

Review article

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HAULAGE ANALYSIS IN THE AIM OF THE COMBINED SYSTEM APPLICATION ON THE LEAD AND ZINC MINE "SASE" SREBRENICA

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ABSTRACT

One of the most important influencing factors on the economy of mines with surface and underground exploitation is the correct choice of haulage technology of ore and waste.

The paper analyzes the haulage of ore and waste in the Lead and Zinc Mine "Sase" Srebrenica and determines the optimal haulage length on the four excavation blocks for the application of the new haulage system by using the mine trucks from the aspect of set criteria, increasing capacity and reducing haulage costs through the techno - economic analysis and optimization. The optimal haulage length is determined through the calculations of the loader capacity and the possible choice of the truck depending on the stated criteria.

Key words: *underground production system, optimal haulage length, combined haulage, operating costs*

INTRODUCTION

The Srebrenica deposit, which is currently being exploited lies in the central part of the lead - zinc deposit and it is the largest in the former Yugoslavia [1]. Exploration, calculations and analyzes on the determining of the optimal haulage length for the application of loading and haulage equipment were performed on the four excavation blocks: EB 213/1, EB 213/2, EB 309/8 and EB 309/9. Mine haulage includes all of the haulage and hoist devices and equipment, machines and installations necessary for transport of the mining products (ores and waste) from the excavations and other stope faces through the mine to the plants of the mineral processing, in this case separation, to the loading into the wagons or other haulage means for the further transport to the customer [2].

The scheme of haulage routes, where is a larger number of excavations, more mining districts and preparatory and survey works is usually very branched and several kilometers long. Based on that, the correct choice of the most favorable haulage means is very important, because increasing the distance between the underground production faces has a negative impact on the operating costs [3]. Operating costs are the one of the most important parameters of the efficiency and effectiveness of a mine, so it is very important that the of haulage problem solve in an adequate manner so that the validity of exploitation from the greater depths and lengths is satisfied. [4].

The modern development of haulage means enables the choice of such combinations of haulage in which each form of haulage is used in the most suitable, optimal techno-economic conditions for the choice of which a detailed techno-economic analysis is necessary. The haulage system directly depends on the excavation method, in this case Sublevel caving method [5].

THE MANNER AND METHODS OF ANALYSES

The analysis was performed in order to determine the possibility of applying a combined haulage system. It is necessary to compare the old haulage system and the new one, to compare the results of the loader work as a loading and haulage unit and the results of the work of the newly proposed technology, in which the mine loader- truck system is used [6].

Defining the input parameters for capacity calculation

In order to compare the haulage system as precisely and exactly, it is necessary to define input data important for the capacity of loading and haulage mechanization for different of haulage lengths depending on that input parameters:

- haulage length
- volume of bucket
- volume of ore
- load/haulage cycle duration
- time loading of bucket
- unloading time of bucket
- full loader driving time
- driving time of empty loader
- technical capacity of the loader
- operational shift capacity
- monthly operating capacity

Definition of capacity for the choice of mine truck

The analysis was done in order to determine the required number of mine trucks in the newly proposed variant-combined haulage system and the same is done by comparing the capacity of the loader as a loading and haulage unit, and on the other hand the loader-mine truck. For that, the conditions regarding to the two basic criteria were used, the weight and volume criteria of truck utilization through the following coefficients.

$$\text{Criterion of weight: } q_{t=V_k \cdot K_p} \cdot \frac{\gamma}{K_r} [t] [7]$$

$$\text{Criterion of volume: } V_m = V_k \cdot K_p \cdot \frac{K_{rt}}{K_r} [m^3] [7]$$

Where is:

V_k – volume of loader bucket

γ – bulk density of ore

K_p – coefficient of bucket filling (0.9)

K_r – coefficient of looseness of the material (1.5)

K_{rt} – coefficient of looseness of the material in the truck

Coefficient of truck utilization according to the weight $K_t = Q_t/Q$ [7]

Coefficient of utilization of volume box $K_v = V_u/V$ [7]

Q_t – the weight of the material loaded in the truck [t], Q - load capacity of the truck [t]

V_u – volume of load material [m^3], V -volume of truck bucket [m^3]

The choice of trucks is made by using the ratio of these two coefficients, to be as close as possible to each other, ie. to keep their relationship as close as possible to 1.

