MINING AND METALLURGY INSTITUTE BOR
UDK: 622

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

UDK: 336.121:622.343/.349(045)=111
DOI: 10.5937/mmeb2501053B

Received: 06.05.2025.
Revised: 28.05.2025.
Accepted: 30.05.2025.

Original Scientific Paper
Mining Engineering

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DETERMINATION OF OPERATING AND MAINTENANCE COSTS OF TRANSPORT EQUIPMENT IN THE DEVELOPMENT OF EXPLORATORY MINE WORKINGS IN A LEAD AND ZINC MINE[**]

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Abstract

This paper examines the costs of mechanized transport used in the construction of exploratory underground corridors over a three-year period. During the execution of the works, data were collected on fuel consumption and spare parts required for the uninterrupted operation of the machinery. Based on the analysis of the collected data on machinery operation, direct dependencies were established between the monthly length of the constructed underground corridors and the operational costs of machinery operation and maintenance for material transport.

Keywords *– Underground corridor construction, Machinery operating costs, Maintenance*

1 INTRODUCTION

Based on the positive results of geological exploration conducted through exploratory drilling, four prospective zones have been identified where further geological investigations [1] and the development of corresponding exploratory mine workings are required, with the aim of defining the boundaries of ore bodies.

Ore extraction is carried out from a polymetallic deposit composed of a large number of ore bodies (more than 90), which, according to current findings, extend over an area approximately 3 [km] in length and more than 1.5 [km] in width. The general strike direction of the deposit is NW–SE.

Table 1 presents the basic physical and mechanical properties of the ores and the surrounding rocks of the ore bodies within the polymetallic deposit. It can be concluded that the geological environment is favorable for conducting exploratory, preparatory, and later exploitation works.

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[**] *This work was financially supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, Contract No. 451-03-136/2025-03/200052.*

Table 1 *Characteristics of ores and associated rocks in the deposit*

Parametar	**Sand stone**	**Skarn**	**Dacite**	**Lime stone**	**Breccia**	**Shale Marl**	**Kaolin**	**Lead–Zinc**
Density [g/cm³]	2,86	3,17	2,71	2,90	3,01	2,88	3,00	3,52
Bulk Density [g/cm³]	2,71	2,94	2,59	2,75	2,81	2,72	2,87	3,33
Porosity [%]	5,06	6,83	4,51	5,26	6,67	5,56		6,23
Compressive Strength [MPa]	99,43	78,85	89,67	80,31	54,51	18,57	23,95	85,47
Tensile Strength [MPa]	10,83	8,44	10,21	7,17	7,20	2,02	5,00	11,04
Internal Friction Angle [°]	51,94	51,94	49,88	55,26	47,73	52,55	41,33	45,56
Elastic Modulus [GPa]	55,73	54,59	38,56	42,86	27,63		4,67	46,75
Seismic Wave Velocity [km/s]	5,11	5,16	5,29	5,02		2,54	4,55	4,59
Relative Humidity [%]	0,58	0,66	0,64	0,67				0,77
Poisson's Ratio	0,17	0,25	0,18	0,19	0,25			0,25
Cohesion [dN/cm²]	199,7	157,1	106,9	152,3	170,3			193,4
Strength (Protodyakonov) Coefficient	9,94	7,88	8,70	8,03	5,45	1,86	2,40	8,55

The favorable geomechanical properties of the rock masses within the deposit are particularly evident during the excavation of horizontal, inclined, and vertical mine workings, as these typically do not require support, except in fault zones.

2 TECHNICAL DESCRIPTION OF EXPLORATORY DRIFTS

The elevation of 515 meters has been determined as the optimal level for driving the drift from which all further geological exploration of the identified prospective zones will be conducted. This elevation simultaneously satisfies the positioning requirements for exploratory drilling in all zones and falls within the potential development range of a future mining level at –200 meters, given that it is located approximately 60 meters below the current lowest level at –150 meters. The plan includes the construction of four types of cross-sections of exploratory mine workings, namely:

Type 1:	Profile 3.0×2.0[m], unsupported,	Fs = 7.05 [m²]
Type 2:	Profile 2.0×2.0[m], unsupported,	Fs = 4.00 [m²]
Type 3:	Profile 4.0×3.5[m], unsupported,	Fs = 12.84 [m²]
Type 4:	Profile 4.0×3.5[m], with steel support,	Fs = 12.84 [m²]

