

RAM measure of hydraulic powered roof supports in underground longwall coal mines

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Abstract

Mining operations in underground coal mines, particularly those using the longwall method, require continuous progress and the avoidance of interruptions, as any stoppage can lead to roof collapse. Given the mechanization of coal mining and the underground extraction of this mineral, the use of powered supports is essential to prevent roof collapse. To maintain continuity in mining operations, increase production, and simultaneously control and reduce costs caused by downtime and failures of roof support systems, it is necessary to assess their reliability. This paper aims to analyze the reliability, maintainability, and availability (RAM) of powered support equipment. To achieve this, the hydraulic powered support system was selected for data collection and analysis. The results indicate that the time between failures (TBF) and time to repair (TTR) data of the subsystems followed a renewal process, except for the TBF data of the hydraulic subsystem, which followed a non-homogeneous Poisson process (NHPP). The reliability of the subsystems decreased to 85% after 25 hours. The maintainability analysis showed that most failures of the powered roof supports are repaired within 1 hour. Furthermore, the powered support systems operate under desirable conditions with 99.58% availability. However, in order to create an efficient and easy-to-manage maintenance schedule, it was suggested that preventive maintenance activities be performed at the end of each working day.

Keywords:

coal mining, roof support systems, reliability, maintainability, availability

1. Introduction

Coal is a vital energy source and the first fossil fuel to be widely used. In many countries, conventional resources such as coal continue to play a significant role in energy production. Consequently, coal mines remain highly important, and countries possessing these resources generate substantial profits from their sale. Currently, most of the world's coal is extracted using the longwall mining method. This method employs various machines and equipment, including shearers, armored face conveyors (AFCs), conveyor belts, and power supports (Boloz et al., 2022). Intense competition in the energy raw materials market drives mining companies to reduce production costs. In this context, it is anticipated that increasing production efficiency will help mitigate negative environmental impacts. One approach to achieving this goal is to continuously enhance the efficiency of equipment and machinery (Uth et al., 2019; Szurgacz et al., 2022a).

The longwall method is an underground mining technique known for its high production capacity and excel-

lent recovery rates in coal mining. This method has consistently been regarded as the most cost-effective approach for coal extraction (Kazanin et al., 2022).

The most important machines used in this method include the drum shearer, AFCs, powered roof supports, and conveyor belt. **Figure 1** shows a view of a longwall mine. In this method, mining operations are conducted beneath the powered supports. The shearer is mounted on the AFC and cuts the coal, dumping it onto the conveyor belt to be transported out of the mine. After the shearer has travelled the entire length of the face, it reverses direction and begins the next cut. As the shearer moves past the powered supports, the supports advance forward, closer to the newly cut surface. The powered supports protect workers and equipment along the working face, while the roof behind the supports is allowed to collapse as the face advances. Mining continues in this manner until the entire coal seam is extracted (Peng, 2019).

The primary function of power holders is to protect the mining operation from the adverse effects of the rock mass and its movement, while simultaneously advancing the shearer and AFC. Considering that a large number of units are required to support the roof, the capital invested in powered supports typically accounts for 60–80% or more of the initial investment in a longwall face, depending on the panel width (Peng, 2019). Further-

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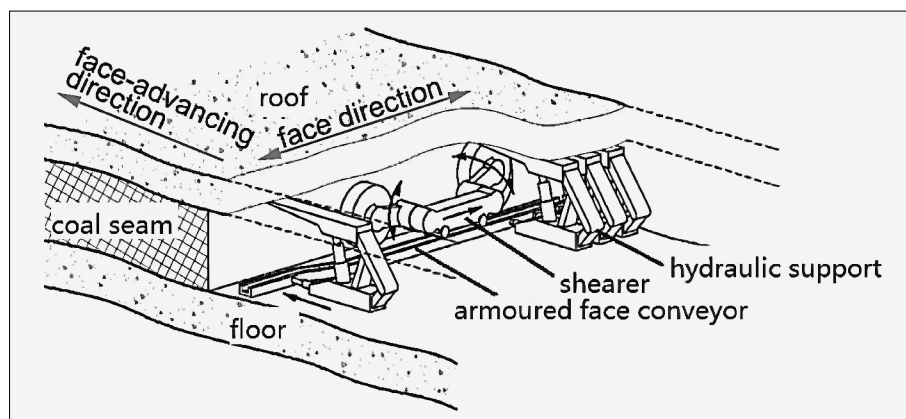


Figure 1. Scheme of the mechanized longwall mining operation (Guan et al., 2023)

more, since powered supports in longwall mechanized mines are responsible for ensuring the safety of both equipment and workers, they are among the most critical components of mechanized mining operations and require proper monitoring and control of their operating parameters (Szurgacz et al., 2022b).

Any failure or stoppage in powered support systems not only compromises the safety of the mining environment but also leads to the suspension of mining operations and, ultimately, the cessation of mine production. As mentioned earlier, from both economic and technical perspectives, powered supports are crucial pieces of equipment in longwall mining. Therefore, it is essential to study the failure behaviour and analyze the reliability and maintainability of this type of equipment. Focusing on the evaluation of RAM (Reliability, Availability, and Maintainability) in mining operations will enhance production, safety, and maintenance.

Mining equipment and systems comprise multiple interconnected components, and their effective operation is crucial for ensuring uninterrupted production within the mine. Due to the complexity of this equipment, it is essential to conduct research on its RAM. The RAM of mining systems and equipment has been a major emphasis in recent years. To date, considerable research has been conducted on the reliability of a variety of systems in the field of mining engineering. **Table 1** provides a summary of the research articles related to reliability analysis of mining machinery and equipment utilized in underground mining operation.

Nowadays, reliability and maintainability of mining equipment and systems in underground coal mines such as shearer (Zhou et al., 2017; Ding et al., 2019; Wang et al., 2025), roadheader (Kahraman et al., 2023; Xiaofeng, 2025), discharge loaders (Sarkhel and 2015), and conveyors (Kumar 2016; Gorai et al., 2017; Masir et al., 2021) have been analyzed and discussed. Furthermore, numerous attempts have been made to analyze and optimize the load capacity of powered roof supports in longwall mining (Szurgacz et al., 2022; Szurgacz, 2024; Wang et al., 2023; Borska and Szurgacz, 2024). However, limited research has been conducted to study the reliability and maintainability of this critical system.

Morshedlou et al. (2014) studied the reliability of powered supports at the Tabas coal mine using a statistical analysis approach. The results of this study indicate that the powered supports follow a Gamma reliability function. The reliability of the equipment decreases to nearly zero after approximately 520 hours of operation. Furthermore, the failure rate analysis reveals an improving trend, characterized by a decreasing failure rate. **Stebnev et al., (2017)** studied the downtimes of mining machines and equipment in the powered longwall mining systems at SUEK-Kuzbass Company, Russia. This paper analyzes and discusses the output per face, productivity, lifetime, and failure-free operation of mining machines, including shearers, powered roof supports, face conveyors, and electrical equipment. In the study, powered support systems produced by different companies were compared in terms of price, service life, and the unit cost of coal production. Failure analysis of equipment and systems over a seven-year period showed that the overall downtime due to mining machine failures was approximately 12%, with failures of powered support systems accounting for 13% of the total downtime. **Szurgacz (2021)** analyzed the effectiveness of powered roof supports. In this study, the overall equipment effectiveness (OEE) indicator was used to assess the degree of utilization. To achieve this, the availability, performance, and quality of powered roof supports were measured under conditions of tremor hazards and no tremor hazards. The results showed that the OEE of powered roof supports in mining tremor hazard conditions ranged from 55% to 65%, while in conditions without mining tremor hazards, it was estimated to be between 75% and 85%. The study noted that these OEE values indicate low effectiveness in utilizing roof support systems, highlighting the importance of reviewing operation and maintenance policies to improve this indicator.