Determining optimal of the haulage lengths

After determining the type of truck for which the degree of compatibility of the capacity of the loader and the mine truck is optimal, additional compatibility is possible by varying the haulage lengths, i.e. determining the optimal haulage lengths at which the use of a combined transport system can be considered [8]. Using a graphical layout, a diagram of the dependence of the capacity of the loading and transport unit on the transport length, it is possible to define the optimal haulage length, as shown in the figure 1.

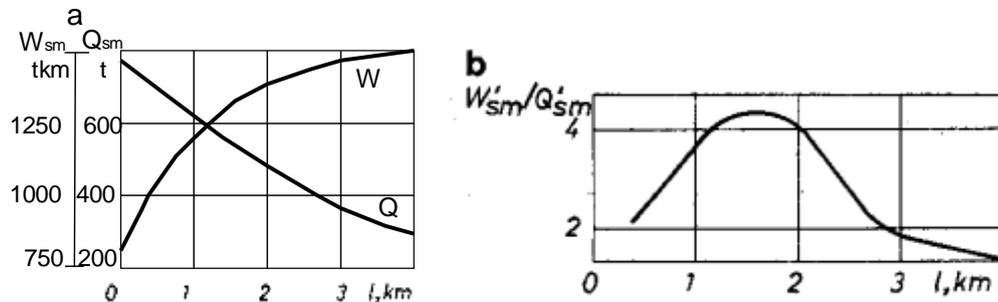


Figure 1. Diagram of dependences: a) truck capacity Q_{sm} and effects W_{sm} b) and ratio W'_{sm}/Q'_{sm} of the haulage lengths l [9]

Analysis of the optimal haulage lengths in accordance with the mining works development

Considering that the several excavation blocks are opened on a certain excavation horizon with the development of the mining works, and thus the lengths of haulage and configurations of haulage routes change, it is necessary to determine the positions of excavation blocks for optimal haulage lengths defined in the previous step of the analysis. The analysis was made on the EB 213/1, EB 213/2, EB 309/8 and EB 309/9.

According to the methodology shown above, the compatibility of loading and haulage units with the capacity of loading and haulage units is defined, which creates the conditions for defining optimal haulage lengths for each excavation block.

Calculation of the fuels, maintenance, tires, spare and labor costs for loaders

The calculation of operating costs is determined depending on the number of loaders, trucks, the required amount of fuel, maintenance costs (tires, spare parts), labor costs, the cost of chambers construction (enlargement of the haulage routes for trucks passing). Based on these parameters, a comparative techno-economic analysis is performed.

THE RESULTS OF THE HAULAGE ANALYSIS AT THE "SASE" SREBRENICA MINE

The annual projected capacity of the mine is a total of 280,000 t of ore and 30,000 t of waste from exploration and preparation works, while the annual projected mass for four blocks, which is the subject of analysis in this paper, is 162 168 t of ore [10]. Differences in the operating costs indicate the techno-economic validity for the new haulage technology introduction, in terms of the necessary additional investment in new / replacement equipment.

The haulage of ore and waste from the excavation blocks consists of two parts: the excavation blocks between II and III horizon and excavation blocks between III and IV horizon. All ore and waste obtained by the blocks excavation are concentrated on the main haulage drift (on II and III horizon) and transported by battery locomotives to the main ore raise (186,187) and the waste raise (185) [10].

Further, the ore and waste are gravitationally lowered to the horizon I, where loading into wagons is performed and transported by the trolley locomotive from the underground mine to the flotation bin, where processing is performed.

