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ANALYSIS OF OPERATING STATES OF HAUL TRUCKS USED IN SURFACE MINING

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Abstract

Mining transport system based on the use of haul trucks should result from thorough analysis of technical and operating issues – which can have a crucial impact on the cost of minerals extraction. This selection should consider hitherto disregarded criteria, such as technical infallibility, operating parameters like mean operating time between failures (MTBF), mean failure intensity and fault modes and effect analysis etc. Considering the above issues, the following article is an attempt to analyse operating parameters of transport fleet of haul trucks for mineral resource in surface mining. Diagram of the typology of technical and operational haul truck states; source: own study; mean failure intensity graph and mean failure intensity graph for the total observation time; relationships between mean expected time between consecutive failures of specific object and (MTBF) mean value of the time, in which specific equipment is in the down time due to a failure are presented in the article. The MTBF index is a basic parameter helpful to determine dependability and can be used for logistic planning, in particular in the field of spare parts. This index allows determining the cost of object use throughout its entire life cycle.

Keywords: *surface mining, haul truck, fault modes and effect analysis, operating states*

1. Introduction

The specification and analysis of operational parameters of technological vehicles used in the surface mining is possible only due to more and more frequently used diagnostic – telemetric systems. While a detailed analysis of machines, operation data in more effective management of a mining plant operations and the mining process itself can result. Determination of operational state indices and their individual components allows to start preventive actions, resulting in the improvement to the organisation of work of the entire mine machinery system. Moreover, the future technical state of machines operated in the surface mining is strictly related to the current state and depends also on the events that occurred in the extraction system. The analysis of dependability parameters can have a significant impact on making decisions, related both to the process of use and maintenance, but primarily to all main operational processes of the mine.

An example of analysis of selected operational parameters in the process of using the fleet of haul trucks in the surface mining is presented below.

2. Technical and operational states of haul trucks in the surface mining

Assuming that the assessment of technical state affects the making of operational decisions, to carry out analyses it is necessary to determine a set of state characteristics, for each examined technical object and for the entire population – an average one. Characteristics (conditioning parameters) belonging to individual states can have a specified (one or more) range of values, which in practice allows to distinguish classes of technical and operational states related to the aspect of a technical object use.

So a set of technical states SKU distinguished for the decision making purposes in the process of use will contain [3, 4]:

$$SKU = \{S_z, S_{zw1}, \dots, S_{zwl}, S_{nz}\}, \tag{1}$$

where:
S_z – total up state,
S_{nz} – fault state,
$S_{zw1}, \dots S_{zwl}$ – conditional up states.

The operational states can be defined as a descriptive attribute defining the operation process phase, i.e. the phase of machine use or maintenance. Various attribute have a determined meaning and form finite subsets of the operational states set SE [3, 4]:

$$SE = SU \cup SO = \{Su_1, Su_2, \dots, Su_l\} \cup, \\ \{So_1, So_2, \dots, So_n\}, \tag{2}$$

where:
$Su_{1\text{-}n}$ – distinguished utilization states,
$So_{1\text{-}n}$ – distinguished maintenance states.

