DETERMINING THE EFFECTIVENESS OF BUCKET WHEEL EXCAVATORS ON THE EXPLOITATION OF OVERBURDEN AT THE SURFACE MINE "FIELD E" USING THE FUZZY TOPSIS METHOD

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Abstract: *Bucket wheel excavators represent the basic mechanization for the exploitation of overburden and coal in the surface mine "Field E" of the Kolubara coal basin. At the "Polje E" surface mine, there are seven systems currently active in exploiting overburden, while two systems exploit coal. At the moment, the oldest active bucket wheel excavator is from 1967, and the newest excavator is from 2016. This paper analyzes bucket wheel excavators used for overburden exploitation, examining their effectiveness in such systems. For this work the following parameters were taken into account: realized production, realized production per hour, effective working time, total downtime, age of the excavator. All these data are related to the year 2023. The analysis for the selection of the most effective bucket wheel excavator was carried out through the analysis of the Fuzzy Topsis method. Based on the analysis, it was concluded which of the bucket wheel excavators was the most efficient in 2023 at the "Field E" surface mine of the Kolubara coal-bearing basin.*

Key words: BUCKET WHEEL EXCAVATOR, OVERBURDEN EXPLOITATION, COAL EXPLOITATION, EFFECTIVENESS, FUZZY TOPSIS METHOD

INTRODUCTION

At the "Field E" surface mine, rotary excavators of different manufacturers, of different years, of different capacities were engaged in the excavation of overburden and coal. The oldest active excavator is from 1967 and the youngest from 2016. In order to maintain stable and continuous operation of these machines, their proper maintenance is primarily necessary. At PK "Polje E", 7 systems are active for the excavation of tailings and two systems for the excavation of coal, as well as the dragline system. At the beginning of each year, the overburden and coal production plan that each system should achieve is defined. At the end of each month and at the end of the year, a summary of the masses is made, where the total amount of excavated material is checked, while considering whether the plan has been achieved or not. The goal of the operation of each system is the achievement of the set plan and that there are as few downtimes as possible through the operation of the system. Many factors can affect overburden production itself, but one of the key factors is downtime and equipment condition.

This paper will analyze the effectiveness of the system, i.e. rotary excavators engaged in the production of overburden at PK "Field E". In the analysis that will be carried out through the Fuzzy Topsis method, the effectiveness of the excavator will be analyzed through the parameters of the achieved production, average capacity, effective working time, downtime, age of the excavator.

SURFACE MINE "FIELD E"

The "Field E" coal deposit is part of the Kolubara coal bearing basin and is a field where the excavation of tailings and coal from PK "Field D" and "Field C" continues. "Field E" officially started operations in October 2022 by joining the field, mechanization, manpower as well as other supporting elements of exploitation. The future area of PK "Field E" will include parts of the populated places of Zeoka, Medoševac, Burovo, Vreoci and Šopić, taking into account the location of important infrastructure facilities, the amount of coal affected by the future open pit mine and the position of supporting facilities built during the opening and construction of PK "Field D"(Figure 1.).

Figure 1, Satellite image of the surface mine "Polje E"

SYSTEMS FOR EXPLOITATION OF TAILS AND COAL

At PK "Field E" 7 systems are active for overburden mining, two systems and one dragline system are active for coal mining (10"Екскаватор Шагающий" and one Marion). At PK "Field E" excavation equipment and equipment used for material disposal are shown in Table 1. Display of the system by floors at the surface mine "Field E" is given in the Figure 2.

Table 1, Presentation of systems and mechanization at the surface mine "Field E"

System	Excavator	Spreader	Conveyor
I BTO	SRs 1200x24/4+VR	A_2RsB3500x60+BRs	/
II BTO	SRs 1201x24/4+VR	A_2RsB3500x60+BRs	BRs1600(17,5+32,5)x15
III BTO	SRs 1200x24/4+VR	A_2RsB3500x60+BRs	/
IV BTO	SRs 1200x22/2+VR	/	/
V BTO	SchRs 1760 x32/5+VR	Ars1800/(14+33+60)x20	/
VI BTO	SRs 1200x24/4+VR	Ars 1600/(37+60)x18	/
VII BTO	SchRs 1400x28/3	PA 200 2200/2000	/
BTU	SchRs 630x25/6	/	BRs 1600/(28+50)x15
	SchRs C700	/	BRs 1200x29/32
BTS	SRs 1300x26/5+VR	/	BRs 1600/(28+50)x17

Figure 2, Display of the system by floors at the surface mine "Field E"

ANALYSIS PARAMETERS

For the analysis in this paper, the parameters that are the basic measure of the system's operation in one year are taken into account. The data used for this analysis is taken into account from the period January 1, 2023 to December 31, 2023. The data was obtained from the documentation for the production of overburden at PK within RB Kolubara. The input data that make up the model are divided into five members:

- Achieved production;
- Average capacity;
- Effective working time;
- Downtime;
- Excavator age.