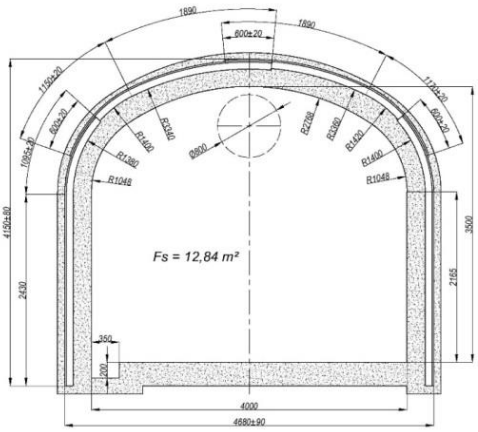


Figure 1 *Profile 4.0×3.5[m], with steel support*

Main Exploratory Decline GIN 200

The entry portal to the main exploratory decline GIN 200 is located on the plateau of the existing haulage adit at the –150 [m] level, for the following reasons:

- The plateau is equipped with complete infrastructure;
- A waste rock dump has already been formed, suitable for depositing material excavated during the development of exploratory workings;
- This location provides access approximately to the central part of the ore-bearing structure, which is highly favorable from the standpoint of future exploitation.

The main exploratory decline GIN 200 is a gently inclined underground opening intended to connect the surface with the exploratory drifts. It will serve for transporting the material excavated from the exploratory workings, personnel access, as well as the delivery of supplies and energy. Additionally, it will be used for workplace ventilation.

From the portal, GIN 200 proceeds horizontally for 15.0 [m], then continues for 430 [m] at a 10% decline down to an elevation of 513.0 [m]. From there, it advances sub–horizontally (with an upward gradient of 3.1%) for 630.1 [m] until it connects with the GIH 200/NW and GIH 200/SE drifts. The connection is made through two curves with a radius of 20.0 [m]. The total length of the main exploratory decline GIN 200, including the curves, is 1111.1 [m].

The cross-sectional dimensions were selected based on the size of the equipment used for drift development (drill rigs, loaders), and the clearance required for the mine truck planned for future ore and waste haulage. Consideration was also given to the positioning of ventilation ducts with a diameter of 800 mm during the decline development.

The cross-sectional area of the decline (without support) is Fs = 12.84 [m²]. The same clear area is maintained when using a four–piece steel arch support system, as well as in the section supported with concrete lining.

Regarding ground support, based on data obtained from the technical borehole, it is estimated that the first 50 meters will be supported with concrete lining. It is also anticipated that approximately 20% of the total decline length (around 210 meters) will require steel arch supports. Along the entire section of the decline with a 10% gradient (430 + 15 = 445 meters), a 25 [cm] thick reinforced concrete floor slab will be installed, which will improve transport efficiency and reduce the operational costs of haulage.

Main Exploratory Drift GIH 200/NW

From its junction with the main exploratory decline GIN 200, this drift extends in a northwestern direction. The total length of the drift is 1707.3 meters, and it is being driven with an upward gradient of 3.51%.

The cross–sectional area of the drift (without support) is Fs = 12.84 [m²]. The same clear area is maintained when supported with a four-piece steel arch support system. The drift is largely unsupported.

Main Exploratory Drift GIH 200/SE

From its junction with the main exploratory decline GIN 200, this drift extends in a southeastern direction. The total length of the drift is 847.0 meters, and it is being driven with an upward gradient of 3.54%.

The cross-sectional area of the drift (without support) is Fs = 12.84 [m²]. The same clear area is maintained when supported with a four-piece steel arch support system. The drift is largely unsupported.

Excavation Technology of the Workings

The excavation of the aforementioned underground workings does not involve any particular specificities and does not differ from the standard procedures used in the development of production mine workings.

The technological process of excavation consists of the following operational steps:

- Drilling of blast holes
- Charging and blasting
- Ventilation
- Loading and haulage of blasted material
- Ground support installation
- Drainage and auxiliary operations

3 OVERVIEW OF DEPLOYED MACHINERY

An overview of the machinery used in the excavation of underground exploratory drifts is presented in Table 2. The overview includes equipment utilized for drilling, loading, and material transport operations [2].

