STUDIES ON AVAILABILITY OF THE MINING EQUIPMENT: AN OVERVIEW**

Abstract

Mining mechanization works in very difficult working conditions, where high productivity, availability, reliability and safety are constantly expected from this mechanization, as the carrier of production. The availability of mining mechanization is a key factor for stable exploitation, and this feature of the equipment is the subject of a long-term and detailed study. In this review, the published scientific, professional articles and doctoral dissertations on the topic of the availability of mining mechanization are presented. These works show the measures that need to be applied in order to improve the availability of mechanization and thus increase the stability of production. These works also analyze the key influencing factors of availability, determine the essential elements of system maintenance and management in order to increase the availability of mining machinery.

Keywords: availability, mining mechanization, safety of functioning, effectiveness

1 INTRODUCTION

The effects of operation the mining mechanization depend on the reliability, availability, their functioning, technical-technological performance, handling, maintenance, logistic support, adaptability - harmony of the relationship between the performance of machines and characteristics of the working environment [1].

Availability is a measure of the usable quality of technical systems. Increasing the availability of mining mechanization enables the safe and stable production.

It is of great importance for mining mechanization to determine the availability of mechanization intended for exploitation in order to reduce the high economic and production costs and ensure the stable exploitation.

The basic division of mining machinery is into basic and auxiliary mechanization. It is made on the basis of the function of specific equipment in the production process. Together, both of these groups make up the complex of mining mechanization at the mine. Mechanization in mining works in the specific, variable and difficult working environment conditions. These machines work in extremely variable operating modes, which affects their working life. One of the consequences of adapting to the conditions

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of the working environment and production requirements is that the mining mechanization is very diverse from different aspects, constructively, the way it affects the working environment, flow of materials, type of driving energy, etc. Figure 1 shows the examples of different types of mining mechanization.

![Bucket Wheel Excavator ER 1250 17/1.5](image1)
![Loader WA 700 Komatsu](image2)
![Hydraulic backhoe excavator PC 2000 Komatsu](image3)
![Bulldozer Komatsu 155](image4)

**Figure 1 Examples of different types of mining mechanization at the mine**

2 AVAILABILITY

The availability represents the probability that the technical system will be able to work correctly at any moment of time, that is, to be included in the work and remain within the allowed deviations of the assigned functions in a given time period and working environment conditions, see [2, 3].

The ISO-IEC standard defines availability as: "The ability of a technical system to be in a state in which it can perform the required function, under 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)" [2, 4].

The availability can also be calculated based on a temporal state picture [5, 6], in which times in good state alternate with times in failure [5, 7]. The temporal picture of the system state is shown in Figure 2.
Considering the broader terms such as the operational reliability and effectiveness, the availability is often considered in the literature as a specific element of these broader terms.

Operational reliability is a common term used to describe the concept of availability and factors that affect it: reliability, maintenance convenience and level of maintenance support [3, 5].

The term technical system effectiveness consists of availability, reliability and functional convenience. Figure 3 shows the definition of effectiveness [2].

![Figure 2 Time picture of the system state [7,8]](image)

**Figure 2 Time picture of the system state [7,8]**

3 REVIEW OF WORKS ON THE AVAILABILITY OF MINING MECHANIZATION

This review paper presents the works, dissertations for determining the condition parameters - the availability of mechanization in mining. In recent years, an increasing number of authors have written works on this topic. Examples of analyzed issues are given below.

In the paper entitled "Determining the Availability of Continuous Systems at the Open Pits Applying the Fuzzy Logic" [9] Gomilanović et al. present a model for determining the availability of continuous systems at the open pits using the fuzzy logic, fuzzy inference system. The applied model was formed by the synthesis of partial indicators of availability. The model is based on an expert system for assessment the availability of continuous mining systems. The availability, as a complex state parameter, is decomposed into partial indicators, reliability and maintenance convenience, and the phase compositions used for the integration of partial indicators are the max-min and min-max compositions. The
main advantage of this model compared to the conventional models is that it takes into account the impact of partial indicators of availability and does not require a long-term monitoring and records necessary to determine the temporal picture of the system state.

Djurić, R. in his doctoral dissertation "The Concept of Availability in Defining the Effective Maintenance of the Auxiliary Mechanization at the Open Pits" [10] shows the analysis of partial indicators of availability and model of their synthesis at the level of availability. The input data for this model are of a hybrid nature (expert ratings and measured values). Partial indicators of the availability are reliability, convenience of maintenance and functionality of technical systems. The synthesis of the mentioned partial indicators was carried out applying the theory of fuzzy logic to the level of availability. Two approaches were developed on the basis of the expert assessment and measured input data. Dissertation presents a case study of evaluation the availability of auxiliary mechanization - bulldozer.

