Assessment of Reliability-Related Measures for Drum Shearer Machine, a Case Study

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ABSTRACT
Longwall mining is one of the most continuous and productive mining methods. Efficiency of this method is directly affected by the involved machineries and systems. The drum shearer plays an important role in the face productivity and the mine life. Therefore, monitoring of this machine can lead the whole extraction operation to a high level of production and safety. There are several reliability-related measures for evaluation of the mining equipment. Availability, utilization, production efficiency and overall production effectiveness are the most important measure which can help us in this way. In this paper, the production and failure data of a drum shearer machine in Parvade coal mine in Iran have been collected from whole of one longwall panel during a two-year period. The mentioned reliability-related measures have been calculated based on the total uptime and downtime of the machine. The results showed that, the studied drum shearer is in good availability level. However, it has average production efficiency, very low utilization and very low overall equipment effectiveness. Also, high waiting and idling time raises from other machineries during the extraction process, was recognized as the main reason for the current low productivity of shearer machine in mine.

INTRODUCTION
Since 2000, global coal consumption has grown faster than any other fuel. The high demand for coal is mainly raised from power plants, steel industries and cement manufacturers [1, 2]. This high level of demand forces the mining companies to produce the coal more and more. Referring to this condition, the market competition and supply-demand stress are directly loaded to coal mining machineries and production systems. Therefore, the proper and reliable function of the mining equipment is essential in obtaining a stable and continuous production.

Longwall mining as a most applied coal mining method is very well-known because of the high level of continuity and productivity. The production chain in longwall mining consists of five main components; drum shearer/plug, armored face conveyor (AFC), power supports, stage loader and main conveyor belt. The drum shearer is known as the most important component due to its direct role in coal cutting and production. Therefore, its reliability is very important in maintaining mine production at a desired level. Hence, assessment of reliability-related measures is essential in monitoring and mapping of operational condition of machine and removing the existing problems.

During the past three decades, the reliability of longwall systems and equipment has been studied by a few researchers. In 80s the reliability analysis of power supports, AFC and the general production system of longwall faces have been typically reported by Haskayne and Farmer [3], Mason [4], Walker [5] and Shpiganovich and Maslovskaya [6]. Mandal and Banik [7] have done a comprehensive study on production loss (production risk), reliability
and availability of equipment of six longwall faces in four Indian coal mines. They studied the AFC, shearer, stage loader and belt system as the components of the production process and presented the risk of production based on the failures of each subsystem. Gupta et al. [8] analyzed the longwall shearer’s reliability and maintenance using the fault tree technique. The purpose of their study was to find weak operational links in the shearer machine. In another study on longwall coal mines, Hao et al. (2009) studied the reliability of the production system of a longwall face in a Chinese mine. Recently, Hoseinie et al. [9-11] have developed a reliability models for the subsystems and whole of the drum shearer machine and have suggested the maintenance programs for them.

In all above mentioned reliability studies in longwall mines, mainly reliability has been analyzed and focused on. In this article, a comprehensive study is down on all operational and production parameters of drum shearer in Parvade coal mine in Iran to find out a holistic view about the machine condition and system health.

RELIABILITY-RELATED MEASURES
Traditionally, mining organizations focus on the key measures of availability and utilization to evaluate the equipment performance. But it should be noticed that these measures alone are insufficient to make informed decisions about equipment strategies [12]. Therefore, a set of measures are needed to obtain a holistic view about the operational condition of mining machineries. The main practical measures which are called reliability–related measures are discussed in this section [13].

Availability
Availability is defined as a proportion of time during which an item or equipment is capable of performing its specified functions (uptime) divided by a total number of hours in a given period [12-15]. In other words, availability is simply defined as the proportion of time the equipment is able to be used for its intended purpose [12, 13] and is expressed by Equation (1):

\[ AV = \left( \frac{TH - DT}{TH} \right) (100) \] (1)

Where,
AV is the availability,
TH is the total hours,
DT is the downtime expressed in hours

Utilization
A piece of equipment that is in an ‘up-state’ (capable of performing the work it was designed to do) is rarely used throughout all of its available time. For example, a given unit may be designated as a back-up/standby unit, or be idle due to stage of the operational cycle or due to a lack of operator [15]. Utilization, called also ‘use of availability’. In other words, the proportion of the time that the equipment is available that it is used for its intended purpose is defined as the utilization [15]. Utilization is a common performance measure in the mining industry. This measure is calculate by Equation (2)

\[ U = \left( \frac{TH - DT - SH}{TH - DT} \right) (100) \] (2)

Where,
SH is the standby hours
**Production Efficiency**
This measure is described simply as the ratio of actual output from a machine (which satisfies the required quality standards) to its rated output during the period of its operation [13, 15]. Production efficiency is expressed by:

\[
PE = \left( \frac{AP}{TH - DH - SH} \right) \left( \frac{RC}{RC} \right) \times 100
\]

Where,
- \(PE\) is the production efficiency,
- \(AP\) is the actual production,
- \(RC\) is the rated capacity expressed in units per hour.