Table 2 *Overview of machinery used for operations execution*

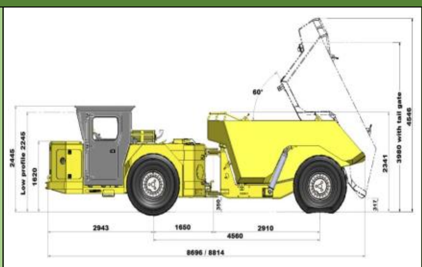
No.	Name	Type	Operating Period
1	Loader	GHH LF 4.1	X. 2019 – IV. 2021
2	Loader	GHH LF 4.1	X. 2019 – IV. 2021
3	Loader	GHH LF 6F	VI. 2020 – VIII. 2023
4	Loader	Atlas Copco ST3.5	III. 2021 – VIII. 2023
5	Drilling Rig	Tamrock HS105D	III. 2021 – VIII. 2023
6	Mine Truck	Aramine T1601C	V. 2021 – VIII. 2023

The objective of this study is to analyze the operational costs of operating and maintaining the machinery used for material transport and haulage from the mine.

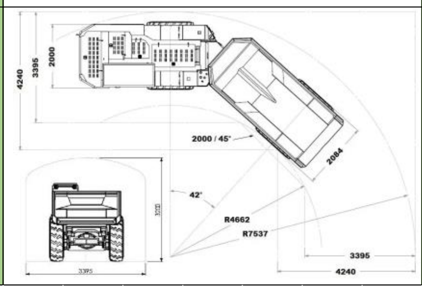
Therefore, the data presented below refer specifically to the underground mine truck T1601C.

WORKING DIMENSIONS, MOVEMENT GEOMETRY, WORKING PERFORMANCE AND EQUIPMENT OF TRUCK T1601C

DIMENSIONS



MOVEMENT GEOMETRY



OPERAT. WEIGHTS	EMPTY	ALLOWED WEIGHT OF TRANSPORTED		MAXIMUM ALLOWED WEIGHT OF	
	17000 kg	15000 kg		17000 kg	
CAPACITY	MAXIMUM LOADING CAPACITY	LOADING CAPACITY UP TO THE EDGE OF THE BED		LOADING CAPACITY WITH INCREASED BED	
	7,5 m³	6,7 m³		7,5 - 9,5 m³	
DIESEL ENGINE	ENGINE MANUFACTURE	CUMMINS			
	MODEL / CODE	QSB6.7 WITH OIL COOLING			
	POWER	164kW			
	MAXIMUM TORQUE	959 Nm pri 1500 o/min			
TIRES	14" R24	OPTIONALLY, 16" R25 TIRES CAN BE INSTALLED			
TANK VOLUME	FUEL TANK	HYDRAULIC OIL TANK			
	220 liters	210 liters			
DRIVING STABILITY CONDITIONS	MAX. MOVEMENT ANGLE	10° FOR A LOADED TRUCK WITH LOWERED BED			
	MAXIMUM SPEEDS ON INCLINE [km/h]	0%	10%	15%	20%
	WHILE MOVING UNDER LOAD	20	9	7,5	4,5
	WHILE MOVING WITHOUT LOAD	20	16	9	4,5

Figure 2 *Technical Specifications and Performance of the T1601C Truck*

4 DATA ANALYSIS ON EXECUTION AND CONSUMPTION

The transport cycle includes loading, hauling the material to the dumping point, unloading, and returning to the loading point. The number of transport cycles completed within a given time period represents the only direct link between the realized work (i.e., the number of meters of mine workings excavated) and the incurred costs, since fuel consumption, lubricants, tire wear, truck depreciation, and similar expenses are determined based on the number of cycles.

In this case, the determination of transport cycles was carried out based on a detailed monthly specification of the constructed mine workings. All the workings were developed with the same nominal profile of 4.0 × 3.5 meters, and therefore share the same clear cross-sectional area. This uniformity simplified the process, as it allowed for the summation of total lengths excavated each month to generate input data for calculating the number of transport cycles.

Based on the monthly excavation lengths and the cross–sectional area of the workings, the monthly volume of material requiring transportation and haulage to the surface was determined. The data specifying the executed work by working type on a monthly basis are presented in Table 3.

