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HAUL ROAD CONDITION IMPACT ON TIRE LIFE OF MINING DUMP TRUCK

Purpose. Off-road tires (OTR) for mining and earthmoving applications which are specially developed for extreme mine site conditions can take 10–20 % of transportation costs. Up to 15 % of OTR content is natural rubber produced from a rubber tree known as hevea brasiliensis. A significant number of OTR fail before the target life built in by tire manufacturers. This has certain negative impacts on the environment and wildlife due to deforestation effect. Thus, the purpose of the work is to increase the durability or, in the terminology of the operators, the "mileage" of the OTR.

Methodology. The current study represents analyses of new modern digital technology for monitoring the mining haul road condition within a site study on Bogatyr Komir coal mine in North Kazakhstan. The influence of operating conditions was controlled, i.e. road quality, temperature conditions, tire pressure, and other parameters on tire life.

Findings. The results show the effectiveness of digital technologies and the possibility of extending the life of tires by following the recommendations of the system in a timely manner. As a result of the analysis of temperature regimes and pressure in tires, especially in summer conditions, recommendations for rational operating conditions were determined, which makes it possible to increase the durability of tires.

Originality. Modern operational digital methodology for monitoring open pit mines road condition defines ton kilometer per hour (TKPH) indicator per every trip, which provides on-time information for road design and maintenance.

Practical value. Growing worldwide demand is driving the development of the mining industry. In the future, more and more fields with a low content of produced raw materials will be put into operation. The development of deposits with a low content of a useful product means that more rock mass must be moved in order for these developments to be profitable. Transportation costs in low-grade mines can be as high as 70 % of mining costs due to more haul trucks and longer roads that need to be commissioned. Thus, an increase in the durability of OTR can give a great economic effect not only in the conditions of the Bogatyr Komir quarry under consideration but also in other mining and processing plants.

Keywords: *mine haul roads, tires life, mining dump truck, natural rubber*

Introduction. The spillover effects of the Russian invasion of Ukraine are accelerating the global slowdown, which the World Bank expects to fall to 2.9 % in 2022. War drives up commodity prices, and the world is still primarily dependent on fossil fuels for energy. Against the background of fears about the termination of Russian gas supplies, some European states are thinking about restoring coal mining. For many countries of the world, coal mining is generally the main source of wealth.

Based on the website Agency for Strategic planning and reforms of the Republic of Kazakhstan Bureau of National statistics, Kazakhstan is among the top ten countries with the largest coal deposits and ranks *8th* in the world in terms of proven coal reserves of all types: from brown to black coal. Proven coal reserves in Kazakhstan are estimated at 34.2 billion tons (4 % of the global volume), including lignite reserves – 62 %, black coal – 38 %. Kazakhstan annually enters 10 world leaders in coal mining. Most of the coal is mined open-pit and has a low cost of production, but due to the high ash content and structural features of coal, exports are limited.

The main production unit used in open-pit coal mining is a dump truck. Currently, Caterpillar, Komatsu, Hitachi-Euclid, Terex and Liebherr are recognized as leading foreign firms and companies in the production of this type of mining equipment. Recently, Chinese mining dump trucks from Lingong Machinery Group (LGMG) have been gaining popularity in Ukraine and Kazakhstan. According to the autoconsulting.ua website, at the beginning of 2020, the LGMG CMT96 mining dump truck was officially delivered to Ukraine for the first time. This powerful modern machine with a 6x4 wheel formula and a load capacity of 63 tons is operated at Vyrovsky quarry, one of the leading mining enterprises in Ukraine, which is part of the Basalt AG group of companies managing 350 facilities for the production and processing of mineral raw materials around the world. Experts believe that today there are simply no direct competitors for LGMG dump trucks in the Ukrainian market.

The cost of mining a mineral is determined by a significant share of the costs of operation of open-pit transport. When using heavy-duty mining dump trucks of 90–220 tons carrying capacity with an effective organization of maintenance and repair, the highest operating costs fall on diesel fuel (50–58 %) and tires (14–16 %) [1]. Consequently, the measures to optimize these costs will be the most effective in terms of reducing the cost of coal mining.

