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Reliability-based maintenance scheduling of powered supports in Tabas mechanized coal mine

A. Morshedlou[1], H. Dehghani[1*], S. H. Hoseinie[2]

1. Department of Mining Engineering, Hamedan University of Technology, Hamedan, Iran
2. Division of Operation and Maintenance Engineering, Luleå University of Technology, Sweden

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**Corresponding author: dehghani@hut.ac.ir (H. Dehghani)*

Abstract

Utilizing the gathered failure data and failure interval data from Tabas coal mine in two years, this paper discusses the reliability of powered supports. The data sets were investigated using statistical procedures and in two levels: the existence of trend and serial correlation. The results show that the powered supports follow the Gamma reliability function. The reliability of the machine decreases to almost zero after 520 operation hours and after 80 hours the probability of failure of powered supports increases to 60 percent. The failure rate of powered support shows an improving behavior and therefore a decreasing failure rate. In the beginning of the process, the failure rate is 0.021 failures per hour. This reaches the rate of 0.012 after a sudden decrease, thence forward on a gently decreasing rate and after 100 hours gets to the rate of 0.01. Regarding the maintenance policy and to protect the machine's operation continuity, preventive maintenance strategy can be chosen. The reliability of the discussed machine can be maintained on a descent level by inspecting and controlling the parts in short term intervals. With regard to reliability plots of powered supports operation, preventive reliability-based maintenance time intervals for 80% reliability levels for powered supports is 15 hours.

Keywords: *Powered Support, Reliability, Failure, Maintenance.*

1. Introduction

The importance of fossil fuels is increasing day by day due to their limited resources; therefore, great attention has been drawn to the industrial equipment related to them. Coal is one of the important fossil fuels, which has many applications in the steel industry and power generation. Nowadays most of the world's coal is mined by mechanized long-wall mining method. The most important equipment used in these mines are Drum Shearer, Armoured Face Conveyor (AFC), Beam Stage Loader (BSL), Powered Supports and Conveyor Belt. Figure 1 shows a mechanized long-wall mine. After the coal is cut by drum shearer, materials are loaded on AFC to be delivered to BSL. As seen in the Figure 1, extraction operation is conducted under the series of powered supports. Powered supports are responsible to maintain the stops and pushing forward AFC and Drum Shearer to keep the production process continuous. Powered supports play a significant role in the production operation. Therefore, their reliability is important to keep mine production at the desired level, to maintain smooth operation, and to achieve better production conditions.