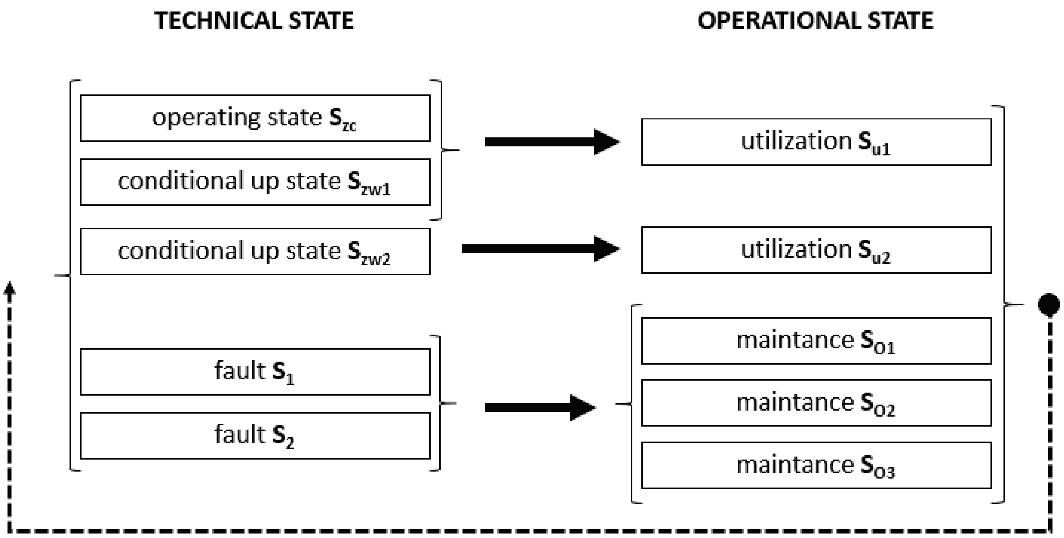

Fig. 1. Diagram of the typology of technical and operational haul truck states; source: own study based on [3, 4]

The distinguished classes of technical and operational states can be related to decisions in the process of haul trucks use. Technological vehicles as objects of operational analyses feature certain operational properties allowing determining dependability characteristics of the entire vehicle. They can allow using the vehicle without limitations or with limitations with respect to the fulfilled functions or other conditions of use or indicate the necessity of maintenance. Three technical states are distinguished for haul trucks: the first two (total up state and conditional up state) qualify the machine for use and the third (fault state) results in qualifying the machine to the maintenance state. Nevertheless, because of the difficulty to classify to the conditional up state, the performed analyses were limited to the occurrence of the up state and the fault state.

3. Mean failure intensity

The failure intensity can be estimated on the basis of statistical studies as the parameter describing an empirical number of haul truck exclusions (failure intensity) from the transport system use due to a failure. This parameter allows determining a mean number of maintenance requests for the same vehicle to the restoration system, neglecting the restoration time. The mean failure intensity was determined as the mean value of exclusions number for the analysed haul trucks population, falling to the entire range of analysed operation time (3,500 mth) acc. to relationship (3). This parameter's value is expressed as [failure/mth]. In this case, the failure intensity is defined as the ratio of the objects number *Δni*, which failed in the considered period of time *Δti* to the product: period *Δti* length and the number (N – ni) of objects fit to use at the beginning of the i-th period *Δti*, i.e. [1]:

$$\lambda_i = \frac{\Delta n_i}{(N - n_i)\Delta t_i} \qquad [failure/mth], \tag{3}$$

where:

Δn_i – number of registered failures in the i-th period of operation (number of analysed objects, machines),

N – sample size (number of analysed machines),

n_i – number of objects, machines fit to use at the beginning of the i-th period

Δt_i – total length of vehicle operation period (3,500 mth), in which the analysis was carried out.

Moreover, the damaged vehicles during the observation are not replaced with fit to use ones. The failure intensity estimation is the more accurate, the larger is the sample size N and the shorter are the time periods *Δti* (if the failure intensity is constant, the length of *Δti* period does not affect the estimation accuracy). Moreover, the requirement related to the object uniformity in the sample and those objects operational conditions uniformity (each object in the sample should operate exactly under the same conditions) must be met.

To determine the dependability mean failure intensity, informing about the number of a haul truck exclusions from the transport system in the given time period, groups N_1 and N_2 of haul trucks were analysed. Group N_1 comprised three haul trucks of average operation equal to 30,108 mth and group N_2 comprised 5 haul trucks of average operation equal to 6,133 mth. For all analysed vehicles the course of failure intensity was determined (acc. to relationship 3), based on the maintenance requests to the restoration system. Those requests, comprising both major failures and also small defects indicated by the self-diagnostic system, were treated equally, because they resulted in the necessity to exclude haul trucks from the technological operations. All maintenance requests were registered in an especially prepared spreadsheet comprising a precise date of the failure occurrence (request), for a specific value of the operation time (in mth), for each haul truck on an individual basis. The period of failure intensity observation comprised 2,500 mth and 3,500 mth for N_1 and N_2, respectively, and all analysed haul trucks had a similar initial operation time and technical state (were fully fit to use).

