About one of the factors determining the failure rate in the working equipment of mining excavators

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Abstract. To date, the development of mining is carried out mainly opencast, which provides competitive economic indicators for the mining industry. Open mining of mineral deposits is characterized by an increase in the volume of processed rock mass and overburden ratios, production processes are improved due to advanced technologies, which entails the use of mining equipment of large unit capacity. So the efficiency of such equipment is ensured by its correct operation, minimizing the cost of its maintenance and repairs. The object of the paper is to establish and evaluate the factor that most significantly determines the failure rate in the working equipment of mining excavators.

1. Introduction

The open-cut mining to develop mineral deposits at this stage in the development of the mining industry remains the main one: 60% - coal mining, 90% iron ore, and 50% non-ferrous metals. The main type of technological equipment in quarries is excavators - mechanical shovels.

The implementation of mining plans is largely determined by the productive and reliable operation of these machines (figure 1, table 1).

![Figure 1. Supplies of cable excavators in the world.](image-url)
Table 1. Dynamics of supplies of mining excavators for quarries and sections of the Russian Federation.

| Type of excavator | Quantity |
|-------------------|----------|
| ECC-10            | 23       |
| ECC -8            | 4        |
| ECC -12           | 22       |
| ECC -15           | 30       |
| ECC -20           | 4        |
| ECC -20KM         | 4        |
| ECC -32P          | 1        |
| **Total**         | **88**   |

The performance of open-pit crawler excavators in opencast mining depends on a large number of factors, which include: mining operating conditions; weather and climate conditions; structure and control modes of the excavator and others.

It should be noted that the variety of factors that cause failures in mining excavators as complex technical systems does not allow compiling their absolutely complete list. Failures can occur for quite trivial reasons, for example, improper assembly of elements, poor contact of conductors, etc. The required malfunctions can be classified depending on the nature of the destructive action (chemical, thermal, mechanical, electrical) and the type of destruction: creep, corrosion, fatigue cracks, etc. [1-5].

The causal relationships between the occurrences of failures of mining excavators are established, for example, using the method of event trees (fault trees) or Ishikawa diagrams in the form of graphical logical constructions, which are then subjected to quantitative and qualitative analysis. This method is a logical method of localizing the most dangerous parts of the system.

All factors related to the contribution to the intensification of resource development by a career excavator and the participation of the excavator driver in this process can be divided into three main groups:

- with minimal driver’s impact on the resource development of the;
- with tangible influence of the driver on the resource development;
- with the decisive driver’s influence on the resource development: control of the excavator, which directly depends on the driver, etc.

2. Methodology

In this paper, we consider the problem of contribution to the intensification of resource development by a career excavator and the driver’s participation in this process.

It is well known that the functionality of any machine, which is constructively laid down by the manufacturer, is implemented by the engineer as far as his skill and work experience, as well as by psychophysical compatibility with the system element “machine”, which can be expressed as an indicator of the comfort level laid down by the machine manufacturer [1, 3, 5].

The task of distributing functions between a person and technical devices based on a comparison of their advantages and disadvantages in solving similar problems was formulated in 1951; active research related to the qualification of technological personnel in the mining industry has been carried out since the middle of the twentieth century.

The comfort level of managing a career excavator for a driver is characterized by many features, among which there is an attention concentration factor due to external (the object of the technological operation is the environment) and internal (comfort ECC control - stability of the technical condition).
Maintaining the driver’s comfort level is directly dependent on the functionality loss level of a career excavator, a decrease in this indicator is compensated by a proportional increase in the load on the driver, the limit of which is within the framework of the psychophysical state of a person [1].

Unqualified control, limited visibility at night and in adverse weather conditions, reduced operating speeds of mechanisms when working in long wall faces, operator fatigue significantly reduce the productivity of mining excavators [5].

Based on the analysis of scientific publications, it can be concluded that the method of functional networks is most promising for determining the quantitative values of reliability indicators of the excavator operator. In this method, the description of the processes of human activity is performed using the following elements [6]: functionaries and compositionists, these units of functioning are typical for almost all processes of the functioning of the "human-machine-environment" (HME) system, and therefore they are called typical functional units (TFU). Functionaries correspond to real operations or actions that a person performs: workers, logical (alternative) and delays. Additional functionaries carry out logical operations: control (self-control) of the correctness of the previous operations, checking the operability of technical equipment, organizational control. The list of key indicators and symbols is given in table 2.

### Table 2. Functionaries.

| TFU                      | Symbol | TFU                      | Symbol |
|--------------------------|--------|--------------------------|--------|
| Working                  | ![p](image) | Functioning monitoring  | ![i](image) |
| Serviceability testing   | ![r](image) | Delay                   | ![y](image) |

Auxiliary and service composers do not reflect real operations, but it is generally accepted that these elements have a probability of error-free execution equal to one, and the time to complete this action is zero. Auxiliary composers are: AND, OR connectors; cycle limiters. Service composers include: elements marking the beginning (starter) or end (finisher) of certain operations that are part of the algorithm or the functioning algorithm as a whole; operation block separators.

The set of TFUs is the final and intermediate objects of functional networks that reflect the process of functioning of the emergency response. For typical functional structures (TFS), which are often found fragments of functional networks; mathematical models have been developed for them, with the help of which the calculation of TFS indicators is performed (table 3).