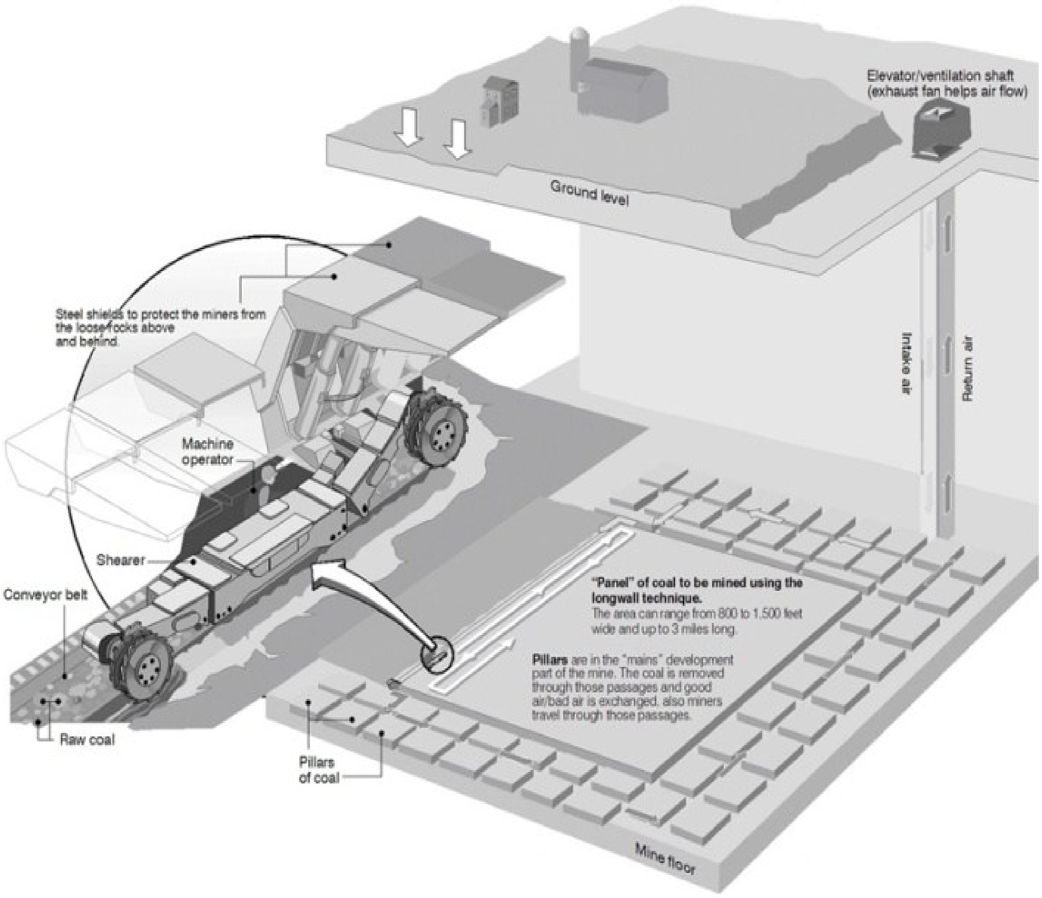

Figure 1. Locating and components of long-wall mining.

More researches have been conducted on reliability and maintenance of mining equipment. The application of reliability engineering in mining industries has been conducted since 1960 [1]. The initial studies have mostly used the qualitative approach and they only consist of descriptions about the machine failures and production delays. Mathematical and quantitative analysis methods have been used since the end of the 1980s. With the developments in new mining equipment, reliability analysis also became more complicated. Because of the two mentioned reasons above, more reliability studies is required on the mining equipment. The reliability studies on long-wall mining equipment during the last two decades are being briefly reviewed in Table 1.

Table 1. Studies conducted in the field of reliability engineering of long-wall mining.

Author	Year	Subject of study
Ivko et al. [2]	1973	Operation of powered supports
Walker [3]	1982	AFC
Mason [4]	1983	Long-wall equipment
Mandal & Banik [5]	1996	Long-wall equipment
Gupta eta al. [6]	2006	Drum shearer
Gupta & Bhattacharya [7]	2007	Conveyor belt
Bing-yuan et al. [8]	2009	Production system
Hoseinie [1]	2011	Drum shearer
Hoseinie et al. [9]	2011	water system
Hoseinie et al. [10]	2011	electrical system
Hoseinie et al. [11]	2011	hydraulic system
Hoseinie et al. [12]	2011	haulage system
Hoseinie et al. [13]	2012	cable system
Hoseinie et al. [14]	2012	Drum shearer

Because of the significant role of powered supports in the production and extraction process in long-wall mines, a fundamental study on reliability of powered supports was conducted.

2. Powered supports

Powered supports system was designed due to the development of steel set supports (friction prop and hydraulic prop). Powered supports system uses hydraulic props. There is a hard cap on top of the props and the bottom of them is connected to AFC. By the advancement of the face, the props of the powered supports system (which are controlled remotely), push the AFC towards the face. Then the hydraulic props lift the cap and press to roof. Thus by utilizing this powered supports system there is no need to separate the pieces of AFC. Powered supports also maintain the stop. Figure 2 shows the powered supports in Tabas coal mine [15].

Figure 2. Powered supports in Tabas coal mine.

3. Reliability analysis process

The quantitative reliability analysis techniques use real failure data (obtained, for instance, from a test program or from field operations) in conjunction with suitable mathematical models to produce an estimation of product or system reliability. Three stochastic processes are generally used for reliability analysis of repairable systems [14]:

(1) Homogeneous Poisson process (HPP);
(2) Renewal process (RP); and
(3) Non-homogeneous Poisson process (NHPP).