Based on the results of examinations, a histogram of failure intensity and the function of failure intensity $\lambda(t)$ was prepared for the analysed haul trucks from groups N_1 and N_2 (Fig. 2 and 3).

In the course of mean failure, intensity for group N_1 of haul trucks it is possible to observe initially an accelerated process of most components wear and ageing, featuring a substantial increase in the failure intensity. Majority of object failures in this period are natural failures, resulting from the actual sub-assemblies wear and ageing. The rate of failure intensity increase then declines, nevertheless it remains on a high level. The smaller is the dispersion of individual components durability, the larger is the rate of failure intensity increase in the period, and hence the more visible is the initial moment of this period. In this case, it would be necessary to analyse further the course of the wear intensity.

In the course of mean failure intensity for group, N_2 of haul trucks it is possible to observe the initial period of objects operation. A significant failure intensity is observed in this period, diminishing over time. This effect is explained by the fact that in the initial period of operation various manufacturing defects, assembling defects etc. are the main reason for failures. Removing such defects we eliminate the reasons for intensified failure intensity, e.g. defective components are replaced with good ones; that has a substantial impact on the reduction of failure intensity.

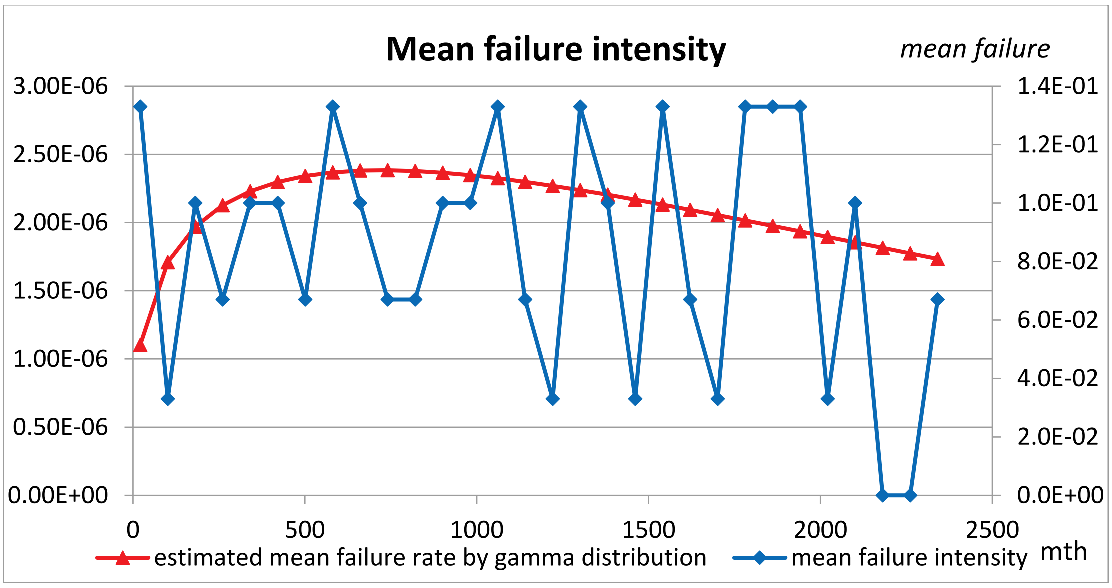

Fig. 2. Mean failure intensity graph for group N_1, for the total observation time of 2,500 mth

