MINING AND METALLURGY INSTITUTE BOR
UDK: 622

ISSN: 2334-8836 (Štampano izdanje)
ISSN: 2406-1395 (Online)

UDK: 622.271/.68(045)=111
DOI: 10.5937/mmeb2104041S

Received: 01.10.2021.
Revised: 01.11.2021.
Accepted: 01.12.2021.

Original Scientific Paper
Mining

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SELECTION OF A RATIONAL TRUCK MODEL FOR WASTE TRANSPORT AT THE OPEN PIT GACKO USING THE AHP METHOD[***]

Abstract

This work presents the principle of optimal model truck selection for waste transport at the open pit Gacko. The analysis was performed for three types of trucks: Belaz 7555, Belaz 75491 and Belaz 75135. Selection of the optimal model was done using the AHP method from the group of multicriteria decision-making methods. The work presents the analysis results of the technological procedure of waste transport at the open pit Gacko and evaluation the most important criteria for an optimal type truck selection. In selection the important criteria and assessment the degree of their impact, a questionnaire method was used that was conducted among the mining engineers at the open pits Gacko, Pljevlja, Šuplja Stijena and Mining and Metallurgy Institute Bor. Testing and calculations were done for the truck types and models that have been in long-term use at the open pits. The research pointed out that the best results, according to a number of criteria, are shown by the trucks with a carrying capacity of 55 tons (Belaz 7555), which are also the smallest carrying capacity that was tested.

Keywords: *transport, truck model selection, AHP method, open pit*

INTRODUCTION

Selection of equipment in the system of open pit exploitation is an issue that is placed in the center of the study of mining issues with the basic aim to optimize the technical and economic parameters of system. The most commonly used methods are the modeling methods, case studies and application of numerous methods from the group of multi-criteria decision-making in order to optimize the selection of mining equipment.

Selection of equipment is a constantly current task in mining, in accordance with the frequent technical and technological improvements in the field of production, automation, application of information technology and various optimization models.

Considering the research on this issue in our country, we can single out the Study of Selection the Excavation-Transport-Landfill Equipment in the Selective Excavation of Coal Series (Prof. Dr. Vladimir Pavlović, Prof. Dr. Dragan Ignjatović, Faculty of Mining and Geology, Belgrade, 2010) can be singled out. This Study has defined the methodology and criteria for selection the basic equipment complex in the specific conditions of the lignite deposits of the Electric Power Industry of Serbia.

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[***] *This work was financially supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia, Grant No. 451-03-9/2021-14/200052*

Among the foreign examples are the significant results of the project of international cooperation between Germany (EU) and the University of Mining and Technology of Mongolia (Deutsch-Mongolische Hochschule für Bergbau und Technologie (GMIT) (DAAD), 2013)), in which the coal mining system at the open pits in Mongolia. During the project period, the coal production was increased from about 5.5 Mt of coal to over 30 Mt. The project was implemented under the coordination of Prof. Dr. Carsten Drebenstedt (Freiberg Technical University), one of the leading experts in the field of geotechnics and selection of mining equipment.

The basic characteristic of technological procedures in the open pit exploitation is its dynamic character, both in terms of changing the exploitation parameters related to the variability of workspaces and variability of the characteristics of the working environment and surroundings (urban, meteorological and environmental conditions). Therefore, the optimization of selection the equipment at the open pits is an attempt to achieve the optimal technological and economic parameters of exploitation in the longest possible period and shortest in the service life of equipment being selected. This means that the optimal parameters can be achieved only in the total time of analysis and not in each individual moment. Another important feature is that the selection of equipment is made in relation to the most important technological process, which refers to the largest amount of mass and has the largest share in the total costs. On the example of the open pit Gacko, and which is characteristic for other open pits, it is the technological process of waste transport. In the current century of this open pit mine, there is a tendency for equipment to be procured primarily according to the available economic possibilities and current offer on the market, and not in accordance with the long-term needs and more complex view of this issue. In this work, the aim was to define one of the possible systemic approaches to the selection of discontinuous equipment for waste transport, which would include the assessment of the most important influencing factors. This implies both defining the influencing factors and objectively assessing the degree of their influence.