Realized production is a parameter that shows how much total overburden (tailings) was mined on the system during one calendar year. The parameter shows how much total tailings were excavated by the rotary excavator and belt conveyor system, the material was transported to the dumper and deposited at the landfills. At the beginning of each year, the annual plan for all systems is presented, where the planned overburden production for each month is presented individually, as well as the total sum at the annual level. The parameter is presented in m^3. Average capacity is a parameter that represents the mean value of excavation capacity on one BTO system during one calendar year. The parameter is measured on the basis of the ratio of the total amount of excavated material and the total operating time of the system.

The effective operating time of the system represents the period of time that the system spent in operation. The operation of the system is planned in shifts of 8 hours of effective work, but the total number of minutes the system can work in one shift is 480 minutes. If there is no state of emergency outside of the 30-minute break or a situation that requires mechanization to stop, the effective working time of each system during the shift is 450 minutes with a planned 30-minute break. The operation of each system is accompanied by certain downtimes with the occasional occurrence of planned and unplanned downtimes. Planned outages refer to pre-defined technological operations and regular service maintenance. Unplanned downtime is an accompanying element that is not an integral part of the system's operating time and cannot be predicted. Although we are talking about continuous exploitation systems, stoppages are an integral part of shift, daily, monthly and annual work. The breakdowns were categorized into groups, namely: technological, mechanical, electrical and other breakdowns.

Technological stoppages include daily technological operations related to the movement, extension and shortening of conveyors, transport of excavation machinery, etc. In addition to technological ones, a significant share is machine breakdowns, which relate to regular service, vulcanization, investment repairs, etc. Electrical failures are much less pronounced. Within the framework of the analysis, there is no categorization of traffic jams according to groups, but traffic jams represent a synthesis of the mentioned groups. The age of the excavator can be one of the key parameters when analyzing the effectiveness of the excavators themselves. Here, the age of the rotary excavators used for exploitation is taken into account. It is complex to determine how the age factor of the excavator affects the sensitivity of the analysis results. Rotary excavators are self-propelled, high-capacity machinery that requires as much material as possible to be excavated with as little downtime as possible. The average age of the mechanization at PK "Polje E" is 39 years, where good equipment maintenance is required. In order to maintain the effectiveness of the rotary excavators used for exploitation, certain services are performed on a monthly and annual level, where overhauls are carried out, i.e. investment repairs of equipment with the aim of enabling them for normal and continuous operation.

The Fuzzy Topsis method was chosen for the analysis. Within the Fuzzy Topsis method, attribute weights and attribute ratings are represented by linguistic variables that are then translated into *fuzzy* numbers (Table 2.). After defining the input parameters for the analysis, a survey was made in which three mining engineers employed at PK "Field E" participated, where they gave ratings for all parameters with linguistic variable ratings from very bad to very good.

Table 2, Value of Fuzzy numbers and linguistic description

Expression	**Fuzzy number**
very poor	1,1,3
poor	1,3,5
average	3,5,7
good	5,7,9
very good	7,9,9

FUZZY TOPSIS ALGORITHM METHOD

The TOPSIS method [3], seeks to rank a set of alternatives based on their distance from the optimal (PIS) and most pessimistic (NIS) points. PIS is a solution that maximizes useful attributes and minimizes cost attributes. The NIS solution represents a reverse logic, it maximizes cost attributes and minimizes useful attributes [4]. The basic rule of this method is that the optimal alternative should have the *shortest* distance from the PIS and the *farthest* from the NIS [5].

In the classic TOPSIS method, attribute weights and alternative ratings are precisely known and can be represented by exact values. The use of exact values represents one of the key issues in the evaluation process, because precise data are not adequate for modeling real 79 decision-making problems. Such conditions resulted in the development of a fuzzy version of the TOPSIS method. Within the FTOPSIS method, attribute weights and attribute ratings are represented by linguistic variables that are then translated into *fuzzy* numbers. In this way, the shortcomings observed in the classic TOPSIS method were prevented. Many FTOPSIS methodologies have been proposed in recent years. Chen & Hwang [6] were among the first to use *fuzzy* numbers in the TOPSIS method.