A review of the aforementioned paper reveals that the reliability of powered support systems has been studied in only a limited number of research efforts. In **Morshedlou et al. (2014)**, powered support systems are considered as a single system. However, breaking down an engineering system into its functional subsystems not only helps identify the subsystems that contribute most

Table 1. A summary of studies on the reliability of underground mining equipment and machinery

Author(s)	Year	Equipment/ system	Modelling method
Prasad and Rao	2008	Dozer Engines	Renewal process and Non-homogeneous Poisson process
Vayenas and Wu	2009	LHD	Non-homogeneous Poisson process
Hoseinie et al.	2013	Shearer machine	Renewal process
Mouli et al.	2014	Dump truck	Renewal process
Thunberg	2016	Underground drilling rigs	Renewal process and Non-Homogeneous Poisson Process
Gorai et al.	2017	Conveyor system	Renewal process
Balaraju et al.	2018	LHD	Non-Homogeneous Poisson Process
Vashistha et al.	2019	LHD	Renewal process
La Roche-Carrier et al.	2020	Rock bolters	Renewal process
Balaraju et al.	2020	LHD	Renewal process
Said	2021	Underground trucks	Non-Homogeneous Poisson Process
Masir et al.	2021	AFC	Non-Homogeneous Poisson Process
Jakkula et al.	2022	LHD	Renewal process
Jakkula et al.	2024	LHD	Renewal process

to system failure but also provides better insights into the failure behaviour of each subsystem. Moreover, this approach supports effective preventive maintenance activities without redundant planning. In **Szurgacz's (2021)** study, the availability, performance, and quality of roof powered supports were addressed by considering only the mean time between failures, mean time to repair, total run time, and ideal cycle time. However, the failure and repair behaviour of the system were neither studied nor discussed. This paper aims to utilize reliability, maintainability, and availability indicators to predict the comprehensive performance of powered support systems, thereby ensuring the safety and continuity of the mining process. These indicators help improve the productivity of mining operations over their life cycle by reducing waste, maximizing profit, and ultimately optimizing overall life cycle costs. The results of this study provide valuable guidance and information to support decision-making related to the design and operation of powered support systems throughout their lifespan.

The paper is organized as follows. Section 2 describes the research methodology, presenting the statistical reliability and maintainability modelling approach. Section 3 details the hydraulic powered supports used in longwall mining operations. In Section 4, the reliability, maintainability, and availability of the powered support system at Parvadeh Tabas Coal Mine, Iran, are analyzed and discussed.

2. Methods

Powered supports emerged following the development and advancement of steel support systems, such as friction and hydraulic supports, used in longwall mining operations. The powered roof support system consists of several hydraulic supports. A solid canopy is positioned on top of these supports, while their bases are connected

to AFC components. As the mining face advances, the supports retract and move forward, controlled remotely. **Figure 2** shows a view of a powered support.

The powered support system can be divided into two main subsystems: mechanical and hydraulic. The mechanical subsystem includes the following main components:

- The *canopy* transfers the pressure from the rock mass to the support.
- The *shield support* consists of a gob shield and side shields.
- *Lemniscate tie rods* connect the gob shield to the base in a straight-line system, providing stable support and maintaining an almost constant distance between the canopy end and the face front throughout the entire range of roof support heights.
- *Legs* consists of a double-acting hydraulic ram and a telescopic relay bar.
- *Floor base* to transmit the bearing force of the support to the floor.
- *Shifting system* consists of a ram installed in the body that acts directly on the advancing system's bar, causing the front of the base to lift during support advancement. This system aids in advancing the support.

The hydraulic system operates various rams, including a two-stage telescopic hydraulic leg, tilt ram, correcting ram, support advancing ram, base lifting ram, base correction ram, supporting ram, ram for maintaining the last support on an incline, face sprag ram, and additional devices for operating the support system on inclines.

In modern longwall mining, self-advancing, hydraulically powered supports are used to extract coal at the face. These powered supports hold up the roof, ensuring a safe working environment for miners, face equipment, and

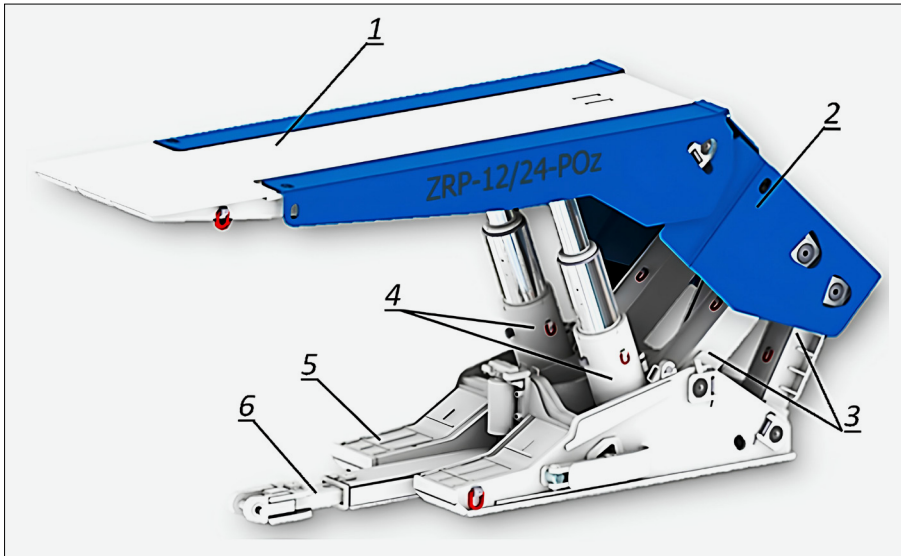


Figure 2. Arrangement of a powered roof support (1: canopy, 2: shield support, 3: lemniscate tie rods, 4: leg, 5: floor base, and 6: shifting system) (Szurgacz et al., 2022b).

other mining operations. Additionally, the hydraulically powered supports push the AFC and advance themselves.

There are four basic designs of powered supports: frame, chock, shield and chock shield. The frame support can be considered an extension of the single hydraulic props that are often used underground and it is the first type of powered support designed for modern self-advancing hydraulic powered supports. The basic arrangement has two hydraulic props or legs in a vertically arranged series connected at the top with a one or two part canopy, which is frequently referred to as just a canopy (Peng, 2019). As opposed to the frame support, chock supports have a solid canopy while the base is composed of two separate pieces that are joined by steel bars, joined at the front or back. This difference is substantial.

Shields are defined as the posterior extension of the caving shield-lemniscate-link system between the base and the canopy. The caving shield is typically pitched and hinged-jointed to the canopy; and the connection with the base is through either the lemniscate assembly or direct. This essentially renders the shield a cinematically stable support, an advantage to frame and chocks. In shields the hydraulic legs are pitched to allow greater range of working height and for more room for traffic. Chock shields have the main advantages of both the chock and shield. Essentially the chock shield is a shield with four legs between the canopy and the base plates. The legs can be oriented vertically or in a V-configurations between the canopy and base, and this is the rationale for the name “chock shield.” Chock shields provide the most efficient support and particularly advantageous in hard roof conditions (Peng, 2019).

The performance evaluation of powered support systems in underground coal mines is conducted using various criteria. To date, multiple tools have been employed to analyze operational and maintenance performance in equipment and machinery production management. The effectiveness of powered support systems is assessed based on their reliability and ease of maintenance.