**Overall Equipment Effectiveness**
This measure gives an overall view of how effectively a machine is being used and is calculated by Equation 4. Overall equipment effectiveness is closely linked to the accounting measure, return on assets, and provides us with an indication of how well we are using our equipment [15].

\[
OEE = (AV) \times (PE) \times (U)
\]

Where,
- \(OEE\) is the overall equipment effectiveness.

As an example, if availability, utilization and production efficiency were all equal to 90%, we might be tempted to think that we are doing a pretty good job, but in fact, the overall equipment effectiveness can be equal to 73%. This means we are only getting 73% of the total potential output out of current equipment. Increasing this figure will mean that we can produce more with the same equipment, or potentially, could produce the same amount with less equipment [15].

**CASE STUDY: PARVADE COAL MINE-IRAN**

**General information**
The Parvade coal mine is located in the eastern Iran and is the largest longwall coal mine of Iran. It is planned to have 27 panels in its lifetime. The most suitable seam for mining (called C1) has 1.8m thicknesses and is extracted by retreat longwall method using a double-drum shearer. The length of studied longwall face is 215m and panel length is 1200m. At the time being, the 3rd panel of this mine is being extracted. Technical characteristics of drum shearer of Parvade coal mine is as follows: 600kW total power installed, supply voltage 1100V, cutting head diameter 1600mm, web depth max. 800 mm, advance speed in cutting 0-9m/min, weight on the conveyor is approximately 35.2 tons. Figure 1 shows the studied drum shearer in Paravade mine.

**Data collection**
In this paper, for calculation of reliability-related measures of the drum shearer, failure and performance data from archived records along with direct observations collected from 1.10.2007 to 1.10.2009 were used. The database consisted of three main data layers (Figure 2):

1) daily operation and production reports (were recorded by shift supervisors);
2) mechanical maintenance reports (recorded by mechanical supervisors and repair men);
3) electrical maintenance reports (recorded by electrical supervisors and service personnel).

These layers were arranged, merged and used as the main database of analysis. After this stage, the time between failures (TBFs), uptime, downtime and standby time of shearer were calculated. The available data was related to the first and second years of production of Parvade mine; therefore, the machine has been studied from the beginning of its life. And the analysis will present the real behavior of machine from the start time.

Figure 1: Drum shearer of Parvade coal mine, Iran

Figure 2: Structure of data collection and parameters calculation in this study
Calculations and Analysis

After the data collection, classification and filtering, the main needed input parameters for reliability-related measures were calculated. It should be noticed that, since the current shearer should be used at least in ten panels of the mine before replacement, all measures have been calculated for whole time period of one panel. Therefore, the all calculations present an average view of machine condition during its working in first panel.

According to available data, the first panel in Parvade longwall mine has been extracted during the 960 working shifts. Each shift is seven hours and 1 hour is considered for shift changing and employees transfer (totally equal to 8 hours). Then total hours (TH) are 6720.

The performance analysis of shearer during the 960 working shifts shows that the machine has have a widely variable operational output and performance (Figure 3). As can be seen in Figure 3, the cutting rate is varying from very low values up to four meters per minute with average of 1.16 m/min. Also, the cutting hours per shift are variable from less than one hour to almost 7 hours with average of 2.74 hours.

![Figure 3: Cutting rate and cutting hours of drum shearer in Parvade coal mine](image)

Downtime is an even more complex concept for calculation, since it depends on several factors and is interpreted in a variety of manners [15]. Usually, in calculating this parameter it generally the shutdown times are counted and used. Shutdowns include all outages due to equipment failures and/or planned maintenance actions (regardless of whether they are corrective, preventive, or predictive in nature) [15]. In this study, two set of data were used for calculating the total downtime of shearer; time to repair (corrective maintenance) and weekly and monthly services. The data analysis showed that the
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machine had 133.7 hours stoppages for corrective maintenance and 114.2 hours for services or doing some inspections. Therefore, total downtime hours (DH) for studied period were \( \approx 248 \).

