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REGULATION OF SPARE PARTS REQUIREMENTS FOR DUMP TRUCKS

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Abstract. As is well known, the mining industry serves as a raw material base for the development of major industrial sectors such as metallurgy, mechanical engineering, energy, chemical production, and construction materials. The repair of mining transport equipment is a key factor under harsh operating conditions such as impact loads, vibration, high humidity, dust, and temperature fluctuations, all of which reduce the efficiency of maintenance and repair operations.

Maintaining the operable condition of machinery requires strict adherence to the system of maintenance and repair (hereinafter – M&R). An important role in this process is played by the production and rational use of spare parts, which ensures the reliability of machines and the stable operation of enterprises. The regulation of spare parts consumption is a crucial factor in sustaining equipment performance under strict norms of spare parts use.

The aim of the study is to develop a method for optimizing spare parts requirements for dump trucks, taking into account the risk factor of shortage or surplus. The main research direction is the construction of a mathematical model that considers the cost structure of repairs and identifies the optimal risk value that minimizes financial losses.

Key words: mining industry, dump truck, spare parts, repair, risk factor, cost optimization, equipment downtime.

Introduction

The main indicator for spare parts consumption has always been the average service life until replacement of a component, assembly, unit, or aggregate. The system of scheduled preventive repairs (SPR), introduced in the 1930s, was based on the average service lives of machine elements, the replacement distribution of which determines the repair cycle structure. Maintaining machine operability is directly associated with the growth of repair work volumes, while simultaneously reducing the consumption of spare parts for operational needs. Moreover, due to the increasing deployment of heavy equipment in the mining industry, accelerated depreciation standards are widely applied, and worn-out machines are written off, which leads to a reduction in spare parts demand. Nevertheless, expenditures for spare parts continue to grow annually, while shortages of fast-wearing and basic components persist [2]. Downtime of mining equipment due to the lack of spare parts reaches 16 % of all unplanned downtime.

Methodology

The research methodology is based on the analysis of the scheduled preventive repair system and the application of probabilistic distribution tools (Newton binomial, Poisson formula, local Laplace theorem). The model accounts for fixed and variable costs, additional expenses for delivery and storage of parts, as well as lost profits caused by downtime. The results demonstrated that the proposed method makes it possible to determine the optimal level of risk at which total repair costs for dump trucks are minimized. It was concluded that the model contributes to more rational allocation of financial resources and reduces losses from spare part shortages or surpluses.

The contribution of the study is the development of an integrated approach to assessing and planning the spare parts requirements for dump trucks, which has high practical value for mining enterprises

Results and Discussion

The process of planning spare parts and their use must be carried out with particular care, since irrational allocation of financial resources and the accumulation of excessive inventory contribute to the inefficient use of materials in the production process. This also leads to a shortage of repair resources and, consequently, to company losses caused by dump truck downtime due to the absence of spare parts.

Based on the principle of minimizing costs, the availability of spare parts can be calculated under given conditions by determining the minimum repair expenses at the optimal risk value.

The introduced parameter kp shows that the lower the expenditures on maintenance, procurement, and delivery of spare parts, the lower the costs from surplus spare parts will be. At the same time, the company’s costs associated with additional downtime of dump trucks during repair will increase.

By introducing the parameter kp, it is possible to trace the dynamics of company costs resulting from dump truck downtime due to the absence of spare parts in stock. To determine the minimum repair costs of a dump truck related to the replacement of a specific unit, it is necessary to define the optimal risk value.

The total costs Cp of a mining enterprise associated with dump truck repair for unit replacement are determined as follows:

$$Cp = Sconst + Svar + Sadd + Pn, \quad (1)$$

where Sconst – conditionally fixed costs in repair;

Svar – conditionally variable costs in repair;

Sadd – additional expenses for spare parts related to ordering, delivery, and storage of missing components;

Pn – lost profit due to additional downtime of the dump truck during repair caused by the absence of spare parts.

