Modeling of technological conditions and analysis of events of functioning BELAZ open pit trucks

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Abstract
The analysis of streams of the events formed by transitions between technological conditions on the basis of created mathematical model of functioning of BELAZ open pit trucks is made. The direction of increase of efficiency of operation of mining-transport cars with possibility of adaptation for the concrete enterprise for criterion of a minimum of expenses for possession is defined.
Key words: MATHEMATHICAL MODEL, OPEN PIT TRUCK, TECHNOLOGICAL CONDITIONS, MARKOV PROCESSES, STATE GRAPH, BELAZ

Introduction.

Positions of open way of development of minerals become stronger, the specific weight of open pit trucks increases. Deepening of developments worsens mining conditions, raises operational loadings, reduces reliability of equipment and efficiency of transportation. Maintenance and repair improvement is one of reserves of depreciation of life cycle of cars [1, 2].

The purpose of work is increase of efficiency of operation of BELAZ open pit trucks at the expense of use of results of modeling of system of maintenance, diagnosing and repair.

Materials and Methods.

Modeling of technological processes of functioning of open pit trucks is a basis for an assessment of efficiency of use of equipment and forecasting of its condition. In work the mathematical apparatus of Markov processes with discrete conditions and continuous time [3, 4] is used.

The actual functioning of BELAZ open pit truck

with electromechanical transmission is characterized by discrete conditions, which is defined by provision on maintenance, diagnosing and repair of BELAZ open pit trucks [5].

They form structure of the count and correspond to his tops – working zones (to the pit territory, etc.), to points (to places, zones) maintenance, diagnosing and repair. Roads (ways, transitions) between technological conditions are arches (edges) of the count. The set of technological conditions of open pit trucks is divided into three subsets: operation, maintenance and repair.

On the basis of mathematical model (fig. 1) the differential equations of probabilities of stay in each of ten technological conditions of functioning of open pit trucks which are united in system (1) are worked out:

$$\begin{cases}
\frac{dP_0(t)}{dt} = -(\lambda_{01}+\lambda_{06}+\omega_{08}+\omega_{09})\cdot P_0(t)+\mu_{10}\cdot P_1(t)+\mu_{20}\cdot P_2(t)+\mu_{30}\cdot P_3(t)+ \\
\quad +\mu_{40}\cdot P_4(t)+\mu_{50}\cdot P_5(t)+\mu_{60}\cdot P_6(t)+\mu_{70}\cdot P_7(t)+\mu_{80}\cdot P_8(t)+\mu_{90}\cdot P_9(t), \\
\frac{dP_1(t)}{dt} = -(\mu_{10}+\lambda_{12}+\omega_{18}+\omega_{19})\cdot P_1(t)+\lambda_{01}\cdot P_0(t), \\
\frac{dP_2(t)}{dt} = -(\mu_{20}+\lambda_{23}+\omega_{28}+\omega_{29})\cdot P_2(t)+\lambda_{12}\cdot P_1(t), \\
\frac{dP_3(t)}{dt} = -(\mu_{30}+\lambda_{34}+\lambda_{35}+\omega_{38}+\omega_{39})\cdot P_3(t)+\lambda_{23}\cdot P_2(t), \\
\frac{dP_4(t)}{dt} = -(\mu_{40}+\lambda_{45}+\lambda_{46}+\omega_{48}+\omega_{49})\cdot P_4(t)+\lambda_{34}\cdot P_3(t), \\
\frac{dP_5(t)}{dt} = -\mu_{50}\cdot P_5(t)+\lambda_{35}\cdot P_3(t)+\lambda_{45}\cdot P_4(t), \\
\frac{dP_6(t)}{dt} = -(\mu_{60}+\lambda_{67}+\omega_{69})\cdot P_6(t)+\lambda_{06}\cdot P_0(t)+\lambda_{46}\cdot P_4(t), \\
\frac{dP_7(t)}{dt} = -(\mu_{70}+\omega_{79})\cdot P_7(t)+\lambda_{67}\cdot P_6(t), \\
\frac{dP_8(t)}{dt} = -(\mu_{80}+\omega_{89})\cdot P_8(t)+\omega_{08}\cdot P_0(t)+\omega_{18}\cdot P_1(t)+ \\
\quad +\omega_{28}\cdot P_2(t)+\omega_{38}\cdot P_3(t)+\omega_{48}\cdot P_4(t), \\
\frac{dP_9(t)}{dt} = -\mu_{90}\cdot P_9(t)+\omega_{09}\cdot P_0(t)+\omega_{19}\cdot P_1(t)+\omega_{29}\cdot P_2(t)+\omega_{39}\cdot P_3(t)+ \\
\quad +\omega_{49}\cdot P_4(t)+\omega_{69}\cdot P_6(t)+\omega_{79}\cdot P_7(t)+\omega_{89}\cdot P_8(t)
\end{cases}, \quad (1)$$