To determine which process is the best analysis method for available data, one must perform a trend analysis and a serial correlation test to determine whether the data are independent and identically distributed (iid) or not. Regarding to results of the trend analysis, if the assumption that the data are identically distributed is not valid, then classical statistical techniques for reliability analysis may not be appropriate; therefore, a non-stationary model such as non-homogeneous Poisson process (NHPP) must be fitted. The presence of no trend and no serial correlation in failure data reveals that the data are independent and identically distributed (iid) and therefore the classical statistical techniques are the best way for reliability modeling. The trend test can be made both analytically and graphically [1, 16]. There are five analytical methods for testing the presence of trend; Reverse Arrangement Test, Military Handbook Test, Laplace Test, likelihood-ratio test and Area Test. Military Handbook Test as one of the applicable analytic tests is a better method at finding significance when the choice is between no trend and a NHPP Power Law model. This test checks the trend presence by calculating the test statistic U (Equation 1) [17]:

$$U = 2\sum_{i=1}^{n} Ln(Tn / Ti) \qquad (1)$$

where, n is total number of failures, Tn is time of the nth failure and Ti time of the ith failure. Under the null hypothesis of a HPP, the test statistic U is chi-squared distributed with 2(n-1) degrees of freedom. If the null hypothesis is rejected at 0.05 level of significance, it means that the TBFs data have a trend and therefore, are not identically distributed [1].

In graphical methods, the trend test involves plotting the cumulative failure numbers against the cumulative time to failure. If the plotted points lie (or approximately) on a straight line, then the data are trend free and identically distributed (id). A test for serial correlation was also done by plotting the ith TBF against the (i-1)th TBF, i = 1, 2,..., n. If the plotted points are randomly scattered without any pattern, it means that there is no correlation in general among the TBFs data and the data are independent.

The Kolmogorov–Smirnov (K-S) test is classically used for the validation and selection of the best-fit distribution. The failure data analysis process, which is used in this study for selecting the best reliability modeling method, is shown in Figure 3. Further explanations will be presented in the case study part [19].

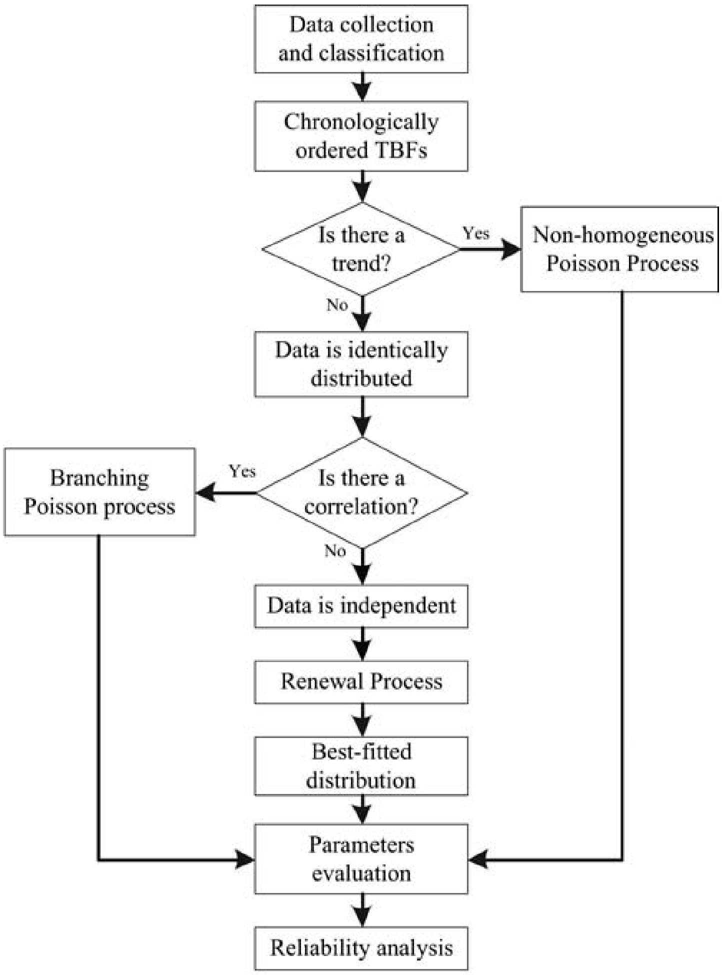

Figure 3. Reliability analysis process [18].