Reliability, which can be adequately assessed using failure analysis, is used as a proxy for performance (Cai et al., 2021). Reliability (R) is defined as the probability that equipment or processes will perform reliably as designed (and identified) without “failure” when used exactly as intended over a specified time period under stated conditions. The formal mathematical definition of reliability is given by **Equation 1**:

$$R(t) = 1 - F(t) = 1 - \int_0^t f(x)dx \quad (1)$$

Where:

$R(t)$ is the reliability at time t ,

$F(t)$ is the cumulative failure distribution function,

$f(x)$ is the failure probability density function.

Complex systems contain numerous mechanical, hydraulic, or electrical subsystems. Each subsystem can fail, which increases the probability of overall system failure. The resulting reliability depends on the reliability of the individual subsystems and their configuration. Series and parallel are two fundamental system arrangements. A series system generally consists of a group of independent subsystems in which the failure of any one component causes the entire system to fail. In contrast, a parallel system fails only if all its subsystems fail. The reliability of series and parallel systems is calculated as **Equations 2 and 3**:

$$R_s = \prod R_i \quad (2)$$

$$R_p = 1 - \prod (1 - R_i) \quad (3)$$

Where:

R_s and R_p are the reliability of the whole system in series and parallel configurations, respectively,

R_i denotes the reliability of the i th independent subsystem.

Maintainability refers to the capability of an item to be kept in, or restored to, a designated state when maintenance is conducted. The **Equation 4** defines the maintainability function.

$$M(t) = 1 - F_r(t) = 1 - \int_0^t f_r(x)dx \quad (4)$$

Where:

$M(t)$ is the maintainability at time t ,

$F_r(t)$ is the cumulative repair distribution function,

$f_r(x)$ is the probability density function of the repair time.

If a system contains independent subsystems, the maintainability of a series (M_s) and parallel (M_p) system can be determined as **Equations 5** and **6**:

$$M_s = \prod M_i \quad (5)$$

$$M_p = 1 - \prod (1 - M_i) \quad (6)$$

Where:

M_i is the maintainability of i th subsystem.

Availability is defined as the probability that the equipment or a system can perform its intended function at time t , whereby the time period includes the running time, logistical time, active repair time, and administrative time. Calculating availability (Av) requires obtaining the uptime and downtime, as shown in **Equation 7** (dos Santos Silva et al., 2016).

$$Av = \frac{MTBF}{MTBF + MTTR} \quad (7)$$

The $MTBF$ represents the average failure time and the $MTTR$ denotes average repair time for the machine. The inverse of availability corresponds to unavailability, or the expected downtime ratio, which is crucial for assessing operational risk.

Considering the structure and network of the system's availability, the overall availability of a system with i serial or parallel subsystems (Av_i) can be calculated as follows:

$$Av_s = \prod Av_i \quad (8)$$

$$Av_p = 1 - \prod (1 - Av_i) \quad (9)$$

Where:

Av_s and Av_p represent the availability of the whole system in serial and parallel configurations, respectively.

Since failures cannot be entirely prevented, periodic inspection and measurement can help mitigate the severity of any failure. To ensure a system functions properly, regular maintenance activities are essential. Maintenance tasks can be divided into two main categories: planned and unplanned. Preventive maintenance (PM) consists of preplanned actions aimed at reducing the im-

pact of known causes that could potentially lead to system breakdowns (Duffuaa and Raouf, 2015, Rahimdel and Ghodrati 2022). PM activities aim to increase the productivity of equipment and facilities while reducing maintenance and insurance expenses (e Costa et al., 2012). In fact, such maintenance operations are performed to ensure the system continues to operate satisfactorily by conducting systematic inspections that identify and address potential failures before they grow into critical issues (Wang and Pham, 2006). PM is planned and performed after a specified period or following a certain amount of system usage to reduce the likelihood of failure (Basri et al., 2017).

The remainder of this section is devoted to presenting the methodology for estimating reliability and maintainability indicators. Data collection, including failure and repair times, is the first step. After establishing the database, an appropriate method is selected for the statistical modelling of the system's performance indicators.

The step-by-step procedure for reliability modelling of a repairable system is illustrated in **Figure 3**. This detailed flowchart facilitates dataset modelling and serves as a foundation for analyzing failure and repair data.

These processes are commonly known as stochastic point processes (Andrzejczak, 2015). For the reliability assessment of repairable systems, three different methods are typically employed:

- Renewal Process (RP)
- Homogeneous Poisson Process (HPP)
- Nonhomogeneous Poisson Process (NHPP)

In repairable systems, the condition of a system after maintenance actions can vary depending on the effectiveness of the repair. In some cases, the system may be restored to a state equivalent to its initial condition, while in others it may retain characteristics of prior deterioration or fall somewhere between these two extremes. When repairs fully restore the system to its original performance level, the failure–repair sequence can be described using a renewal framework. Within this framework, system failures followed by repairs are treated as recurrent events with statistically independent and identically distributed intervals. Analytical expressions for the renewal function are available only for a limited class of probability distributions, including exponential, gamma, and phase-type models (Arnold et al., 2020; Muralidharan, 2008).

The Homogeneous Poisson Process (HPP) is a special type of renewal process in which the inter-event times are independent and identically distributed (iid) exponential random variables. The HPP is an orderly stochastic point process characterized by stationary and independent increments. In an HPP, the inter-arrival times are independent and exponentially distributed with parameter λ , and the number of events follows a Poisson distribution. In reliability studies, the HPP has been used

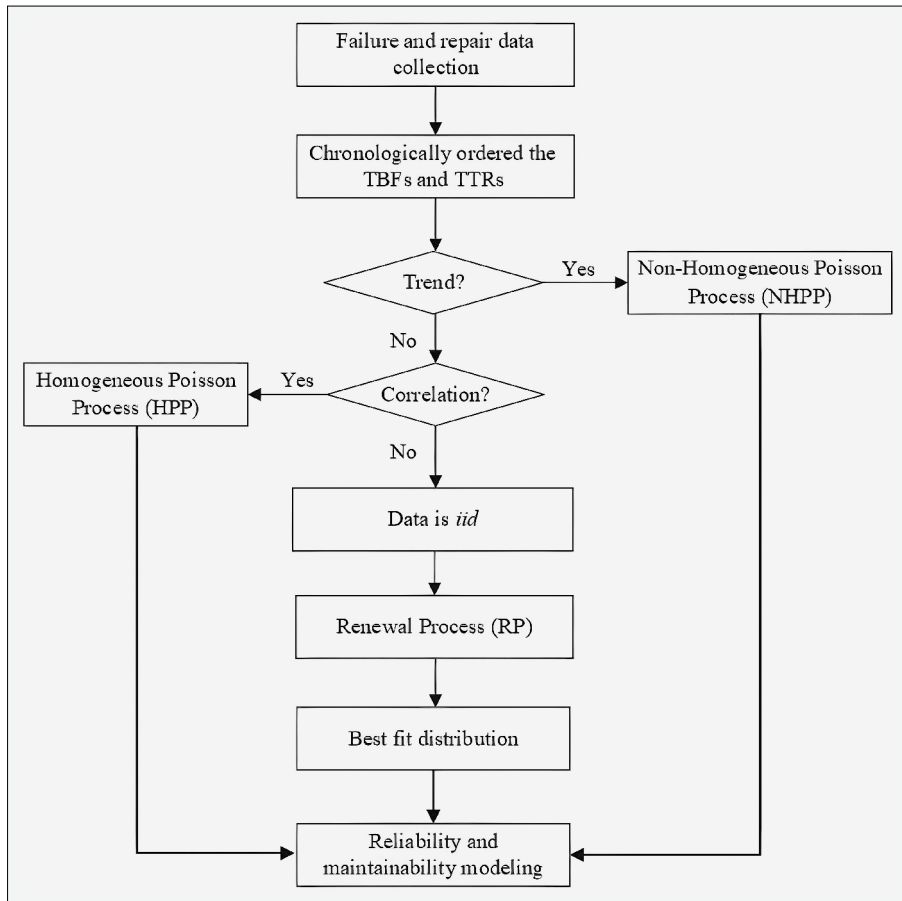


Figure 3. Process flowchart for the reliability and maintainability modelling

to model failures in repairable systems during certain phases of the system's life. However, because the arrival rate in an HPP is constant, it is inadequate for modelling system wear-out or growth, or for developing policies related to maintenance, overhaul, or trade-in (Muralidharan, 2008; Arnold et al., 2020).

