Mathematical model for the optimization of production base load of pit transport

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Abstract
The issue of optimization of technical service for repair and maintenance of pit transport by reducing downtime is investigated.

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Relevancy

In modern world of mining industry at high cost of fuels and lubricants and cost of machine hour, the question of costs reduction connected with repair and maintenance of open-pit transport is very important. There set a **goal** in research: to prepare mathematical model for the optimization of technical service on the base of mathematical statistics machinery, due to decrease of downtime and reduction of costs connected with the delivery of transport to the place of repair or maintenance.

Here we consider the structure of the production facilities based on queuing theory. It is equipped with a point of technical influences with the intensity ν (daily dump trucks per service point) of arrival dump trucks in zone of routine maintenance or current repair, the duration of service of cars (die dump trucks) exponentially distributed with parameters λ (number of dump trucks requiring maintenance per day).

Let us accept the following assumptions: 1) If at the time of dump truck goes to maintenance or repair at least one point is free, the service begins immediately, otherwise the dump truck is queued; 2) dump truck does not leave the queue until it wait for the start of the technical effects.

In the area of maintenance or repair are «*k*» dump trucks, the probability will be denoted:

$$P_0'(t) = -\lambda P_0(t) + \nu P_1(t)$$

$$P_k'(t) = -(\lambda + k\nu)P_k(t) + \lambda P_{k-1}(t) + (k+1)\nu P_{k+1}(t)$$

when $1 \le k \le n$

$$P_k'(t) = -(\lambda + n\nu)P_k(t) + \lambda P_{k-1}(t) + n\nu P_{k+1}(t)$$

when $k \ge n$ (1)

Equation (1) represents an infinite system, where "*previous*" values $P_k(t)$ depend on the "*next*" $P_{k+1}(t)$, so its solution presents considerable difficulties. Let us consider a stationary solution of the system (1.1), which can be obtained at steady state

$$(P_0'(t) \to 0, \quad P_k'(t) \to 0 \quad at \quad t \to \alpha)$$

If $\alpha = \dfrac{\lambda}{\nu} < n$, than the probability that the system is in E_k at steady state is given by the following formulas:

$$P_0 = \left[1 + \sum_{k=1}^{n-1} \frac{\alpha^k}{k!} + \frac{\alpha^n}{(n-1)!(n-\alpha)}\right]^{-1},$$

$$P_k = \frac{\alpha^k}{k!} P_0 \quad at \quad k < n,$$

$$P_k = \frac{\alpha^k}{n! n^{k-n}} P_0 at \quad k \ge n,$$

If $\alpha \ge n$, than the queue for service is increasing with time. Next we may suppose that the condition $\alpha < n$ is satisfied.

Here are some of the performance characteristics of the system with the expectation under the condition of steady state operation. All positions occupied with the technical influences and "*S*" dump trucks are in the queue is the probability P_{n+S} :

$$P_{n+S} = \frac{\alpha^{n+S}}{n! n^S} P_0 \quad at \quad S > 0,$$

$$q = \sum_{S=0}^{\infty} P_{n+S} = \sum_{S=0}^{\infty} \frac{\alpha^{n+S}}{n! n^S} P_0 = \frac{\alpha^n P_0}{n!} \sum_{S=0}^{\infty} (\frac{\alpha}{n})^S = \frac{\alpha^n P_0}{(n-1)!(n-\alpha)}$$

The average queue length:

$$M\Theta = \frac{\alpha^{n+1} P}{(n-1)!(n-\alpha)^2}$$

The average number of "*k*" dump trucks serviced in line will be:

$$K = \left[\sum_{k=1}^{n-1} \frac{\alpha^k}{(k-1)!} + \frac{\alpha^n n^2}{n!(n-2)} + \frac{\alpha^{n+1}}{(n-1)!(n-\alpha)^2}\right] P_0$$

The average number of free service points

$$N_0 = \sum_{k=0}^{n-1} \frac{n-k}{k!} \alpha^k P_0$$

Law distribution of waiting time for dump trucks service is given by the formula

$$P(\gamma > t) = q e^{-(n\nu - \lambda)t}$$

That is valid if $t > 0$.

If $t \le 0$ that $P(\gamma > t) = 1$.

The function $P(\gamma > t)$, thus has a point gap $t = 0$ equal to the probability of employment of all points.

Average waiting time $\overline{\omega} = \dfrac{q}{\nu(n-\alpha)}$.

Full mean residence time in the system is the sum of the values of the average waiting time of the technical influences and technical influences, that is:

$$\frac{q}{\nu(n-\alpha)} + \frac{1}{\nu} = \frac{q + (n-\alpha)}{\nu(n-\alpha)}$$

Dispersion of a random variable γ is calculated by the formula

$$D\gamma = M\gamma^2 - (M\gamma)^2 = \frac{q(2-q)}{\nu(n-\alpha)^2},$$

The average loss of time for waiting by dump trucks, got on the point of technical influences during the reporting time:

$$\overline{\omega}\lambda T = \frac{q\alpha T}{n-\alpha}.$$

If we consider the system from an economic point of view, it is necessary to calculate the cost per unit of time (days) of standby points and downtime of dump trucks. The equations for the options under consideration can be written:

$$R_1 = (C_1 M\Theta_1 + C_2 N_{01})24,$$

$$R_2 = (C_1 M\Theta_2 + C_2 N_{02})24,$$

$$R_n = (C_1 M\Theta_n + C_2 N_{0n})24,$$

where C_1 - cost per hour of fasting, UAH; C_2 – hourly rate of dump truck.