Triantaphyllou & Lin [7] developed FTOPSIS in which the relative proximity of each alternative is calculated based on *fuzzy* arithmetic operations. Chen [8] extended the TOPSIS method to situations of *fuzzy* group decision-making and thus used triangular *fuzzy* numbers and a defined precise *Euclidean* distance between two *fuzzy* numbers. In the framework of the work, the *fuzzy* TOPSIS extension of the method proposed by Chen [8] was used, which consists of the following steps:

Step 1: The first stage is the formation of a commission made up of decision makers, the commission consists of K decision makers, the *fuzzy* rating of each decision maker D_k $(k = 1, 2,..., K)$ is represented by a triangular *fuzzy* number R_k $(k = 1 ,2, ..., K)$ with membership function.).

Step 2: Identification of basic decision attributes.

Step 3: Selection of appropriate linguistic variables for attribute evaluation

Step 4: Aggregation of attribute weights.

Fuzzy ratings of decision makers are expressed using triangular *fuzzy* numbers $Rk\ (a_k, b_k, c_k)$, $k = 1, 2,..., K$ using the expression:

$$a=min_k\{a_k\}, b=\frac{1}{K}\sum_{k=1}^{k} b_k, c=max_k\{c_k\}$$

If the *fuzzy* rating and weight of the k^{th} decision maker are $x_{ijk}\ (a_{ijk}, b_{ijk}, c_{ijk})$ *i* $w_{ijk}\ (w_{jk1}, w_{jk2}, w_{jk3})$ $i = 1, 2,..., m$; $j = 1, 2,\dots, n$ respectively, then the aggregated *fuzzy* rating (x_{ij}) of the alternative with respect to a certain attribute is given $(x_{ij}) = (a_{ij}, b_{ij}, c_{ij})$, which can be represented by the expression.

$$a=min_k\{a_{ijk}\}, b=\frac{1}{K}\sum_{k=1}^{k} b_{ijk}, c=max_k\{c_{ijk}\}$$

Aggregated *fuzzy* weights (w_{ij}) of each attribute were calculated using the expression $(\tilde{w}_j) = (w_{j1}, w_{j2}, w_{j3})$

where is:

$$w_{j1}=min_k\{w_{jk1}\},w_{j2}=min_k\{w_{jk2}\},w_{j3}=min_k\{w_{jk3}\},$$

Step 5: The *fuzzy* decision matrix is constructed based on the expression:

$$\begin{bmatrix} \check{x}_{11} & \cdots & \check{x}_{1n} \\ \vdots & \cdots & \vdots \\ \check{x}_{m1} & \cdots & \check{x}_{mn} \end{bmatrix}$$

while attributes are calculated using the expression . $\tilde{W} = [\tilde{w}_1, \check{w}_2, \ldots , \check{w}_n]$

where $(x_{ij}) = (a_{ij}, b_{ij}, c_{ij})$ and $(w_j) = (w_{j1}, w_{j2}, w_{j3})$, $i = 1, 2,\ldots, m; j = 1, 2,\ldots,$ n can be approximated by positive triangular *fuzzy* numbers.

Step 6: After constructing the *fuzzy* decision matrix, normalization of the matrix was performed using a linear transformation scale. The calculation was made using the expression:

$$\check{r}_{ij}=\left(\frac{a_{ij}}{c_j^*},\frac{b_{ij}}{c_j^*},\frac{c_{ij}}{c_j^*}\right),c_j^*=max_i c_{ij}$$

The normalized *fuzzy* matrix is calculated using the expression:

$$\check{R}=[\check{r}_{ij}]_{mxn}\ i=1,2,\ldots,;j=1,2,\ \ldots,n$$

where r_i is normalized value $(x_{ij}) = (a_{ij}, b_{ij}, c_{ij})$.

where r_{ij} is normalized value *(xij) = (aij, bij, cij).*

Step 7: Considering the different weights for each attribute, the weighted normalized *fuzzy* decision matrix is constructed with the help of the expression:

$$\check{V}=[\check{v}_{ij}]_{mxn}\ i=1,2,\ldots,;j=1,2,\ \ldots,n$$

$$\check{v}_{ij}=\check{r}_{ij}(\cdot)\check{w}_j$$

where w_j represents the weight of attribute C_j.

Within the weighted normalized *fuzzy* decision matrix, normalized positive triangular *fuzzy* numbers can approximate the elements v_{ij}, A_i, j.

Step 8: *Fuzzy* positive (FPIS, A*) and *fuzzy* negative ideal solution (FNIS, A--) are represented by the expression:

$$A^*=\{\check{v}_1^*,\check{v}_2^*,\ \ldots\ ,\ \check{v}_i^*\}=\{max_i v_{ij}(i=1,2,\ldots,\ m;,\ j=1,2\ldots,\ n)\}$$

$$A^-=\{\check{v}_1^-,\check{v}_2^-,\ \ldots\ ,\ \check{v}_i^-\}=\{max_i v_{ij}(i=1,2,\ldots,\ m;,\ j=1,2\ldots,\ n)\}$$

The basis of the weighted normalized *fuzzy* decision matrix, the rank belongs to the closed interval [0,1]. Thus, FPIS and FNIS can be defined as (1, 1, 1) and (0, 0, 0), respectively.