When replacing a dump truck unit, the conditionally fixed expenses of the mining enterprise are determined as follows:

$$Sconst = m_{up.т}\ N\ Pvir\ hp, \quad (2)$$

where $m_{уп.т}$ – the share of conditionally fixed costs in the cost of transporting 1 ton of ore; N – the cost of 1 ton of ore; Pout – the output of the dump truck, t/h; hp – the downtime of the dump truck during the replacement of a unit (assembly), h.

$$Hp = hn+(h_з+h_{d.з}ch)\ mp, \quad (3)$$

where h_n – the standard time for unit replacement, h; $h_з$ – the time required to place an order for a missing spare part, h; $h_{st.del}$ – the storage and delivery time of spare parts, h.

When replacing a unit, the conditionally variable expenses are determined as follows:

$$C_{per} = (1\text{-}m_{up.p})\ F_{np}, \quad (4)$$

where (1 – mup.p) – the share of conditionally variable costs in the normative (estimated) cost of repair; Fnp – the normative (estimated) cost of major repair and replacement of a dump truck unit.

For the use of repair equipment and shop expenses, the total amount of labor costs for repair workers, normative expenditures for spare parts for current and major repairs of the unit are determined by the sum of labor costs of repair workers.

According to formula (5), we determine the additional expenses for spare parts arising from delivery, ordering, and storage of missing components at the time of repair.

$$C_{dop} = (T_{zch}+T_{d.zch})\ l_{и}\ l_p, \quad (5)$$

where T_{zch} – the price of spare parts for unit repair at the beginning of the planned period; $T_{d.zch}$ – customs duties and expenses for storage and delivery of parts for unit repair at the beginning of the planned period.

Lost profit is the profit from product sales that the enterprise expected to receive in the planned period but did not due to additional downtime of dump trucks.

Lost profit is determined by the following formula:

$$P_n = P_y\ Q_{vyr}, \quad (6)$$

where $P_н$ – the lost profit of the enterprise due to dump truck downtime during repair; Pu – the specific planned profit of the enterprise.

As we can see, depending on the number of tested units and the corresponding risk coefficient value np, the annual number of major overhauls of a unit $d_{кр.а}$ is determined at the risk coefficient of spare parts shortage np, based on the resource distribution law of the unit using the Newton binomial expansion, the local Laplace theorem, or the Poisson formula.

$$d_{кр.а} = h(np), \quad (7)$$

It should be noted that the execution of a major overhaul of a unit in the planned period depends on the quality of the previously performed repair.

A significant role is played by the provision of genuine spare parts, the conditions under which the repair is carried out, and the limitations of the repair facility in terms of selecting friction pairs.

According to the resource distribution law, the actual number of major overhauls of a unit during the planned period may fluctuate within certain limits, which may result in a surplus of units stored in the enterprise warehouse.

$$C_{din} = S1\ (1+np_n^{(\mu)}) \quad (8)$$

where Cdin – the dynamic turnover effect of costs lost due to a surplus of units resulting from a low risk of their shortage;

μ – the cost evaluation period, years, assumed to be 1.5–2 times longer than the average service life of standard objects;

m – the year within the evaluation period μ (m = 1, 2, 3, …, τ);

s1 – the costs of purchasing unused units stored in the enterprise warehouse during the planned period, thousand rubles;

n – the accumulation rate (the share of profit allocated for the reproduction of fixed assets); (t) – the year within the evaluation period μ (t = 1, 2, 3, …, τ);

$p_n^{(\mu)}$– the coefficient for additional turnover costs arising from investment in secondary (standard) objects, determined with sufficient accuracy by the following expression.

$$p_n^{(\mu)}(x+a)^n = 1 + N\bar{m}_n + nU^2\sum_{k=1}^{\bar{m}_1-\bar{m}c-\bar{m}осв} k + \frac{N}{\bar{m}_{сл}}\sum_{k=1}^{\bar{m}_1-\bar{m}c} k \;, \quad (9)$$

where Cdyn – the dynamic turnover effect of costs lost due to a surplus of units resulting from a low risk of their shortage; μ – the cost evaluation period, years, assumed to be 1.5–2 times longer than the average service life of standard objects; m – the year within the evaluation period μ (m = 1, 2, 3, …, τ); s1 – the costs of purchasing unused units stored in the enterprise warehouse during the planned period, thousand rubles; n – the accumulation rate (the share of profit allocated for the reproduction of fixed assets); (t) – the year within the evaluation period μ (t = 1, 2, 3, …, τ);

$p_n^{(\mu)}$ – the coefficient for additional turnover costs arising from investment in secondary (standard) objects, determined with sufficient accuracy by the following expression.

where N – the coefficient of capital investment efficiency; for second-stage facilities it is taken as approximately 0.08;

m̄_s = min{m̄₁; m̄₂} > 0 – the smaller of the two positive values m_1 and m_2, where

$\bar{m}_1 = \mu - m_{osv} - \bar{m}_s - \bar{m}_{osv} + 1$, and $\bar{m}_2 = \bar{m}_{sl} - \bar{m}_{osv}$.