For example, according to data of Ternovka mining-transportation department of SevGOK, amount of dump trucks received for technical influences per day makes $\lambda = 18$ units, the number of points n = 9, the service rate of one point is $\nu = 2{,}66$ daily.

Let us consider two variants, under which production units are located close to the work area of dump trucks, in order to determine the optimal structure of the production base. In this case, the number of dump trucks arriving for technical influences by reducing travel time and waiting technical influences increases, as well as the intensity of the service point. Herein the control of technical condition of dump trucks will become permanent. For the second case: $\lambda = 19$ of dump trucks, $\nu = 3$; the third case: $\lambda = 20$, $\nu = 3{,}42$. Numerical results allowed drawing a dependency shown below.

The simulation results have given an analysis of production facilities, it serves for career transport (Fig. 1), we came to the conclusion that the increase in the number of dump trucks results in increase in the probability of downtime of dump trucks in the queue for service. To reduce the probability of downtime, it is necessary either to increase the intensity of service, which is conditioned by the usage of more expensive equipment on the points of maintenance and repair, or increase the time between failures for used utility vehicles or increase maintenance time of career transport. All this leads to the increase in the cost of the investment project quarry.

However, you can reduce the probability of downtime and more efficient use of post production base career by reducing travel time and waiting technical influences. Result of the simulation is presented in the figure below.

It is shown (Fig. 2) that the change in the location of the technical service allows you to increase the intensity of maintenance of mining equipment.

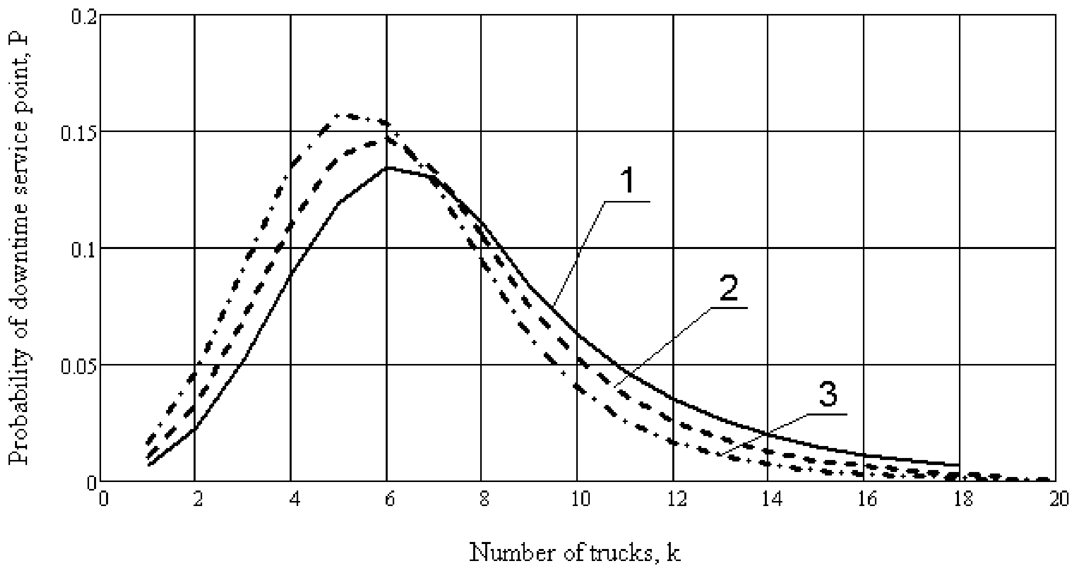

Figure 1. The probability of downtime of dump trucks depending on the open-cut transport park.
1 – $\lambda = 18$, $\nu = 3{,}42$; 2 – $\lambda = 19$, $\nu = 3$; 3 – $\lambda = 20$, $\nu = 3{,}42$.

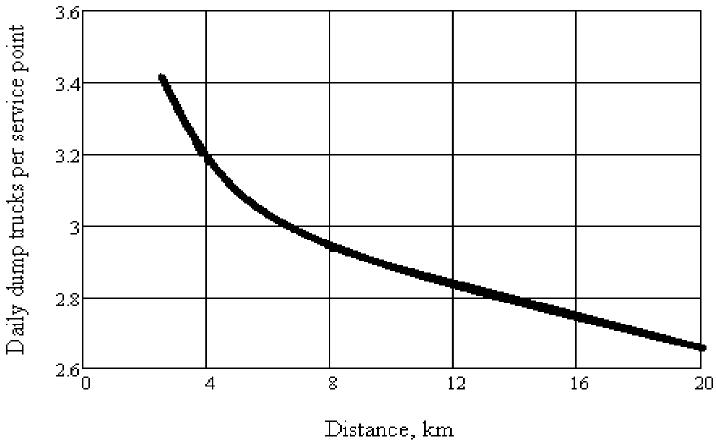

Figure 2. Service rate of dump trucks depending on the distance

The calculations showed that the average waiting time of technical influences is 3.5 times reduced, and the costs associated with the cost of work, reduced by 1.3 times, which reduces the number of points of technical service.

Conclusions

Analysis of the work of technical service, which performs maintenance and repair of dump trucks, showed that the rational use of technical services in the area of work or of dump trucks close to the work area of career transport.

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