### Table 3. Models for assessing the reliability of the HME operation processes.

| Number and content of TFS | TFS scheme | Equivalent TFU |
|---------------------------|------------|----------------|
| Consistent execution of work steps P | ![image] | Work operation |
3. Implementation

The working cycle of a single-bucket mining excavator is part of the work process. This process consists in the development and movement of the rock, and the movement of the excavator to the bottom, if necessary.

During the working cycle, the excavator performs the following operations: digging the soil (cutting and filling the bucket with it); removing the bucket with soil from the bottom; moving a bucket filled with soil to the place of unloading; unloading soil from a bucket into a dump or into a vehicle; moving the bucket (turning the platform) to the bottom; lowering the bucket to prepare for the next digging operation [8-10].

In the process, the excavator driver controls the following main parameters: the interaction of the bucket with the face; collapse of the upper edge of the face and the presence of oversize; the correct access of vehicles and the completeness of its loading; warning of vehicle impacts on the tail; head blocks and approaching the bucket to the boom; warning of bucket impacts on caterpillars, movement on the site; location of transport and the appearance of foreign objects; top edge of the face and side window; basic media displayed on the control panel; correct closing and opening of the bottom of the bucket; harness integrity; prevention of bucket hits on the transport vessel [11].

Having performed the driver’s activity analysis, a functional structural diagram of the activity was developed (figure 2). Table 4 shows the list of operations that an excavator driver performs during an 8 hour shift. During this time, he performs loading of one BelAZ dump truck 13 times, provided that the range of transportation of the rock mass is 2.2 km.

The calculation was carried out for three different groups of drivers (the work of the driver at a high, sufficient and satisfactory level). Table 5 presents the source data for the operations considered in the functioning algorithm.
Figure 2. Functional and structural diagram of the production activity of a mining excavator driver.

Table 4. The list and content of operator’s production activity operations.

| TFU designation and operation number | Contents of operation                                                                 |
|--------------------------------------|--------------------------------------------------------------------------------------|
| P1                                   | Inspection of the complete outdoor unit cell                                        |
| P2                                   | Inspection of cable from cell to excavator                                          |
| P3                                   | Excavator box entry inspection                                                      |
| P4                                   | Inspection of wires (must be clamped with a clamp)                                  |
| P5                                   | Check shift change log                                                              |
| P6                                   | Inspection of electrical equipment: brushes of the generator group, all engines must be grounded; brushes holders in engines turn-move, support-rise; inspection of automated insulation control device |
| P7                                   | Inspection of the excavator on the mechanical part: the connection of the handle-bucket mounts; connection of the rocker-bucket mounts, ring trimming; inspection of caterpillar tracks trimming. |
| P8                                   | Record in the journal about the shift turnover.                                      |
| P9                                   | Drive activation                                                                    |
| P10                                  | Inspection of fan motors: turning, lifting, running.                                |
| P11                                  | Excavator moving to the face                                                        |
| P12                                  | Turning on hydraulic equipment.                                                     |
| P13                                  | Installation of an excavator for loading rock mass                                  |
K1  Control by the operator for: the correct approach of the dump truck to the
evacuator for loading the rock mass; oversized; visor collapse.
P14  Oversize layouts.
P15  Signaling of the start of loading according to the signal table
P16  Rock digging
P17  Excavation of a bucket with soil from the face
K2  Monitoring by the operator of the appearance of foreign objects within a
    radius of 25 meters.
P18  Excavator stops before removing foreign objects.
P19  Moving bucket to unloading point
K3  Control by the operator of the bucket shock on the vehicle
P20  Eliminating bucket hits on vehicles
P21  Opening the bottom of the bucket
P22  Bucket moving to the face
P23  Bucket bottom closure
P24  Signaling the end of loading of a dump truck according to the signal table
P25  Hydraulic oil level control
P26  Air pressure control
P27  Drive voltage control, head lift, turn-stroke.
P28  Drive cutting
K4  Control by the operator for: the condition of the tracks; rope integrity; cable
    condition
P29  Problem solving
P30  Journal record on completion of work

I:=n  n repetitions of operations until the dump truck is filled
K:=h  h number of dump trucks for a period of time

| Table 5. Initial data on TFU reliability indicators for the excavator operator. |
|---------------------------------------------------------------|
| The number of operations of the driver production activity | B¹ | B⁰ | K¹¹ | K¹⁰ | K⁰⁰ | Reference |
|---------------------------------------------------------------|
| P13, P17, P19, P28, P30                                   | 0,99 | 0,003 | -   | -   | -   | [12] |
| P14, P18, P20, P29                                       | 0,9/0,75/0,55 | 0,1/0,25/0,45 | -   | -   | -   | [11] |
| P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, P11, P12, P15, P16, P21, P22, P23, P24, P25, P26 | 0,99 | 0,001 | -   | -   | -   | [12] |
| K1, K2, K3, K4                                           | -   | -   | 0,9/0,75/0,55 | 0,1/0,25/0,4 | 0,9/0,75/0,55 | [11] |

4. Conclusions
A mathematical model for the excavator driver’s production activity has been developed. Using the
functional network method, the operation reliability of the considered HME is calculated.

Based on the calculations, it was found that the probability of an error-free execution of work for a
high-level driver is 95%, of sufficient level - 88% and of satisfactory level - 79%.

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