According to the above, the haulage of ore and waste consists the three parts:

- Ore and waste haulage by loading and haulage diesel machines on the excavation blocks
- Gravitational sinking of ore and tailings from the exploitation blocks by main bars (185,186,187) to the main haulage drift
- Horizontal overall rail haulage at the level of I, II and III horizons

With the increase of haulage length on the sublevel drift there is a decrease in the capacity of the loading and transport machine, therefore there is a need for the introduction of a combined type of haulage on the excavation blocks, namely the loader-mine truck. Figure 2. shows the preparation, development and haulage on the one excavation block.

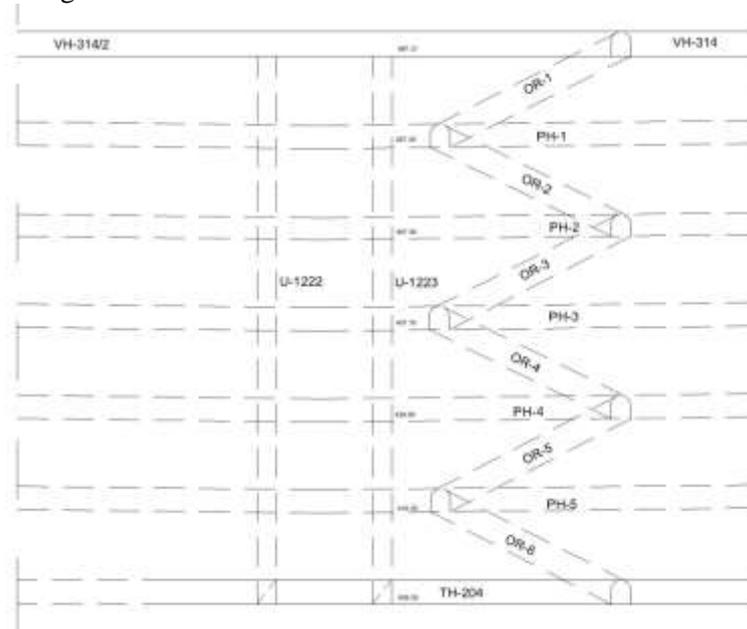


Figure 2 . Longitudinal profile of the excavation block [10]

Input data for the calculation of the capacity of the loading and transport unit.

The following table 1. shows the capacity of the loading and haulage machine for different haulage lengths.

Table 1. Calculation of the capacity of the loading and haulage machine for different haulage lengthson EB 213/1, EB 213/2, EB 309/8, EB 309/9

Mark	L(m)	Vk(m ³)	$\gamma(t/m^3)$	t _c (min)	t _u (min)	t _i (min)	t ₁ (min)	t ₂ (min)	Qt (t/h)	Qsmj (t/smj)	Qmj (t/mj)
EB 213/1	49	1,5	3,24	2,59	0,86	0,57	0,59	0,42	67,47	329,79	29 516,21
	98	1,5	3,24	3,75	0,86	0,57	1,18	0,84	46,61	227,83	20 390,79
	147	1,5	3,24	4,91	0,86	0,57	1,77	1,26	35,61	174,06	15 578,37
	196	1,5	3,24	6,08	0,86	0,57	2,36	1,68	28,78	140,68	12 590,86
EB 213/2	51	1,5	3,27	2,64	0,86	0,57	0,61	0,44	66,89	326,94	29 261,18
	102	1,5	3,27	3,85	0,86	0,57	1,23	0,87	45,83	224,02	20049,53
	153	1,5	3,27	5,05	0,86	0,57	1,84	1,31	34,94	170,79	15285,71
	204	1,5	3,27	6,26	0,86	0,57	2,45	1,74	28,2	137,88	12340
EB 309/8	55	1,5	3,14	2,73	0,86	0,57	0,66	0,47	62,03	303,2	27 136,4
	110	1,5	3,14	4,04	0,86	0,57	1,33	0,94	41,97	205,15	18 360,93
	165	1,5	3,14	5,33	0,86	0,57	1,98	1,41	31,79	155,39	13 907,40
	220	1,5	3,14	6,64	0,86	0,57	2,65	1,88	25,54	124,84	11 173,18
EB 309/9	64	1,5	3,14	2,95	0,86	0,57	0,77	0,55	57,41	280,62	25 115,49
	128	1,5	3,14	4,45	0,86	0,57	1,54	1,09	38,07	186,09	16 655,05
	192	1,5	3,14	5,97	0,86	0,57	2,31	1,64	28,39	138,77	12 419,92
	254	1,5	3,14	7,44	0,86	0,57	3,06	2,17	22,79	111,4	9 970,3