Step 9: In the next step, the distance of each alternative from FPIS and FNIS is calculated using the expression

$$D_i^* = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^*), i=1,2, \ldots ,m$$

$$D_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^-), i=1,2, \ldots ,m$$

where the distance between two numbers $a=(a_1,a_2,a_3)$ and $b=(b_1,b_2,b_3)$ can be calculated using the Vertex method, according to the expression

$$\mathrm{d}(\tilde{a},\tilde{b}) = \sqrt{\frac{1}{3}[(a_1-b_1)^2+(a_2-b_2)^2+(a_3-b_3)^2]}$$

Step 10: The similarity coefficient to the ideal solution is calculated using the expression.

$$CC_i = \frac{D_{j-}}{D_{j*}+D_{j-}}, \ i=1,2, \ldots,m$$

Step 11: The ranking of alternatives is made possible by analyzing the similarity coefficient. The optimal alternative is the one with the highest similarity coefficient CC_j, and the order of alternatives can be represented based on the ranking of CC_j in descending order.

ANALYSIS RESULTS

In the previous part of the paper, it was explained that in order to obtain the results in this analysis, the descriptive ratings according to the fuzzy Topsis method from 1-5 given by the mining engineers for each of these parameters were taken into account (tables 4-6). The values in parentheses in Table 3 represent a percentage of the total planned production for each system. The working time is shown as a percentage of the total working time of the excavator, i.e. the system of 8760 h.

Table 3, Input parameters for calculation

Excavator	Realized production	Average capacity	Working time	Downtime	Excavato age
	m^3	m^3/h	h	h	year
SRs 1200x24/4+VR	2 509 308(89%)	716	3506,73(40%)	5253,15(60%)	56
SRs 1201x24/4+VR	1 775 207(44%)	580	2836(32%)	5924(68%)	22
SRs 1200x24/4+VR	2 970 718(98%)	685	4337,99(49%)	4422(50%)	48
SRs 1200x22/2+VR	1 251 061(66%)	700	1788,25(20%)	6971,35(79%)	57
SchRs 1760 x32/5+VR	6 974 818(86%)	1759	3964,55(45%)	4975,05(55%)	34
SRs 1200x24/4+VR	2 691 443(98%)	798	3370,99(38%)	5389,01(62%)	48
SchRs 1400x28/3	9 046 789(91%)	2117	4273,23(48%)	4486,37(51%)	8

Table 4, Linguistic evaluations of mining engineer no. 1

Excavator	**Realized production**	**Average capacity**	**Working time**	**Downtime**	**Excavator age**
	m^3	**m^3/h**	**h**	**h**	**year**
SRs 1200x24/4+VR	average	good	poor	poor	poor
SRs 1201x24/4+VR	poor	poor	poor	poor	good
SRs 1200x24/4+VR	good	average	good	good	poor
SRs 1200x22/2+VR	average	average	poor	poor	very poor
SchRs 1760 x32/5+VR	average	average o	good	average	good
SRs 1200x24/4+VR	good	good	poor	good	poor
SchRs 1400x28/3	good	good	good	average	very good

Table 5, Linguistic evaluations of mining engineer no. 2

Excavator	**Realized production**	**Average capacity**	**Working time**	**Downtime**	**Excavator age**
	m^3	m^3/h	h	h	year
SRs 1200x24/4+VR	average	good	average	poor	poor
SRs 1201x24/4+VR	very poor	poor	poor	poor	good
SRs 1200x24/4+VR	good	good	good	good	average
SRs 1200x22/2+VR	average	good	poor	very poor	very poor
SchRs 1760 x32/5+VR	average	average	average	average	good
SRs 1200x24/4+VR	good	good	average	good	average
SchRs 1400x28/3	good	average	good	average	very good

Table 6, Linguistic evaluations of mining engineer no. 3

Excavator	**Realized production**	**Average capacity**	**Working time**	**Downtime**	**Excavator age**
	m^3	**m^3/h**	**h**	**h**	**year**
SRs 1200x24/4+VR	average	average	poor	poor	poor
SRs 1201x24/4+VR	very poor	poor	poor	very poor	good
SRs 1200x24/4+VR	good	average	good	good	poor
SRs 1200x22/2+VR	poor	average	very poor	very poor	very poor
SchRs 1760 x32/5+VR	average	average	average	average	good
SRs 1200x24/4+VR	good	average	average	good	poor
SchRs 1400x28/3	good	average	good	good	very good

The next step is to convert descriptive ratings into **fuzzy ratings** (Table 7-9).