In the operation of passenger [2, 3] and freight [4] motor vehicle tires, the key properties are road grip, stability, and effective water evacuation in the presence of precipitation. Due to the fact that agricultural tractors [5] do not have rear shock-absorbing suspension, the rear wheels wear out deeply and faster, which is why they place especially high demands on tires – they use special tires with a deep cross-country tread. When operating large-sized tires, all of the above-mentioned properties fade into the background, and wear resistance, cut resistance, and heat resistance come to the fore, which ultimately results from the mileage of tires achieved.

The most important factor in the efficient use of tires is their choice in accordance with the working conditions. The required traction, flotation and tire life are achieved by choosing the right size, tread pattern and air pressure in the tires. The tires for mining trucks are subject to special requirements, since their operation is carried out in difficult road conditions. The performance and durability of tires is influenced by the average density and strength of the transported rocks, the correct loading of the dump truck and the uniformity of the rock mass, the condition and type of road surface, the road profile, and the level of organization of the current maintenance of roads. Tires must be properly used and maintained to achieve maximum performance. Working under severe conditions leads to an increase in temperature in the tires. As the operating temperature of the tire increases, the strength of the rubber and carcass decreases significantly. Problems arise when tires operate at temperatures above design, when the likelihood of delamination, and then failure, is very high.

Thus, the purpose of the paper is to increase the durability or, in the terminology of the operators, the "mileage" of off-road large-sized tires for mining dump trucks. This topic is a continuation of the work by the authors aimed at improving the efficiency of the use of dump trucks in open pit mines [6].

The data shows that the achievable tire life for a mining dump truck is notably higher than the recorded tire life. This is due to abnormal wear of tires or tires that fail prematurely. In 2014 it was determined that 41 % of all tires failed prematurely [7]. The factors affecting tire life include [8]:

- road conditions (curves, grades, super elevation, haul length, road surface, and maintenance);
- operating conditions (average speed, speed in curves);
- truck conditions (weight distribution, struts, air pressure in tires, tire matching, tread depth, and tire type);
- weather (temperature and precipitation).

Table 1 shows typical values for tire life reduction caused by inflation pressure and various road conditions. Tire inflation pressure should be monitored regularly because it can significantly affect tire life. Traveling at a speed that is compatible with the curve radius and superelevation can minimize tire damage occurring on curves.

Southeast Asia covers about 90 % of the world's natural rubber production. Tire manufacturers purchase about 70% of the total production. Overall demand for natural rubber since 2000 has increased by around 30 % worldwide. Rubber production has expanded to Africa in the past 20 years. The total global area utilized for rubber production has increased by more than 35 % (about 13 million hectares) [9]. The territory of Spain is 13.7 million hectares for reference. Growing natural rubber production contributes to the deforestation process, unfortunately. Deforestation fronts will account for over 80 % of the forest loss projected globally by 2030, i. e. up to 170 million ha [10].

More than 20 million tons of tires are scrapped worldwide. Unfortunately, more than 30 % of OTR from mining dump trucks are scrapped before the target life.

Mismanagement of off-the-road tire operation may cause serious safety accidents such as tire explosions. It happens when a mixture of volatile gases inside tire auto-ignites – generally at a pressure exceeding 1000 psi. Tire explosion may cause serious damage to equipment and the health of the operator [11].

Table 1

Factors affecting average tire life (TLR = tire life reduction)

Inflation Pressure	TLR, %	Road Conditions	TLR, %
Recommended pressure	0	Average soil, no rock	0
10 % under	–10	Average soil, scattered rock	–10
20 % under	–25	Well maintained with smooth gravel	–10
30 % under	–70	Poorly maintained with ungraded gravel	–30 or more
20 % over	–10	Scattered blast rock	–40or more
Curves	TLR, %	Grades	TLR, %
None	0	None	0
Smooth	–10	< 6 %	–10
Sharp	–20 or more	< 15 %	–30

Literature review. Many authors have written about the importance of correct design, construction, and maintenance of transport roads for extending tire life and overall cost of transportation.