Table 3 *Specification of executed works on a monthly basis*

SPECIFICATION OF EXECUTED WORKS ON A MONTHLY BASIS															
Year	Month	Portal	GIN 200	GVS 1/N	RGVS 2/N	TS GIN 200	UK 1 DK 1 DK 2	SIH 0	SIH 1	SIH 2	GIH 200 SZ	TS 200SZ	VH 200	GIH 200 JI	Total per month [m]
2019	XI	7,00													
	XII	8,00													
2020	I		17,60												17,60
	II		25,58												25,58
	III		28,75												28,75
	IV		24,40												24,40
	V		22,34												22,34
	VI		37,10												37,10
	VII		34,31												34,31
	VIII		44,29												44,29
	IX		44,26												44,26
	X		61,73												61,73
	XI		53,14												53,14
	XII		41,24												41,24
2021	I		53,35												53,35
	II		63,01	18,10											81,11
	III		101,80	2,12											103,92
	IV		116,70		14,70		10,30								141,70
	V		129,80			9,40	12,80								152,00
	VI		99,40												99,40
	VII		102,90				13,50							6,10	122,50
	VIII										14,30			144,40	158,70
	IX										50,00			75,20	125,20
	X										84,20			79,90	164,10
	XI										49,00			81,00	130,00
	XII													38,50	38,50
2022	I								30,70	18,70					49,40
	II								77,30	23,00					100,30
	III								81,30	59,50					140,80
	IV									33,60				22,00	55,60
	V		27,70											77,50	105,20
	VI													96,30	96,30
	VII							42,60			61,40				104,00
	VIII							49,40			58,00				107,40
	IX							62,20			34,90				97,10
	X							3,70		77,40	16,90				98,00
	XI									35,60	42,40	6,80			84,80
	XII									28,70	51,20	3,70			83,60
2023	I									19,40	42,30				61,70
	II										57,20				57,20
	III										49,80				49,80
	IV										48,90				48,90
	V										96,30				96,30
	VI										20,30		30,90		51,20
	VII										59,70				59,70
	VIII										59,60				59,60
	IX														
	X														
	XI														
	XII														
TOTAL			**1.129,40**	**20,22**	**14,70**	**9,40**	**36,60**	**157,90**	**189,30**	**295,90**	**896,40**	**10,50**	**30,90**	**620,90**	

The truck capacity was determined based on the allowable payload defined by the manufacturer, taking into account that the average bulk density of the transported material is 2.85 [g/cm³]. With this value and considering the loading capacity limit of 15,000 [kg], the truck loading capacity is calculated to be 5 [m³]. Based on the defined truck capacity and the previously specified volume of material to be transported, the required number of transport cycles per month is determined.

By defining the number of working days in each month, the monthly number of cycles is converted into the daily number of cycles. Considering the number of shifts, the number of transport cycles performed by the truck during a single shift is obtained. This is a critical piece of data, as it will be used in the following sections to define the number of operating hours and fuel consumption.

At the end of this section, which addresses transport cycles, the length of the transport route per cycle can be defined. For this determination, the input data includes the locations where the material is loaded into the truck. In the specific case analyzed, material loading was conducted either in the loading chamber UK1, located in the main exploratory decline GIN200 at a distance of 330 meters from the beginning of the ramp, or at the loading extension at the end of the main exploratory decline GIN200. Depending on these locations, the transport route length was defined for each possible scenario. The transport distances were further categorized based on the inclination of the drift.

All data calculated and described in the preceding text are presented in Table 4, which provides an overview of the total bulk volume of material for transport, the number of cycles, and transport distances.