In fig. 1 the specified model of functioning of open pit trucks in the form of a state graph and transitions is presented. The offered specified count provides ten technological conditions. Probes showed that open pit trucks to a third of calendar time are in maintenance operation and repair, and labor costs for this work reach more than a half of the general expenses for transportation.

Normalizing and initial conditions for system of the equations (1) look like

$$P_0(t)+P_1(t)+P_2(t)+P_3(t)+P_4(t)+P_5(t)+P_6(t)+P_7(t)+P_8(t)+P_9(t)=1, \quad (2)$$

$$P_0(0)=1, P_1(0)=P_2(0)=P_3(0)=P_4(0)=P_5(0)=P_6(0)=P_7(0)=P_8(0)=P_9(0)=0, \quad (3)$$

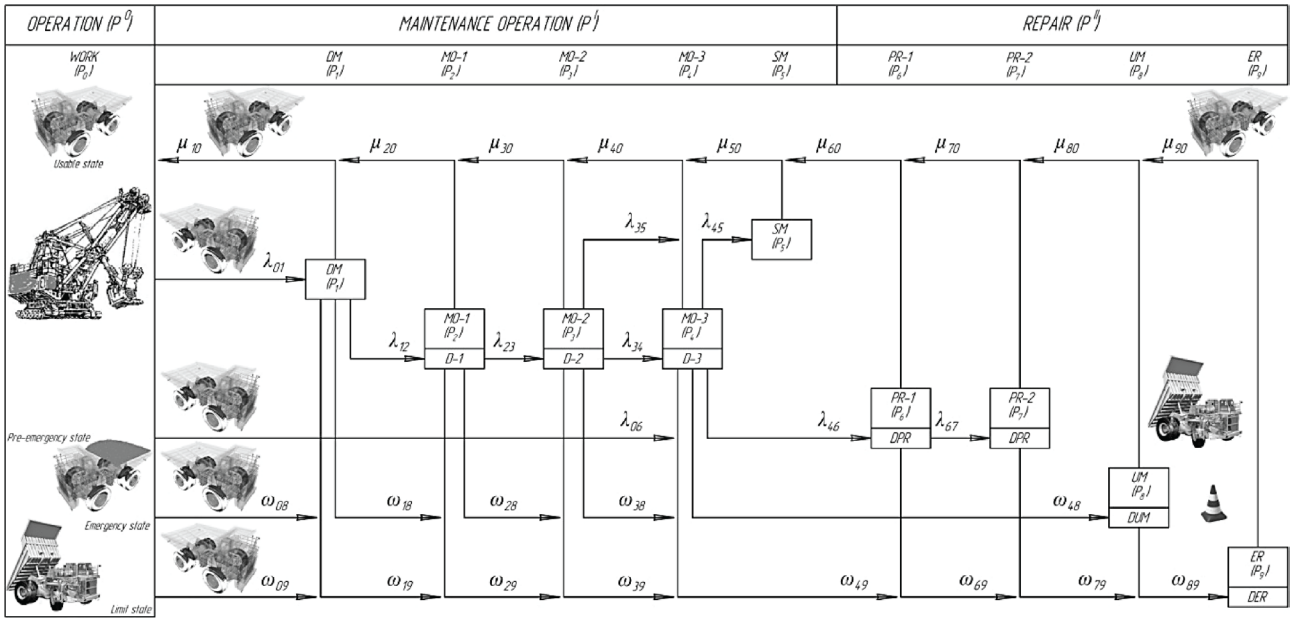

Figure 1. The specified count of technological conditions of BELAZ open pit trucks

