Reliability modelling of draglines for availability estimation and maintenance planning

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ABSTRACT

Walking draglines are the dominant production equipment for overburden excavation in surface strip mining operations. Given that the average unit cost of production by dragline is US$ 3.5/m^3 for coal, the one percent increase in the machine productivity can provide significant benefits to the industry. Effective use of draglines requires a thorough knowledge of machine productivity, efficiency, and reliability. Production engineers must be guided by appropriate strategies to preserve the structural and operating performance of draglines.

Modelling dragline reliability is a valuable tool to estimate the dragline's long-term preventive and corrective maintenance times and availabilities, to develop preventive maintenance plans, and to make future projections about the machine's performance. This paper presents the development of reliability models for two walking dragline units of Marion 7820 (40 yd^3) and Page 736 (20 yd^3), which have been operating in the Tunçbilek open cast coal mine of Turkish Coal Enterprises (TKI) in Turkey.

Research methodology encompasses four main stages: (i) obtaining the input data and analysis; (ii) fitting probability distribution to failures of draglines; (iii) estimating model parameters; (iv) making future projections and suggestions for developing modified preventive maintenance plans and availability predictions.

Monthly maintenance records, operating hours and mechanical and electrical failure hours between 1998 and 2009 were acquired from the company. The number of mechanical and electrical failures is treated as a non-stationary Weibull process with intensity function of the failure rate. Then, the operating hours with 90 percent reliability for a given time period are evaluated in order to predict availability of the draglines. Also, maintenance hours per each breakdown are plotted and duration of breakdown throughout the years is analysed. Moreover, the expected number of failures for a given period of time is computed for planning the maintenance. The results indicated that Page 736 is more reliable than the Marion 7820 model.

INTRODUCTION

Walking draglines have been extensively used in strip mining operations for overburden removal because of their economic advantages over truck-shovel excavation. They are massive and expensive machines as illustrated in Figure 1, with a typical machine weight of over 4000 tonnes and a capital investment of up to US$100 million. The bucket volume varies between 90–120 cubic metres and the dragline is operated continuously except for preventive and corrective maintenance actions (Dayawansa, 2004). Economic and sustainable mining operations require maximised dragline productivity, as well as a minimised downtime of draglines. Thus, availability estimation and preventive maintenance planning are critical for sustainable surface mining operations.

Maximum productivity and machine longevity could be achieved through efficient excavation to sustain the overall productivity of a surface mine. The efficient use of draglines entails maximising the dragline payload (bucket load), minimising duty cycle time, and increasing service time (availability and machine longevity). It was claimed (Lubbert, Mead & Wiltowski, 2001) that, with most large dragline mining operations in coal mines, one second reduction in the average cycle time would uncover an additional US$500 000 worth of coal in a year at US$36.71 per tonne in 2001 (ECCOU, 2003). In addition, there is a direct relationship between productivity gains and machine wear and tear problems. Thus, increasing the bucket payload and/or operating the machine with higher speed may cause problems of excessive stresses, machine fatigue, and shorter machine life. As the suspended load is increased, the increased productivity benefits are large enough to compensate for the decreased machine availability. However, if the suspended load increases above a critical value, the increased productivity can no longer compensate for the increased downtime (Guan et al., 1999). Since availability is a critical performance indicator in dragline operation, increased downtime is undesirable and it is a major problem in mining operations. It was claimed by Townson, Murthy & Gurgenci (2003) that the loss of revenue associated with dragline downtimes could be substantial, and in extreme cases it could reach up to US$1 million/day.

