Determining the weight of factors affecting the TKPH of large-sized tires

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Abstract. Proper operation, timely inspection and regular maintenance can extend the service life of tires and reduce the cost of their replacement. When calculating the actual TKPH of tires, all global tire manufacturers and specialists at mining and metallurgical plants use a single formula. This formula takes into account only the average load on the tire, the average speed of the vehicle, the ambient temperature and the transportation distance. It does not take into account other factors, such as: the longitudinal slope of the route, the tire pressure, the road conditions, the type and composition of the tire rubber, the technical condition of the vehicle, the correct placement of the load on the body, the residual tread depth of the tires, etc. To create competitive tire designs, a comprehensive method for calculating the strength and thermal parameters, the development of new design methods and new experimental methods will be needed. This article presents an analysis of all the factors affecting the actual TKPH in quarry conditions, and based on the experimental results, the degree of significance of the influence of each factor on the TKPH of tires is determined.

1 Introduction

Large-size tires are written off by tire engineers together with the manufacturer's representatives based on technical inspection and diagnostics. The main reasons for writing off large-size tires are tread wear, frame damage, overheating, fatigue cracks and other defects [1]. The main cause of cracks in tires used in the mining industry is the impact of hard rock (abrasive) formation. It can be assumed that each surface of the tire material contains microcracks of a certain size, which can be formed under the influence of load during the working cycle [2].

Large tire companies worldwide manufacture standard, heat-resistant, and cut-resistant models of large-size and super-large-size tires for industrial vehicles for various climatic and operating conditions. Priority in this area is given to research aimed at the efficient use of resources through the correct selection of tires, taking into account the quarry operating conditions [3]. Of particular importance are studies on improving the method for calculating the actual TKPH of tires for heavy-duty quarry dump trucks, taking into account constant changes in quarry routes, the average longitudinal slope of routes and road surfaces, rock

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strength, tire load, ambient temperature, and average operating speed of the dump truck by determining the correction factors for the TKPH of tires [4].

Operation of motor transport in deep quarries has the following significant features, which ultimately determine its efficiency [5]: continuous, two-shift operation of heavy-duty quarry dump trucks; complex profile of technological roads (the average longitudinal slope of the transportation distance reaches up to 8%, long turns, the presence of serpentines, etc.); the predominant direction of movement with a load on the rise; constant deterioration of operating conditions, the quarry depth increases from 20 to 50 m per year, an increase in the strength of the mined rock as the quarry deepens; sharply continental climatic conditions, manifested in sharp amplitudes of day and night, summer and winter temperatures, arid nature, an insignificant amount of precipitation, low relative humidity. The length of the day in summer is approximately 15 hours, the air temperature is up to +500C, in winter – approximately 9 hours and the temperature is up to -250C [6 - 8].

Large-size and super-large-size tires of quarry dump trucks belong to the class of off-road tires, distinguished by special properties: multi-layer, heavy weight, specific deformation and destruction, specific types of failures. These features of large-size tires (LST) with increasing speed of vehicles, as well as operating conditions high temperatures in summer, difficult terrain, heavy loads, etc. determined a conceptual approach to them in scientific, technological and experimental directions [9].

The resource of LST in quarry conditions is affected by various factors that can be divided into the following 3 groups [10]:

- mining and geological/geographical - type of soil; climate; weather temperature; amount of precipitation; humidity; rock hardness; local relief; condition of face and waste roads; length of transportation distance; number of turns; longitudinal and transverse slopes of routes;
- operational – overall dimensions of the vehicle; axle load; average and maximum speed; tire size; different axle weight distributions; different drive types; tire position: axle, driving, steered, dual; cornering speed; vehicle loading; tire load; work location: overburden or ore;
- technological – technical condition of the dump truck; transmission type; internal tire pressure; tread pattern; tire type and model; tread rubber composition (heat-resistant, wear-resistant and standard); tire design; tire mounting and dismounting, basic tire TKPH indicator.

An ambient temperature of 38°C is considered optimal for the operation of large-size tires for the following several reasons related to their performance characteristics and thermal balance [8, 9].