In the paper "Readiness as a Feature of a Rotary Excavator Maintenance" [11] Jovančić, P. shows the analysis of machine downtime from the aspect of readiness as an initial, basic indicator of the maintenance system. The concept of availability is similar to the concept of readiness. Readiness as opposed to the availability does not include the time when a technical system has been in storage. The analysis was performed on the example of the SchRs 800 rotary excavator, which excavates coal at the open pit Drmno for a period of three years (1997-1999). In this paper, the authors conclude that the proper and timely maintenance should be imperative for all maintainers in order to better time and capacity utilization of the equipment.

In the papers "Fuzzy Logic Model for Evaluation the Safety of Mechanization Functioning at the Open Pits" [12] and "Application of the Fuzzy Logic Modeling in Evaluation the Safety of Mechanization Functioning at the Open Pits" [13] Jagodić, D. e al. defined a mathematical-conceptual model for evaluation the safety of machine functioning of the auxiliary mechanization at the open pits of Elektroprivreda Srbije, which enables the analysis and structuring of partial indicators of reliability, convenience of maintenance and logistic support for maintenance and their synthesis to the level of operational safety. Functional safety is the most complete term to describe the availability of a technical system, as a measure of its usable quality. The obtained results of the evaluation model of safety of functioning and indicators of bulldozer work point to the necessary correction of the mechanization control, maintenance policy, identification and diagnosis of defects, critical failures, etc.

Bugarić, U. et al. in the paper "Analytical Determination of the Availability of a Rotary Excavator as a Part of Coal Mining System- Case Study: Rotary Excavator SchRs 800.15/1.5 of the Drmno open pit" [14] present a model for analytical determination of the availability of a rotary excavator SchRs 800.15 /1.5 as a part of the first BTD system at the open pit Drmno. The application of this method for determining the availability allows efficiently determining the influencing factors of the system operation as a function of time. By modeling the work process as a function of time, using the appropriate statistical methods, the functional dependence of parameters, such as availability, duration of failure, duration of work as a function of time, is defined. The parameter values, obtained by the statistical analysis, show in which stage of life the rotary excavator is. The obtained parameters serve to determine the availability of the rotary excavator.

The paper "The Effect of the Maintenance System Control on the Operational Availability of the Technical Systems" by Avdić, H. et al. [15] presents the effect of the maintenance system control on the operational availability in the Banovici brown
coal mine. Increased requirements for the rationalization of resources, as well as the requirements for increasing the utilization of production capacities, place high demands on the availability and reliability of the technical systems. The basis of the paper is a proposal for control the maintenance system in the Banovići brown coal mine in order to efficiently perform the production tasks and reduce the mechanization failures. The proposed way of control the maintenance system with default operational availability in the complex systems such as the maintenance system in the Banovići brown coal mine implies the establishment of a pyramidal maintenance organization. The proposed maintenance organization would involve the unification of the mechanical and electrical sectors.

In the paper "Predicting the Availability of Continuous Mining Systems Using the LSTM Neural Network" [8] Gomilanović, M. and co-authors deal with the development of a model for predicting the availability of continuous mining systems at the open pits using the artificial neural networks. The main idea of this paper is the improvement of the analytical approach, the starting assumption of which is that the distribution of the length of time of the system in failure has an exponential distribution. In this work, data related to the I BTD system of the open pit Drmno Kostolac was used. This work aims to improve already existing models for predicting the availability of continuous systems at the open pits. Based on the RMSE, MAE and R2 values presented in this paper, it is concluded that the model obtained using the neural network has a higher predictive power compared to the analytical approach. Based on the presented model, a suitable simulation is created giving the availability range of considered system. Based on simulation, a more accurate picture of the availability of continuous systems at the open pits is given. The availability of continuous systems obtained by this model well reflects the current state of the I BTD system at the open pit Drmno.

Biserčić, A. in his master thesis entitled "Methodology for Predicting the Availability of Mining Systems at the Open Pits" [16] presents an innovative methodology for predicting the availability of mining systems at the open pits. In this paper, the new methodologies are developed for online and offline reliability and availability prediction, the success of which will be evaluated precisely by how well they approximate the real intensity function (that is, the intensity of failures and repairs in different time windows over time) as well as how well they predict the failure types which will happen.