Here:

- **mosv** – the period for achieving the design capacity (productivity) of first-stage equipment, years;
- **m̄c** – the construction (manufacturing) period of standard (subsequent-stage) facilities, years;
- **m̄osv** – the period for achieving the design capacity (productivity) of standard facilities (equipment of subsequent stages), years;
- **m̄sl** – the service life of standard facilities, years; **k = 1, 2, 3, …** – natural numbers.

At the same time, the turnover of costs is carried out in the following sequence. Further, depreciation charges allocated from profits for the replacement of equipment that has exhausted its service life, invested in the purchase of first-stage facilities, generate during their operation the first-stage costs for acquiring third-stage facilities. Preliminary calculations show that by the fourth or fifth turnover cycle, the amount of additional costs from the operation of second and subsequent-stage facilities becomes so small that it does not significantly affect the final result. Moreover, due to the cost assessment period, it is advisable to assume it to be no less than twice the maximum service life of a haul truck unit.

Formula (6), taking into account expression (8), shows:

$$\text{Cdyn}=\text{S1}\left[1+\gamma\begin{pmatrix}1 + N\bar{m}_n + nU^2\sum_{k=1}^{\bar{m}_1-\bar{m}c-\bar{m}осв} k + \\ + \frac{N}{\bar{m}_{сл}}\sum_{k=1}^{\bar{m}_1-\bar{m}c} k\end{pmatrix}\right], \quad (10)$$

In the planned period, the costs P1 for the acquisition of spare parts for the major overhaul of units that remain unused during the planned period can be determined as:

$$\text{S1} = [h_{kp.a}(\text{fp}) - h_{kp.a}(\text{fp}=0{,}5)]\ \text{S}np,$$

where $h_{kp.a}(\text{f}p)$ – the number of major overhauls of the unit per year at a risk coefficient fp; $h_{kp.a}$ (Кр = 0,5) – the number of major overhauls of the unit per year at a risk coefficient Кр = 0,5 i.e., determined based on its average service life; Cnp – the standard cost of spare parts for the major overhaul of the unit.

The total annual costs associated with haul truck downtime for unit replacement during repair can be expressed by substituting formulas (2)…(8) into expression (1) as follows:

Zsum = Zpost + Zper + Zdop + Pn + Az or

$$\text{Zsum} = \left\{ \begin{matrix} f_{up.t}\text{c}Q_{vyr} \times \\ \times \left[\!\left[\frac{m_n+}{(m_z+m_{d.zch})k_p}\right]\!\right] + \\ \\ +\left(1 - f_{up.p}\right)\text{c}_{np} + Э_z + \\ +(F_{zch} + F_{d.zch})\text{р}_{и}\text{р}_{\text{р}} + \\ +\text{X}_{\text{y}}Q_{vyr}\left[m_{n\,+(m_z+m_{d.zch})\text{P}_{\text{p}}}\right] \end{matrix} \right\} t_{kp.a} \qquad (11)$$

Next, we obtain expression (12). Consequently, the model for estimating the total annual costs of the enterprise associated with the repair of a haul truck through the replacement of a specific unit, and depending on the risk coefficient, takes the following form:

$$\text{Zsum} = \left\{ \begin{matrix} \left(f_{up.t}\text{c}Q_{vyr} + \text{X}_{\text{y}}Q_{vyr}\right) \times \\ \times \left[m_{n\,+(m_z+m_{d.zch})\text{P}_{\text{p}}}\right] + \\ +\left(1 - f_{up.\text{p}}\right)\text{c}_{np} + A_z + \\ +(F_{zch} + F_{d.zch})\text{p}_i\text{p}_{\text{p}} \end{matrix} \right\} t_{kp.a} \qquad (12)$$

Thus, this method can be applied to optimize the financial resources required for the acquisition of spare parts, which makes it possible to optimize the process and costs both from shortages and from surpluses of spare parts.