Table 7, Fuzzy ratings of mining engineer no. 1

Excavator	Realized production	Average capacity	Working time	Downtime	Excavator age
	m^3	m^3/h	h	h	year
SRs 1200x24/4+VR	3,5,7	5,7,9	1,3,5	1,3,5	1,3,5
SRs 1201x24/4+VR	1,3,5	1,3,5	1,3,5	1,3,5	5,7,9
SRs 1200x24/4+VR	5,7,9	3,5,7	5,7,9	5,7,9	1,3,5
SRs 1200x22/2+VR	3,5,7	3,5,7	1,3,5	1,3,5	1,1,3
SchRs 1760 x32/5+VR	3,5,7	3,5,7	5,7,9	3,5,7	3,5,7
SRs 1200x24/4+VR	5,7,9	5,7,9	1,35	5,7,9	1,3,5
SchRs 1400x28/3	5,7,9	5,7,9	5,7,9	3,5,7	7,9,9

Table 8, Fuzzy ratings of mining engineer no. 2

Excavator	Realized production	Average capacity	Working time	Downtime	Excavator age
	m^3	m^3/h	h	h	year
SRs 1200x24/4+VR	3,5,7	5,7,9	3,5,7	1,3,5	1,3,5
SRs 1201x24/4+VR	1,1,3	1,3,5	1,3,5	1,3,5	5,7,9
SRs 1200x24/4+VR	5,7,9	5,7,9	5,7,9	5,7,9	3,5,7
SRs 1200x22/2+VR	3,5,7	5,7,9	1,3,5	1,1,3	1,1,3
SchRs 1760 x32/5+VR	3,5,7	3,5,7	3,5,7	3,5,7	5,7,9
SRs 1200x24/4+VR	5,7,9	5,7,9	3,5,7	3,5,7	3,5,7
SchRs 1400x28/3	5,7,9	3,5,7	5,7,9	3,5,7	7,9,9

Table 9, Fuzzy ratings of mining engineer no. 3

Excavator	Realized production	Average capacity	Working time	Downtime	Excavator age
	m^3	m^3/h	h	h	year
SRs 1200x24/4+VR	3,5,7	3,5,7	1,3,5	1,3,5	1,3,5
SRs 1201x24/4+VR	1,1,3	1,3,5	1,3,5	1,1,3	5,7,9
SRs 1200x24/4+VR	5,7,9	3,5,7	5,7,9	5,7,9	3,5,7
SRs 1200x22/2+VR	1,3,5	3,5,7	1,1,3	1,1,3	1,1,3
SchRs 1760 x32/5+VR	3,5,7	3,5,7	3,5,7	3,5,7	5,7,9
SRs 1200x24/4+VR	5,7,9	3,5,7	3,5,7	5,7,9	3,5,7
SchRs 1400x28/3	5,7,9	3,5,7	5,7,9	5,7,9	7,9,9

When *fuzzy* numbers are defined, *Fuzzy* ratings of decision makers are determined and a unique matrix is formed for further calculation for this method (Table 10).

Table 10, Unique matrix for decision-making

Excavator	**Realized production**	**Average capacity**	**Working time**	**Downtime**	**Excavator age**
	m^3	**m^3/h**	**h**	**h**	**year**
SRs 1200x24/4+VR	3,5,7	3,6,33,9	3,3,66,7	1,3,5	1,3,5
SRs 1201x24/4+VR	1,1,66,5	1,3,5	1,3,5	1,2,33,5	5,7,9
SRs 1200x24/4+VR	5,7,9	3,5,66,9	5,7,9	5,7,9	1,4,33,7
SRs 1200x22/2+VR	1,4,33,7	3,5,66,9	1,2,33,5	1,1,66,5	1,1,3
SchRs 1760 x32/5+VR	3,5,7	3,5,7	3,5,66,9	3,5,7	3,6,33,9
SRs 1200x24/4+VR	5,7,9	3,6,33,9	3,4,33,7	3,6,33,9	1,4,33,7
SchRs 1400x28/3	5,7,9	3,5,66,9	5,7,9	3,5,66,9	7,9,9

Next is the calculation of the Normalized *Fuzzy* matrix. In order to do this, it is necessary to define **BENEFIT** and **NONBENEFIT** (Cost) criteria. Benefit criteria are Realized production, average capacity, working time and age of the excavator, while *Cost* criterion is downtime (Table 11).