- Balance between tire cooling and heating. Tyres heat up due to deformation during movement (hysteresis) – energy is converted into heat, due to friction with the road – the higher the load, the more heat is generated, and as a result of speed – fast driving increases heating.
- Tires are cooled by contact with air - cold air cools the tire faster and due to the thermal conductivity of the rubber - internal air circulation occurs in the tire. At an ambient temperature of 38°C, the balance between heating and cooling remains optimal, reducing the risk of overheating, but not making the rubber too hard [8, 10].
- Testing by manufacturers of most tires for quarry equipment by testing in conditions of 30 – 40°C, since in quarries of Central Asia, Africa, South America and Australia the average summer temperature is 35 – 50°C. At temperatures above 45°C, heat transfer slows down, which increases the risk of destruction of the tire carcass.
- The effect of temperature on the rubber compound. At temperatures below 25°C, the rubber becomes harder, reducing grip, but reducing heating. At temperatures

above 40°C, the rubber begins to lose elasticity and wear accelerates. The value of 38°C is the point at which optimum rubber flexibility, normal heat exchange without overheating and minimal risk of thermal fatigue are observed.

When the ambient temperature is below 38°C, the tires cool quickly, which leads to uneven wear and the risk of cracks, the tires become harder, but overheat less. And when the temperature is above 38°C, then the tires are not cooled enough and cause overheating and destruction of the tires. Therefore, an ambient temperature of 38°C is the golden mean for the optimal temperature regime of large-size tires. At 30 – 40°C, the tires operate stably, without overheating and excessive cooling. Sensors are used to monitor the temperature in the tire and do not allow overheating above 110°C. It is necessary to maintain the correct pressure, since underinflated tires heat up and deteriorate faster. It is important to observe the speed limit, since an average operating speed above 20 km/h causes a risk of overheating and rupture of the tire. Compliance with the loads eliminates the possibility of overloading the dump truck, and a resulting decrease in the TKPH of the tires [4, 9].

Currently, Navoi MMC has more than 4,000 vehicles, including more than 470 technological vehicles. In 2024, the plant used more than 19,000 vehicle tires worth about 1.4 trillion soums.

As of January 2025, the fleet of Navoi MMC quarry dump trucks of various modifications and carrying capacity amounted to 477 units, the total carrying capacity of the fleet is 56,275 tons, the average carrying capacity of the fleet is 119 tons, the average age of the fleet is 5.5 years. These quarry dump trucks use tires manufactured by such large tire companies as BRIDGESTONE, GOODYEAR, LUAN, MICHELIN, TECHKING, ADVANCE, AEOLUS, MAXAM, BELSHINA and NOBLE.

2 Analysis of factors affecting tkph of tyres

TKPH is a key indicator that determines the resistance of quarry tires to heating under load. It depends on many factors, which can be conditionally divided into external conditions and operating parameters [10].

The main factors affecting TKPH of large-size tires:

- The average load on the tire is the main cause of tire wear: the higher the load, the more heat is generated and TKPH decreases. Incorrect distribution of the load can overload individual tires and accelerate their wear.
- High speed of the dump truck increases the temperature of the tires and increases the risk of overheating. Manufacturers indicate the maximum speed for each tire so as not to exceed its TKPH.
- The longitudinal slope of the road ($6 \leq \alpha \leq 10\%$) reduces the TKPH of the tires, as it increases rolling resistance and reduces the speed of the vehicle, and also requires increased engine power and increases the load on the tires.
- The ambient temperature, hot climate increase the temperature of the tires, and this reduces the TKPH. Cold or cool operating conditions increase the service life of the tires: the possibility of overheating the tires is minimal.
- The service life of the tires depends on the length of the route: on long routes, the tires do not have time to cool down, which reduces the TKPH. Breaks in operation help maintain the optimum temperature.
- The condition of the road, for example, a flat surface minimizes the heating of the tires, which leads to a high TKPH. On a dirt or rocky road, there is more friction and impacts on the tires, and this reduces the TKPH.
- Reducing the tire pressure increases friction and heating of the tire, deformation of its sidewalls and the temperature inside it, which leads to accelerated wear and, as

a result, to a decrease in the TKPH. Increased tire pressure reduces the contact patch, contributes to a hard ride, increases the risk of punctures and uneven tread wear. Optimum pressure provides maximum TKPH, uniform tread wear and normal tire temperature conditions.

- A deviation in tire pressure by 5 – 10% can reduce TKPH by 3 – 7%, especially in difficult conditions (deep quarries). In this regard, regular pressure monitoring is a key factor in extending the life of tires and maintaining their TKPH at the maximum level [9].
- The type and composition of rubber, soft mixtures provide better grip, but heat up more, and hard mixtures are more resistant to overheating, but can be destroyed more quickly upon impact.
- The heat transfer coefficient of a tire depends on its design (e.g. valve holes, heat-dissipating elements). Some tires have improved thermal regulation, which increases their TKPH.
- The technical condition of dump trucks that meets the accepted standards, serviceable suspension and shock absorbers reduce the force of impacts on tires, and malfunctions (axle misalignment, worn tire) can overload individual wheels and reduce TKPH.