For systems in which maintenance actions do not restore the system to a like-new condition, the non-homogeneous Poisson process provides a more realistic modelling approach. This framework relaxes the assumption of complete renewal by allowing the failure occurrence rate to vary as a function of time, thereby reflecting minimal or imperfect repair scenarios. As a result, NHPP models are particularly effective in representing systems whose failure behaviour evolves due to aging, operational stress, or maintenance interventions. The inclusion of a time-dependent intensity function enables the analysis of changing failure patterns throughout the system's operational life, especially in environments characterized by periodic inspection and maintenance activities (Saldanha et al., 2001; Asfaw and Lindqvist, 2015; Slimacek and Lindqvist, 2016; Brown et al., 2023; Yarmohammadi et al., 2022).

The selection of each modelling methodology is based on the type of data being collected. As mentioned in Figure 3, a testing procedure is conducted to perform trend and serial correlation tests on the data to assess the

attribute and procedure to model the data. If a trend is detected in the failure data, an NHPP approach (e.g. a power-law process) is employed to model the data. If a trend is not present, the data will be analyzed for the testing of the presence or absence of serial correlation. If serial correlation is evidenced, an HPP approach (e.g. a branching Poisson process) is assumed to model the data. If there is neither a trend nor serial correlation, the failure data are considered independent and identically distributed (iid), and the appropriate statistical model is fitted to the data. A Renewal Process (RP) and classical statistical methods treat the data as a counting process where the inter-occurrence times are iid with an arbitrary life distribution.

Goodness of Fit (GoF) measures the extent to which a statistical model fits a set of observed data. GoF indices quantitatively summarize the differences between the observed data values and those predicted by the model (Maydeu-Olivares and Garcí'a-Forero, 2010). In this test, the decision to reject or fail to reject the null hypothesis for each candidate distribution is made by comparing the test statistic to its critical value at a specified significance level (Joo et al., 2018). There are different GoF tests such as Anderson-Darling (Scholz and Stephens, 1987), Cramer-von Mises (Darling, 1957), chi-square (Albrecht, 1980), and Kolmogorov-Smirnov (Massey, 1951). In this paper, the Kolmogorov-Smirnov

(K–S) test was employed. This test compares the empirical cumulative distribution function of the data with the theoretical cumulative distribution function of various candidate models. If the p -value of the K–S test exceeds the significance level of 0.05 (or, equivalently, if the test statistic is less than the critical value), the null hypothesis is not rejected, and the distribution is considered an acceptable model (Joo et al., 2018).

This section continues with methods for assessing trends and correlations in failure data. The failure pattern of a device is referred to as a trend. Various methods exist to examine the presence or absence of trends in failure data. In graphical methods, if the time interval between system failures increases, the system exhibits a decreasing trend. Conversely, if the time interval between failures decreases as the device ages, the system shows an increasing trend. If there are no significant changes in the time between failures throughout the device's life, the device is considered stable and trend-free. Several graphical and analytical tests are available to assess trends in data. In graphical tests, the cumulative failure time is plotted against the cumulative number of failures. A straight line indicates no trend, while convex or concave curves suggest the presence of a trend. However, graphical methods have limited reliability. The **Military Handbook-189 (1986)** analytical method is one of the most widely used techniques for assessing trends in failure data. In this method, the U index is calculated using the **Equation 10** to evaluate the trend (Ascher and Feingold, 1984; Kumar and Kelefsjo, 1992; Saldanha et al., 2001):

$$U = 2 \sum_{i=1}^{n-1} \ln (T_n / T_i) \quad (10)$$

Where:

- n is the total number of failures,
- T_n is the time of the n th failure,
- T_i is the time of the i th failure.

Assuming the null hypothesis is a HPP, U has a Chi-squared (χ^2) distribution with $2(n-1)$ degrees of freedom. Serial correlation can be visually determined by plotting the i th TBF against the $(i-1)$ th TBF. If the plotted values present as a random scatter with no apparent trend, then the TBFs are free from serial correlation.

4. Results

This part of the study is dedicated to measuring the reliability, maintainability, and availability of powered support systems in Tabas Parvadeh Coal Mine. Parvadeh No. 1 Mine in Tabas has been built as the first mechanized coal mine in Iran, with the annual production capacity value between 1.2 to 1.5 million ton of coal. The Parvadeh coal area is located in an extent of approximately 12,000 square kilometres and consists of a geological reserve of 1.1 billion tons of coking coal. It is one

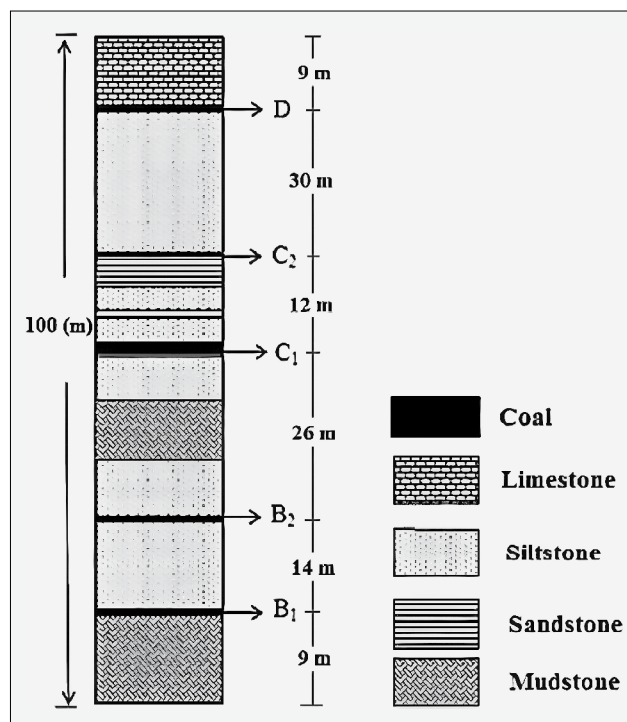


Figure 4. The coal basin stratigraphic column of Tabas Coal Mine (Molayemat and Mohammad Torab, 2017; Jozanikohan et al., 2021)

Table 2. The specifications of the panel W₃ (TPCC, 2024)

The length of tail gate (m)	1934	Extracted tonnage (tons)	1110555
The length of main gate (m)	2005	Date of start of extraction	Feb. 2022
Panel length (m)	207	Coal layer height (m)	2.2

of the four coal regions in Tabas, where it is the largest coking coal deposit in Iran. The location of the area lies 75 km south of Tabas city in the South Khorasan Province. The total number of coal seams in Parvadeh No. 1 is 15 coal seams. Within a 100-meter stratigraphic interval, five main seams of coal designations are identified as D, C1, C2, B1, and B2. **Figure 4** shows the stratigraphic column of Parvadeh coal basin in Tabas.

