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ANALYTICAL MODEL FOR DETERMINING THE AVAILABILITY OF CONTINUOUS SURFACE EXPLOITATION SYSTEMS, CASE STUDY: I BTD SYSTEM OF THE OPEN PIT DRMNO[**]

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Abstract

This paper presents an analytical model for determining the availability of a continuous coal system at the open pit Drmno. A continuous coal-fired system is a technical system with sequential connection of elements in terms of reliability and functioning. Realization of the safe production is the main goal of continuous systems at the open pits. In order to achieve this goal, it is necessary to determine the availability of a continuous system. To determine the availability, data related to the I BTD system of the open pit Drmno Kostolac, more precisely the base with various downtimes over a period of 3 years (2016-2018), was used. This paper presents a case study for determining the availability of a continuous system at the coal open pit Drmno using an analytical model. The model can be applied to determine the availability of continuous systems at the open pit in the function of design, planning and implementation of production and maintenance systems and, as such, is applicable in the other industrial areas as well.

Keywords: *availability, continuous system - I ECC system, open pit*

1 INTRODUCTION

At the open pits of the Electric Power Company of Serbia, the continuous systems are used for coal mining. These are high-capacity, complex mining systems, the operation of which is extremely important for the reliable supply of coal to the Thermal Power Plant. Continuous surface mining systems represent the systems where the flow of material is continuous. The application of high capacitive continuous systems reduces the costs of transport, and therefore the total costs of exploitation itself. In this regard, the availability of one system was analyzed on an example of the open pit Drmno.

Coal mining in the Kostolac Basin began in 1870. The open pit Drmno is the only active mine in the Kostolac basin. The open pit Drmno produces 25% of coal (lignite) in Serbia, see [1].

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Based on the long-term monitoring and development of the lignite open pits, it has been proven that the continuous systems with rotary excavators and belt conveyors are the most efficient loading and transport system for these needs, see [2]. The mechanization, applied as a part of these systems, is complex and made according to the special requirements because these systems must satisfy and be adapted to the specific working conditions [3].

This paper presents a case study for determining the availability of a continuous coal system at the open pit Drmno consisting of the following elements (subsystems): rotary excavator SRs 400, self-propelled conveyor BRs 2400, a series of conveyors and crushing plant. The following figures show the elements of the I BTD system of the open pit Drmno.

Figure 1 *Rotary excavator SRs 400*

Figure 2 *Self-propelled conveyor BRs 2400*

Figure 3 *Belt conveyors*

Figure 4 *Crushing plant*

2 AVAILABILITY

According to the ISO-IEC standard, the availability is defined as: "The ability of a technical system to be in a state in which it can perform the required function, under the given conditions and at a given moment of time, i.e., during a given time interval, assuming that the necessary supply is provided (external resources)" [4,5].

The availability is calculated on the basis of a time state picture, in which times when the system is in the "up-time" differ with the times when the system is in the "down-time" [6,7]. The temporal picture of the state is shown in Figure 5.

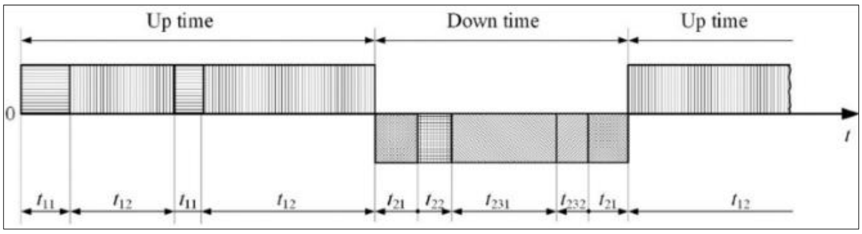

Figure 5 *Time picture of the state [6,7]*

The availability is also determined as the quotient of the total time during which the system is in a correct state and the total time that makes up the time in correct operation and the time in failure [8,9]:

$$A(t) = \frac{\sum t_{11}, t_{12}}{\sum t_{11}, t_{12}, t_{21}, t_{22}, t_{231}, t_{232}} \quad (2.1)$$

Operational availability $A_o(t)$ from a denominator above the mentioned equation (down time) excludes losses of an organizational and logistical nature.

$$A_{\text{o}}(t) = \frac{\sum t_{11}, t_{12}}{\sum t_{11}, t_{12}, t_{231}, t_{232}} \quad (2.2)$$