Table 4 *Quantity of transported material and number of cycles*

QUANTITY OF TRANSPORTED MATERIAL AND NUMBER OF CYCLES															
Year	Month	Produced meters	Nominal profile (m)	Clear surface area (m²)	Material quantity (m³)	Truck capacity (m³)	Cycles per month	Number of work. days	Number of cycles per day	Number of shifts	Number of cycles per shift	Transport on flat section	Transport on upward inclinen	Movement outside	Return to loading
2021	V	152,00	4 x 3,5	12,85	1953,20	5,00	391	28	14	2	7	335,00	435,00	200,00	770,00
	VI	99,40	4 x 3,5	12,85	1277,29	5,00	255	28	9	2	5	335,00	435,00	200,00	770,00
	VII	122,50	4 x 3,5	12,85	1574,13	5,00	315	29	11	2	5	335,00	435,00	200,00	770,00
	VIII	158,70	4 x 3,5	12,85	2039,30	5,00	408	30	14	2	7	667,00	435,00	200,00	1102,00
	IX	125,20	4 x 3,5	12,85	1608,82	5,00	322	29	11	2	6	667,00	435,00	200,00	1102,00
	X	164,10	4 x 3,5	12,85	2108,69	5,00	422	30	14	2	7	667,00	435,00	200,00	1102,00
	XI	130,00	4 x 3,5	12,85	1670,50	5,00	334	29	12	2	6	667,00	435,00	200,00	1102,00
	XII	38,50	4 x 3,5	12,85	494,73	5,00	99	22	4	1	4	667,00	435,00	200,00	1102,00
2022	I	49,40	4 x 3,5	12,85	634,79	5,00	127	22	6	1	6	335,00	435,00	200,00	770,00
	II	100,30	4 x 3,5	12,85	1288,86	5,00	258	27	10	1	10	335,00	435,00	200,00	770,00
	III	140,80	4 x 3,5	12,85	1809,28	5,00	362	31	12	1	12	335,00	435,00	200,00	770,00
	IV	55,60	4 x 3,5	12,85	714,46	5,00	143	30	5	1	5	667,00	435,00	200,00	1102,00
	V	105,20	4 x 3,5	12,85	1351,82	5,00	270	29	9	1	9	667,00	435,00	200,00	1102,00
	VI	96,30	4 x 3,5	12,85	1237,46	5,00	247	30	8	1	8	667,00	435,00	200,00	1102,00
	VII	104,00	4 x 3,5	12,85	1336,40	5,00	267	31	9	1	9	667,00	435,00	200,00	1102,00
	VIII	107,40	4 x 3,5	12,85	1380,09	5,00	276	30	9	1	9	667,00	435,00	200,00	1102,00
	IX	97,10	4 x 3,5	12,85	1247,74	5,00	250	30	8	1	8	667,00	435,00	200,00	1102,00
	X	98,00	4 x 3,5	12,85	1259,30	5,00	252	31	8	1	8	667,00	435,00	200,00	1102,00
	XI	84,80	4 x 3,5	12,85	1089,68	5,00	218	30	7	1	7	667,00	435,00	200,00	1102,00
	XII	83,60	4 x 3,5	12,85	1074,26	5,00	215	22	10	1	10	667,00	435,00	200,00	1102,00
2023	I	61,70	4 x 3,5	12,85	792,85	5,00	159	23	7	1	7	667,00	435,00	200,00	1102,00
	II	57,20	4 x 3,5	12,85	735,02	5,00	147	27	5	1	5	667,00	435,00	200,00	1102,00
	III	49,80	4 x 3,5	12,85	639,93	5,00	128	31	4	1	4	667,00	435,00	200,00	1102,00
	IV	48,90	4 x 3,5	12,85	628,37	5,00	126	30	4	1	4	667,00	435,00	200,00	1102,00
	V	96,30	4 x 3,5	12,85	1237,46	5,00	247	30	8	1	8	667,00	435,00	200,00	1102,00
	VI	51,20	4 x 3,5	12,85	657,92	5,00	132	30	4	1	4	667,00	435,00	200,00	1102,00
	VII	59,70	4 x 3,5	12,85	767,15	5,00	153	31	5	1	5	667,00	435,00	200,00	1102,00
	VII	59,60	4 x 3,5	12,85	765,86	5,00	153	30	5	1	5	667,00	435,00	200,00	1102,00

The duration of a single transport cycle is determined based on the truck's travel speed across defined transport sections (e.g., flat sections, inclined sections).

According to the technical specifications of the T1601C truck, the maximum permis sible travel speeds are provided depending on whether the truck is loaded or empty, and on the gradient of the haul road.

For more detailed analyses of speed and rolling resistance, a traction force diagram (Figure 3) is used, showing the relationship between tractive force (vertical axis in kN) and distance (horizontal axis in m) [3].