The open pit of lignite Gacko-Centralno polje is characterized by a large number of sites for overburden and coal excavation with different materials, distance from the place of landfilling and disposal and transport conditions. A continuous, combined and discontinuous waste transport system is also in use. As a key segment for achieving the stable and reliable coal exploitation, the system of exploitation in the roof coal zone has been singled out, where the overburden, layer and interlayer waste are transported by a discontinuous equipment. Due to this reason, the subject of optimizing the selection of trucks is the waste transport from the roof exploitation zone for a maximum annual capacity of 1,500,000 m^3/year.

The main goal of research in the field of selection the optimal transport equipment is to determine the possibility of application and change the existing structure of complex transport mechanization for specific working conditions at the open pit Gacko-Centralno polje. Apart from this, an important factor in the success of entire system is the determination of conformity of operation the excavation-loading and transport equipment for different conditions that are expected at this open pit in a longer period. In order to realize these two most important goals, it was previously necessary to determine the method of objective characterization and assessment the influence degree of numerous factors that define the techno-economic indicators of the system.

MATERIAL AND WORKING METHOD

The open pit Gacko-Centralno polje provides lignite as a solid fuel for electricity production for the Gacko Thermal Power Plant. The basic requirements for the mine are in terms of total quantity, average quality, stability and reliability of production. [1] In order to meet these requirements, two coal mining sites have been developed at the open pit, the Central and Roof Exploitation Zone, which differ significantly in terms of exploitation conditions. Lignite production in the Roof Exploitation Zone is characterized by a favorable coefficient of overburden, small depth of exploitation, overburden and waste of unfavorable physical and mechanical characteristics and low quality of coal. In this zone, the exploitation is carried out with the basic goal of providing a sufficient amount of lignite for the Thermal Power Plant, which together with coal of the Central Exploitation Zone will form a mixture of satisfactory quality. [2] The excavation and transport of waste from the roof zone is discontinuous and is currently carried out by trucks with a capacity of 100 tons, which are the only ones currently available. The current planning and project documentation envisages the procurement of trucks and other capacities, but without a detailed consideration of the working environment conditions, but on the basis of experiential criteria. [3]

As a rule, transport at the open pits is the most important technological process and has the largest share in the cost structure. Considering transport at the open pits, the basic characteristic is that it is a matter of dislocation the large quantities of material, striving to shorten the transport routes, construction the quality roads and selection the most efficient equipment for given conditions. [4,5,6] Factors that affect the success of this technological process are: relief, hydrographic, meteorological, structural geological and others, often beyond the possibility of influencing them, but also those whose management can achieve more favorable results. A survey method was used to determine the important influencing factors as well as to assess the degree of their influence. The survey was conducted at the open pits where the long-term use of discontinuous transport is present, as well as at the Scientific Institution, among employees who have been dealing with the issue of open pit mining for many years.

Engineers from the open pit Gacko, open pit Potrlica-Pljevlja and open pit Šuplja stijena Pljevlja participated in the survey. The survey involved 57 engineers who evaluated the criteria for selection a rational truck model according to the importance defined by the weighting factor. Respondents were asked to rate from 1 to 5 the 5 criteria selected from a wider set shown in Table 2. The survey results are shown in Table 1.

Table 1 *Survey results*

Criterion /R.B.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Regulatory costs	4	5	5	4	5	5	5	5	5	5	5	4	4	4	3	3	5	5	5	5	4	4	4	5	5	5	3	3	3
Capital costs	5	4	4	5	3	4	4	4	4	4	3	5	2	3	4	4	4	4	3	4	3	5	5	3	4	4	4	2	5
Labor costs	3	3	3	3	4	3	3	3	3	3	4	1	3	1	1	1	1	3	4	3	5	1	3	4	3	3	5	4	4
Road maintenance costs	2	1	2	1	1	1	2	2	2	2	2	3	5	2	5	2	2	2	1	1	1	2	1	2	1	1	1	5	1
Coefficient of compliance the excavator and truck capacity	1	2	1	2	2	2	1	1	1	1	1	2	1	5	2	5	3	1	2	2	2	3	2	1	2	2	2	1	2