Results and Discussion

The conducted analysis showed that the share of downtime of dump trucks due to the lack of spare parts reaches 16 % of all unplanned downtime, which indicates the high importance of proper planning of maintenance and operational resources.

Calculations based on the proposed formulas (1) – (12) made it possible to highlight the following key patterns:

1. The total costs of the enterprise for dump truck repairs depend not only on conditionally fixed and variable expenses, but are also largely determined by additional costs for ordering, delivering, and storing spare parts, as well as by lost profits from downtime.
2. Optimization of the risk coefficient (kp) makes it possible to balance expenses: at too low a risk, surpluses of spare parts are formed, increasing storage costs; at too high a risk, downtime increases due to shortages.
3. The developed model has shown that the use of probabilistic methods (Newton's binomial theorem, Laplace's theorem, Poisson's formula) provides more accurate forecasting of the number of major overhauls of components and makes it possible to minimize the total costs of the enterprise.

4. As a result of modeling, it was established that applying this approach reduces annual costs associated with dump truck repairs by optimizing the stock structure and preventing both shortages and surpluses of spare parts.

Thus, the obtained results confirm that the proposed methodology is an effective tool for managing maintenance and operational processes in the mining industry.

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1. Zh.M. Kuanyshbayev – Processed the results, compared them with established findings, and summarized the outcomes.
2. D.V.Kapskii – The materials were provided.
3. A.A. Ibrayeva – Analyzed the data and performed computational work

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РЕГУЛИРОВАНИЕ ПОТРЕБНОСТИ В ЗАПАСНЫХ ЧАСТЯХ ДЛЯ АВТОСАМОСВАЛОВ

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Аннотация. Как известно, горнодобывающая промышленность служит сырьевой базой для развития таких крупных отраслей, как металлургия, машиностроение, энергетика, химическая промышленность и производство строительных материалов. Ремонт горнотранспортного оборудования является ключевым фактором в условиях жесткой эксплуатации, таких как ударные нагрузки, вибрация, высокая влажность, запылённость и колебания температуры, которые снижают эффективность технического обслуживания и ремонтных операций.

Поддержание работоспособного состояния техники требует строгого соблюдения системы технического обслуживания и ремонта (далее – ТОиР). Важную роль в этом процессе играет производство и рациональное использование запасных частей, что обеспечивает надёжность машин и стабильную работу предприятий. Нормирование расхода запасных частей является важнейшим фактором поддержания работоспособности техники в условиях строгих норм их использования.

Ключевые слова: горнодобывающая промышленность, автосамосвал, запасные части, ремонт, фактор риска, оптимизация затрат, простой оборудования.

АВТОСАМОСВАЛДАРҒА ҚОСАЛҚЫ БӨЛШЕКТЕРГЕ ҚАЖЕТТІЛІКТІ РЕТТЕУ

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Аңдатпа. Белгілі болғандай, тау-кен өнеркәсібі металлургия, машина жасау, энергетика, химия өнеркәсібі және құрылыс материалдары өндірісі сияқты ірі өнеркәсіп салаларының шикізат базасы болып табылады. Қатты пайдалану жағдайларында (соққы жүктемелері, діріл, жоғары ылғалдылық, шаңдану және температура ауытқулары) тау-кен көліктерін жөндеу техникалық қызмет көрсету мен жөндеу жұмыстарының тиімділігін төмендететін негізгі фактор болып саналады.

Техниканың жұмысқа қабілеттілігін сақтау үшін техникалық қызмет көрсету және жөндеу жүйесін (бұдан әрі – ТҚжЖ) қатаң сақтау қажет. Бұл үдерісте қосалқы бөлшектерді өндіру және ұтымды пайдалану маңызды рөл атқарады, ол машиналардың сенімділігін және кәсіпорындардың тұрақты жұмысын қамтамасыз етеді. Қосалқы бөлшектер шығынын нормалау – оларды қатаң нормаларда пайдалану жағдайында техниканың жұмысқа қабілеттілігін қолдаудың негізгі факторы болып табылады.

Түйін сөздер: тау-кен өнеркәсібі, автосамосвал, қосалқы бөлшектер, жөндеу, тәуекел факторы, шығындарды оңтайландыру, жабдықтың бос тұруы.