Table 11, Unique decision-making matrix with Benefit and non-benefit criteria

Criterion	**Benefit**	**Benefit**	**Benefit**	**Cost**	**Benefit**
Excavator	**Realized production**	**Average capacity**	**Working time**	**Downtime**	**Excavator age**
	m^3	**m^3/h**	**h**	**h**	**year**
SRs 1200x24/4+VR	3,5,7	3,6,33,9	3,3,66,7	1,3,5	1,3,5
SRs 1201x24/4+VR	1,1,66,5	1,3,5	1,3,5	1,2,33,5	5,7,9
SRs 1200x24/4+VR	5,7,9	3,5,6666,9	5,7,9	5,7,9	1,4,33,7
SRs 1200x22/2+VR	1,4,33,7	3,5,66,9	1,2,33,5	1,1,66,5	1,1,3
SchRs 1760 x32/5+VR	3,5,7	3,5,7	3,5,66,9	3,5,7	3,6,33,9
SRs 1200x24/4+VR	5,7,9	3,6,33,9	3,4,33,7	3,6,33,9	1,4,33,7
SchRs 1400x28/3	5,7,9	3,5,66,9	5,7,9	3,5,66,9	7,9,9

The next step is the assignment of weighting factors according to which new values are obtained in Tables 13 and 14. The value of *Fuzzy* numbers and the linguistic description of the weighting criteria is given in Table 12.

Table 12, Value of Fuzzy numbers and linguistic description of weight criteria

Expression	**Fuzzy number**
very poor	1,1,3
poor	1,3,5
average	3,5,7
good	5,7,9
very good	7,9,9

Table 13, Matrix with weight criteria

Criterion	Benefit	Benefit	Benefit	Cost	Benefit
wj	7,9,9	5,7,9	5,7,9	5,7,9	5,7,9
Excavator	Realized production	Average capacity	Working time	Downtime	Excavator age
	m^3	m^3/h	h	h	year
SRs 1200x24/4+VR	3/9,5/9,7,9	3/9,6,33/9,9/9	3/9,3,66/9,7/9	1/5,1/3,1/1	1/9,3/9,5/9
SRs 1201x24/4+VR	1/9,1,66/9,5/9	1/9,3/9,5/9	1/9,3/9,5/9	1/51,/2,33,1/1	5/9,7/9,9/9
SRs 1200x24/4+VR	5/9,7/9,9,9	3/9,5,66/9,9/9	5/9,7/9,9/9	1/9,1/7,1/5	1/9,4,33/9,7/9
SRs 1200x22/2+VR	1/9,4,33/9,7/9	3/9,5,66/9,9/9	1/9,2,33/9,5/9	1/5,1/1,66,1/1	1/9,1/9,3/9
SchRs 1760 x32/5+VR	3/9,5/9,7,9	3/9,5/9,7/9	3/9,5,66/9,9/9	1/7,1/5,1/3	3/9,6,33/9,9/9
SRs 1200x24/4+VR	5/9,7/9,9/9	3/9,6,33/9,9/9	3/9,4,33/9,7/9	1/9,1/6,33,1/3	1/9,4,33/9,7/9
SchRs 1400x28/3	5/9,7/9,9/9	3/9,5,66/9,9/9	5/9,7/9,9/9	1/9,1/5,66,1/3	7/9,9/9,9/9

Table 14, Values with weighting factors

Criterion	Benefit	Benefit	Benefit	Cost	Benefit
w_j	7,9,9	5,7,9	5,7,9	5,7,9	5,7,9
Excavator	Realized production	Average capacity	Working time	Downtime	Excavator age
	m^3	m^3/h	h	h	year
SRs 1200x24/4+VR	0,33,0,55,0,77	0,33,0,70,1	0,11,0,40,0,77	0,2,0,33,1	0,11,0,33,0,55
SRs 1201x24/4+VR	0,11,0,18,0,5555	0,11,0,33,0,55	0,11,0,33,0,55	0,2,0,43,1	0,55,0,77,1
SRs 1200x24/4+VR	0,55,077,1	0,33,0,63,1	0,55,0,77,1	0,11,0,14,0,2	0,11,0,48,0,77
SRs 1200x22/2+VR	0,11,0,48,0,77	0,33,0,63,1	0,11,0,26,0,55	0,2,0,6,1	0,11,0,11,0,33
SchRs 1760 x32/5+VR	0,33,0,55,0,77	0,33,0,55,0,77	0,33,0,63,1	0,14,0,2,0,33	0,33,0,70,1
SRs 1200x24/4+VR	0,55,0,77,1	0,33,0,70,1	0,11,0,48,0,77	0,11,0,16,0,33	0,11,0,48,0,77
SchRs 1400x28/3	0,55,0,77,1	0,33,0,63,1	0,55,0,77,1	0,11,0,18,0,33	0,77,1,1

After the obtained values are multiplied by the weight criteria defined for these parameters (Table 15).