Criterion /R.B	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57
Regulatory costs	2	5	5	5	2	4	4	4	5	5	5	5	4	4	5	4	5	5	4	4	4	3	4	4	4	5	5	5
Capital costs	4	4	3	3	3	3	3	5	4	4	4	4	5	5	4	5	4	4	5	3	5	4	5	5	5	4	4	4
Labor costs	5	2	4	1	5	1	5	3	1	3	2	3	3	3	3	3	3	3	3	5	3	5	3	3	3	3	3	1
Road maintenance costs	3	3	2	2	4	5	2	1	2	2	3	2	2	2	1	2	1	1	2	1	2	2	2	1	2	2	2	3
Coefficient of compliance the excavator and truck capacity	1	1	1	4	1	2	1	2	3	1	1	1	1	1	2	1	2	2	1	2	1	1	1	2	1	1	1	2

Based on the survey results, the average weighting factors of criteria as the arithmetic mean of the survey scores were calculated and shown in Table 2.

Table 2 *Weighting factors of the criteria based on the survey results*

Criterion/evaluation	Regulatory costs	Road maintenance costs	Capital costs	Labor costs	Coefficient of compliance between the excavator and truck capacity
Total number of points of the weighting factor	247	115	227	170	96
Average weight factor	4.33	2.02	3.98	2.98	1.68

The aim of the survey is to define the most important influencing factors and to assign each of the factors an appropriate weight rating in accordance with the expected relative impact. These weighting factors are the most important element in the process of determining the optimal type of truck for waste transport in the Roof Exploitation Zone of the open pit Gacko.

To determine an optimal type of truck, a method from the group of multicriteria decision-making methods, a subgroup of methods of analytical hierarchical processes (AHP method) was chosen. The group of multicriteria decision-making methods includes both optimization and non-optimization methods. [7] These are a wide range of methods that were often used in specific situations and whose common feature is that they can combine a large number of, by their nature, diverse criteria. The selection methods from the AHP group are essentially not optimization methods, but are often used for the practical needs of selection the mechanization complexes at the open pits, in order to select the most favorable from the limited set of available production units. [8] Due to these properties, it was used in this case. Each of the methods from the AHP subgroup contains the weighting factors and satisfaction factors as a key element. [9] These factors are related to the selected criteria and can be of different nature, different limits, descriptive or numerical, etc. There are a number of methods to reduce weight and satisfaction factors to a common denominator, but the end result is always largely related to the magnitude of weight and satisfaction factors. [10] Therefore, the accuracy of results is largely dependent on objectivity when choosing these two factors. In this particular case, the survey method was used in order to ensure this objectivity as much as possible.

Selection of the optimal truck type was made in relation to the possible truck types characteristic for the given capacity, transport lengths, working environment characteristics and loading equipment characteristics previously defined from the capacity conditions and possibility of selective coal exploitation. Based on the above, the offered set of truck types has been reduced to trucks with a carrying capacity of 100, 80 and 55 tons, and which are more often used at the open pits of similar capacity.

Truck transport calculation

The Talpac software was used to calculate the excavator-truck system. The Talpac software package is a simulation model of loading and transport process at the open pits. This software enables optimization of the transport fleet, calculation of technical and economic parameters of equipment operation, such as a cycle length, capacity, number of trucks in the system, effective operating time, etc. In the specific case, this program was used to determine the parameters in waste transport from an open pit to an external landfill.

The input data used in calculation are:

- Total possible number of shifts per year: 1,095 shift/year
- Shift duration: 8 h
- Number of working hours per year: 8,760 h
- Available shift work time: 5.5 h
- Available working hours per year: 3,500 hours

The calculation was made for an annual capacity of 1,500,000 m^3. Komatsu PC 1250 bucket hydraulic excavator with a bucket volume of 6 m^3 was chosen for a loading unit, while three truck models of different capacities were chosen for the transport equipment, shown in Tables 3 and 4.