Among the coal seams in this area, only seam C1 is currently being mined. The mining operation utilizes the longwall backward method. This study evaluates the powered support systems used in the W3 panel. The specifications of this mining workshop are presented in **Table 2**. **Figure 5** illustrates the layout of the panels in the mine under study.

This paper aims to conduct a RAM analysis of the hydraulic FAZOS-10/28 POz powered roof supports (manufactured by FAZOS Company) used in the Parvadeh Tabas Coal Mine. In this context, the P means chock support, O refers to shield support, and z refers to roof support designed to operate with the roof caving system.

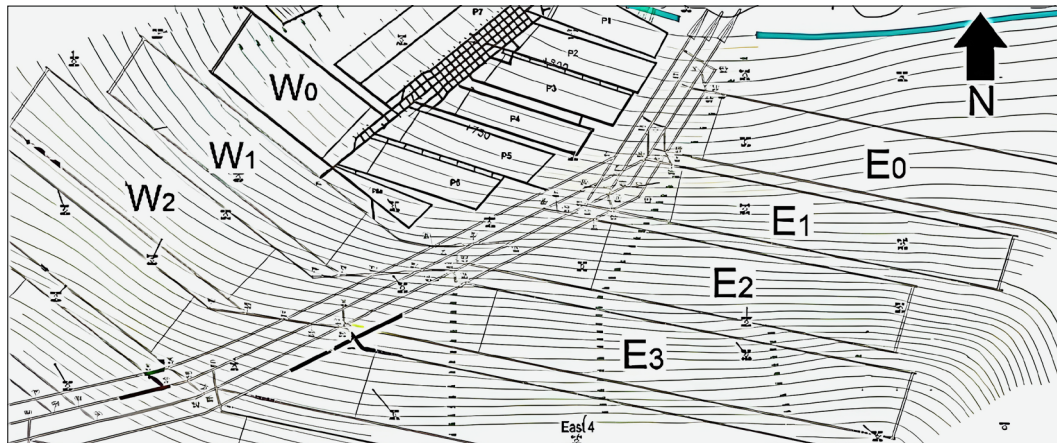


Figure 5. Layout of Various Panels in the Parvadeh-I Coal Mine (Aghababaei et al. 2019)

Table 3. The test statistic *U* at a 95% confidence level for TBF and TTR data

Subsystem	Data type	Mean	DoF	Calculated statistic <i>U</i>	Lower Chi ² value	Upper Chi ² value	Null-hypothesis	Trend	Modelling method
Mechanical	TBF	156.02	76	67.22	56.92	97.35	not rejected	no trend	RP
	TTR	0.50	102	92.12	79.7	126.57	not rejected	no trend	RP
Hydraulic	TBF	350.26	62	24.33	44.89	81.38	rejected	increasing trend	NHPP
	TTR	0.37	78	87.94	58.65	99.62	not rejected	no trend	RP

Table 4. The best-fit distribution for TBF and TTR data

Subsystem	Data type	Best-fit distribution	Estimated parameter
Mechanical	TBF	Lognormal	$\sigma = 1.14, \mu = 4.43$
	TTR	Lognormal	$\sigma = 0.85, \mu = -1.06$
Hydraulic	TBF	PLP	$\alpha = 0.81, \beta = 244.08$
	TTR	Lognormal	$\sigma = 0.77, \mu = -1.40$

This support system features a two-leg design, equipped with two telescopic hydraulic legs. The subassemblies of the support system are connected to each other through joint components and powered hydraulic elements.

A database of support system downtimes, collected over an 18-month period, was divided into two subsystems that impeded the machine’s ability to operate and progress. The parameters were time between failures (TBF), time to repair (TTR), cumulative TBF and TTR, and total hours of breakdown time for each system. The dataset for RAM Analysis was from daily reports over an 18-month period of mining operations. The data tables were designed to sort and arrays the data chronologically. The TBFs and TTRs when stoppages and repairs were incurred within each subsystem were categorized for reliability and maintainability (RAM) analysis.

After gathering and preparing the failure and repair data, trend and serial correlation tests were carried out with the intent to select suitable reliability and maintainability modelling methods. In consideration of the tests considered, the accompanying computed values of both

the test statistic (Equation 10) and the Chi² test statistic were used. Table 3 provides the results. According to Table 2, there was no trend in the TBF and TTR data of the mechanical subsystem and the TTR data of the hydraulic subsystem; furthermore, there was no correlation. Thus, these datasets were iid, and the renewal process (RP) method was decided on, for modelling reliability. The TBF data of the hydraulic subsystem did show an increasing trend; thus, the NHPP modelling method, based on the power-law process (PLP), was used for reliability modelling. EasyFit software (Schittkowski, 2002) was used to apply the Kolmogorov–Smirnov statistical test to identify the best-fitting distributions and their parameters. The results of the analysis of data and stated parameters are shown in Table 4. Using Table 3 and Equation 1, the reliability functions were calculated. The resulting reliability plots for subsystems are presented in Figure 6. The reliability of the powered support system as a whole is calculated using Equation 2 and is shown in Figure 7.

Using the calculated parameters for the best-fitted distributions of the TTR data, as shown in Table 3, the maintainability of both subsystems was plotted and presented in Figure 8. Furthermore, based on the serial configuration of the subsystems, the maintainability of the entire system was calculated using Equation 5 and illustrated in Figure 9.

Availability is the probability that equipment or a system is functioning satisfactorily under specified conditions. Conversely, it represents the likelihood that the system is neither failed nor undergoing repair when it is