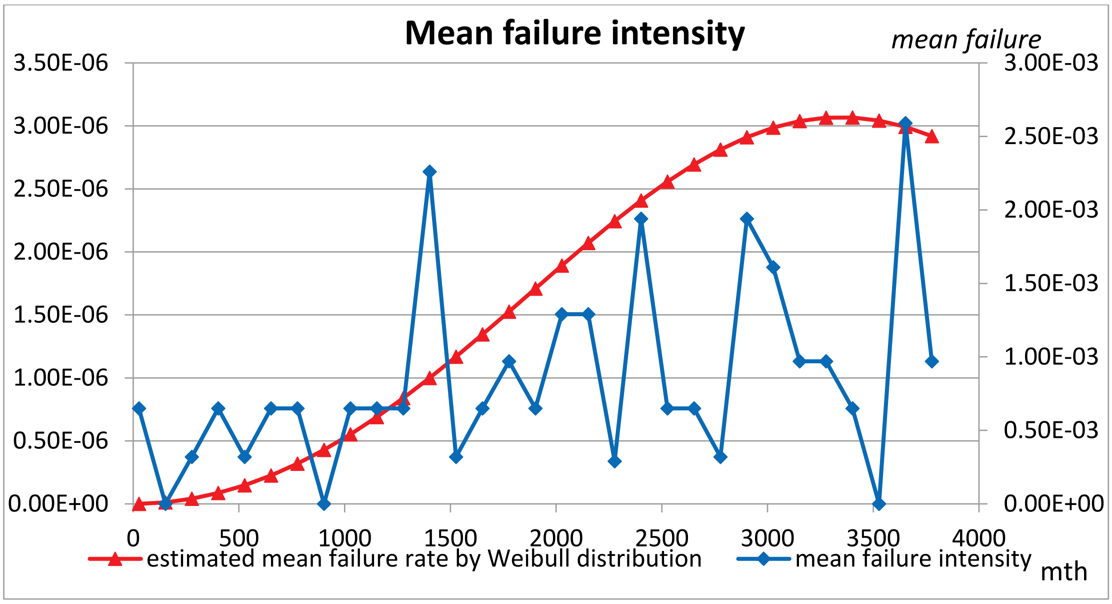

Fig. 3. Mean failure intensity graph for group N_2, for the total observation time of 3,500 mth

4. Mean operating time between failures, mean time to restoration

To assess the effectiveness of haul trucks operation it is necessary to choose appropriate indices. Two approaches are recommended in the case of similar analyses:

- first: selection of indices from among the available ones, which after the analysis will meet requirements specified by standard PN-EN 15341:2007,
- second: start from the method, which begins the assessment of various machine maintenance processes via a functional analysis.

The following prevail among indices used to assess the effectiveness of technical objects (including vehicles) operation: MTBF (Mean Time between Failures) and MTTR (Mean Time to Repair) [2, 5].

The MTBF index illustrates how frequently, from statistical point of view, a specific technical object is damaged. In practice, this index can be helpful to determine the schedule of planned preventive inspections.

The MTTR index determines a mean time necessary to remove the failure. It is also used to evaluate the effectiveness of the repair service (external) and of own maintenance services, and also to assess the repair jobs carried out by them [2, 5].

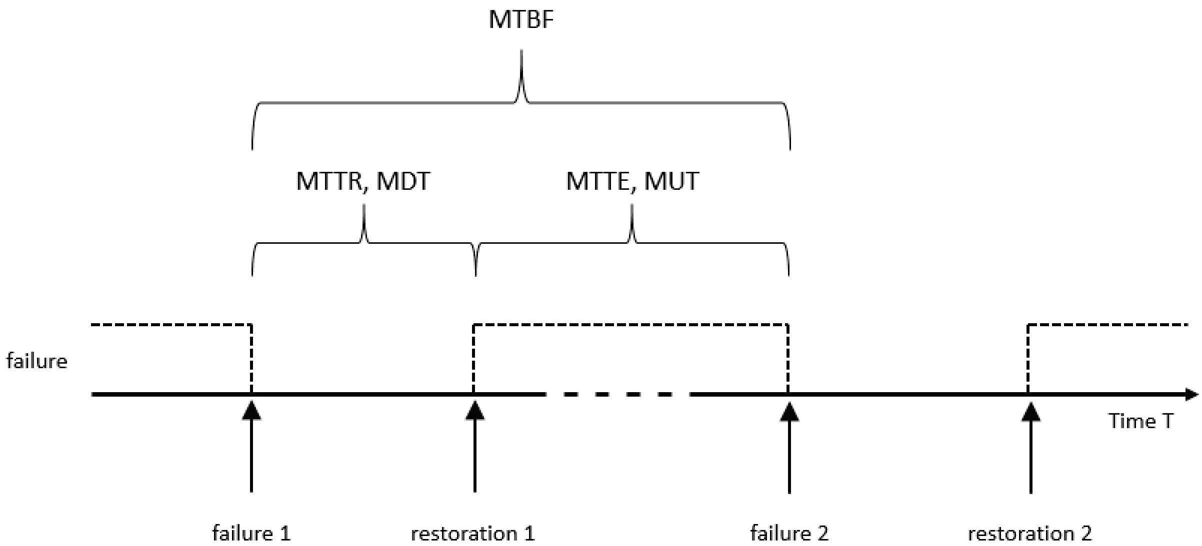

Fig. 4. Relationships between MTBF and MTTR indices [2, 5]; MDT – mean down time, MTBF – mean time between failures, MTTF – mean time to failure, MTTR – mean time to restoration, MUT – mean up time