A critical investigation into tire life on an iron ore haulage system [7].

Guidelines for mine haul road design [8] describe many aspects of mine haul road management.

An alternative source of natural rubber can be Taraxacum kok-saghyz plant, which is widely growing in Central Asia. The roots of these plants may contend up to 5.3 % of natural rubber [12].

Prediction of rubber tire life is an important part of the researcher's studies. Artificial neural network approaches can be used to predict the fatigue properties of natural rubber composites. The average prediction accuracy of the established artificial neural network was 97.3 % [13].

On-highway trucks are widely used on mine sites for support operations such as fuel trucks, explosive delivery and charging, tire handling, heavy-duty service trucks, and various material delivery. Practice shows that 80 % of tire damage on on-highway trucks is not repairable [14].

Modeling various scenarios of haul road design as part of mine design is quite important. These studies were published in Numerical modeling of transport roads in open pit mines [15], Application of advanced data analytics to improve haul trucks energy efficiency in surface mines [16], Optimum ramp design in open pit mines [17]. Fuel consumption is one of the highest parts of transportation costs. Optimization of fuel efficiency is shown in publications: Effective power and speed of mining dump trucks in fuel economy mode [18]. A discrete-event model to simulate the effect of truck bunching due to payload variance on cycle time, hauled mine materials and fuel consumption [19].

Research methods. The Ekibastuz coal deposit was discovered in 1867 and is located near the city of Ekibastuz in Pavlodar oblast of the Republic of Kazakhstan. Bogatyr Komir is one of the biggest coal mines in the world. In 1913, mining concession was granted to Kirgizian Mining Joint Stock Company of Leslie Urquhart (UK) and Gerbert Guver (USA) former president. In 1918, the Soviet power was established. As of 2021, the company produced 50 million metric tons of coal, which is about 40 % of Kazakhstan's coal production. Since its discovery, it has mined approximately 1 gigaton of coal and it has additional 2.5 gigatons of coal reserves. Bogatyr Komir operates two mines: Bogatyr Mine and Severny Mine. Internal waste dumping has been taking place over last 7 years. Bogatyr Komir mines have over 500 km of haul roads.

It is important to carry out site research to identify the impact of current mine operations regarding a tire consumption. The study conducted in 2021 at the Bogatyr Komir coal mine in Kazakhstan is represented in this paper. The mine is located in northeast Kazakhstan near Ekibastuz town in Pavlodar oblast and operates BelAZ 75131 dump trucks for transportation. Dump trucks are equipped with 33.00R51 OTR and have 130 tons of nominal payload.

In order to make site assessments for tire life, we use "Racelodgic V-box Micro" equipment.

The applied equipment is a measuring and fixing device based on the use of GPS navigation. Normal measurement accuracy is – 10 Hz (10 times per second). The device allows determining the following parameters with high accuracy:

- vehicle speed;
- time;
- distance traveled;
- altitude relative to sea level;
- trajectory of movement;
- acceleration/deceleration longitudinal and transverse;
- radius of turns and speed of their passage;

- calculation of the TKPH indicator for each trip.

The received data is recorded on a memory card, for further decryption, the original Racelodgic V-box Tools software is used.

The TKPH formula calculates the average speed the tire can run within a safe temperature range and within an appropriate truck payload

$$TKPH = \frac{(Ql + Qe)}{2} \cdot \frac{(N \cdot L)}{H}, \qquad (1)$$

where Ql is load per tire on the loaded vehicle; Qe is load per tire on the empty vehicle; N is the number of cycles per working day; L is the length per cycle in kilometers; H is the number of operating hours per day.

In mining applications, we must consider weather conditions and load distribution.