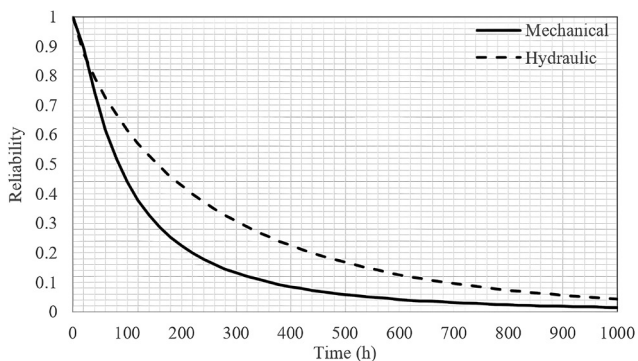


Figure 6. Reliability plots for subsystems of powered support system

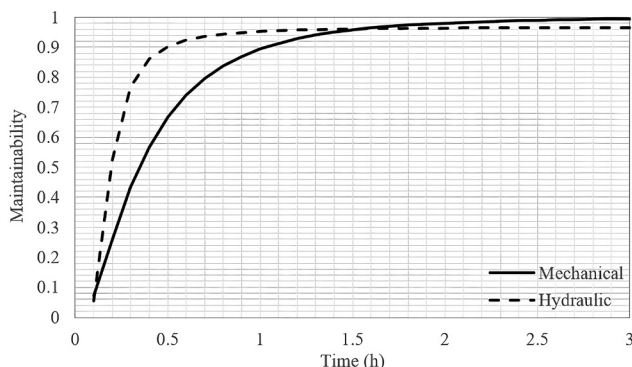


Figure 8. Maintainability plots for subsystems of powered support system

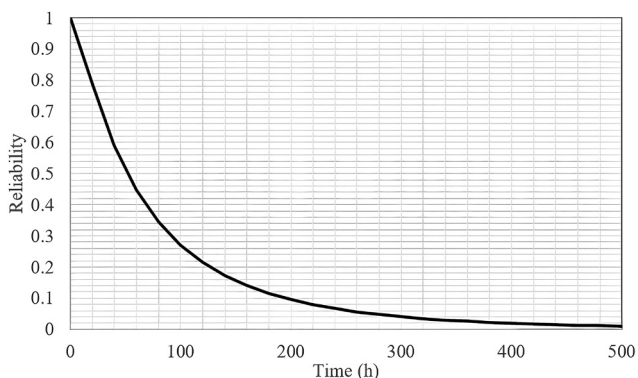


Figure 7. Reliability of the powered support system in Tabas Coal Mine

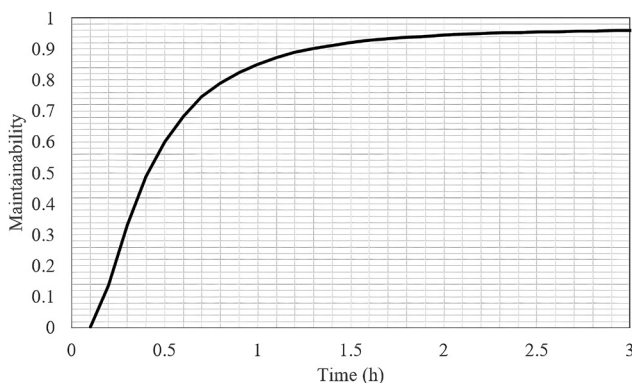


Figure 9. Maintainability of the powered support system in Tabas Coal Mine

Table 5. Availability of powered roof support’s subsystems

Subsystem	MTBF (min)	MTTR (min)	Availability (%)
Mechanical	9361.20	60	99.68
Hydraulic	21015.60	22.20	99.89

needed. To calculate the availability index, the mean time between failures and the mean time to repair are first determined. The availability index is then calculated using Equation 7. The results are presented in Table 5.

5. Discussions

Regarding the reliability analysis, the reliability of both subsystems decreased to 85% after 25 hours. After 25 hours, the reliability of the hydraulic subsystem remains higher than that of the mechanical subsystem throughout all time intervals. This indicates that the service life of the hydraulic subsystem is longer compared to the mechanical subsystem. For instance, the reliability of the mechanical and hydraulic subsystems drops to 50% at 85 hours and 155 hours, respectively. It should be noted that the reliability of both subsystems approaches zero at approximately 1100 hours. Due to the series configuration of the subsystems, failure in any one subsystem halts the overall operation. On the other hand, the powered support system functions only when both sub-

systems are functioning properly. As seen in Figure 6, the failure probability of the powered support system increases to 20% after only 19 hours of operation. The reliability of the entire system decreases to 50% within 52 hours. This downward trend continues until 300 hours, at which point the system reliability falls below 4%.

Referring to maintainability analysis, the maintainability at the beginning of the repair operation steadily increased. The maintainability of the mechanical and hydraulic subsystems reached 90% and 95%, respectively, after one hour of repair. This indicates that most failures in these subsystems are repaired within one hour. The maintainability plot of the whole system (see Figure 7) shows that 85% of failures require one hour to be repaired. The maintainability of the powered support systems exceeds 95% at 2.5 hours. Conversely, only 5% of failures require more than 2.5 hours to be repaired and return to their active state.

High availability for both subsystems is reported in Table 5. This indicates that both subsystems can operate consecutively at a high level of functioning without interference. Since the availability structure is a series configuration, the availability of the whole system can satisfy Equation 8 as follows:

$$\begin{aligned}
 Av_s &= \prod Av_i = Av_{Mechanical} \times Av_{Hydraulic} = \\
 &= 0.9968 \times 0.9989 = 99.58\%
 \end{aligned}$$

The availability analysis of powered roof supports indicates the probability of the powered support systems in Tabas Coal Mine operating under desirable conditions is 99.58%.

The results of the reliability and maintainability study indicate that the powered support system in the Parvadeh Mine operates with a significant probability of failure; however, these failures can be repaired promptly. This suggests that the preplanned tasks are designed to address the known causes of potential failures and reduce the frequency of premature failures. The preventive maintenance (PM) can be either condition-based or based on the historical data of equipment failures. In this study, the PM intervals were estimated using a reliability model. To achieve this, an 80% reliability threshold was considered to ensure both efficiency and performance. On the other hand, the probability that the equipment will continue operating without failure from the start of operation until the next PM action is at least 80%. Equivalently, this means that a maximum failure probability of 20% is accepted before performing preventive maintenance. Regarding the reliability analysis, the reliability of the powered support system in the Parvadeh mine decreased to 80% after approximately 18 hours. This means that if no maintenance is performed before the start of the fourth shift, the failure probability of the powered support system increases to 20%. In this approach the reliability-based maintenance intervals for mechanical and hydraulic subsystems is calculated as about 19 hours. Given that inspecting power retainers during coal mining operations might interrupt the continuity of the mining process, it is recommended that these inspections be conducted at the end of each work period, approximately every 22 hours. Following this schedule, the powered support system will achieve a reliability of approximately 76%. After preventive maintenance, the equipment will operate at full (100%) reliability at the start of the next working day.

6. Conclusions

This research assessed the reliability, maintainability, and availability of powered support systems with a focus on the Parvadeh Tabas Coal Mine in Iran. Initially, all main components and items of the support systems were classified into two serial subsystems: mechanical and hydraulic. Afterward, failure and repair data for each subsystem were collected and analyzed through an 18-month study. Results show that the reliability of both subsystems drops to zero around 1100 hours. Maintainability analysis showed that most failures of the support system are repaired within one hour. Availability analysis revealed that the overall system availability exceeds 99 percent. To establish an effective and manageable maintenance schedule for powered support systems, it was recommended that the preventive maintenance tasks be performed at the end of each working day.

The findings of this study help identify the causes and problems occurring during the operation of roof supports. They provide a basis for implementing improvements and corrective actions to enhance the effectiveness of the coal production process in mechanized long-wall mines. Nevertheless, this study has some limitations that can be addressed in future research. The failure behaviour of additional subsystems, such as control systems and sensors—both critical to machine performance—can be incorporated into RAM analysis. Moreover, studying the economic dimensions through the analysis of maintenance costs and coal production losses due to powered systems' failures is proposed for future research. Additionally, environmental factors such as dust, humidity, temperature, and terrain conditions that may affect support systems should also be considered in future studies.

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7. References

- Aghababaei, S., Jalalifar, H., & Saeedi, G. (2019). Prediction of face advance rate and determination of the operation efficiency in retreat longwall mining panel using rock engineering system. *International Journal of Coal Science & Technology*, 6(3), 419-429.
- Albrecht, P. (1980). On the correct use of the chi-square goodness-of-fit test. *Scandinavian Actuarial Journal*, 1980(3), 149-160.
- Andrzejczak, K. (2015). Stochastic modelling of the repairable system. *Journal of KONBiN*, 35(1), 5.
- Arnold, R., Chukova, S., Hayakawa, Y., & Marshall, S. (2020). Geometric-like processes: An overview and some reliability applications. *Reliability Engineering & System Safety*, 201, 106990.
- Ascher, H. and Feingold, H. (1984), *Repairable System Reliability*, Dekker, New York.
- Asfaw, Z.G. and Lindqvist, B.H. (2015). Unobserved heterogeneity in the power law nonhomogeneous Poisson process. *Reliab Eng Syst Saf.*, 134, 59–65.
- Balaraju, J., Govinda Raj, M., & Murthy, C.H.S.N. (2018). Estimation of reliability-based maintenance time intervals of Load-Haul-Dumper in an underground coal mine. *Journal of Mining and Environment*, 9(3), 761-770.
- Balaraju, J., Govinda Raj, M., & Murthy, C.S. (2020). Performance evaluation of underground mining machinery: A case study. *Journal of Failure Analysis and Prevention*, 20(5), 1726-1737.