The internal availability is obtained when only the active corrective maintenance time $A_i(t)$ is taken into account:

$$A_i(t) = \frac{\sum t_{11}, t_{12}}{\sum t_{11}, t_{12}, t_{231}} \quad (2.3)$$

The availability can also be shown as a ratio of *MTBF* and *MDT* indicators,

$$A = \frac{MTBF}{MTBF + MDT} \quad (2.4)$$

- $MTBF$ - *mean time between failure*
- MDT - *mean down time in failure*

It is usual to display the availability as a number or coefficient k_A, but in certain situations and under certain assumptions, the availability can be displayed in the form of function *A(t).* In that case, the assumptions about the exponential distribution of reliability $R(t) = e^{-\lambda t}$ and the convenience of maintenance $M(t) = 1 - e^{\mu t}$ are used, where λ and μ are the failure and maintenance intensities determined by:

$$\lambda = \frac{1}{MTBF} \quad \text{and} \quad \mu = \frac{1}{MDT}. \quad (2.5)$$

The availability function *A(t)*, then takes the form:

$$A(t) = \frac{\mu}{\lambda + \mu} + \frac{\lambda}{\lambda + \mu} \cdot e^{-(\lambda + \mu) \cdot t}, \quad (2.6)$$

from where the stationary availability value is obtained as:

$$A = k_A = \lim_{t \to \infty} A(t) = \frac{\mu}{\lambda + \mu} = \frac{1}{1 + \frac{\lambda}{\mu}} = $$
$$= \frac{1}{1 + B}, \quad (2.7)$$

where k_A represents the availability coefficient and is obtained when $A(t)$ is calculated for $t \to \infty$, i.e., when the availability value becomes stationary [9].

3 ANALYTICAL MODEL TO DETERMINE THE AVAILABILITY

Based on the data obtained from the Electric Power Company of Serbia and the open pit Drmno, surface mine, a database was created related to the electrical (cable break, TT connection break, etc.), mechanical (damage to the superstructure bearings, broken tracks, replacement of teeth, etc.) and other failures (repair, service, etc.) of the I BTD system in a period of three years (2016-2018). Table 1 presents a part of the failure database that was used for the model. Table 2 presents the failures of the I BTD system at the open pit Drmno for a period of three years (2016-2018).

Table 1 *Presentation of a part of database on failures of the I BTD System*

Date	Month	Year	System	Facility	Failure	Start of failure	End of failure	Time in failure	Total time in failure (min.)	Note	Shift
1/1/2016	January	2016	I BTD	RB SRs-400	Electrical	10:00:00	10:50:00	00:50	50	/	1
1/1/2016	January	2016	I BTD	Crushing Plant	Others	13:00:00	14:30:00	01:30	90	/	1
1/1/2016	January	2016	I BTD	RB SRs-400	Electrical	19:00:00	19:10:00	00:10	10	/	2

Figure 6 presents a view of the regular connection of the I BTD system at the open pit Drmno.

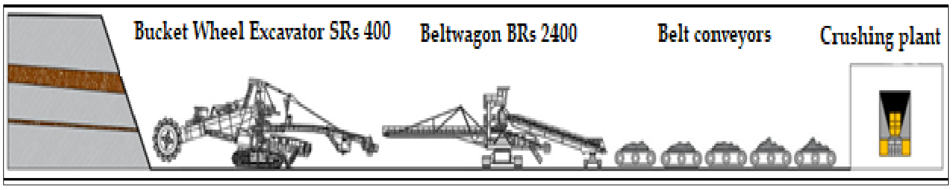

Figure 6 *Layout of the BTD system at the open pit Drmno [7,10]*

Table 2 *Failures of the BTD system at the open pit Drmno for a period of three years (2016-2018)*

Ord. No.	System	Type of failure	Sample size	Parameter μ	Parameter λ
1.	I BTD system	Electrical failures	983	0.01778	0.00163
2.	I BTD system	Mechanical failures	1504	0.01476	0.00226
3.	I BTD system	Other failures	2414	0.00679	0.00230
4.	I BTD system	All (EMO) failures	4901	0.00956	0.00474

λ – parameter – failure intensity
μ – parameter – maintenance intensity

Figure 7 presents the distribution of the I BDT system failures by types of failures in total failures for the period 2016-2018.

Figure 8 presents the distribution of the I BTD system failures by facilities for different types of down time for the period 2016-2018.