Jagodić, D. in his doctoral dissertation entitled "Development of a Model of the Usability Quality of Auxiliary Mechanization at the Lignite Open Pits" [2] presents an innovative mathematical-conceptual model for evaluating the usability quality of auxiliary mechanization at the coal open pits. This model includes the analysis and synthesis of the following indicators: reliability, convenience of maintenance, functionality, logistical support for maintenance, severity of failure, frequency of occurrence of failure, detectability, effectiveness, availability, safety of functioning, risk, costs. The model is based on a phase logic. The phase model was formed in three levels applying the appropriate models of phase composition (max-min, min-max, Cartesian product-ordered pairs) to the higher levels of synthesis to the overall rating of usable quality. Verification of the model was carried out through a case study, evaluation the use quality of a dozer. The presented concept of evaluation the use quality of auxiliary mechanization provides guidelines for optimization the process of equipment control at the coal open pits in order to better use the auxiliary mechanization as well as the entire system of coal exploitation.

Ivezić, D. et al. in the paper "A Fuzzy Expert Model for Availability Evaluation" [17] present the concept of availability in...
In this paper, the authors created an expert phase model that analyzes and integrates the reliability, convenience of maintenance and functionality of three types of bulldozers (Liebherr, Dressta, Caterpillar) that work at the coal open pits (Drmno, Tamnava West Field and Field D) within the Elektroprivreda Srbije. Based on the evaluation results, a comparison of the mentioned auxiliary equipment—bulldozers was made. Conclusions are given that can be useful for improving the convenience of maintenance, logistics and during the purchase of the new machines.

In the paper "Development of the Availability Concept Using the Fuzzy Theory with the AHP Correction, Case Study: Bulldozers at the Lignite Open Pit" Djenadić S. et al. [7] developed a model for defining the availability of auxiliary mechanization that relies on the phase theory and a multicriteria method in evaluating the AHP (method of analytical hierarchical processes). The basis of the work is the expert evaluation of the formed partial indicators that enter the availability structure. In this work, the structure of availability is constructed in the form of three partial indicators that have a direct impact on availability, namely: reliability, maintainability and supportability. In the expert evaluation, the evaluations of four experts were taken, who evaluated each of the three analyzed machines from the area of three previously defined partial indicators assigning the grades—linguistic variables (A—best grade, B, C, D, E—worst grade) that have their own class membership functions. Two machine states were analyzed, when the machines were used for 2 years (new machines, in the warranty period) and when the machines were used for seven years (machines before scrapping). The authors used the obtained results on expert opinion to form a phase model with a max-min composition. The case study was done on the example of bulldozers working at the coal open pits. The model itself was verified by comparison with the conventional method of assessment the availability.

The authors Tanasijević, M. et al. in the paper "A Fuzzy-Based Decision Support Model for Effectiveness Evaluation - Case Study of the Investigation of Bulldozers" [18] present the effectiveness as a comprehensive concept and measure of the level of usability of the observed technical system. This paper presents the analysis and structuring of partial indicators. The model was developed to synthesize them to the level of effectiveness. The paper used indicators of a hybrid nature, such as the measured values and expert evaluations. A phased reasoning model for their processing and integration into effectiveness is presented. This concept gives the possibility to evaluate the technical system in terms of making decisions about the remaining possibilities and optimizing the costs of the life cycle. The model is applied on the example of auxiliary machines, bulldozers. The case study covers two approaches. The first approach is based on the expert assessments, and the second on the measurement and statistical data processing.

In the paper "Analysis of the Availability and Utilization of Dragline for Enhancement the Productivity at the Open Pits - Case Study", Mohammadi, M. [19] presents a case study for dragline excavators at one of the largest coal open pit in India. The study shows trends in the availability of these excavators over 11 years. Also, this study highlights the reasons for changing the availability and ineffective operation of draglines.

4 DISCUSSION AND CONCLUSION

This review paper presents the published scientific, professional works and doctoral dissertations on the topic of the availability of mining mechanization. Also, in these papers, the key influential factors of availability are analyzed, the essential elements of system maintenance and management are determined in order to improve the availa-
bility of mining machinery. Based on this review, it can be concluded that the availability of mining mechanization is extremely important for the exploitation process itself. In all the presented papers, the authors emphasized the importance of the availability of mining mechanization as a complex concept of the technical system state. Its determination is a complex task and is considered from two aspects. The first is that the availability itself is a factor that affects the security of functioning and effectiveness and represents their essential element. On the other hand, the availability itself is a function of a greater number of sub-indicators of the technical system state. These sub-indicators are obtained by a detailed analysis of the individual production systems or entire complex of mechanization in mines, and the value is determined by the synthesis of these indicators. The result, that is, the availability value, was determined in several different ways, using an analytical model for determining the availability, using a phase model and a model based on an artificial neural network. All of these ways of determining the availability require a long-term observation of the time picture of the system state or the use of expert evaluation.

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