Under realistic loading and haulage conditions, the following travel speeds have been defined:

Loaded truck traveling on flat underground roadway: **v_1 = 7 [km/h]**

Loaded truck ascending a 10% incline underground: **v_2 = 4.5 [km/h]**

Loaded truck traveling on flat surface outside the mine: **v_3 = 8 [km/h]**

Empty truck traveling on flat underground roadway: **v_4 = 8 [km/h]**

Empty truck descending a 10% incline underground: **v_5 = 8 [km/h]**

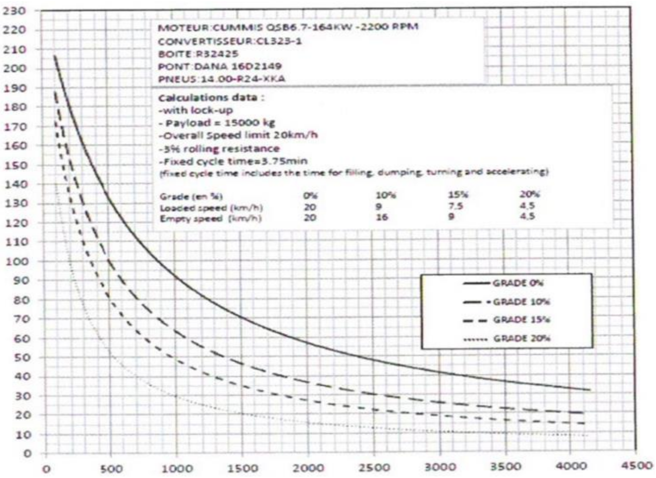


Figure 3 *Diagram of the Relationship Between Tractive Force and distance*

Depending on the loading location—either at the UK1 loading chamber or at the loading extension at the end of the main exploratory decline GIN200 - there are two distinct transport route lengths, and consequently, two different cycle durations for these characteristic haulage cycles.

Basic formula for calculating the transport cycle time is:

$$T_C = T_L + \frac{L_1}{v_1} + \frac{L_2}{v_2} + \frac{L_3}{v_3} + \frac{L_4}{v_{4/5}}$$

where are:

T_L – truck loading time [h]

L_1 – distance of transport on flat section [km]

L_2 – distance of transport on upward inclinen [km]

L_3 – distance of movement outside [km]

L_4 – distance of return to loading [km]

Cycle 1 represents loading at the UK1 loading chamber.

The transport cycle time is calculated as:

Tc□ = 0.15 + (0.335 / 7) + (0.435 / 4.5) + (0.200 / 8) + (0.770 / 8) = 0.416 [h] = 25 [min]

Cycle 2 represents loading at the extension at the end of GIN200.

The transport cycle time is calculated as:

Tc_2 = 0.15 + (0.667 / 7) + (0.435 / 4.5) + (0.200 / 8) + (1.102 / 8) = 0.505 [h] = 30 [min]

With the defined transport cycle durations from the previous section, it is possible to determine (or verify from operational records) the total number of truck operating hours on a monthly basis. Additionally, by summing up the transport distances and the number of cycles, the total distance traveled per month can be calculated. These figures serve as input data for determining the truck's monthly fuel consumption, and subsequently, the average monthly fuel consumption during operational activities. The calculated data are presented in Table 5.

