \end{cases} \tag{3}$$

- Relation of ranking, defined by the ranking degree S(a, b):

$$S(a,b) = \begin{cases} C(a,b) \text{ if } D_j(a,b) \leq C_j(a,b) \\ C(a,b) \prod\limits_{j \in J(a,b)} \frac{1-D_j(a,b)}{1-C_j(a,b)} \end{cases} \tag{4}$$

where J (a, b) is set of criteria for which D_j(a, b) > C(a, b).

In Phase III, the variants are arranged on the basis of the ranking degrees S (a, b) obtained. This phase starts with defining the values [19].

$$\lambda = \max S(a,b), \quad a,b \in A \tag{5}$$

Only those pairs of variants (a, b) for which S (a, b) is "close enough" to λ shall be further analysed. This proximity is determined by a difference of λ-s(λ), where s(λ) is the so-called cut-off level [20]. On the basis of the λ value, the so-called qualification factor of each variant Q(a) is calculated, i.e., the difference between the number of variants that the given variant a exceeds, and the number of variants by which the given variant a is exceeded [20].

Variant mapping is based on two classification algorithms: descending distillation and ascending distillation. Both distillations aim to rank variants from the best (with the highest qualification factor Q(a)) to the worst, i.e., with the lowest qualification factor. In the case of a descending distillation, the mapping process starts by selecting the best variant and placing it at the top of the ranking. Then, from among the remaining variants, the best variant is again selected and placed on the next place of the ranking. This procedure is repeated until set A is exhausted. In the case of ascending distillation, the mapping process begins with selecting the worst variant and placing it at the end of the ranking.

The procedure continues in similar way to that of descending distillation, except that in subsequent iterations, the worst element is always selected from the remaining variants to be considered and placed in successive "bottom" positions [21,22].

The final step of Phase III is to create the final ranking based on the descending and ascending distillation, based on the following principles [21,22]:

- Variant a is considered to be better than variant b (aPb) if in at least one of the absolute distillations, a is placed before b, and in the other, a is at least as well classified as b;
- Variant a shall be assessed equally to b (aIb), if both variants belong to the same class in each of the two rankings;
- Variants a and b are incomparable (aJb), if in one of the two rankings, variant a is in a better position than b in the ascending distillation, while variant b is in a better position than a in the second mapping.