4. Failure rate analysis

Failure Rate (FR) of each machine in their life time follows a specific trend. Failure rate is significant in reliability engineering and maintenance management due to its importance in evaluating the effectiveness of the system and its operational status. Each machine spent three specific periods in its lifetime as shown in Figure 4. This curve is known as bathtub curve in reliability engineering [20, 21].

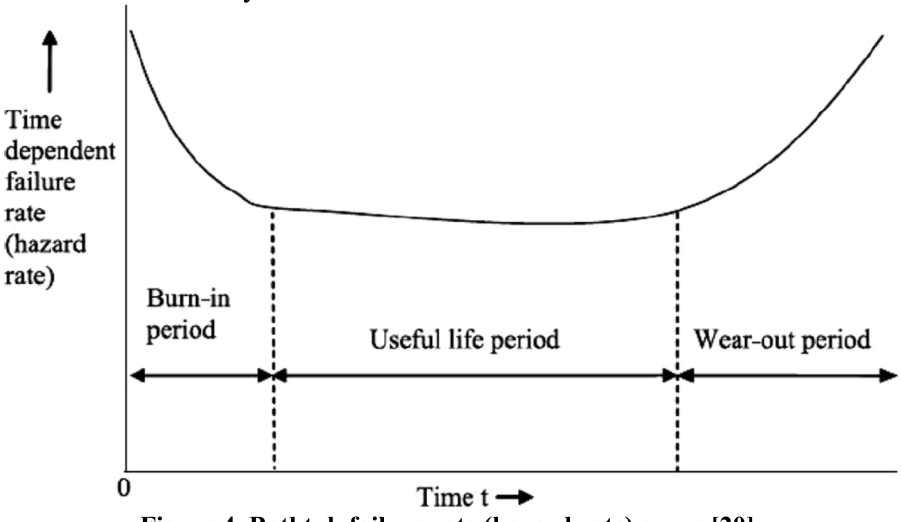

Figure 4. Bathtub failure rate (hazard rate) curve [20].

Determination of the failure rate of a machine provides a decent perspective of its operational condition and preparation level. Also, the determination of this index allows users to estimate the remaining useful life of the system as well as the exhaustion rate of the machine. With the help of this index, failure of one part of the equipment and optimum time to replace it can be predicted. In addition to these, the failure rate curve could be performed in order to extract valuable information that follows [22]:

- Prediction of the optimum time and the cost of the warranty period
- Prediction and management of spare parts
- Estimation of the end of the start time period.

5. Case study

The Tabas coal mine is located in the central desert of Iran and is the largest long-wall coalmine of Iran. The extent of these areas is about 30 thousand square kilometers. Parvadeh region covers an area of about 1200 square kilometers located 70 kilometers south of the city of Tabas. The region has the largest coal reserves in the country and its coal reserves are estimated about 1.1 billion tones [1].Currently the mine has a nominal annual capacity of 750 thousand tons of coal concentrate per year. To mobilize and exploit this mine, 2600 billion rials have been invested and 1,200 jobs have been created. To evaluate the reliability of powered supports, failure data from two years of operation of this machine in the Tabas coal mine are being used.

6. Data analysis

After data collection, the validation of the iid nature of the TBF data was performed. First, military handbook analytic trend test were applied on the data. The computed values of the test statistic for the both machines are given in Table 2.

Table 2. The results of analytic test on powered supports.

Parameters	Powered supports
Degree of freedom	12
Calculated U	6.98
Rejection of null hypothesis is at 5 percent level of significance	5.23
Modeling method	Renewal process

7. Reliability analysis

In order to calculate the best-fit distribution curve, Easyfit software was used. The Kolmogorov-Smirnov (K-S) test, shape of the distribution function and mean time to failure were used for selecting the best distribution among the top choices. The result of data analysis and best-fit distributions are illustrated in Table 3.