As more accurate methods than the analysis of the weight of factors, regression or correlation analysis methods are used, based on operating data and the use of expert assessments of plant engineers, tire manufacturers and dump truck drivers, as well as methods for analyzing tire failure statistics (mechanical damage, carcass rupture, delamination, cuts, punctures with damage to the carcass cord layers, fracture or delamination of the carcass, thermal destruction of the tire, uneven or complete wear of the tread, etc.).

Taking these factors into account, the formula for calculating the actual TKPH of tires during operation can be expressed as follows:

$$TKPH_f = \frac{Q_c+Q_v}{2} \cdot V_{\text{cp}} \cdot K_1 \cdot K_2 \cdot K_3 \cdot \ldots \cdot K_n \quad (1)$$

where Q_c is the tire load for a loaded vehicle, t; Q_v is the tire load for an empty vehicle, t; V_{cp} is the average operating speed, km/h; K_1 is the correction factor taking into account the transportation distance (each tire manufacturer has its own coefficients); K_2 is the correction factor taking into account the ambient temperature (each tire manufacturer has its own coefficients); $K_3 \ldots K_n$ are the correction factors taking into account other factors affecting the TKPH of tires.

In formula (1), the TKPH correction factors are multiplied because each of them modifies the base value independently, but their effects are summed up in the final result. Each factor is responsible for a certain aspect of operation, for example:

- temperature affects the rate of heating of tires. At high temperatures, heating from the slope becomes even stronger;
- the length of the route affects the duration of the thermal load. With a long route and heat, the overheating effect increases;
- the longitudinal slope changes the load on the tires and, accordingly, their heating, etc.

These factors are independent of each other, but they affect the same parameters - heating and wear of tires. Multiplying the factors better reflects the real complex effect of operating conditions on TKPH, and this serves as a standard approach in engineering and economic calculations when independent factors affect one result.

3 Experiment

Experimental studies were conducted at the Muruntau quarry, which belongs to the Navoi Mining and Metallurgical Company. First, the quarry operating conditions were studied and the following was established:

1. Quarry depth – 700 m, on average – 400 m.
2. Brands and models of dump trucks: CAT-793D (cargo capacity 218 t, 38 units), CAT-789C, D (181 t, 11 units), Komatsu 860E (254 t, 10 units), Komatsu 830E-1AC (220 t, 11 units), BelAZ-7513 (130 t, 30 units), BelAZ-75307 (220 t, 6 units) and BelAZ-75310 (220 t, 46 units).
3. The road surface of technological roads is laid based on the rock of a specific quarry: solid rock is laid, the rock strength according to the M. Protodyakonov scale is about 9÷14.
4. Access roads to excavators and to the unloading site from the total transportation distance - approximately up to 20%.
5. Width of technological roads, according to the quarry passport, m: maximum - 22 ÷ 26 m, average - 19 m.
6. Assessment of longitudinal slopes, %: maximum - 12, average - 5÷6.
7. Transportation shoulder (one way), m: maximum - up to 14 km; minimum - up to 1 km; average - 4.6÷5.8 km.
8. Type of transported rock, loosening coefficient, rock weight, kg/m3: overburden – hard rock with a density of 1.8 ÷ 2.3; ore – hard rock with a density of 2.3 ÷ 2.8.
9. Loading equipment (model, bucket capacity): EKG-15, bucket capacity – 15m³, EG-20, EG-25, bucket capacity – 20 and 25m³.
10. Ambient temperature: in winter – maximum -250C, average -0 ÷ -100C, in summer – maximum +500C, average +32 ÷ +400C.

The routes (234 in total) of heavy-duty quarry dump trucks (177 units) and the location of excavators (horizontally) at the quarry were studied and analyzed. The statistics of premature failure (Table 1) and the average mileage of large-size tires operated at Navoi Mining and Metallurgical Company in 2023 and 2024 were analyzed.

Table 1. Cause of tire failure and their number, in 2023 – 2024.