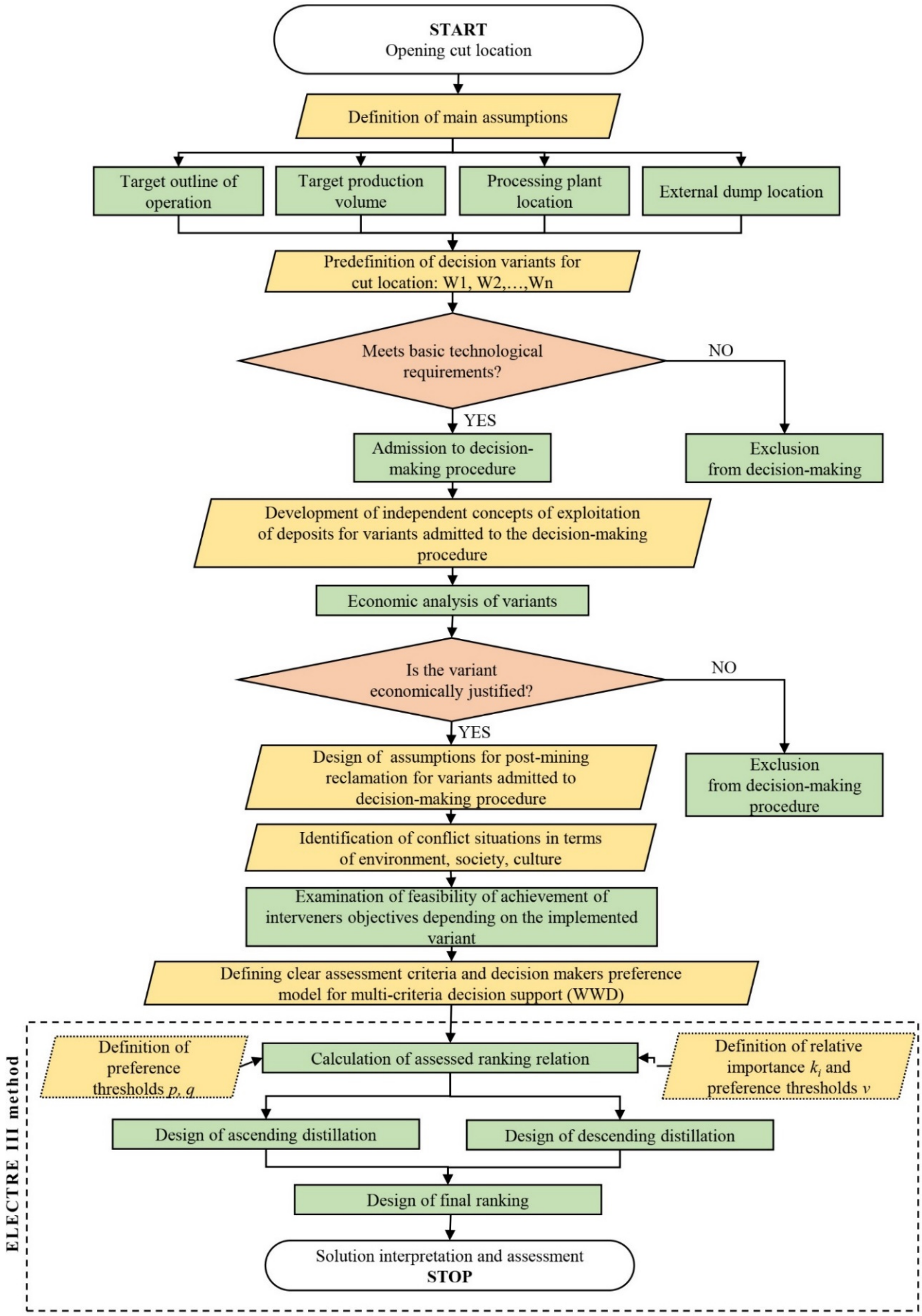
The result is the final variants mapping, in which the situations of equivalence I, preference P and incomparability J [21,22] may occur between the variants. In the ranking matrix, relations are presented between pairs of variants and expressed in the form of symbols of: equivalence-I, preference-P, inverse preference-P and incomparability-J [21,22].

The application of the methodology described above required defining the concerns necessary to correctly solve the decision problem, i.e.,

- The possibility of comprehensive assessment of the variants for the implementation of surface mining of a deposit of a different nature, due to location of the opening cut;
- The possibility to assess variants before their implementation, primarily to support the discussion preceding investment decisions;
- The possibility of taking into account variants of interest of multiple actors during the assessment (e.g., local authorities, inhabitants, social and environmental groups, other economic actors);
- The possibility of the active participation of decision-makers and interveners in the decision-making process;
- The possibility of including, in the variant assessment, many aspects of a technical and organisational, economic, as well as social and environmental nature;
- The possibility to use available calculation methods, computer tools, e.g., for mining design, GIS analyses in real estate management, visualisation of the effects of reclamation and revitalisation of post-mining areas, etc.

Bearing in mind the above observations, a universal algorithm was developed for conducting a comprehensive, multi-criteria assessment of variants/projects for the implementation of an investment consisting in the construction of a surface mine, depending on the variable location of the opening cut and taking into account technical and organisational, economic as well as social (including environmental) criteria. The block diagram of the algorithm is illustrated by Scheme 2.

As a result of applying the methodology taking into account the above concerns, it is possible to obtain a list (ranking) of mining project implementation variants in the order from the best, i.e., the one that allows compromise on the objectives of individual interveners, while taking care of the implementation of the decision-maker's preferences, to the worst, i.e., one that least guarantees the achievement of the sub-objectives.



Scheme 2. Universal algorithm of the method of selecting the opening cut location (own study).