For calculating the standby hours (SH), the main parameter which has been considered is the interaction of AFC and drum shearer during the cutting, loading and hauling process in face. As common problem in longwall faces, sometimes, shearer cuts a lot of coal in a short period of time but AFC can't haul it with same rate, then system blocks. In these cases, shearer waits for AFC to empty the working face, then starts. This problem can be seen also in power supports movements or stage loader performance. Because, all of these machineries are placed in a series production chain. In this study, we call all these kind of delays as "idling" time and classify it in the standby hours. The available data showed that, in Paravde mine, there was 3846.5 standby hours (SH) which is considerably high value.

The final input parameters for the main calculations are actual production and rated capacity (planned production). The mine production database showed that the actual production of this panel was 0.743 million tons. The rated capacity of machine was 450 tons per hour. However, current machine has capability of 1500 tons production per hour, the mine managers and planners have set the 400 ton/hour, to slowly warm up the production and for introducing the personals with new mechanized systems which are installed in mine. In the next panels this value has been improved and came up.

Regarding the above explanations, the basic and calculated input parameters for assessing of reliability-related measures are summarized in Table 1.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total studied working shifts</td>
<td>960</td>
</tr>
<tr>
<td>Total hours (TH)</td>
<td>6720</td>
</tr>
<tr>
<td>Total time to repair</td>
<td>133.7</td>
</tr>
<tr>
<td>Total servicing and inspection hours</td>
<td>114.2</td>
</tr>
<tr>
<td>Downtime (DT)</td>
<td>248 hours</td>
</tr>
<tr>
<td>Operation hours (cutting hours)</td>
<td>2625.5</td>
</tr>
<tr>
<td>Standby hours (SH)</td>
<td>3846.5</td>
</tr>
<tr>
<td>Actual production (AP)</td>
<td>743000 ton</td>
</tr>
<tr>
<td>Rated capacity (RC)</td>
<td>400 ton/hour</td>
</tr>
</tbody>
</table>

**Table 1:** Summary of basic and calculated input parameters

**Reliability-related measures**

After calculation of the input parameters using the available data from mine operation, now, the main measures can be assessed using the Equations (1) to (4). The values of calculated measures are shown in Figure 4. As can be seen in this figure, due to very low failure time, the availability of the shearer is very high and equal to 96.3%. Nevertheless, the utilization is 36.7%. Regarding the high availability, the data shows that the standby hours is very high in Parvade mine which decreases the utility in considerable level. As discussed above, standby hours are caused by interaction of shearer with other machines in production process. Therefore, for increasing of the utility, the mine mangers should specially improve or remove of the sources of idling in production face.

The production efficiency which represents the ability of machine in achieving the production goal, is in average level in Parvade mine. The 62.9% value for this measure shows that the shear machine could satisfy the 62.9 of expected production in an expected
period of time. As it is obvious from the PE formula, the main reasons of this reduction are
the machine downtime and high standby hours.

Figure 4: Reliability-related measures of drum shearer in Parvade coal mine

The last and the most important measure is OEE which is very low in studied machine. As
discussed before, OEE is a very simple metric to immediately indicate the current status of
a production process and also a complex tool allowing us to understand the effect of the
various issues in the manufacturing process and how they affect the entire process [17].
Therefore, the very low value of this measure shows that the whole production process in
mine face should be reviewed in a profound way. Because, the main reasons of this low
OEE is the huge waiting and idle time of drum shearer which considerably caused by other
machineries in the longwall production chain or the geological problems.

CONCLUSION

Regarding the continuous production process in longwall mines, the productivity analysis
and monitoring the system effectiveness is an applicable approach to achieve a healthy
and perfect production. The drum shearer as a heavy cutting machine affects the whole
production components in face and also is affected by other equipment as well.

In this paper, four well-known reliability-related measures; availability, production
efficiency, utilization and overall equipment effectiveness were applied for evaluation of the
operational condition and the productivity of longwall shearer in Parvade mine, Iran. A
huge set of field data involving the failure and production records were used to calculation
of the needed parameters.

The investigations showed that the studied machine is working in a good availability level.
Because, it is a new machine just passing its burn-in time period of life. Nevertheless, the
utilization is very low. The further analysis showed that the waiting and idle time of this
machine is so high and 1.5 time more than the effective coal cutting hours. In fact this
machine is waiting for the other equipment in longwall face and should stop for a long time
because there is a missed component in production line. Therefore, the best way for
improving the utilization of drum shearer in Parvade mine we is to have a robust plan for
monitoring the other equipment of the production process too.

The multiplication of the three factors which one of them is considerably low, causes a
very low OEE value for studied machine. As a brief result, it is obvious that the shearer
machine individually is in good operational condition but as a component of a production
process, its productivity is really low and is in unacceptable level. It means that we have a
huge amount of production loss and related costs in which are not sensible for us.
Acknowledgement

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References