Here are the results of the measures taken on-site. The route of the movement of dump trucks at the Bogatyr coal mine is shown in Fig. 1. The V-box complex is installed on the BelAZ-75131 with fleet number 159. The route of movement in the mine: from the EKG Excavator to the internal waste dump. The date of the measurement is 05/17/2021, the start time is 13 : 10, and the end time is 12 : 10, for this period the BelAZ-75131 dump truck made 3 trips, of which 2 were complete programs suitable for recognition in the calculation of the TKPH indicator. The total distance covered is 24,156 meters. The results are shown in Table 2.

Based on the data obtained, the V-box Test Suite program calculated the TKPH index for tires of the front and rear axles, which was carried out taking into account a load of 136 tons and with a temperature in the summer $t = +35$ °C in the daytime (Fig. 2). According to the data of the Hydro-meteorological Center of the Republic of Kazakhstan in the area of Ekibastuz, in June-July 2020, the maximum temperature during the day was $t = +34$ °C, and the maximum temperature at night was $t = +27$ °C.

According to the data obtained for all 3 trips, the value of the average operating speed was up to 22.54 km/h; loaded up to 23.79 km/h; empty at 22.0 km/h. The peak speed of the empty truck reached 36 km/h and the loaded truck up to 35 km/h (Fig. 3).

Analyses of data collected. Analysis of the obtained data on the longitudinal slopes of technological roads showed that

Table 2

For each trip, the distance travelled, the time elapsed, the TKPH indicator for dump truck BelAZ-75131 No. 159

Run	1	2	Avg.	Max	Min
Time	22m52s	21m44s	22m18s	22m52s	21m44s
Loaded	09m53s	10m03s	09m58s	10m03s	09m53s
Empty	12m59s	11m41s	12m20s	12m59s	11m41s
Distance (m)	7197.71	6715.18	6956.45	7197.71	6715.18
Loaded (m)	3625.22	3594.58	3609.90	3625.22	3594.58
Empty (m)	3572.49	3120.61	3346.55	3572.49	3120.61
Avg. speed (km/h)	22.54	22.35	22.45	22.54	22.35
Loaded (km/h)	23.79	22.67	23.23	23.79	22.67
Empty (km/h)	21.43	22.00	21.71	22.00	21.43
Cycle TKPH Front	748	747	747	748	747
Cycle TKPH Rear	576	580	578	580	576

90 % of the route with a loaded dump truck from the point of loading to unloading is carried out uphill and does not exceed 8 %. Table 3 shows the dependence of tire mileage as a percentage of road slopes. For example, when driving a dump truck loaded uphill with slopes up to 8 %, the tire mileage will be 100 %, then when driving downhill and with a load, the tire mileage will be up to 61 %.

The *TKPH* calculation showed for the tire 33.00R51 AG01A $TKPH = 620$ with a reserve of values for the rear axle, and for the front axle, it exceeds the allowable value. Therefore, in the pressure recommendation for the front axle, it is necessary to provide tire pressure 1 bar higher than the standard value, thereby reducing the likelihood of a critical tire temperature.

The tire life coefficient can be estimated by formula

$$Y = X1 \cdot 1 + X2 \cdot 0.81 + X3 \cdot 0.64, \qquad (2)$$

where $X1$ is the length of haul road with less than 8 % decline (0.732 km); 1 is the coefficient of normal tire wear; $X2$ is the length of haul road with 8–10 % decline (0.2 km); 0.81 is the coefficient of tire life reduction; $X3$ is the length of haul road with 10–12 % decline (0.063 km); 0.64 is the coefficient of tire life reduction; Y is the tire life coefficient

$$0.732 \cdot 1 + 0.2 \cdot 0.81 + 0.063 \cdot 0.64 = 0.934.$$

Thus, lost tire life coefficient on studied haul road is $Y = 0.934$ or 6.6 % of tire life increase opportunity.