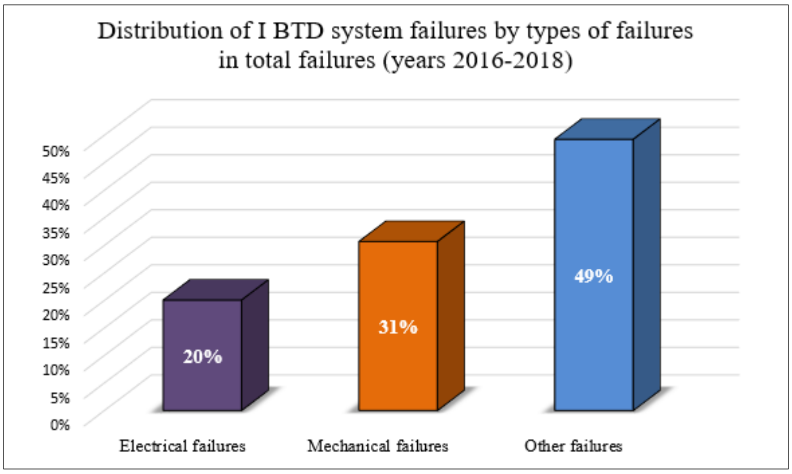

Figure 7 *Distribution of the I BDT system failures by types of failures in total failures for the period 2016-2018*

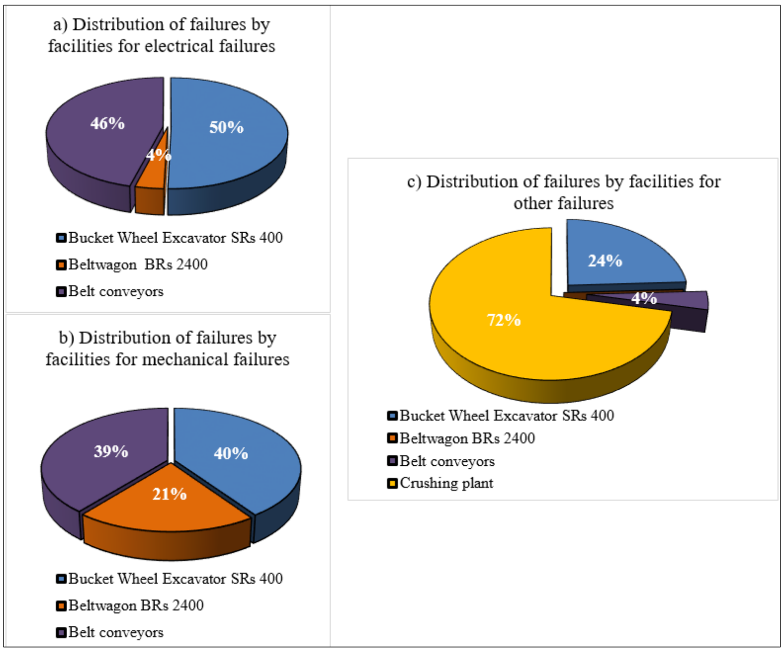

Figure 8 *Distribution of the I BTD system failures by facilities for different types of down time*

Based on the results of statistical processing of data on the operation time until failure and repair time, the analytical expression for availability is of the form:

$$A(t) = \frac{\mu_{EMO}}{\lambda_{EMO}+\mu_{EMO}} + \frac{\lambda_{EMO}}{\lambda_{EMO}+\mu_{EMO}} \cdot e^{-(\lambda_{EMO}+\mu_{EMO})\cdot t}, \quad (3.1)$$

$$A(t) = \frac{0.00956}{0.00474 + 0.00956} + \frac{0.00474}{0.00474 + 0.00956} \cdot e^{-(0.00474+0.00956)\cdot t},$$

$$A(t) = 0.66854 + 0.33146 \cdot e^{-0.0143\cdot t},$$

where: $k_A = \frac{\mu_{EMO}}{\lambda_{EMO}+\mu_{EMO}} = \mathbf{0.66854}$ – availability coefficient, i.e., stationary value of the availability A.

4 CONCLUSION

The availability of the I BTD system at the open pit Drmno, calculated by this model, corresponds to the real state of this system in the field. For the high-capacity mining systems such as the continuous coal mining (I BTD), it is important to determine its availability in order to define the picture of the system state necessary in the planning phase. The time in which the system is not in operation entails the high economic and production costs. This model has a role to help responsible persons (engineers) at the open pit in planning and control of exploitation, adopting the appropriate maintenance strategy, all with the aim of stable coal production and cost reduction. The availability of the specific system as a whole is the basic input data for the production planning at the open pit Drmno, but also other activities in the field of planning, production monitoring or equipment maintenance.

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