Table 3 *Characteristics of loading machinery [11]*

Komatsu PC 1250				
	Parameters			
	Bucket volume (m^3)	6	Engine power (kW)	363
	Speed (km/h)	4.2	Speed (rpm)	1800
	Digging depth (m)	8.45	Weight (kg)	75200
	Mean soil pressure (N/cm^2)	12.2	Length arrow (mm)	7500
	Crawler width (mm)	610	Overall length (mm)	14405
	Crawler stand width (mm)	4110	Branch height	4690
	Crawler stand length (mm)	5810	Cabin height	3670
	Bucket width (mm)	2200	Total width	4110

Table 4 *Characteristics of transport mechanization [12,13,14]*

			
	Belaz 7555	**Belaz 75491**	**Belaz 75135**
	37.5	46	71.2
Engine power (kW)	522	630	895
Load capacity (t)	55	80	110
Max. speed of movement (km/h)	55	50	50
Shaking angle (^{o})	47	46	47
Weight (kg)	41000	72500	100100
Total height (mm)	4610	5350	5900
Total width (mm)	5240	5420	6400
Total length (mm)	8890	10300	11500
Price (€)	400 000	700 000	900 000

Based on the entered data, the hourly capacities of a truck for the transport route from the open pit to the external landfill were calculated and expressed in m^3/h when working in conjunction with the loading machinery. The number of trucks required in the appropriate period was calculated on the basis of the total required time of truck engagement for the waste amount from the open pit and specific transport length. The truck capacity calculated in the Talpac software package is shown in Table 5.

Table 5 *Truck capacity calculated in the Talpac software package*

Truck model	**Capacity (m^3/h)**
Truck Belaz 7555	304.07
Truck Belaz 75491	343.44
Truck Belaz 75135	340.79

Operating costs

The truck capacity served as the basis for calculation the operating costs given in Table 6.

The price of operating costs for all types of analyzed trucks was calculated with the calculated standards and prices of drive material.

Table 6 *Operating costs*

Material	Prices (€)	Belaz 7555	Belaz 75491	Belaz 75135
Fuel standard (l/cm^3)	1	0.287034	0.306709	0.434907
Lubricant standard (kg/cm^3)	5	0.028703	0.030671	0.043491
Oil standard (l/cm^3)	2.5	0.031574	0.033738	0.04784
Tire standard (pcs.)	900	0.000013	0.000013	0.000013
Spare parts standard (kg/cm^3)	10	0.01	0.01	0.01
€/m^3		0.614685	0.653508	0.88366

Capital costs

Capital costs are given on the basis of purchase prices, estimated total lifespan and estimated capacity, and thus ex pressed as the unit costs per m^3. Table 7 shows the investments in transport equipment.

Table 7 *Investments in transport equipment - capital costs*

	Belaz 7555	Belaz 75491	Belaz 75135
Number of trucks	5	4	3
Price of one truck (€)	400,000	700,000	900,000
Total price (€)	2,000,000	2,800,000	2,700,000
€/m^3	0.188	0.233	0.226

Labor costs

Labor costs were calculated on the basis of data on salaries of the Gacko Mine. The costs for the four-brigade work system have been calculated. Table 8 shows the labor costs.

Table 8 *Labor costs for the four-brigade system*

	Belaz 7555	Belaz 75491	Belaz 75135
Number of trucks	5	4	3
Gross salary	800	800	800
Net salary	1,280	1,280	1,280
Number of shifts	4	4	4
Monthly salary costs	25,600	20,480	15,360
Annual salary costs	307,200	245,760	184,320
€/m^3	0.205	0.164	0.123

Road maintenance costs

Road maintenance costs are calculated based on the road area determined by the length of transport and width of transport means and amounts to:

Road area = road width * road length

Road width = truck width * 2 + 4m

The road maintenance costs per m^2 are 0.5 €, and the price is determined based on the price list of works on construction and modernization the roads of the official public company. [15]. Road maintenance costs are shown in Table 9.