Table 5 *Total mileage, operating hours, diesel fuel consumption*

TOTAL MILEAGE, OPERATING HOURS, AND DIESEL FUEL CONSUMPTION									
Year	Month	Produced meters [m]	Quantity for export [m³]	Cycles per month	Cycle length [m]	Cycle duration [min]	Total mileage [km]	Operating hours [h]	Diesel fuel consumption [lit]
2021	V	152,00	1953,20	391	1740	25	680,3	162,9	2834
	VI	99,40	1277,29	255	1740	25	443,7	106,3	1848
	VII	122,50	1574,13	315	1740	25	548,1	131,3	2283
	VIII	158,70	2039,30	408	2404	30	980,8	204,0	4086
	IX	125,20	1608,82	322	2404	30	774,1	161,0	3225
	X	164,10	2108,69	422	2404	30	1.014,5	211,0	4226
	XI	130,00	1670,50	334	2404	30	802,9	167,0	3345
	XII	38,50	494,73	99	2404	30	238,0	49,5	991
2022	I	49,40	634,79	127	1740	25	221,0	52,9	921
	II	100,30	1288,86	258	1740	25	448,9	107,5	1870
	III	140,80	1809,28	362	1740	25	629,9	150,8	2624
	IV	55,60	714,46	143	2404	30	343,8	71,5	1432
	V	105,20	1351,82	270	2404	30	649,1	135,0	2704
	VI	96,30	1237,46	247	2404	30	593,8	123,5	2474
	VII	104,00	1336,40	267	2404	30	641,9	133,5	2674
	VIII	107,40	1380,09	276	2404	30	663,5	138,0	2764
	IX	97,10	1247,74	250	2404	30	601,0	125,0	2504
	X	98,00	1259,30	252	2404	30	605,8	126,0	2524
	XI	84,80	1089,68	218	2404	30	524,1	109,0	2183
	XII	83,60	1074,26	215	2404	30	516,9	107,5	2153
2023	I	61,70	792,85	159	2404	30	382,2	79,5	1592
	II	57,20	735,02	147	2404	30	353,4	73,5	1472
	III	49,80	639,93	128	2404	30	307,7	64,0	1282
	IV	48,90	628,37	126	2404	30	302,9	63,0	1262
	V	96,30	1237,46	247	2404	30	593,8	123,5	2474
	VI	51,20	657,92	132	2404	30	317,3	66,0	1322
	VII	59,70	767,15	153	2404	30	367,8	76,5	1532
	VIII	59,60	765,86	153	2404	30	367,8	76,5	1532
AVERAGE							**532,7**	**114,1**	**2219**

Tire consumption is presented in Table 6. Based on available data, tire usage is provided for the T1601C truck as well as for the GHH LF6 and ST3.5D loaders. This was done to ensure that the tire consumption overview can be used for further analysis of operating costs and other machinery performance.

Table 7. presents the total monthly cost of spare parts required for the maintenance of the truck.

Table 6 *Tire consumption*

TIRE CONSUMPTION			
Year	Month	14" - T1601C	17,5" - GHHLF6 + ST 3,5
2020	VI - XII		10
2021	I - IV		9
	V - XII	16	18
2022	I - XII	12	13
2023	I - VIII	3	7
IN TOTAL		**31**	**57**

Table 7 *Spare parts costs for maintenance*

SPARE PARTS COSTS FOR MAINTENANCE OF THE T1601C TRUCK						
Number	Name	Code	Replacement period [h]	Monthly quantity	Unit price [€]	Monthly costs [€]
1	Primary air filter	8035212	125	1,00	99,30	99,30
2	Secondary air filter	8035213	250	0,50	85,40	42,70
3	Engine oil filter	8034231	250	0,50	17,00	8,50
4	Engine fuel filter	8034230	250	0,50	14,30	7,15
5	Water separator filter	7796975	250	0,50	29,65	14,83
6	Hydraulic tank filter	7702298	500	0,25	43,85	10,96
7	Belting on the engine	7785901	1000	0,25		
8	Tires	14.00 R24		31 / 28	1231,60	1363,60
IN TOTAL						1547,04

5 ANALYSIS OF OBTAINED RESULTS

The total monthly operating and maintenance costs are obtained by summing the costs of spare parts required for maintenance, fuel and lubricant costs, labor costs for both machine operators and maintenance personnel, and machine depreciation costs.

The average monthly fuel consumption is 2,219 [lit].

The unit price of one liter of Euro diesel is €1.60.

Therefore, the total monthly fuel cost is: 2,219 × 1.6 = €3,550

The monthly salary of the truck operator is €1,600.

The monthly salary of the maintenance mechanic is €1,000, but this amount is divided by the number of machines serviced by the same mechanic. In this case, the mechanic was responsible for maintaining four machines operating simultaneously. Thus, the monthly cost allocated to the truck for mechanic labor is: 0.25 × 1,000 = €250

The average monthly consumption of SAE10W oil is 110 [lit].

The unit price per liter of SAE10W oil is €3.00.

Therefore, the total monthly cost for oil is: 110 × 3 = €330

Based on the previously determined data, the total monthly cost of operating and maintaining the T1601C truck is:

$$Tu = 547 + 3{,}550 + 1{,}600 + 250 + 330 = €7{,}277$$

Using this value, the unit operating and maintenance cost per meter of completed mining work and per unit volume of transported material can be calculated. The results are presented in Table 8 and diagram in figure 4.