№	Size tire	Manufacturer	Reason for tire failure and their number			Total
			Separation of the tread, sidewalls, delamination of the cord	Accelerated (aggressive) tread wear	Mechanical damage (punctures, cuts, chipped lugs)	
1	50/80R57	BRIDGESTONE	14	1	3	18
2	46/90R57	GOODYEAR	9	2	2	13
3	46/90R57	LUAN	15	8	47	70
4	40.00R57	MICHELIN	164	8	31	203
5	46/90R57	TECHKING	148	93	230	471
6	37.00R57	MICHELIN	7	0	0	7
7	33.00R51	ADVANCE	6	0	1	7
8	33.00R51	AEOLUS	39	0	1	40
9	33.00R51	MAXAM	7	35	5	47

10	33.00R51	MICHELIN	80	6	5	91
11	33.00R51	NOBLE	2	1	0	3
12	33.00R51	TECHKING	12	0	3	15
13	27.00R49	ADVANCE	26	31	5	62
14	27.00R49	AEOLUS	2	6	1	9
15	27.00R49	GOODYEAR	1	0	3	4
16	27.00R49	MAXAM	1	0	0	1
17	27.00R49	MICHELIN	198	0	8	206
18	27.00R49	NOBLE	22	17	1	40
19	27.00R49	TECHKING	20	25	6	51
20	24.00R35	GOODYEAR	6	0	3	9
21	24.00R35	MAXAM	139	1	98	238
22	24.00R35	MICHELIN	75	0	0	75
23	24.00R35	TECHKING	22	0	4	26
24	45/65R45	MICHELIN	1	0	1	2
25	23.5R25	BRIDGESTONE	0	8	0	8
Total			1016	242	458	1716

Calculation of the weight of factors influencing the TKPH of tires using expert assessments. The use of expert assessments allows taking into account the experience of specialists (tire engineers, tire manufacturing experts, dump truck drivers) and quantitatively determining the influence of each factor on the TKPH. We have developed a methodology for assessing the weight of factors influencing the TKPH.

The study used the expert assessment method, including:

1) questionnaires from specialists to obtain subjective assessments of factors;
2) the method of paired comparisons to rank the importance of factors;
3) the method of weighted coefficients to convert assessments into numerical values.

The calculation of the weight of the factors was carried out in the following order:

Step 1: Identification of factors for evaluation. We interview experts and select the above 11 factors (tire load, average operating speed, ambient temperature, route length, longitudinal slope of routes, internal tire pressure, road condition, tread rubber composition, tire heat transfer coefficient, technical condition of the dump truck and tread depth) that affect the TKPH of tires.

Step 2: Conducting a survey of experts. We select a group of 10 experts, for example: tire engineers and technical personnel of tire manufacturers (Table 2).

Table 2. List of experts.

№	Brand name	Dealer company name	Full name of the representative
1	MICHELIN	Michelin Kazakhstan LLP	Irismetov Izzatbek – supplier representative, technical expert
2	BRIDGESTONE	Marubeni Corp.	Mikhailenko Maksim – technical expert
3	GOODYEAR	Loaadi Otr Auto and Components Trading – FZCO	Berdikulov Laziz – technical expert.
4	TECHKING	Techking Tires Limited	Mamatov Zhurabek – technical expert

5	LUAN	HAIAN RUBBER GROUP CO	Alex Dong – technical expert
6	MAXAM	-	Zhokhanov Zhamshid – technical expert
7	AEOLUS, NOBLE, ADVANCE	Ventopro Pte., Ltd	Tyan Stanislav – technical expert
8	BELSHINA	HaulTrucks	Surodin Artem – supplier representative, technical expert
9	Tire Engineer	Automobile Transport Department Central Mining Administration	Tozhiyev Okhunjon Gulom ugli
10	Tire Engineer	Automobile Transport Department Northern Mining Administration	Safarov Orif Sunnatillaevich

Each expert was given a questionnaire where they assessed the influence of factors in the conditions of the Muruntau quarry on a scale (0÷10 points). The experts assessed how much each factor affected the TKPH of tires, where 0 is the minimum influence; 10 is the maximum influence. After that, all the experts' answers were collected and a generalized table was created (Table 3).

Table 3. Experts' assessment and results of the weighting of factors.

№	**Factors Affecting the TKPH of Tires**	**Experts and their assessments**										**Average score**	**Weight, %**
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**		
1	Tire load	3	5	5	4	6	3	5	3	5	4	4.3	7.45
2	Average travel speed	8	7	6	8	9	7	8	7	9	7	7.6	13.17
3	Ambient temperature	7	7	8	8	8	7	9	8	8	8	7.8	13.52
4	Route length	9	6	7	6	5	8	9	7	7	6	7	12.13
5	Road longitudinal slope	8	8	6	7	9	8	7	7	8	9	7.7	13.34
6	Tire pressure	6	6	7	5	5	5	6	6	4	4	5.4	9.36
7	Tire heat transfer coefficient	4	3	2	4	3	2	4	3	2	3	3	5.20
8	Tire rubber composition	3	3	4	3	5	4	4	3	3	5	3.7	6.41
9	Technical condition of the dump truck	5	6	5	4	3	4	6	5	3	4	4.5	7.80
10	Condition of utility roads	2	5	4	6	7	7	4	5	4	3	4.7	8.15
11	Tread depth	1	2	1	3	2	3	2	3	1	2	2	3.47