In an effort to improve availability and utilisation, the two significant parameters affecting dragline performance, probabilistic approaches have also been pursued. A simulation model for analysing alternative dragline deployment schemes for different geological and mining conditions was developed by Bandopadhyay & Ramani (1985). The results showed that the variables with the greatest effect on productivity are the availability and cycle time. Stress monitoring along the boom of the dragline was studied by Guan et al. (1999). One extremely important finding through their work has been the identification of the importance of the operating performance on machine availability. The cycle time and the idle time frequency distribution of the dragline data as operating were analysed in the field (Rai, Trivedi & Nath, 2000). The effect of dragline load and operator efficiency on dragline availability, maintenance and output was investigated and the model optimised the dragline load to maximise the yield per unit time (Townson, Murthy & Gurgenci, 2003). This study employed mathematical modelling using statistical field data obtained from different maintenance databases. Reduction of metal fatigue in dragline booms via improved operator feedback was studied by McInnes & Meehan (2005). The authors developed a set of algorithms to provide feedback in real-time to the operator at the end of each cycle. The results showed that significant causes of extra fatigue include swinging the bucket out of the boom plane, high-frequency dynamic vibration, and extreme digging conditions. It is anticipated that providing real-time feedback will significantly reduce machine downtime without affecting productivity. The kinematic and dynamic models of dragline front-end components for analysing stress and moment distribution along the boom for efficient excavation were developed (Demirel, 2006).

The main objective of this study is to develop reliability models to project the availability or breakdown times of the draglines and provide an aid in developing appropriate preventive maintenance plans for the draglines, as to maximise their availability and utilisation, and ultimately their productivities.

METHODOLOGY

This study presents the development of reliability models for two walking draglines, Page 736 (20 yd^3) and Marion 7820 (40 yd^3) utilised in Tunçbilek open cast lignite coal mine in Turkey, based on historical breakdown and availability data from 1998 to 2009. The Tunçbilek open cast lignite coal mine is governed by Western Lignite Enterprise Establishment Directorate of Turkish Coal Enterprises in Turkey. The establishment has 229 million tonnes of total lignite reserve, approximately 84% of which could be extracted by surface mining methods. Annual production capacity of the establishment is 6.1 million tonnes achieved by dragline and shovel-truck systems.

The research methodology essentially entails: (i) pre-processing of the acquired data; (ii) finding the distribution fit for the data; (iii) estimating distribution parameters analytically; (iii) finding reliabilities; (iv) projecting potential failure times; (v) proposing maintenance plans based on the results.

Reliability modelling

Dragline failure probability distribution

Reliability modelling in this study was initiated by acquiring mean time between failure data, which is the time elapsed between failures in hours, for Page 736 (20 yd^3) and Marion 7820 (40 yd^3) walking draglines. Sample sizes were selected to be around one thousand (1037 data for Marion 7820 and 923 data for Page 736) considering the multiple failure modes of these complex machineries. Power cut induced failure data were eliminated from the sample. Since mean time between time data was originally taken in days, they were converted to hours and ordered chronologically. After the pre-processing was completed, the best fit for the probability distribution of the data set was found using the easy fit programme. The Kolmogorov-Smirnov test was applied to determine the goodness of the fit. Two-parameter Weibull distribution, given by Equation 1 (Smith, 1993), was found to be the best fitted distribution for both Marion 7820 and Page 736 draglines mean time between failures data sets.

$$F(x) = 1 - e^{-(\frac{x}{\alpha})^{\beta}} \tag{1}$$

Weibull distribution has two parameters: scale parameter (α) and shape parameter (β).

Subsequent failure projections

Reliabilities of draglines for different operating hours were projected for dragline operation and mine planning purposes. For this purpose the Weibull distribution function was solved for operating hours for different reliability values ranging from 0.10 to 0.99. Obtained reliability results were tabulated in Table 2 and illustrated in Figure 4.

Table 2 Reliability estimates for different operating hours

Reliability	Page 736 hours	Marion 7820 hours
0.01	481.09	325.89
0.10	211.14	153.44
0.25	115.55	88.40
0.50	50.71	41.62
0.75	17.84	16.01
0.90	5.41	5.37
0.99	0.33	0.42