Table 15, Values that are multiplied with weight attributes

Kriterijum	Benefit	Benefit	Benefit	Cost	Benefit
wj	7,9,9	5,7,9	5,7,9	5,7,9	5,7,9
Excavator	**Realized production**	**Average capacity**	**Working time**	**Downtime**	**Excavator age**
	m³	**m³/h**	**h**	**h**	**year**
SRs 1200x24/4+VR	7*0,33,9*0,55, 9*0,77	5*0,33,7*0,70, 9*1	5*0,11,7*0,40, 9*0,77	5*0,2,7*0,33, 9*1	5*0,11,7*0,33, 9*0,55
SRs 1201x24/4+VR	7*0,11,9*0,18, 9*0,55	5*0,11,7*0,33, 9*0,55	5*0,11,7*0,33, 9*0,55	5*0,2,7*0,43, 9*1	5*0,55,7*0,77, 9*1
SRs 1200x24/4+VR	7*0,55,9*0,77, 9*1	5*0,33,7*0,63, 9*1	5*0,55,7*0,77, 9*1	5*0,11,7*0,1 4,9*0,2	5*0,11,7*0,48, 9*0,77
SRs 1200x22/2+VR	7*0,11,9*0,48, 9*0,77	5*0,33,7*0,63, 9*1	5*0,11,7*0,26, 9*0,55	5*0,27*,0,6, 9*1	5*0,11,7*0,11, 9*0,33
SchRs 1760 x32/5+VR	7*0,33,9*0,55, 9*0,77	5*0,33,7*0,55, 9*0,77	5*0,33,7*0,63, 9*1	5*0,14,7*0,2, 9*0,33	5*0,33,7*0,70, 9*1
SRs 1200x24/4+VR	7*0,55,9*0,77, 9*1	5*0,33,7*0,70, 9*1	5*0,11,7*0,48, 9*0,77	5*0,11,7*0,1 6,9*0,33	5*0,11,7*0,48, 9*0,7
SchRs 1400x28/3	7*0,55,9*0,77, 9*1	5*0,33,7*0,63, 9*1	5*0,55,7*0,77, 9*1	5*0,11,7*0,1 8,9*0,33	5*0,77,7*1, 9*1

In the next step, the values of A+ and A- are obtained, i.e. positive and negative solutions (Table 16).

Table 16, Obtained values after multiplication with the weight attributes of both A+ and A-

Criterion	Benefit	Benefit	Benefit	Cost	Benefit
w_j	7,9,9	5,7,9	5,7,9	5,7,9	5,7,9
Excavator	**Realized production**	**Average capacity**	**Working time**	**Downtime**	**Excavator age**
	m³	**m³/h**	**h**	**h**	**year**
SRs 1200x24/4+VR	2,33,5,7	1,66,4,93,9	0,55,2,85,7	1,2,33,9	0,55,2,33,5
SRs 1201x24/4+VR	0,77,1,66,5	0,55,2,33,5	0,55,2,33,5	1,3,9	2,77,5,44,9
SRs 1200x24/4+VR	0,77,4,33,7	1,66,4,4,9	2,77,5,44,9	0,55,1,1,8	0,55,3,37,7
SRs 1200x22/2+VR	2,33,5,7	1,66,4,4,9	0,55,1,81,5	1,4,2,9	0,55,0,77,3
SchRs 1760 x32/5+VR	3,88,7,9	1,66,3,88,7	1,66,4,4,9	0,71,1,4,3	1,66,4,92,9
SRs 1200x24/4+VR	3,88,7,9	1,66,4,92,9	0,55,3,37,7	0,55,1,1,3	0,55,3,37,7
SchRs 1400x28/3	3,88,7,9	1,66,4,4,9	2,77,5,44,9	0,55,1,24,3	3,88,7,9
A+	3,88,7,9	1,66,4,92,9	2,77,5,44,9	1,4,2,9	3,88,7,9
A-	0,771,66,5	0,55,2,33,5	0,55,1,81,5	0,55,1,1,8	0,55,0,77,3

Table 17 shows the obtained values representing the distance from the positive value and the values of the total distance of the positive value Di+.