- Basri, E. I., Abdul Razak, I. H., Ab-Samat, H., & Kamaruddin, S. (2017). Preventive maintenance (PM) planning: a review. *Journal of quality in maintenance engineering*, 23(2), 114-143.
- Bołoz, Ł., Rak, Z., & Stasica, J. (2022). Comparative analysis of the failure rates of shearer and plow systems—a case study. *Energies*, 15(17), 6170.
- Borska, B., & Szurgacz, D. (2024). Research and Simulation on the Development of a Hydraulic Prop Support System of Powered Roof Support to Increase Work Safety. *Methods and Protocols*, 7(2), 33.
- Brown, B., Liu, B., McIntyre, S., & Revie, M. (2023). Reliability evaluation of repairable systems considering component heterogeneity using frailty model. *Proceedings of the Institution of Mechanical Engineers, Part O: Journal of Risk and Reliability*, 237(4), 654-670.
- Cai, B., Zhang, Y., Wang, H., Liu, Y., Ji, R., Gao, C., ... & Liu, J. (2021). Resilience evaluation methodology of engineering systems with dynamic-Bayesian-network-based degradation and maintenance. *Reliability Engineering & System Safety*, 209, 107464.
- Darling, D. A. (1957). The kolmogorov-smirnov, cramer-von mises tests. *The annals of mathematical statistics*, 823-838.
- Ding, H., Yang, L., & Yang, Z. (2019). A predictive maintenance method for shearer key parts based on qualitative and quantitative analysis of monitoring data. *IEEE access*, 7, 108684-108702.
- dos Santos Silva, F. J., Viana, H. R. G., & Queiroz, A. N. A. (2016). Availability forecast of mining equipment. *Journal of Quality in Maintenance Engineering*, 22(4), 418-432.
- Duffuaa, S. O., & Raouf, A. (2015). Preventive maintenance, concepts, modeling, and analysis. In *Planning and Control of Maintenance Systems: Modelling and Analysis* (pp. 57-94). Cham: Springer International Publishing.
- e Costa, C. A. B., Carnero, M. C., & Oliveira, M. D. (2012). A multi-criteria model for auditing a Predictive Maintenance Programme. *European Journal of Operational Research*, 217(2), 381-393.
- Gorai, A. K., Kumar, P., & Patel, A. K. (2017). Reliability analysis of the main conveyor system in underground coal mine to determine the maintenance schedules. *International Journal of Mining and Mineral Engineering*, 8(3), 207-233.
- Guan, Z., Wang, S., Wang, J., & Ge, S. (2023). Longwall Face Automation: Coal Seam Floor Cutting Path Planning Based on Multiple Hierarchical Clustering. *Applied Sciences*, 13(18), 10242.
- Hoseinie, S. H., Ahmadi, A., Ghodrati, B., & Kumar, U. (2013). Reliability-centered maintenance for spray jets of coal shearer machine. *International Journal of Reliability, Quality and Safety Engineering*, 20(03), 1340006.
- Jakkula, B., Mandela, G. R., & Chivukula, S. M. (2022). Reliability, availability and maintainability (RAM) investigation of Load Haul Dumpers (LHDs): a case study. *International journal of system assurance engineering and management*, 13(1), 504-515.
- Jakkula, B., Mandela, G. R., & Tripathi, A. K. (2024). Reliability analysis of complex repairable systems using artificial neural networks: A case study on underground mining machinery. *Precis. Mech. Digit. Fabr*, 1(4), 189-200.
- Joo, M., Doh, J., & Lee, J. (2018). Determination of the best distribution and effective interval using statistical characterization of uncertain variables. *Journal of Computational Design and Engineering*, 5(3), 358-367.
- Joo, M., Doh, J., & Lee, J. (2018). Determination of the best distribution and effective interval using statistical characterization of uncertain variables. *Journal of Computational Design and Engineering*, 5(3), 358-367.
- Jozanikohan, G., Nosrati Abarghoeei, M., & Sedighi, H. (2021). Geochemical study of rare earth elements content in Tabas Coal Ash, Parvadeh Coal Mine. *Journal of Mining and Environment*, 12(4), 1143-1153.
- Kahraman, S., Rostami, M., & Dibavar, B. (2023). Evaluating machine utilization times for roadheaders used in coal mines: Regression and artificial neural network analyses. *Scientific Mining Journal*, 62(3), 141-151.
- Kazanin, O. I., Sidorenko, A. A., Sidorenko, S. A., Ivanov, V. V., & Mischo, H. (2022). High productive longwall mining of multiple gassy seams: Best practice and recommendations. *Acta Montan. Slovaca*, 27, 152-162.
- Kumar, P. (2016). Reliability, availability and maintainability analysis of the main conveyor system in underground coal mine: a case study of Churcha (RO) mine (Doctoral dissertation), National Institute of Technology Rourkela.
- Kumar, U. and Kelefsjfo, B. (1992), Reliability analysis of hydraulic system of LHD machine using the power low process model, *International Journal of Reliability Engineering and System Safety*, Vol. 35 No. 3, pp. 217-224.
- La Roche-Carrier, N., Dituba Ngoma, G., Kocaefe, Y., & Erchiqui, F. (2020). Reliability analysis of underground rock bolters using the renewal process, the non-homogeneous Poisson process and the Bayesian approach. *International Journal of Quality & Reliability Management*, 37(2), 223-242.
- Masir, R. N., Ataei, M., Sereshki, F., & Qarahasanlou, A. N. (2021). Availability simulation and analysis of armored face conveyor machine in longwall mining. *Rudarsko-geološko-naftni zbornik*, 36(2), 69-82.
- Massey Jr, F. J. (1951). The Kolmogorov-Smirnov test for goodness of fit. *Journal of the American statistical Association*, 46(253), 68-78.
- Maydeu-Olivares A, and Garcí'a-Forero C. (2010). Goodness-of-Fit Testing, *International Encyclopedia of Education* (2010), vol. 7, pp. 190-196.
- MIL-STD-2173, 1986, Reliability Centered Maintenance, Department of Defense, Washington, DC, USA.
- Molayemat, H., & Mohammad Torab, F. (2017). Evaluation of coalbed methane potential in Parvadeh IV coal deposit in central Iran using a combination of MARS modeling and Kriging. *Journal of Mining and Environment*, 8(2), 305-319.
- Morshedlou, A., Dehghani, H., Hoseinie, S.H., (2014). Reliability Analysis of powered supports in Tabas Mechanized Coal Mine, The 2nd National Iranian Coal Congress, Shahrood, Iran.
- Mouli, C.; Chamarthi, S.; Chandra, G.; Kumar, V. Reliability Modeling and Performance Analysis of Dumper Systems in Mining by KME Method. *International Journal of Current Engineering and Technology*. 2014, 255–258