For easy reference of the results of the haulage analysis, it is presented in tabular form through all phases and on the all four excavation blocks, for all parameters listed in point 2.1. The choice of the optimal haulage length was made by comparing the capacity of the loader and the potential mine truck by a certain diagram: haulage length / monthly capacity of the machine. The following is a comparison of the three types of mine trucks and their possible choice based on certain parameters that are necessary for further techno-economic analysis. Based on the above parameters, the operating costs of such equipment were defined and then compared with the current, actual operating costs of the available equipment.

RESULTS OF CALCULATION AND THE CHOICE OF TRUCK TYPE

A variant of introducing combined haulage and one of the possible solutions to improve the capacity and efficiency of haulage is including of mine trucks in the haulage process, with prior determination of the optimal haulage length for their application. The choice of the mine truck was made according to standard criteria, according to the criterion of weight and volume conditions for the considered trucks [11]. According to the stated criteria, a truck of the FYKC-12 type was selected, table 2.

Table 2. Calculation and choice of mine truck

Type of truck	FYKC-8	FYKC-10	FYKC-12	Capacity of mine truck		
	According to the weight condition			L	204	51
q_t		$q_t=2,92$ t		Vk	6	6
n_k	3	3	4	γ	3,27	3,27
Q_t	8,76	8,76	11,68	t_u	0,67	0,67
k_t	1,1	0,88	0,97	t_i	1,5	1,5
	According to the volume condition			t_1	2,04	0,51
V_m		1,35		t_2	1,75	0,44
n_k	3	3	4	t_c	8,73	5,32
V_u	4,05	4,05	5,4	Q_t	80,88	132,77
K_v	1,01	0,81	0,9	Q_{mj}	37 641,91	58 083,71

Determining the optimal haulage length for the application of the loader-mine truck system

The following is an overview of the dependence of the loader capacity and the mine truck of the transport route length and the choice of the optimal transport length based on the presented diagram, figure 3.

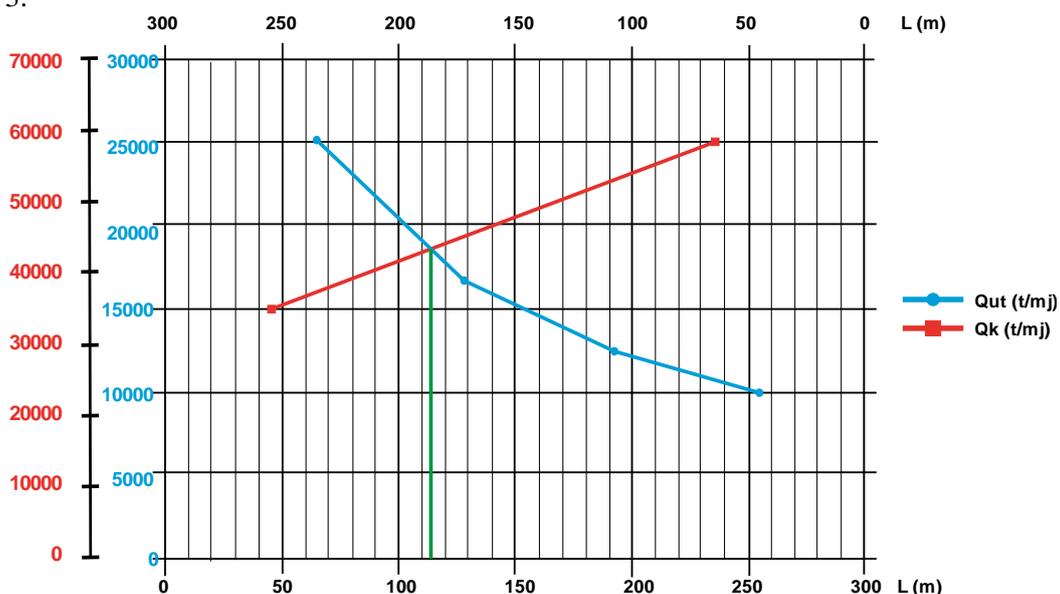


Figure 3. Diagram of determining the optimal transport length based on comparing of the loader capacity and mine truck EB 309/9