The MTBF index was adopted as a mean operating time between failures within a specified time. This index is calculated acc. to:

$$MTBF = \frac{number\ of\ failure \cdot number\ of\ up\ time}{number\ of\ failure\ during\ the\ test} = \frac{T_1+T_2+T_3 \ldots +T_{n-1}+T_n}{n}. \quad (4)$$

Therefore, the MTBF is a mean expected time between consecutive failures of specific object, assuming that it is subject to alternating periods of failures and repairs. The following relationship defines MTBF as an inverse of failure occurrence frequency $\lambda(t)$.

This index value depends on the haul trucks use intensity and on the conditions, under which they are operated. It is also required to determine the profile of use, i.e. the operational conditions and the operating time (hours). For vehicles and their sub-assemblies, the operating hours should be additionally provided considering the operation specific nature (type of transport roads, time of operation under load, time of idle operation etc.).

The MTTR index was adopted as a mean time of actual repair duration from the moment of request to the moment of its completion. It is calculated according to the relationship:

$$MTTR = \frac{internal\ sum\ of\ repair\ time}{number\ of\ failure} = \frac{t_1+t_2+t_3 \ldots +t_{n-1}+t_n}{n}. \quad (5)$$

The MTTR is a mean value of the time, in which specific equipment is in the down time due to a failure. The MTTR is also defined as the mean down time MDT. It comprises the time of a failure detection, its recognition and distinguishing, request serving, ordering to the restoration system, which should remove the failure, time of its removal and the operating test.

Tab. 1. Results of analysis for group N1 and N2 haul trucks

Parameter	**Group N_1**	**Group N_2**
MTBF [h]	79.6	220.3
MTTR [h]	2.9	1.9
Actual operating time [h]	2424	3639
Availability	0.714	0.825

The period of MTBF and MTTR indices observation comprised approx. 30,000 mth and more than 6,000 mth, for group N_1 and N_2, respectively. All the analysed haul trucks had a similar initial operation time and technical state (were fully fit to use). As it can be noticed, for the averaged values of MTBF and MTTR indices haul trucks from group N_1 were showing much higher unreliability and time to restore full fitness than group N_2 haul trucks.

The analysis of the above indices can be an introduction to the development of a methodology to determine the schedule of planned preventive inspections for mining machines.

5. Summary

A set of parameter values of individual state characteristics, which allow characterising the haul trucks technical and operational state, is a direct effect of a telemetric – diagnostic system operation. At the assessment of operational indices based on telemetric analyses it is necessary to classify the observable state, using previously developed and adopted criteria. Determination of a distinguishable state is a necessary condition to make decisions on further operational actions – use or maintenance. The assessment of haul trucks dependability should be based on analyses of such parameters as: failure intensity and MTBF and MTTR indices, considering changes of their values depending on the operation time of the vehicle, treated as a holistic system; and in more detailed analyses – individual sub-assemblies. The operation time should be considered primarily as the time of their use, not the mileage. The MTBF index is also a basic parameter helpful to determine dependability and can be used for logistic planning, in particular in the field of spare parts. This index allows determining the cost of object use throughout its entire life cycle. The dependability theory is based on the probability calculus and on the mathematical statistics, therefore quantitative assessment of vehicle dependability should be considered in a probabilistic manner, as a probability of fulfilling specified practical requirements for vehicles.

In further analyses, it is advisable to build a model of operational assessments for a haul truck fleet, taking into account:

1. Ranking of technical objects based on the history of events and on the structure of technical and operational states;
2. Analyses of detailed dependability indices;
3. Preparation of action scenarios resulting from the performed analysis.

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