- Muralidharan, K. (2008, July). A review of repairable systems and point process models. In *ProbStat Forum*, 1(1), 26-49.
- Peng, S. (2019). Longwall mining. CRC Press.) (Mitchell, G. W. (2009). Longwall mining. Australasian coal mining practice, 340-373.
- Prasad, P. V. N., & Rao, K. R. M. (2008, January). A study on optimal age replacement of dozer engines. In 2008 Annual Reliability and Maintainability Symposium (pp. 31-36). IEEE.
- Rahimdel, M. J., & Ghodrati, B. (2022). Remaining useful life improvement for the mining railcars under the operational conditions. *International Journal of Mining, Reclamation and Environment*, 36(1), 46-67.
- Said, U. (2021). A Methodology for Maintenance Evaluation and Improvement of Repairable Systems in a Mine (Doctoral dissertation, Toronto Metropolitan University).
- Saldanha, P. L., De Simone, E. A., & e Melo, P. F. (2001). An application of non-homogeneous Poisson point processes to the reliability analysis of service water pumps. *Nuclear engineering and design*, 210 (1-3), 125-133.
- Saldanha, P. L., De Simone, E. A., & e Melo, P. F. (2001). An application of non-homogeneous Poisson point processes to the reliability analysis of service water pumps. *Nuclear engineering and design*, 210(1-3), 125-133.
- Saldanha, P. L., De Simone, E. A., & e Melo, P. F. (2001). An application of non-homogeneous Poisson point processes to the reliability analysis of service water pumps. *Nuclear engineering and design*, 210(1-3), 125-133.
- Sarkhel, S., & Dey, U. K. (2015). Reliability modelling of side discharge loader for availability estimation and maintenance planning in underground coal mines. *Int J Sci Eng Res*, 6, 847-854.
- Schittkowski, K. (2002). EASY-FIT: a software system for data fitting in dynamical systems. *Structural and Multidisciplinary Optimization*, 23(2), 153-169.
- Scholz, F. W., & Stephens, M. A. (1987). K-sample Anderson-Darling tests. *Journal of the American Statistical Association*, 82(399), 918-924.
- Slimacek, V. and Lindqvist, B.H. (2016). Nonhomogeneous Poisson process with nonparametric frailty. *Reliab Eng Syst Saf.*, 149, 14–23.
- Stebnev, A. V., Mukhortikov, S. G., Zadkov, D. A., & Gabov, V. V. (2017). Analysis of operation of powered longwall systems in mines of SUEK-Kuzbass. *Procedia*. 2012. No. 16, 1264-1268.
- Szurgacz, D. (2021). The effectiveness of the use of a powered roof support in the light of research and analysis. In *E3S Web of Conferences* (Vol. 278, p. 01007). EDP Sciences.
- Szurgacz, D. (2024). Research on the Strain and Stress of Powered Roof Support Construction to Limit Damage. *Machines*, 12(12).
- Szurgacz, D., Borska, B., Diederichs, R., & Zhironkin, S. (2022a). Development of a Hydraulic System for the Automatic Expansion of Powered Roof Support. *Energies*, 15(3), 680.
- Szurgacz, D., Borska, B., Zhironkin, S., Diederichs, R., & Spearing, A. J. (2022). Optimization of the load capacity system of powered roof support: A review. *Energies*, 15(16), 6061.
- Szurgacz, D., Trzop, K., Gil, J., Zhironkin, S., Pokorný, J., & Gondek, H. (2022b). Numerical Study for Determining the Strength Limits of a Powered Longwall Support. *Processes*, 10(3), 527.
- Tabas Parvadeh Coal Company (TPCC). (2024). Report of the Technical Office of the No. 1 Tabas Coal Mine.
- Thunberg, H. (2016). Reliability-based Maintenance Plan for Underground Drilling Rigs.
- Uth, F.; Polnik, B.; Kurpiel, W.; Baltés, R.; Kriegsch, P.; Clause, E. An innovate person detection system based on thermal imaging cameras dedicate for underground belt conveyors. *Min. Sci.* 2019, 26, 263–276.
- Vashistha, S., Kumar Agrawal, A., Siddiqui, M. A., & Chattopadhyaya, S. (2019, November). Reliability and maintainability analysis of LHD loader at Saoner Mines, Nagpur, India. In *IOP Conference Series: Materials Science and Engineering* (Vol. 691, No. 1, p. 012013). IOP Publishing.
- Vayenas, N., & Wu, X. (2009). Maintenance and reliability analysis of a fleet of load-haul-dump vehicles in an underground hard rock mine. *International Journal of Mining, Reclamation and Environment*, 23(3), 227-238.
- Wang, D., Li, R., Cheng, J., Zheng, W., Shen, Y., Zhao, S., & Wu, M. (2023). Research on the calculation model and control method of initial supporting force for temporary support in the underground excavation roadway of coal mine. *Axioms*, 12(10), 948.
- Wang, H., & Pham, H. (2006). Reliability and optimal maintenance. London: Springer London.
- Wang, J., Zhang, R., Jiang, R., Zhang, X., Li, K., Song, S., ... & Wu, J. (2025, July). Reliability model and analysis of long wall coal shearer machine. In *Third International Conference on Advanced Materials and Equipment Manufacturing (AMEM 2024)* (Vol. 13691, pp. 497-510). SPIE.
- Xiaofeng, L. I. U. (2025). Fault diagnosis and maintenance of electromechanical equipment of coal mine roadheader. *Coal Mine Modernization*, 34(1), 47-51.
- Yarmohammadi, M., Afshar, A., Mahmoudvand, R., & Nasiri, P. (2022). Predicting intensity function of nonhomogeneous Poisson process. *Journal of Statistical Modelling: Theory and Applications*, 3(2), 39-50.
- Zhou, D., Zhang, X., & Zhang, Y. (2017). Reliability analysis of the traction unit of a shearer mechanism with response surface method. *Journal of Mechanical Science and Technology*, 31(10), 4679-4689.

SAŽETAK

RAM analiza hidrauličkih samohodnih sustava podgrade u podzemnim ugljenokopima sa širokočelnim otkopavanjem

Rudarske aktivnosti u podzemnim ugljenokopima, osobito pri primjeni metode širokočelnoga otkopavanja, zahtijevaju neprekidno odvijanje proizvodnoga procesa i izbjegavanje zastoja jer svako neplanirano zaustavljanje može dovesti do gubitka stabilnosti i urušavanja krovine. S obzirom na visoku razinu mehanizacije u podzemnoj eksploataciji ugljena primjena hidrauličkih samohodnih sustava podgrade predstavlja osnovnu sigurnosnu mjeru za osiguranje stabilnosti radnoga prostora. Kako bi se osigurala kontinuirana proizvodnja, povećala učinkovitost rada te istodobno smanjili troškovi uzrokovani zastojima i kvarovima opreme, nužno je provesti sustavnu procjenu pouzdanosti, održivosti i dostupnosti (RAM) sustava podgrade. Cilj ovoga rada jest provedba RAM analize hidrauličkih samohodnih sustava podgrade u stvarnim radnim uvjetima. U tu svrhu analiziran je hidraulički sustav samohodne podgrade kao tehnički sustav sastavljen od više funkcionalnih podsustava. Rezultati pokazuju da podatci o vremenu između kvara (TBF) i vremenu popravka (TTR) većine podsustava slijede obnovljivi (*renewal*) proces, dok podatci o TBF-u hidrauličkoga podsustava slijede nehomogeni Poissonov proces (NHPP). Pouzdanost analiziranih podsustava smanjila se na približno 85 % nakon 25 sati rada. Analiza održivosti pokazala je da se većina kvarova hidrauličke samohodne podgrade otklanja unutar jednoga sata. Nadalje, izračunana dostupnost sustava iznosi 99,58 %, što upućuje na vrlo povoljne radne uvjete. Ipak, radi uspostave učinkovitoga, normativno utemeljenoga i operativno jednostavnoga plana održavanja preporučuje se provođenje preventivnoga održavanja na kraju svakoga radnog dana.

Ključne riječi:

podzemna eksploatacija ugljena, hidraulička samohodna podgrade, pouzdanost, održivost, raspoloživost

Author's contribution

The author prepared the whole work.