Table 3. The results of data analysis and best-fit distributions.

Modeling method	Best fit distribution	parameters	
Renewal process	Gamma	$\alpha = 0.784$	$\beta = 115.31$

The reliability and failure curve of powered supports was plotted using the above-mentioned, distributions and its parameters, as illustrated in Figures 5 and 6.

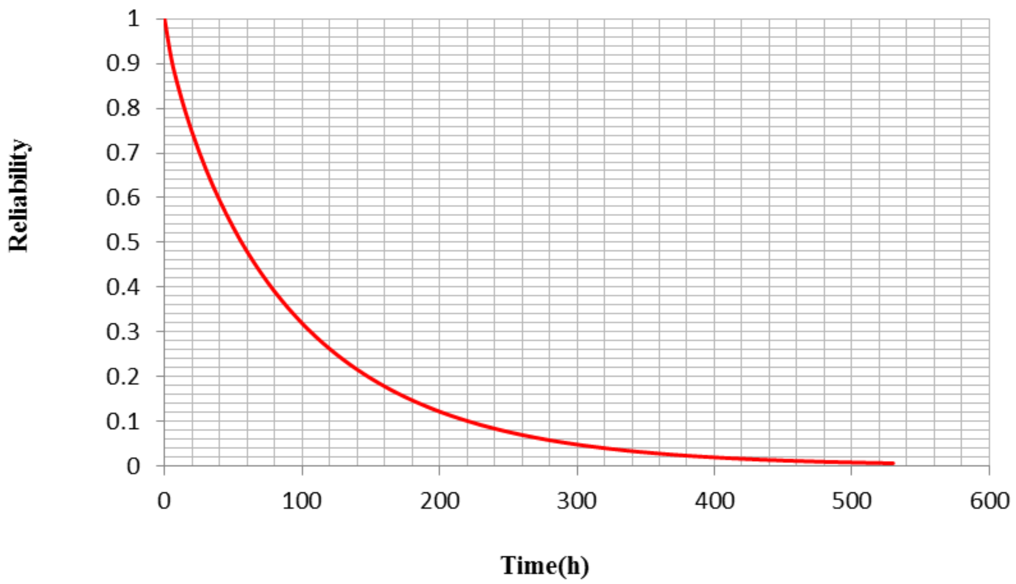

Figure 5. Reliability plot of powered supports.

As it can be seen in this figure, the reliability of the powered supports reduces to zero in a period of about 520 hours. There is a 60-percent chance that the powered supports operation will not fail for the first 80 hours of operation. It shows that powered supports need serious attention and have high potential for causing the production stoppages, which is, the worst and the most critical threat for production continuity in long-wall mines.

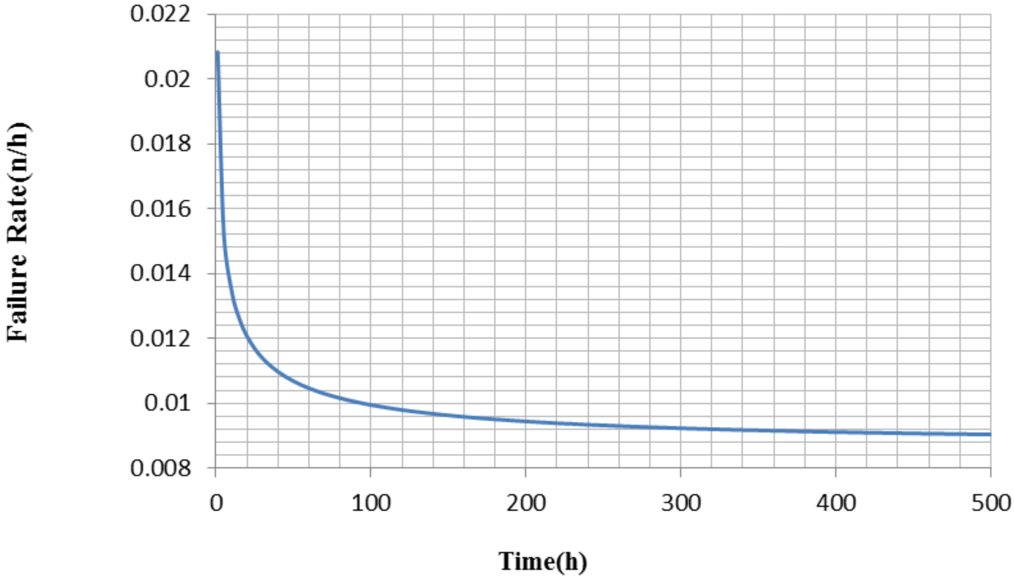

Figure 6. The Failure rate plot of powered supports.