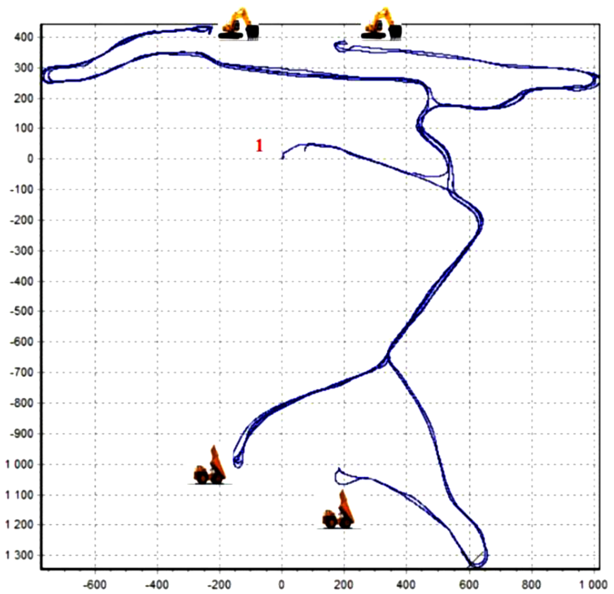

Fig. 1. The route of the movement of dump trucks at the Bogatyr coal mine:

1 — V-box installation point

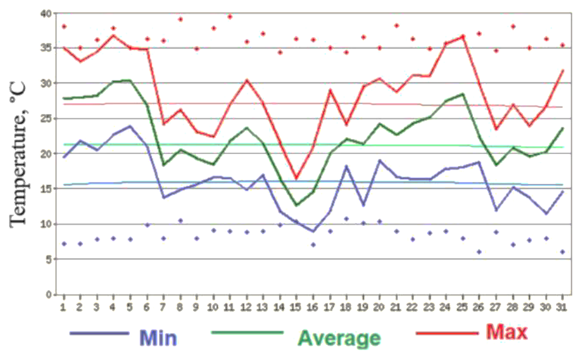

Fig. 2. July 2021 temperature data as per Ekibastuz meteo station

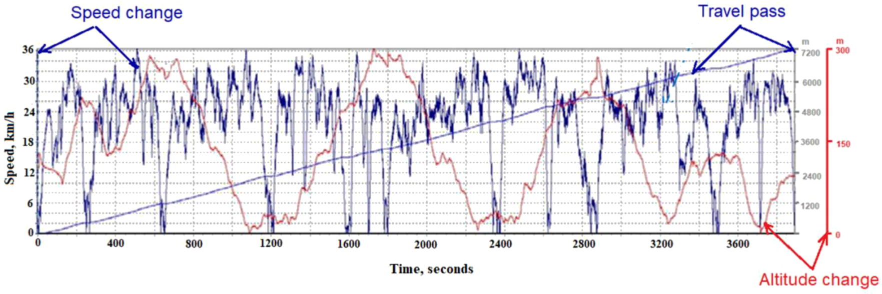

Fig. 3. Speed records of dump trucks for each trip. Speed chart

Table 3

Dependence of tire life as a percentage of road slopes

Decline slope, %	Loaded cycle uphill, %	Loaded cycle downhill, %
8	100	61
10	81	44
12	64	32

Conclusions and recommendations. Temperature peaks over 38 °C during summer can result in heat peeling of the tread due to exceeding the TKPH of the tire. Max speed in the loaded state recorded is up to 36 km/h and for an empty dump truck more than 35 km/h. We recommend limiting the movement of loaded dump trucks to 30 km during this period. The limitation will not allow the tire temperature to reach a critical value, which will eliminate exceeding the TKPH of the tires and will reduce the wear rate in the hot season. So, monitor the recommended pressure in the tires of the front axle.

The speed of passing on turns with a minimum radius of curvature, in order to exclude the impact of critical lateral forces on the tires, is necessary to arrange a counter slope, which is presented in Table 4. Without a counter-slope, the passing speed should be lower.

Slopes up to 8 % are the most optimal compromise between speed, production, and tire life.