Step 3: Normalization of ratings (weighted coefficients). We convert the scores into a percentage ratio of the impact on the TKPH of the tires. To do this, we sum up all the average ratings.

$$S_{\text{cp}} = 4.3 + 7.6 + 7.8 + 7 + 7.7 + 5.4 + 3 + 3.7 + 4.5 + 4.7 + 2 = 57.7 \quad (2)$$

After this, we calculate the weight of each factor as a percentage (Table 3):

$$\theta_i = \frac{O_f}{S_{\text{cp}}} \cdot 100 \quad (3)$$

In order to study the significance of factors affecting the actual TKPH of dump truck tires operating in the Muruntau quarry, the following conclusions can be drawn based on expert opinions:

1. As a result of research conducted by many scientists, it was found that the most important factor is the tire load. However, in this experiment, the experts' opinions were different. The reason for this is that all dump trucks have a load control system: for example, the BelAZ-7513 dump trucks have a Load and Fuel Control system, the CAT-789 dump trucks have a VIMS system, and the Komatsu HD785-7 recorded the parameters of the pressure sensors on the vehicle's suspension cylinders (all 4 sensors) [8].
2. The most important factors - ambient temperature and route length - affect more than 25% of the TKPH of tires in Muruntau conditions. But each manufacturer has correction factors for their tires that take into account the ambient temperature and route length.
3. Average speed and longitudinal slope of the road affect over 26%. Vehicle speed is a controllable factor, i.e. on cool days you can drive at high speed, and on hot days - at low speed. The longitudinal slope of the routes is an uncontrollable factor, which also increases year after year, because today the quarry depth reaches 700 m (Figure 1).

Fig. 1. Changes in operating conditions at the Muruntau quarry of JSC Navoi MMC for 2023–2025.

Permanent and temporary technological roads in quarries are adapted to the requirements of passports (the longitudinal slope of permanent technological roads is reduced to 8%, and temporary roads to 10%, when moving downhill loaded dump trucks downhill, a longitudinal slope of up to -7% is ensured) quarry roads [10].

4. The internal pressure in the tire affects 9.36%, according to experts. This is also a controllable factor - currently all quarry dump trucks are equipped with TPMS devices (Figure 2). TPMS+ from PressurePro, PULSE provides users with the ability to view tire pressure and air temperature in the cabin online. It consists of sensors, antennas, a monitor in the cabin and a controller. It is possible to transmit a signal via 3G and 4G communication to notify the operator or technician remotely. The sensors are available in two types: external mounting (on the filling valve) and internal mounting.

Fig. 2. Tire Pressure and Temperature Monitoring System (TPMS)

5. It was established that the composition of tire rubber, the heat transfer coefficient of tires, the technical condition of the dump truck, the condition of the access roads and the tread height are less significant factors (3÷8%).

4 Conclusion

Optimization of the tire TKPH is as follows:

- tire load control (≤ maximum recommended) using pressure sensors on the vehicle suspension cylinders (all 4 sensors), the parameters of which recorded the weight of the load;
- limiting the speed of a loaded dump truck to 18 km/h on difficult routes, especially in summer;
- maintaining tire pressure in the optimal range (±5%) using a dynamic tire pressure equalization valve. This valve turns 2 paired wheels of a quarry dump truck into a communicating vessel with the same pressure in both tires. This promotes uniform distribution of the load on the wheel, regardless of the road surface relief, turning angle and other external factors, thereby increasing the mileage of the tires.
- the influence of the longitudinal slope on the redistribution of the load, resulting in accelerated tire wear. When designing roads in quarries, it should be taken into account that the optimal longitudinal slope reaches 8%. If technically possible, it is necessary to straighten the benches (uneven slope).

Expert assessments make it possible to quantitatively determine the influence of factors on the TKPH. This method allows systematizing the knowledge of specialists and taking into account many parameters that are difficult to measure experimentally.

The main factors affecting the TKPH of tires in the Muruntau quarry conditions: speed, ambient temperature, transportation distance and longitudinal slopes of routes (affect more than 52%).

The use of this method, in combination with statistical analysis of tire failures, will determine the weight of factors with even greater accuracy.

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