4. Definition of the Variant Set and the Family of Assessment Criteria

A set of solutions A was determined by a set of variants consisting in the implementation of a mining investment in the extraction of a selected lignite deposit. These variants differ in the opening cut location, which has a decisive influence on a number of aspects related to subsequent mining operations. Due to the way lignite deposits are exploited in a continuous system with circular belt transport, the opening cut location is not entirely arbitrary, and the number of variants is finite. A wider range of independent opening cuts were initially determined, three of which, based on the knowledge of the characteristics of the technology used and the associated constraints, were not admitted to the decision-making procedure. Ultimately, the set of decision-making variants constitute:

– Variant 1—opening cut W1;
– Variant 2—opening cut W2;
– Variant 3—opening cut W3.

The above-mentioned variants ultimately constitute a direct (directly defined) and permanent (a priori defined) set of solutions, which does not change during the decision-making procedure.

According to the MCDA methods guidelines, when constructing the criteria family, particular attention should be paid to their complementarity. The criteria family to be used as attributes to assess the elements of the solution set should be comprehensive and coherent. The establishment of a comprehensive family of decision criteria guaranteeing the exhaustiveness of assessment in MCDA methods is problematic, because the size of the F set for which the highest quality of the decision-making process is achieved should be within the range of the so-called "magic number" i.e., set of 7 ± 2. Another characteristic feature of the F set of components is the non-redundancy of criteria, i.e., the uniqueness in the scope of meaning of each criterion. All the criteria specified are quantitative in nature and have a clearly defined preference direction (criteria maximised or minimised). The authors have established a set of criteria to assess the decision variants by dividing them into three basic groups:

– Technical and organisational criteria;
– Economic criteria;
– Social criteria.

The first group of criteria is characterised by a whole range of issues related to surface mining technology, starting with preparatory works, through the provision, proper exploitation and dumping, as well as decommissioning and reclamation of the mining plant. The criteria of this group are of particular importance for the mine management, i.e., persons holding the positions of Manager of Mining Plant, Chief Mining Engineer, Managers of the individual departments of mining technology, environmental protection and real estate management, dehydration and preparation of exploitation, overburden removal and coal extraction, dumping, and all higher and lower level supervisors. Within the group of technical and organisational criteria, the following criteria are specified:

– Volume of external dump—a minimised criterion resulting from the developed schedules of the exploitation progress. The value of the criterion is expressed in (million m^3);
– Volume of external dump masses necessary for re-exploitation—a minimised criterion resulting from the developed schedules of the exploitation progress. The value of the criterion is expressed in (million m^3);
– Time needed to make the deposit available—a minimised criterion resulting from the developed schedule of the exploitation progress. The value of the criterion is expressed in months;
– Volume of the final excavation—a minimised criterion resulting from the developed schedules of the exploitation progress. The value of the criterion is expressed in (million m^3);
– Number of modifications of the main transport slipway—a minimised criterion resulting from the developed schedules of the exploitation progress. The value is expressed in the number of rebuildings.

The second group of criteria is characterised by the most important economic indicators allowing the assessment of the amount of capital employed to construct the assessed variants of opening cuts, as well as the effectiveness of the investment from the perspective of the entire operation. The criteria of this group are of particular importance for the entities responsible for the investor's finances, and in particular for developing the economic basis for investment decisions. Within the group of economic criteria, the following criteria are specified:

- Amount of capital employed for the construction of the opening cut—a minimised criterion resulting from the analysis of the total capital expenditure necessary for the construction of an opening cut. The value of the criterion is expressed in monetary value;
- Economic efficiency of the investment—a maximised criterion resulting from the analysis of the NPV index of the economic assessment of the project. The value of the criterion is expressed in monetary value.

The last group is characterised by criteria related to social acceptance of the planned investment. These criteria are of particular importance for all groups of interveners not related to the investor, but which are directly or indirectly affected by the project. These groups include local authorities, the local community, social and environmental groups and other economic actors. This topic has been the subject of a number of publications, including Uberman, Naworyta [23] or Naworyta, Badera [24]. Within the group of social criteria, the following are specified:

- Probability of reducing the intensity of social conflicts—the maximised criterion describes the percentage chance of reducing the intensity of the identified social conflicts:
    - On an environmental basis;
    - On an economic basis.

  The value of the criterion is described on a percentage scale.