Along the route loaded up-hill due to redistribution of load on axles more incentive tire wear takes place:

Table 4

Relationship between radius, speed and banking for zero lateral force

Radius (m)	Speed, km/h									
	15	20	25	30	35	40	45	50	55	65
	Banking, %									
50	3.5	6	10	–	–	–	–	–	–	–
60	3	5	8	12	–	–	–	–	–	–
70	2.5	4.5	7	10	–	–	–	–	–	–
80	2	4	6	9	12	–	–	–	–	–
90	2	3.5	5.5	8	10.5	–	–	–	–	–
100	1.5	3	5	7	9.5	–	–	–	–	–
125	–	2.5	3.5	5.5	7.5	10	–	–	–	–
150	–	2	3	5	6.5	8.5	10.5	–	–	–
175	–	–	2.5	4	5.5	7	9	11	–	–
200	–	–	–	3.5	5	6	8	10	12	–
250	–	–	–	–	4	5	7	8	10	–
300	–	–	–	–	3	4	5	6	8	10

8–10 % slope reduces tire life by 19 %;
10–12 % slope reduces tire life by 36 %;
12 %+ slopes are not recommended from a tire life extension point of view.

The average weight of 33.00R51 tire is 2.2 tons and consists of around 10 % of natural rubber.

Proper haul road design and condition monitoring can reduce the consumption of tires in mining operations thus contributing to reducing the cost of mining and the environment.

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Вплив стану технологічних доріг на ходимість шин кар'єрних самоскидів

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Мета. Позашляхові великогабаритні шини (ВГШ) для гірничодобувної промисловості й землерийних робіт, спеціально розроблені для екстремальних умов гірничих робіт, можуть становити 10–20 % транспортних витрат. До 15 % вмісту ВГШ посідає натуральний каучук, отриманий із каучукового дерева, відомого як гевея бразильська. Значна кількість ВГШ виходить з ладу, не досягнувши ресурсу закладеного виробниками ВГШ. Це впливає на довкілля й дику природу через ефект вирубки натуральних лісів. Таким чином, метою роботи є підвищення довговічності або, із термінології експлуатаційників, – «ходимості» ВГШ.

Методика. Дане дослідження є аналізом нової сучасної цифрової технології моніторингу стану технологічних доріг у рамках вивчення вугільного розрізу «Богатир Комір» у Північному Казахстані. Контролювався вплив умов експлуатації, а саме якості доріг, температурного режиму, тиску у шинах та інших параметрів на ресурс шин.

Результати. Результати показують ефективність цифрових технологій і можливість продовження терміну служби шин за рахунок своєчасного дотримання рекомендацій системи. У результаті аналізу температурних режимів і тиску в шинах, особливо в літніх умовах, визначені рекомендації для раціональних умов експлуатації, що дозволяє збільшити довговічність ВГШ.

Наукова новизна. Сучасна оперативна цифрова методологія моніторингу стану доріг кар'єрів визначає показник тонно-кілометрів на годину за кожен рейс, що забезпечує своєчасну інформацію для проектування та обслуговування доріг.

Практична значимість. Попит, що росте в усьому світі, стимулює розвиток гірничодобувної промисловості. У майбутньому в експлуатацію буде вводитися все більше і більше родовищ із низьким вмістом сировини, що видобувається. Розробка родовищ із низьким вмістом корисного продукту означає необхідність переміщати більше гірничої маси, щоб ці розробки були прибутковими. Транспортні витрати в розробках із низьким вмістом корисного продукту можуть досягати 70 % витрат на видобуток через більшу кількість кар›єрних самоскидів і збільшення довжини доріг, що необхідно ввести в експлуатацію. Таким чином, підвищення довговічності ВГШ може дати великий економічний ефект не тільки в умовах кар'єру «Богатир Комір», що розглядається, але й інших гірничо-збагачувальних комбінатів.

Ключові слова: *кар'єрні технологічні дороги, ресурс шин, кар'єрний самоскид, натуральний каучук*

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