As can be seen, the failure rate in the powered supports100 h was defined as burn-in time. The FR of this machine starts from 0.021 and decreases to 0.012 at the end of the burn-in time. After 100 hours, the FR decreases with very low rate and approaching to be constant. Therefore, this machine, which has passed 200 hours of its useful life, is in good operational condition.

8. Maintenance scheduling

After a lot of investigation, due to the low operational hours of the machines, the only reason for not getting the desired production rate detected that is the lack of the proper maintenance schedule. One of the best ways to provide an appropriate performance in mining projects is to use the reliability engineering approach. The reliability-based preventive maintenance (PM) seems to be the best policy to keep the system reliability at an acceptable level. In this approach, the preventive maintenance intervals, estimated by the reliability model are used to get the desired performance and operational reliability.

With regards to reliability plot shown in Figure 5, reliability-based PM time intervals for powered supports of Tabas coal mine was calculated and presented in Table 4. In many engineering operations, 80% is selected as the best practical value for efficiency and performance evaluation. In this paper, the desired level of reliability of powered supports operation of Tabas coal mine was allocated at 80% for the scheduling preventive maintenance.

According to Table 4 to have an appropriate, reliable operation and optimizing the maintenance schedule, it is suggested that the powered supports of Tabas coal mine should be checked and serviced every 15 hours operation. For each maintenance operation, production process must be stopped. This policy would reduce the system stops due to the maintenance operation.

Table 4. Reliability-based preventive maintenance time interval.

Reliability-based preventive maintenance time intervals (h)	Equipment	Reliability level (%)		
		70	**80**	**90**
	Powered supports	25	15	5

Finally, using the above-suggested schedule, the reliability of the powered supports operation is reasonably improved. As shown in Figure 7, after each preventive maintenance operation, the reliability of powered supports operation increases related to the maintenance tasks. It is obvious that the improved reliability plot has a slight reduction rate. According to Figure 4, because the powered support is in the second period of its operational function, the machine has a low failure rate.

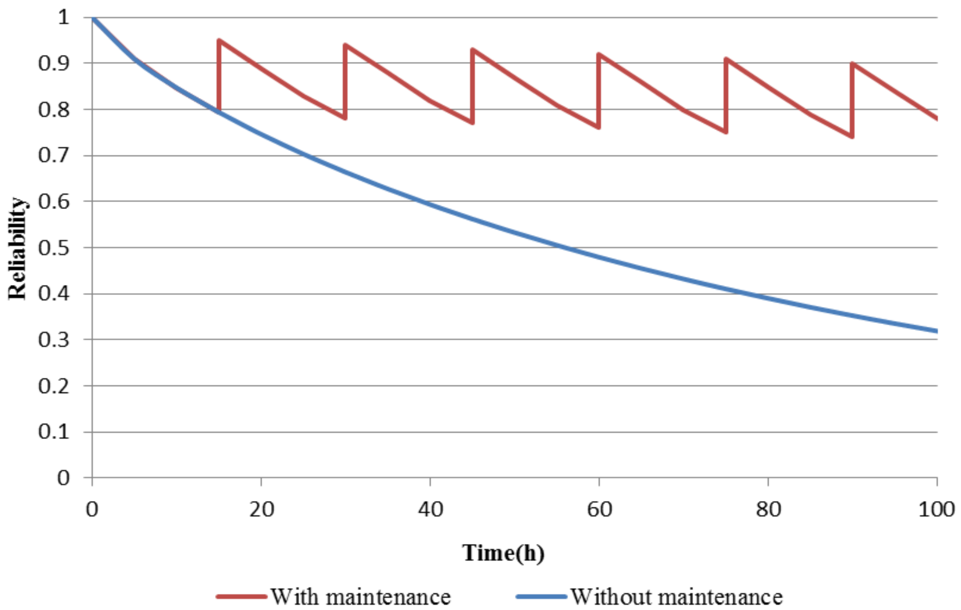

Figure 7. Effects of suggested preventive maintenance schedule on reliability of powered supports operation.