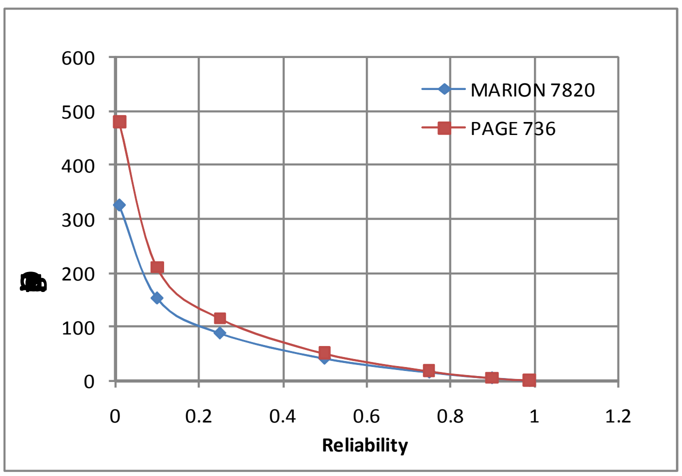

Figure 4 Reliability estimates vs operating hours

Although both draglines have low operating hours (5 hours) at high reliability (90%), Marion 7820 dragline has lower operating hours when compared to the Page 736 for the same reliability.

Also, the number of failures over time was given by a discrete uniform process for both draglines. This implies that the probability of experiencing n failures over the first t units of operational time is given by discrete uniform distribution given by Figure 5.

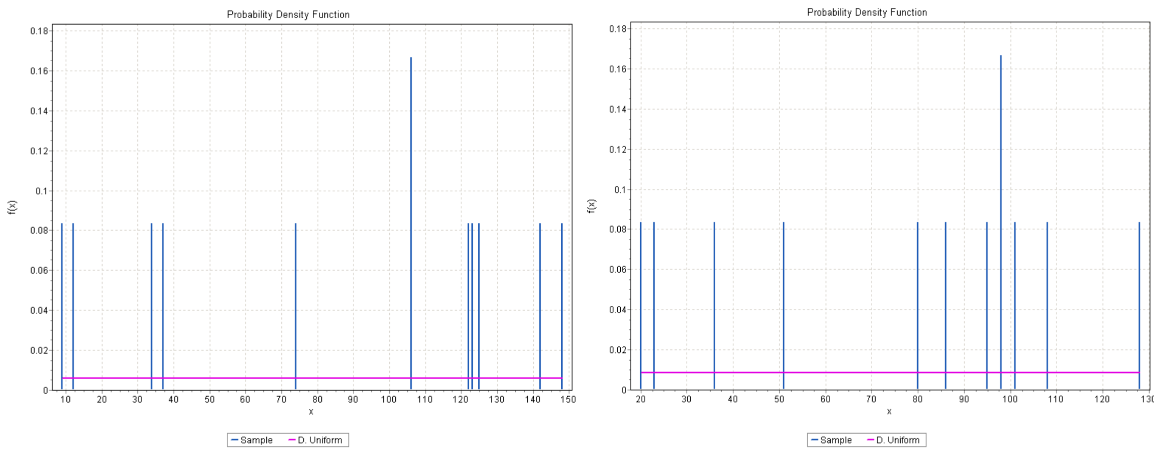

Figure 5 Probability density function for Marion 7820 (left) and Page 736 (right) failure rates

Maintenance modelling and planning

The draglines are supposedly subjected to i) shutdown maintenance; (ii) planned maintenance; and (iii) corrective or non-planned maintenance. In this study only corrective maintenance data were utilised because of the lack of shutdown and planned maintenance actions. Corrective maintenance is performed to fix and to restore a failed component to an operational state (Townson, Murthy & Gurgenci, 2003). Total corrective maintenance time with respect to operating hours on an annual basis was observed for the Page 736 and Marion 7820 draglines and the results are presented in Figures 6 and 7.