5. Preference Models of Decision-Makers Adopted for the Analysis

In order to model the sensitivity of the analysis using the ELECTRE III method, the characteristic threshold values (q_j, p_j and v_j) should be determined taking into account the characteristics of the decision problem. In the conducted analysis, the decision-maker is a collective decision-maker, and constitutes an independent expert team, whose competences allow for a comprehensive assessment of variants through a selected family of decision criteria.

The expert team consisted of three groups:

- Group 1. Mining manager holding the position of the technical director of a surface lignite mine with the rights of a Mining Plant Manager;
- Group 2. Expert in the field of surface mining, with particular emphasis on lignite deposits, an expert in the economic aspects of mining investments;
- Group 3. Expert in planning mining investments, carrying out procedures to assess the impact of mining projects on the environment, with particular emphasis on gaining public acceptance.

A team of experts having access to all the information produced and stored by the analysts formulated their own preferences in the form of the relative importance of particular criteria, i.e., k_i coefficient, by weighting the individual criteria and determining the values of the thresholds of:

- Equivalence q_j;
- Preference p_j;
- Veto v_j.

The thresholds are determined on the basis of a criteria assessment matrix constructed by the analyst taking into account a set of decision solutions A and a predefined family of F criteria and their values. The expert determination of the thresholds between the equivalence threshold q_j and the veto threshold v_j results in two ranges of weak (Q) and strong (P) preferences.

The matrix of criteria values adopted for the analysis is presented in Table 1, while the values of the obtained parameters of the preference models of the decision-makers is presented in Table 2.

Table 1. Matrix of criteria values adopted for the analysis (own elaboration).

	Number of Criterion	**K1**	**K2**	**K3**	**K4**	**K5**	**K6**	**K7**	**K8**
Variant designation	Criterion name	Volume of an external heap	Volume of external dump masses necessary for re-exploitation	Time needed to make the deposit available	Volume of the final excavation	Number of modifications to the main transport slipway	Volume of capital employed for constructing the opening cut	Economic efficiency of investment (NPV)	Possibility to reduce the intensity of social conflicts
	Unit	mln m^3	mln m^3	month	mln m^3	pieces	million €	million €	%
	Direction of preference	min.	min.	min.	min.	min.	min.	max.	max.
Variant W1		567.0	223.0	18	883.0	7	2553.83	32.98	40
Variant W2		367.5	91.0	15	1209.0	3	1807.64	291.09	25
Variant W3		334.5	60.5	15	1192.0	4	1723.03	284.40	25

Table 2. Preference models of decision-makers (own elaboration).

Please CRITERIA	**Units**	**Preference Direction**	**Preference Model Group 1**				**Preference Model Group 2**				**Preference Model Group 3**			
			Relative Importance	**Equivalence Threshold**	**Preference Threshold**	**Veto Threshold**	**Relative Importance**	**Equivalence Threshold**	**Preference Threshold**	**Veto Threshold**	**Relative Importance**	**Equivalence Threshold**	**Preference Threshold**	**Veto Threshold**
		K_{pi}	k_i	q_j	p_j	v_j	k_i	q_j	p_j	v_j	k_i	q_j	p_j	v_j
K1	mln m^3	min.	25	10	100	150	10	20	50	350	15	25	75	100
K2	mln m^3	min.	20	40	50	100	5	30	100	200	10	5	25	50
K3	month	min.	5	2	4	12	15	3	6	16	5	3	5	12
K4	mln m^3	min.	10	50	100	400	10	100	200	1100	20	50	100	500
K5	pieces	min.	15	1	3	5	5	1	2	6	5	2	5	6
K6	million €	min.	8	300	1000	4000	20	200	500	1200	5	100	500	1500
K7	million €	max.	12	100	300	1000	25	100	200	1000	10	100	200	1000
K8	%	max.	5	5	15	35	10	10	30	35	30	5	10	15
			∑100				∑100				∑100			

The individual preference models of the decision-makers were developed independently, i.e., the experts were not able to consult their choices among themselves. An analyst who cooperated with the individual specialists created a mathematical description of the decision-making problem and only in this respect consulted and explained the phenomena described by the coherent criteria family. In addition, the analyst outlined the impact of the preference thresholds adopted by the decision-makers, paying particular attention to such a targeting of the computational experiment that best reflects the expectations of the expert. Independent ranking decisions in the form of enhancing the relative significance of k_i and giving preference thresholds (q_j, p_j, v_j) constituted complete input data to the ELECTRE III method calculation algorithm.