Probability of finding of open pit trucks in a servicing subset is defined by the sum of probabilities of all types of service (fig. 1)

$$P^{I}(t) = P_1(t) + P_2(t) + P_3(t) + P_4(t) + P_5(t) \quad (4)$$

The probability of finding of open pit trucks in a subset of repair is defined as the sum of probabilities of all types of repair (fig. 1)

$$P^{II}(t) = P_6(t) + P_7(t) + P_8(t) + P_9(t) \quad (5)$$

Analyzing in common the general and specified mathematical models, we carry out classification and we define properties of streams of events, technological conditions and transitions between them. Functioning of open pit trucks happens on three streams: two streams of removal from service and to one stream of return to it. The conclusion of the open pit truck comes from operation in a stationary stream of planned transformations and a non-stationary casual stream of refusals. Return of the open pit truck to operation happens in the integrated commixed stream of restoration, which is formed after end of all types of maintenance and working capacity restoration in subsets of maintenance operation and repair.

The stream of transformations according to plan transfers the dump truck from an operation subset to a subset of maintenance operation with intensity of external transition λ^{OI}. This event happens most often during daily and each shift service (fig. 1) to intensity λ_{01}, that is

$$\lambda^{OI} = \lambda_{01} \quad (6)$$

The stream of transformations is supplemented with transfer of the open pit truck from an operation subset in a repair subset with intensity of external transition λ_{06}, which in association with intensity of external transition from service λ_{46} forms the integrated entrance stream in a repair subset to planned repairs with total intensity $\lambda_{06} + \lambda_{46}$. On set it is also the stream of planned transformations directed from operation to planned maintenance operation and repairs (fig. 2).

Intensity of planned transitions of open pit trucks between technological conditions practically don't depend on time $\lambda_{ij}(t) = \lambda_{ij} \approx const$, where i – is an index of the beginning of an arch of the count,
– is an index of the end of an arch of the count. According to "Situation" tolerances from standards of maintenance rate of MO-1 and MO-2 make ±10%, for other types of service and repairs – ±5%.

Other reason of a conclusion of the open pit truck from an operation subset in a subset of repair is sudden refusals, which form a stream of refusals. It consists of external and internal transitions with intensity which is time function $\lambda_{ij}(t)$. Two technological conditions are final tops of such transitions: current and emergency repairs. Direct straight lines are external transitions ω_{08} and ω_{09} transitions from operation to the current and emergency repairs respectively.