Based on the diagram, the optimal haulage length is approximately equal to 114 m, likewise on the other excavation blocks the optimal lengths were determined: EB 213/1, EB 213/2, EB 309/8 and about 90 m for the first two blocks, while on EB 309/8 it is 104 m.

For further calculation, the costs are shown on the basis of maximum haulage length that is currently visible on this excavation block, which is about 254 m, and also creates the highest costs.

Calculation of the operating costs

The calculation was done for the existing haulage system as well as for the newly proposed one (tables 3 and 4), it was done for a maximum haulage length of 254 m with loaders with a capacity of 119 643.6 t/year. Likewise, the capacities on haulage lengths of 128 m and 64 m were determined. The obtained values are given in tables 3 and 4.

Table 3. System of haulage with loaders

Load	LH 203		
Haulage length L(m)	254	128	64
$Q_{\text{god}}(\text{t/god})$	119 643,6	199 860,6	301 385,9
Number of loaders N_{ut}	2	1	1
Required amount of fuel $P_{\text{gu}}[\text{l/god}]$	145 826,24	93 744,73	62 273,16
Fuel costs $T_{\text{gt}}[\text{KM/t}]$	1,98	1,28	0,84
Ongoing maintenance costs $T_{\text{todr}}[\text{KM/t}]$	0,39	0,26	0,17
Number of tires N	24	14	10
Tire costs $T_{\text{pt}}[\text{KM/t}]$	0,69	0,48	0,34
Spare parts costs $T_{\text{rd}}[\text{KM/t}]$	0,19	0,13	0,08
Labor costs $T_{\text{rs}}[\text{KM/t}]$	0,83	0,27	0,18
Total costs [KM/t]	4,08	2,42	1,61

Table 4. System with loader and mine truck

Loader + mine truck	LH 203 + FYKC-12		
Haulage length L(m)	254	128	64
$Q_{\text{god}}(\text{t/god})$	384 964,56	550 000	674 815,68
Number of trucks N_{ut}	1	1	1
Required amount of fuel $P_{\text{gu}}[\text{l/god}]$	129 599,36	91 021,3	74 069,92
Fuel costs $T_{\text{gt}}[\text{KM/t}]$	1,76	1,23	1,01
Ongoing maintenance costs $T_{\text{todr}}[\text{KM/t}]$	0,35	0,25	0,20
Number of tires N	16	12	8
Tire costs $T_{\text{pt}}[\text{KM/t}]$	0,78	0,59	0,39
Spare parts costs $T_{\text{rd}}[\text{KM/t}]$	0,18	0,12	0,10
Labor costs $T_{\text{rs}}[\text{KM/t}]$	0,28	0,20	0,16
Chamber construction costs $T_{\text{ik}}[\text{KM/t}]$	0,11	0,11	0,11
Total costs [KM/t]	3,46	2,5	1,97

The graph (Figure 4) shows the minimum production capacity, which from the aspect of techno-economic analysis is acceptable for the application of haulage, the system of loader-mine truck on the specific case of the mine "Sase" Srebrenica. The calculation of the techno-economic analysis came to

the conclusion that the loader-mine truck system on the haulage length of 254 m is cheaper by 0.62 KM/t of produced ore, with savings of 100 544 KM on an annual level.

Mine loaders in the mine currently satisfy the needs of the annual mine capacity, that in case of increasing capacity and haulage lengths, as one of the solutions to economically haulage of the entire mine can consider purchasing of mine trucks to achieve significant savings.