Computational experiments involving the mapping of competitive variants of making a lignite deposit available were carried out using the ELECTRE III/IV software package, version 3.1 a. The scope of the experiments included carrying out three independent calculation procedures individually for each preference model of the decision-maker described in Table 2, taking into account the matrix of criteria values from Table 1.

The result of the calculation procedures is the final ranking of solutions (variants). The calculation algorithm of the ELECTRE III tool is based on the value of the ranking relation S (a, b), which gave rise to the construction of two complete distillations. These distillations are based on the classification algorithm. Initially, a descending distillation was created, which ranked the A set of variants for opening cut location in order from best to worst, then the ascending distillation was created, which ranked the solutions for making the deposit available in order from the worst to the best. The calculation procedure is based on the criteria score matrix, taking into account a pre-defined matrix of criteria values and a set of solutions (variants). Based on the defined input data, the ELECTRE III tool's algorithm determined the ranking relation for three variants, which allowed the construction of complete distillations. The method allows for situations of incomparability and the equivalence of solutions. The variant that is not comparable with a group of other variants is placed at the bottom of the group in the descending distillation and at the top in the case of an ascending distillation structure. Variants that are considered equivalent shall be placed in an equivalent location regardless of the distillations.

The ranking relation S (a, b) means the degree of credibility of the hypothesis that variant a exceeds b (aPb). The relations between the variants were checked by means of concordance tests. They consisted of checking the relations between each pair of variants a i b, i.e., whether aPb and/or bPa. The final solution of the procedure is the intersection of two complete distillations represented by one final ranking of variants.

6. Discussion of the Results

Ultimately, each of the calculation procedures carried out, resulting in final rankings, is illustrated by the final distillation graphs. These graphs illustrate the relations between all variants. The variants in the final ranking combined with arrows mean that the higher variant is preferred over the lower variant, while the equivalent variants are placed in the same block. In the procedures carried out, there was no instance of the non-comparability of variants, but if there was, the variants would not be graphically connected to each other.

Tables 3–5 show the results of the computational experiments for the three preference models of the decision-maker, including the Ranking Matrix, Credibility Matrix, Concordance Matrix and Final Graph.

The set of results of the first computational experiment, which was described by the model of preferences of the decision-maker, the mining manager's expert with the rights of the Manager of Mining Plant, is illustrated by Table 3.

The set of results of the second computational experiment, which was described by a model of the decision-maker's preferences, the expert in the economics of mining investments, illustrates Table 4.

The set of results of the third experiment, which was described by a model of preferences of the decision-maker, the expert in the field of carrying out environmental impact assessments of mining projects and gaining public acceptance for such projects, illustrates Table 5.

Table 3. Final Ranking, Ranking Matrix, Concordance Matrix, Credibility Matrix of the expert in the economics of mining investments (own elaboration).

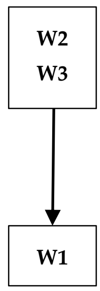
	Ranking Matrix			**Ranks in Final Preorder**		**Final Graph**
	W1	W2	W3	Rank	Alternative	
W1	I	P^-	P^-	1	W2 W3	
W2	P	I	I			
W3	P	I	I	2	W1	
	Concordance Matrix					
	W1	W2	W3			
W1	1	0.175	0.175			
W2	0.850	1	0.927			
W3	0.850	1	1			
	Credibility Matrix					
	W1	W2	W3			
W1	1	0	0			
W2	0.850	1	0.927			
W3	0.850	1	1			

Table 4. Final Ranking, Ranking Matrix, Concordance Matrix, Credibility Matrix of the expert in the economics of mining investments (own elaboration).