9. Conclusions

Because of the significant role of powered supports in the continuity of production and extraction process in long-wall mines, assessing the reliability of these mines is essential. In this paper, the powered supports data of Tabas Coal Mine were evaluated and analyzed. Finally, the results are as follows:

- The data analysis showed that the TBFs data of powered supports followed the gamma distribution.

-The reliability of the powered supports reduces to zero in a period of about 520 hours. There is a 60-percent chance that the powered supports operation will not fail for the first 80 hours of operation.

- The FR of powered supports starts from 0.021 and decreases to 0.012 at the end of the 100 hours. After that, the FR decreases with very low rate and approaching to be constant.

- To maintain the continuity of operation of equipment, prevention maintenance can be used. According to the reliability analysis, the reliability-based maintenance interval for 80% reliability level for powered supports operation was calculated. This means that powered supports must be checked and inspected every 15 hours.

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تحلیل قابلیت اطمینان نگهدارنده‌های قدرتی در معدن زغال‌سنگ مکانیزه طبس

عمید مرشدلو[۱]، حسام دهقانی[۱*]، سید هادی حسینی[۲]

۱- دانشکده مهندسی معدن، دانشگاه صنعتی همدان، ایران

۲- بخش مهندسی عملیات و تعمیر و نگهداری، دانشگاه صنعتی Luleå، سوئد

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* نویسنده مسئول مکاتبات: dehghani@hut.ac.ir

چکیده:

در این مقاله، قابلیت اطمینان نگهدارنده قدرتی با استفاده از داده‌های خرابی و زمان بین خرابی‌های ثبت‌شده در طی دو سال در معدن زغال‌سنگ طبس، مورد بررسی قرار گرفته است. داده‌ها با استفاده از روش‌های آماری و طی دو مرحله شامل بررسی وجود روند و وجود همبستگی مورد ارزیابی قرار گرفتند. نتایج تحلیل‌ها نشان می‌دهند که تابع توزیع قابلیت اطمینان نگهدارنده قدرتی از تابع گاما تبعیت می‌کند. قابلیت اطمینان نگهدارنده قدرتی پس از ۵۲۰ ساعت عملیات پیوسته به نزدیکی صفر می‌رسد و عملکرد آن متوقف خواهد شد و پس از طی حدود ۸۰ ساعت، احتمال خرابی آن به بیش از ۶۰ درصد می‌رسد. نگهدارنده قدرتی دارای رفتار خرابی رو به بهبود و نرخ خرابی کاهشی است. نرخ خرابی در زمان شروع کار برابر با ۰/۰۲۱ خرابی در ساعت بوده و با نزول سریع پس از ۲۰ ساعت، به ۰/۰۱۲ می‌رسد. از این زمان به بعد نرخ خرابی با یک روند کاهشی ملایم، در زمان ۱۰۰ ساعت به مقدار ۰/۰۱ می‌رسد. با توجه به سیاست تعمیر و نگهداری و حفظ پیوستگی در سیستم تولید، رویکرد تعمیر و نگهداری پیشگیرانه انتخاب شد. قابلیت اطمینان دستگاه با توجه به برنامه تعمیر و نگهداری انتخاب‌شده می‌تواند در یک سطح مناسب از پیش تعیین‌شده حفظ شود. با توجه به نمودار قابلیت اطمینان نگهدارنده قدرتی برای حفظ میزان قابلیت اطمینان دستگاه در ۸۰ درصد، فاصله زمانی تعمیر و نگهداری پیشگیرانه ۱۵ ساعت تعیین شد.

کلمات کلیدی: نگهداری قدرتی، قابلیت اطمینان، خرابی، تعمیر و نگهداری.