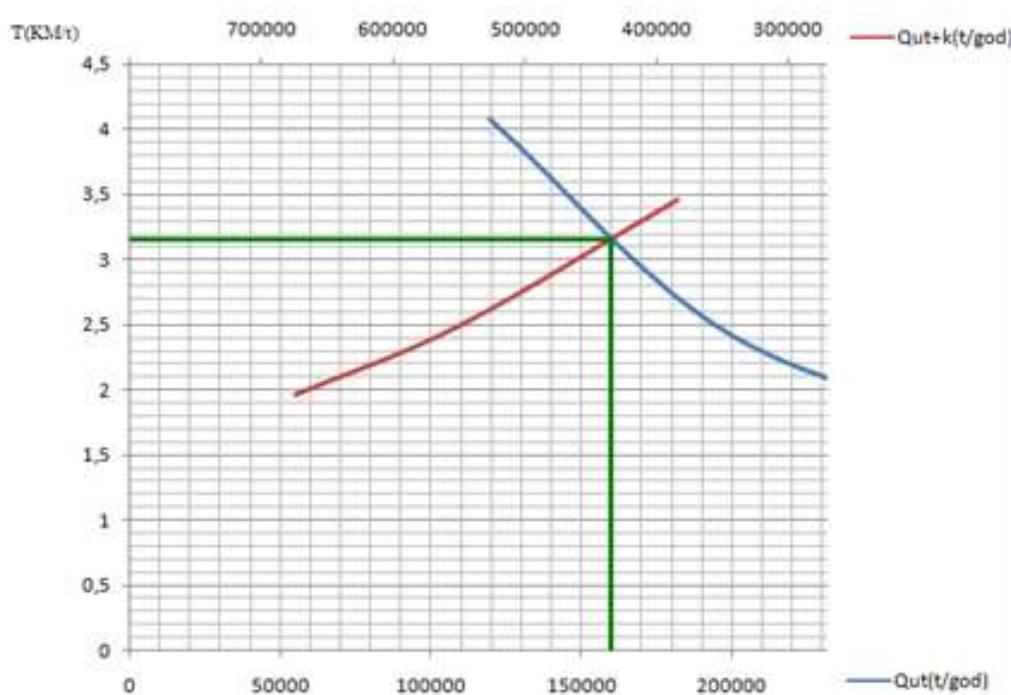


Figure 4. Diagram of the curves of the dependence of costs and capacity of loading and haulage machines and trucks

DISCUSSION AND RECOMMENDATIONS

The analysis of haulage and calculations not including and consider the capital costs of purchasing the equipment for the needs of the realization of the combined haulage system, because the investment costs define the capital costs in the total production costs.

This paper defines the operating costs, both for the operation of the loader and for the combined system of work loader-mine truck. There is a noticeable difference in operating costs between these two modes of haulage and it is evident that with the increase in haulage length, the difference in operating costs grows in favor of the use of combined haulage. Defining haulage lengths at which it is possible to change the work technology will certainly depend on the size of the capital costs.

Further analysis could change the results of this analysis by taking into account the capital costs, but it would certainly not change the point of the obtained results. The validity for the introduction of a combined haulage system certainly exists, but the required production capacity and the size of the of capital costs will be finally determined, by changing the production capacity, the impact of costs also changes [12].

CONCLUSION

The analysis of the specific case yields the results that determine the reduction of operating costs and to what extent, and this depends in addition to the above, on changes in annual production capacity, market conditions and sales price of final products, financing conditions and purchase prices of equipment, as other influential parameters [13].

The calculation took into account the maximum haulage length on each block, which is divided into 4 different lengths and calculated the capacity of the loader, while for the mine truck, the maximum and minimum haulage length was taken to obtain the optimum curve. No waste were transported through the calculation, because the waste haulage lengths are shorter than the ore haulage lengths. A techno-economic analysis was also performed, in which two haulage systems were compared.

Based on the results of the analysis, it can be concluded that the loader-mine truck system refund more for longer haulage lengths because due to the larger capacity of this system compared to the system with loaders, the operating costs will be reduced quantitatively, while operating costs will be higher.

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