Table 8 *Operating costs of the T1601C truck*

OPERATING COSTS OF THE T1601C TRUCK						
Year	Month	Produced meters [m]	Quantity for export [m³]	Operating costs [€]	Operating costs per meter of drift excavated [€/m]	Operating costs per unit of material volume [€/m³]
2021	V	152,00	1953,20	7277	47,88	3,73
	VI	99,40	1277,29	7277	73,21	5,70
	VII	122,50	1574,13	7277	59,40	4,62
	VIII	158,70	2039,30	7277	45,85	3,57
	IX	125,20	1608,82	7277	58,12	4,52
	X	164,10	2108,69	7277	44,34	3,45
	XI	130,00	1670,50	7277	55,98	4,36
	XII	38,50	494,73	7277	189,01	14,71
2022	I	49,40	634,79	7277	147,31	11,46
	II	100,30	1288,86	7277	72,55	5,65
	III	140,80	1809,28	7277	51,68	4,02
	IV	55,60	714,46	7277	130,88	10,19
	V	105,20	1351,82	7277	69,17	5,38
	VI	96,30	1237,46	7277	75,57	5,88
	VII	104,00	1336,40	7277	69,97	5,45
	VIII	107,40	1380,09	7277	67,76	5,27
	IX	97,10	1247,74	7277	74,94	5,83
	X	98,00	1259,30	7277	74,26	5,78
	XI	84,80	1089,68	7277	85,81	6,68
	XII	83,60	1074,26	7277	87,05	6,77
2023	I	61,70	792,85	7277	117,94	9,18
	II	57,20	735,02	7277	127,22	9,90
	III	49,80	639,93	7277	146,12	11,37
	IV	48,90	628,37	7277	148,81	11,58
	V	96,30	1237,46	7277	75,57	5,88
	VI	51,20	657,92	7277	142,13	11,06
	VII	59,70	767,15	7277	121,89	9,49
	VIII	59,60	765,86	7277	122,10	9,50
AVERAGE					**92,23**	**7,18**

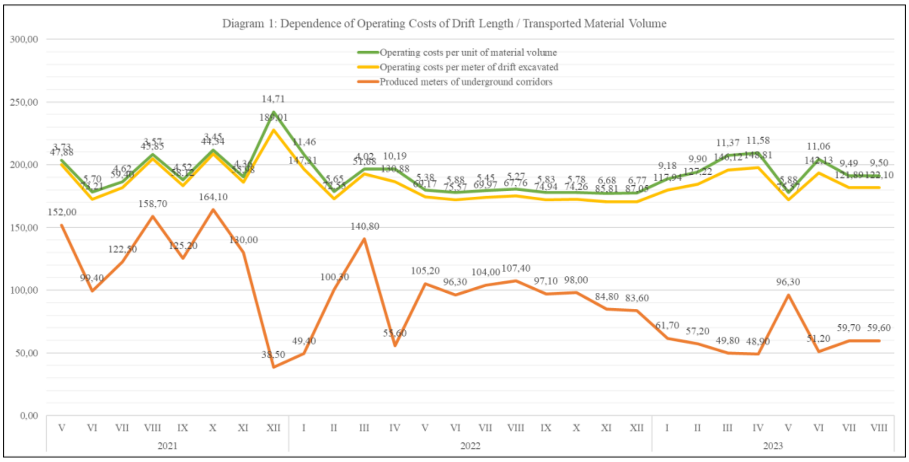


Figure 4 *Dependence of operating costs of drift length / transported material volume*

6 CONCLUSION

This study presents the methodology for determining the operational costs of equipment used for material transport during the excavation of exploratory underground drifts. Transport cycles were defined based on the total volume of material to be removed from the mine, in accordance with the technical specifications of the transport equipment.

Based on field-collected data, the actual consumption of spare parts for the underground truck was determined. By compiling the total operating and maintenance costs of the equipment, a correlation was established between the length of excavated underground workings and the operational costs.

The obtained data, expressed in €/m, can be used for cost estimation of operating and maintaining the same or similar equipment in future projects

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