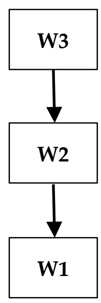
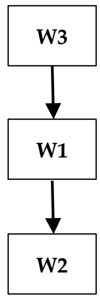
	Ranking Matrix			**Ranks in Final Preorder**		**Final Graph**
	W1	W2	W3	Rank	Alternative	
W1	I	P^-	P^-	1	W3	
W2	P	I	P^-	2	W2	
W3	P	P	I	3	W1	
	Concordance Matrix					
	W1	W2	W3			
W1	1	0.350	0.350			
W2	0.875	1	0.838			
W3	0.875	1	1			
	Credibility Matrix					
	W1	W2	W3			
W1	1	0	0			
W2	0.875	1	0.838			
W3	0.875	1	1			

Table 5. Final Ranking, Ranking Matrix, Concordance Matrix, Credibility Matrix of the expert in the economics of mining investments (own elaboration).

	Ranking Matrix			Ranks in Final Preorder		Final Graph
	W1	W2	W3	Rank	Alternative	
W1	I	P	P^-	1	W3	
W2	P^-	I	P^-	2	W1	
W3	P	P	I	3	W2	
	Concordance Matrix					
	W1	W2	W3			
W1	1	0.567	0.583			
W2	0.500	1	0.841			
W3	0.500	1	1			
	Credibility Matrix					
	W1	W2	W3			
W1	1	0	0			
W2	0	1	0.841			
W3	0	1	1			

The results of computational experiments have shown that using a coherent criteria family and preference models of decision-makers who take into account the interests of different interveners, the construction of a surface mine by making it accessible through an opening cut in location W3, is a compromise variant. The indication of solution W3 as the most advantageous variant is obvious, which is confirmed by all final rankings of the conducted computational experiments. Although the preference for opening cut W3 is unambiguous, the ways in which the final rankings of the specific decision-maker's preference models were built, differ. The advantage of W3 over other solutions in the model of the expert in the economics of investment is undisputed and is the result of a great importance attached to the family of criteria from the economic group. The criteria of the amount of capital employed for the construction of the opening cut and the economic efficiency of the investment, achieved the best values in this variant. On the other hand, the model of preferences shaped by the expert in the field of conducting environmental impact assessment procedures and gaining social acceptance for mining investments has attached the utmost importance to the criterion influencing the probability of reducing the intensity of social conflicts. As a result, variant W1 was placed on the first place in the ascending distillation ranking. Despite a lower significance assigned to the criteria from the technical and organisational and economic groups, variant W3 was ranked first or first ex aequo in both rankings. The ranking generated by computational experiments for the decision-maker's preferences modelled by the mining manager with the rights of the Manager of Mining Plant does not find significant differences between variants W2 and W3, but indicates a lower preference for the W1 opening cut, mainly due to the unfavourable values from the technical and organisational group, and in particular the volume of external dump and the volume of external dump's masses necessary for re-exploitation, whose total sum of relative significance is 45 points, and has a significant impact on the ranking construction.

7. Conclusions

This article is devoted to the topic of strategic design in surface mining. Its primary objective was to present a universal, coherent method of selecting the most advantageous variant of the mining project consisting in the surface mining of the deposit, depending on the opening cut location. As a result of the literature review, analysis of the current binding legislation and historical reviews, as well as current investment plans in the mining industry, it was suggested that the issue of selecting the opening cut location is a multi-dimensional decision problem that should be considered in a holistic approach [25–27]. This is particularly true in the case of large surface lignite mines [28]. Due to the different, often opposing perspectives of the interveners involved in the decision-making process, it is impossible to achieve an optimal solution. The prime concern is that optimisation of each chosen objective takes place by infringing other objectives. In this case, however, the definition of the most advantageous solution was obtained as a result of the compromises reached between the objectives. The rationale behind the identification of the research problem, which, due to its heterogeneous structure, is a so-called mathematically ill-defined problem, prompted the authors to apply multi-criteria decision support (MCDA) methods in the field of operational research [28,29]. The main result of the authors' research is the development of a universal algorithm of proceeding in the assessment of variants for the implementation of an investment involving the surface mining of deposits, with particular emphasis on the opening cut. In addition, it is important to note that for the first time, the issue of selecting the opening cut location has been defined as a multi-criteria mapping issue, taking into account the interests of many actors and different aspects of the issue. A tool has been selected to solve the decision problem with the required sensitivity to the preferences of the decision-makers. To this end, the decision-maker's preference models have been developed based on cooperation with experts in the areas closely related to the implementation of mining investments. The method was tested on the example of a selected lignite deposit.

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