Table 17, Distances from the positive solution Fpis

Excavator	Realized productio n	Average capacity	Working time	Downtime	Excavator age	Di+
SRs 1200x24/4+VR	1,86	0	2,28	1,08	4,03	9,26
SRs 1201x24/4+VR	4,2	2,82	3,19	0,69	1,10	12,06
SRs 1200x24/4+VR	0	0,29	0	4,56	3,07	7,93
SRs 1200x22/2+VR	2,63	0,29	3,37	0	5,35	11,65
SchRs 1760 x32/5+VR	1,86	1,30	0,88	3,83	1,75	9,62
SRs 1200x24/4+VR	0	0	2,10	3,90	3,07	9,07
SchRs 1400x28/3	0	0,29	0	3,87	0	4,17
A+	3,88,7,9	1,66,4,92,9	2,77,5,44,9	1,4,2,9	3,88,7,9	/

Table 18 shows the obtained values representing the distance from the negative value and the total remote negative value of Di-.

Table 18, Distances from the negative solution Fnis

Excavator	Realized production	Average capacity	Working time	Downtime	Excavator age	Di-
SRs 1200x24/4+VR	2,42	2,83	1,30	4,23	1,46	12,24
SRs 1201x24/4+VR	0	0	0,30	4,32	4,57	9,19
SRs 1200x24/4+VR	4,25	2,68	3,37	0	2,75	13,05
SRs 1200x22/2+VR	1,92	2,68	0	4,56	0	9,16
SchRs 1760 x32/5+VR	2,42	1,59	2,83	0,74	4,26	11,84
SRs 1200x24/4+VR	4,25	2,83	1,46	0,69	2,75	11,98
SchRs 1400x28/3	4,25	2,68	3,37	0,71	5,35	16,35
A-	0,77,66,5	0,55,2,33,5	0,55,1,81,5	0,55,1,1,8	0,55,0,777,3	/

After the final steps are completed, the system is ranked (Table 19).

Table 19, Ranking system by efficiency based on the Fuzi Topsis method parameter

Excavator	Di+	Di-	CI	Rank
SRs 1200x24/4+VR	9,262972	13,8025045	0,598405359	4
SRs 1201x24/4+VR	12,06447	10,61341544	0,468007237	6
SRs 1200x24/4+VR	7,926167	14,60861722	0,648269662	2
SRs 1200x22/2+VR	12,90764	9,160050113	0,415088668	7
SchRs 1760 x32/5+VR	9,623158	13,33390829	0,58081936	5
SRs 1200x24/4+VR	9,077563	13,54139204	0,598674519	3
SchRs 1400x28/3	4,171791	17,60860696	0,808461206	1

ANALYSIS OF ANALYSIS RESULTS AND CONCLUSION

In this work, the effectiveness of the system was analyzed, i.e. rotary excavators engaged in the production of overburden at the surface mine "Field E". With the analysis done through the Fuzzy Topsis method, the effectiveness of the excavator was analyzed through the parameters of the achieved production, average capacity, effective working time, downtime and age of the excavator.

According to the entered parameters, the worst ranked excavators are the SRs 1200x22/2+VR with IV BTO system and the SRs 1201x24/4+VR excavator, which the analysis itself confirmed. A good example of how important accurate input parameters are is the excavator SchRs 1760 x32/5+VR with the V BTO system, which according to the total amount of overburden excavated was in the second position on "Field E", but considering that the analysis also included other factors: working time, downtime, average capacity and age of the excavator, according to which it was worse compared to other excavators. According to all those parameters, that excavator is ranked fifth in this analysis. Given that the excavators with the I and VI BTO systems are identical excavators type SRs 1200x24/4+VR and with the entered data they were identical in small differences in production and number of working hours and average capacity. According to the data, the excavator with the VI BTO system had a larger amount of excavated overburden, fewer working hours and a higher average capacity, and it is 8 years younger than the excavator with the I BTO system. The analysis showed that it is in third place and that it is better in terms of effectiveness than the excavator with I BTO by 0.02%. Here you can see how important the factor of the age of the excavator is and how much it influenced the result of the excavator itself. The rotary excavator SRs 1200x24/4+VR, which was ranked second in this analysis, achieved good results in the production of overburden with 98% of the planned production and with 50% of the working hours achieved, with its 48 years of operation. This analysis has shown how important accurate data is and how important it is that they are accurately analyzed and explained.

Finally, according to the results obtained from the analysis, the most effective rotary excavator at PK "Field E" during 2023 was the excavator SchRs 1400x28/3. According to the achieved production parameter, which is characterized in the work as the most important attribute, the excavator SchRs 1400x28/3 proved to be the most efficient with the realization of a higher capacity compared to other excavators and because the last one was put into operation in 2016. Despite the fact that the excavator SchRs 1400x28/3 had a lower number of working hours than the second-placed excavator SRs 1200x24/4+VR with III BTO system, according to the analysis, it was obtained that it was the most effective with all the parameters entered in the analysis.

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