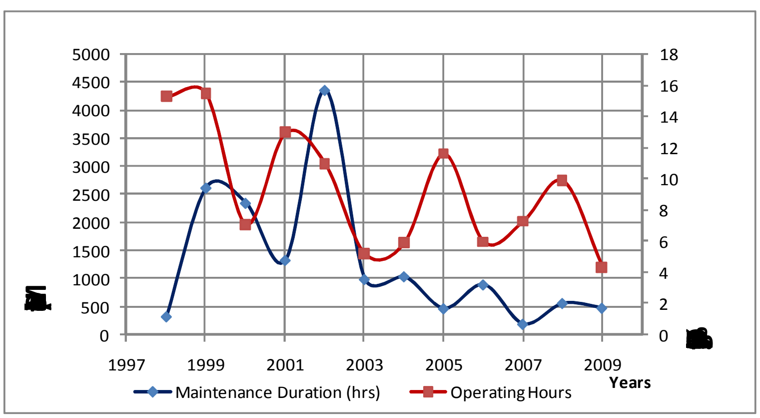

Figure 6 Maintenance duration vs operating hours during 1998–2009 for Page 736

For Page 736 dragline, both maintenance duration and operating hours have fluctuating curves for 1998–2009 as it can be seen in the Figure 6. Maximum maintenance time was experienced in the year 2002 and then it started to decline. After 2005 it almost maintained a constant corrective maintenance rate. On the other hand, maximum operating hours at 90 percent reliability was achieved in 1999 and then it followed a fluctuating curve between 4–15.5 hours.

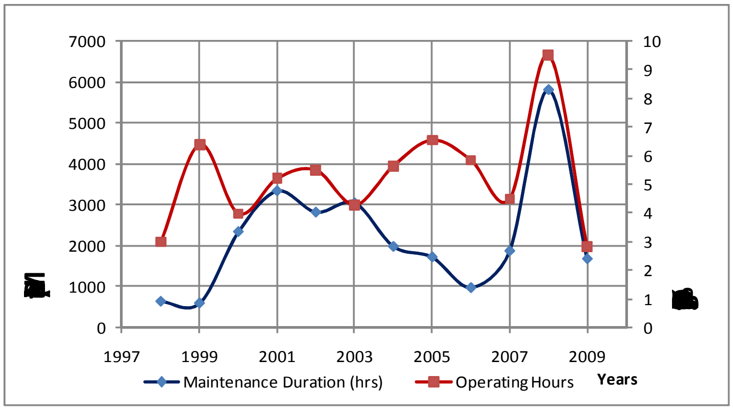

Figure 7 Maintenance duration vs operating hours during 1998–2009 for Marion 7820

For Marion 7820 dragline, maintenance duration and operating hours do not follow a certain trend for 1998–2009 as it can be seen in the Figure 7. The annual maintenance time and operating hours individually had followed an opposite trend with respect to each other until 2007 as it was expected. Then they both increased sharply from 2007 to 2008 and it started to decline from 2008 to 2009. Maximum maintenance time and operating time were observed in the year 2008 at 5800 hours and 9.51 hours at 90% reliability, respectively. The total maintenance times per each breakdown rate for both draglines were also analysed on an annual basis. On the other hand, maintenance times per breakdown for Marion 7820 has changed slightly from 10 to 75 during 1998–2007, and in 2007 it increased dramatically up to 170 hours and then started to decline in 2008.

RESULTS AND DISCUSSION

In this study mean time between failures and maintenance data of two (out of nine) walking draglines in Turkey were utilised to develop reliability models and significant results were obtained. The number of data acquired was around one thousand excluding energy cut induced failures. Component failures were not analysed separately yet any failure caused downtime for the dragline was considered as a failure. The failure rate determined by the shape parameter ($\beta < 1$ for both cases) was found to be decreasing failure rate. Considering the ages of the draglines it was expected to be increasing failure rate, however, new technologies used in maintenance or more awareness may caused the failure rate is subject to decrease in recent years. The reliability model results presented that Page 736 (20 yd^3) is seemed to be more reliable and less likely to fail when compared with Marion 7820 (40 yd^3) although Page 736 was started to be operated 6 years earlier than Marion 7820. This may be caused by the difference between bucket capacities. The operating hours without failure range from 41 to 51 hours with 50 percent reliability.

CONCLUSION

The results of the study provide insight into dragline operations in a Turkish Coal Enterprises governed mine in Turkey. This study showed that reliability perception by mining engineers is essential in order to increase reliability and hence the productivity. This implies that both draglines are not operated efficiently and reliabilities obtained are significantly low. The main reason for this ignorance is the lack of incentive for increasing coal production, which is mainly not viable due to replacement of coal with natural gas in Turkey. The research findings provided an aid to be able to characterise the dragline operations and to generate more efficient preventive maintenance plans.

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NOMENCLATURE

F(x)	cumulative probability density function
e	natural logarithm
α	scale parameter
β	shape parameter
x	random variable

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