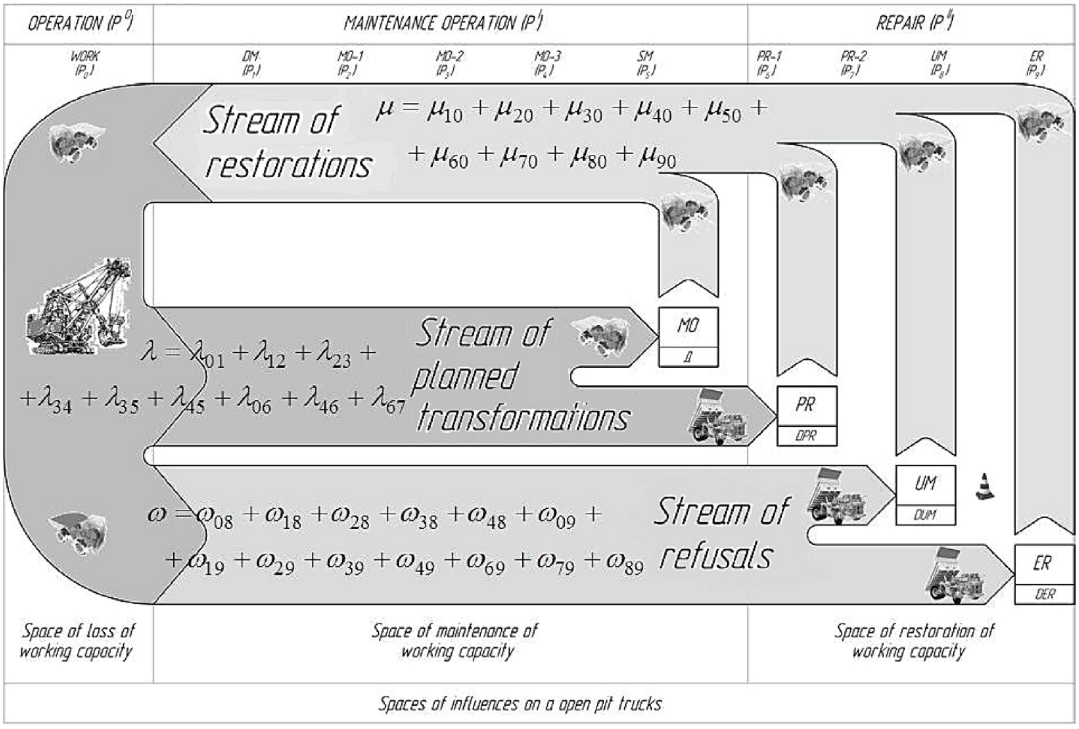

Figure 2. Formation of Streams of Events of Functioning of BELAZ open pit trucks

Transition from operation to repair combined as it is formed as of not planned transitions of refusals ω_{08}, ω_{09} and planned transition of transformations λ_{06}. Casual transitions ω_{08} and ω_{09} have intensity, a time-dependent $\omega_{ij}(t)$ and forming uniform and non-stationary stream of refusals as it consists of the sudden events leading to the current or emergency repairs.

Thus $\lambda^{O\,II} = \lambda_{06} + \omega_{08} + \omega_{09}$ (7)

The separate group is formed by internal transitions within subsets. Such transitions are both in a subset of maintenance operation: λ_{12}, λ_{23}, λ_{34}, λ_{35}, λ_{45}, for which $1 \le i \le 4$, $2 \le j \le 5$ (all of them are planned), and in a repair subset: λ_{67}, ω_{69}, ω_{79}, ω_{89} (only λ_{67} – is planned).

In practice there is a combined transition from servicing to repair, which is formed of planned transition of transformations λ_{46} and group of not planned sudden casual transitions to maintenance $j = 8$ and to emergency repair $j = 9$. That is

$$\lambda^{I\,II} = \lambda_{46} + \omega_{18} + \omega_{28} + \omega_{38} + \omega_{48} + \omega_{19} + \omega_{29} + \omega_{39} + \omega_{49} + \omega_{69} + \omega_{79} + \omega_{89}. \quad (8)$$

After the end of all types of maintenance of working capacity in a subset of maintenance operation the uniform planned stream of return to operation after servicing with intensity is formed

$$\mu^{I\,O} = \mu_{10} + \mu_{20} + \mu_{30} + \mu_{40} + \mu_{50} \quad (9)$$

After the end of all types of restoration of working capacity in a subset of repair the non-uniform commixed stream of return to operation after repairs with intensity is formed

$$\mu^{II\,O} = \mu_{60} + \mu_{70} + \mu_{80} + \mu_{90} \quad (10)$$

These streams unite in the commixed full stream of restorations

$$\mu^{I\,O} + \mu^{II\,O} = \mu_{10} + \mu_{20} + \mu_{30} + \mu_{40} + \mu_{50} + \mu_{60} + \mu_{70} + \mu_{80} + \mu_{90}, \quad (11)$$

for which $j = 0$. Thus all technological conditions of subsets of servicing and repair have direct transition to an efficient condition of a subset of operation.

Results. Thus, the mathematical model of functioning of the open pit truck contains 10 conditions united in 3 subsets, 31 transitions between them, from which 22 – are transitions of transformations and re-

fusals and 9 – are transitions of restorations, 22 – are external and 9 – are internal. The decision of system of the differential equations will allow to define probabilities of finding of open pit trucks in various technological conditions, intensity of transitions between them and to correct operating system of maintenance operation rationally.

Conclusions

Within the developed mathematical model the analysis of streams of the events formed by transitions between technological conditions of open pit trucks of the Krivorozhsky iron ore pool is made.

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