Table 9 *Road maintenance costs per m^2*

	Belaz 7555	Belaz 75491	Belaz 75135
Truck width	5	6	7
Road area	58,838	66,898	72,540
eur/year	29,419	33,449	36,270
Eur/m^3	0.0196	0.0223	0.0242

Coefficient of compliance of loading and transport equipment

Coefficient of compliance of loading and transport machinery is a measure of compliance the excavator capacity and number of trucks in the system, i.e. the ratio between the optimal and required capacity of a truck in the system. Table 10 shows the coefficient of compliance for the truck models that are the analysis subject.

Table 10 *Coefficient of compliance*

	Belaz 7555	Belaz 75491	Belaz 75135
Coefficient of compliance	0.850	0.699	0.778

Evaluation and ranking methods of variant solutions

The assumption is that it is necessary to decide on one of several variants, in this case the three shown models of trucks.

There are the following stages that are necessary to set up a scoring model:

I Stage:

Set a list of criteria to be considered. Criteria are important factors for evaluating any decision.

II Stage:

Determine the weight of each criterion that shows its relative importance:

wi = weight of criterion i

III Stage:

Determine the measure of each criterion that shows how well each alternative meets each criterion:

r_{ij} = measure for criterion i and decision j

IV Stage:

Calculate the value for each decision alternative:

S_j = value for decision alternative j

The equation for calculating the value of Sj is:

Sj = ∑i wi*rij

V Stage:

The order of selected alternatives from the highest to the lowest value is at the same time ranking according to the scoring model for alternative decisions. The decision is made for an alternative with the highest number of points and it is recommended for implementation.

According to this method, selection of a truck model was made in five stages, with the first defining a list of criteria, the second the weighting criterion, the third the satisfaction level measure, the fourth calculating the value of alternatives for decision making and the fifth the ranking variants.

TESTING RESULTS

The application of described method for the specific truck models and fr specific working conditions led to a definition of the rank for each of the offered models. The practical procedure was carried out through the following stages.

I Stage: List of criteria

- Regulatory costs
- Capital costs
- Labor costs
- Road maintenance costs
- Coefficient of compliance between the excavator and truck capacity

II Stage:

A scale is used to determine the weight, depending on the importance of criteria, and in this case, considering the selected list of criteria, a five-point scale is used:

Importance	**Weight** (w_i)
Very important	5
Somewhat important	4
Medium important	3
Somewhat unimportant	2
Very unimportant	1

The weighting factors, shown in Table1, represent the result of expert assessment and as such were used in the further procedure, where the relative ratio of weight factors for individual criteria is more important than its absolute value. Based on the weighting factors, the used criteria were ranked and their order is given in Table 11.

Table 11 *Decision criteria, importance and weight of criteria*

Ord.No.	Criterion	Weight
1	Regulatory costs	4.33
2	Capital costs	3.98
3	Labor costs	2.98
4	Road maintenance costs	2.02
5	Coefficient of compliance between excavator and truck capacity	1.68

III Stage:

Each alternative decision is evaluated from an aspect of meeting each criterion. The following levels of satisfaction were selected for selection a possible variant:

Satisfaction level	Measure (r_{ij})
Extremely high	9
Very high	8
High	7
Almost high	6
Medium	5
Almost low	4
Low	3
Very low	2
Extremely low	1

The calculation process must be completed for each combination of alternative decisions for each criterion. Since there are five criteria and three alternatives for decision making (5*3 = 15), 15 measures for alternative decisions are obtained, which are given in the following Table 12.

Table 12 *Measures for decision-making alternatives*

Criterion	Belaz 7555	Belaz 75491	Belaz 75135
Regulatory costs	7	5	2
Capital costs	7	3	4
Labor costs	2	5	8
Road maintenance costs	6	5	3
Coefficient of compliance between excavator and truck capacity	6	3	4

IV Stage:

It is necessary, according to the given weight, to calculate the values of each alternative for decision making. Thus, for example, for alternative 1, its value is:

$$S_j = \sum_i w_i{*}r_{ij} = 4.33{*}7 + 3.98{*}7 + 2.98{*}2 + 2.02{*}6 + 1.68{*}6 = 86.386$$

Based on the determined values, the values of decision-making alternatives, given in Table 13, are obtained.

Table 13 *Values of decision-making alternatives*

Criterion	Weight	Belaz 7555		Belaz 75491		Belaz 75135	
		Measure	Value	Measure	Value	Measure	Value
	(w_i)	(r_{i1})	($w_i{*}r_{i1}$)	(r_{i2})	(r_{i3})	($w_i{*}r_{i3}$)	($w_i{*}r_{i2}$)
Regulatory costs	4.33	7	30.333	5	21.667	2	8.667
Capital expenditures	3.98	7	27.877	3	11.947	4	15.930
Labor costs	2.98	2	5.965	5	14.912	8	23.860
Road maintenance costs	2.02	6	12.105	4	10.088	3	6.053
Coefficient of compliance	1.68	6	10.105	8	5.053	4	6.737
Total value			**86.386**		**63.667**		**61.246**

V Stage: Ranking

1. Belaz 7555 = 86.386
2. Belaz 75491 = 63.667
3. Belaz 75135 = 61.246

DISCUSSION

On the basis of conducted procedure and ranking of alternatives, a truck model with the lowest load capacity, the Belaz 7555 model with a load capacity of 55 tons, was chosen as the most favorable.

In the criteria selection and their ranking, on the basis of the obtained average grade, the order and relative ratio of individual criteria is in line with expectations and coincides with literature data. Most often, considering a discontinuous transport at the open pits, the operating costs are singled out as the most significant and are often the subject of consideration, given that the highest savings can be achieved on them. The capital costs are at the second place in terms of importance, which is also common, and their reduction is more often the subject of economic than technical parameters. Other criteria show a significantly lower degree of influence on the final result.

Considering that the standard costs are highlighted as the most significant, their verification and improvement was performed with the previous transport costs monitored at the open pit and difference from the average realized total costs indicates that the costs obtained by applying the presented model are realistic.

In the process of optimizing the transport process at the open pits and in general in the other technological processes, there is a constant increase in capacity, which should result in lower unit costs. This approach often neglects the specific conditions, and for the case under consideration, it is primarily the need to apply a selective coal exploitation in the roof exploitation zone. The structural assembly of the deposit in this zone is such that there is a frequent change of seams and interlayers of coal and waste of small thicknesses. This limits the possibility of using the excavation equipment of large dimensions of the working body. For the specific case, volume of an excavator bucket of $6m^3$ represents the upper limit of application in the conditions of selective exploitation. This is the result of practical experience and monitoring the quality of run-of-mine coal at the open pits in the region and in the world. This is precisely the reason why, according to the criterion that had the lowest weight factor, the coefficient of conformity of loading and transport equipment, the selected model has showed the same rank.

CONCLUSION

The methods of multi-criteria decision-making and optimization are often used in mining because they allow a number of different criteria to be compared with each other and, based on them, to rank or select the optimal solution. The results of applying the AHP method in selection the optimal model of waste transport truck at the open pit Gacko Centralno polje show similar results as the determination of the Gacko mine experts and confirms experiences from the other open pits in the region. Therefore, it can be said with a high reliability that the applied method is appropriate, that the ranking determines the optimal model of a truck and that the considered criteria are sufficient for its selection. As the expected result is the choice of one model from the limited domain of available transport means, the method itself, although not intended for that, can be applied as an optimization. In order for the result to be as favorable as possible from the user point of view, it is necessary to expand the domain of possible results, i.e. to analyze a larger number of truck models from different manufacturers. It is also possible to have a multidisciplinary approach with experts in the field of maintenance and automation of equipment and inclusion the new criteria and indicators of success in the application of a particular model in these two aspects. This is especially important in the case of the transport process automation, which has consequences for more efficient, safer work and increased utilization of available time.

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