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Reliability analysis of a Dragline: A Case Study

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ABSTRACT

In the present scenario,the demand of coal growing continuously in the world that needsto deploy highly mechanized earthmoving machinery (HEMM) to meet the demand of the industries.Dragline is a HEMM used in surface mines to remove overburden and dump into the decoaled area.The occurrence of failure of the dragline and its components influences the production of the mines, increasing the maintenance cost, and downtime losses. This research workfocusesto estimate the reliability ofvarious components of the dragline using time to failure (TTF) data of respective failure components. The modelling and analysis of TTF data were done and identify the best-fit distribution by using EASYFIT software. The reliability of the individual component is identified that helps the maintenance engineer to develop the preventive maintenance policy that can improve the dragline productivity by reducing the unexpected breakdown failure. This research will help technicians in identifying the critical components of draglines for better maintenance planning, leading to increased equipment availability, and reduced production losses in the industries.

KEYWORDS: Dragline, Reliability, Time to failure (TTF), Opencast mining

1. INTRODUCTION

Mining industries are focusing to improve the reliability and maintainability of heavy earthmoving machinery (HEMM) to increase their productivity and performance toachieve the annual targets. The HEMM consists of different subsystems/componentsand wheneverafailure occurs in any component thatdirectly affects the reliability and maintainability of the system. Draglines are the heavy earth moving machinery (HEMM) deployed in a large opencast coal mine for overburden removal [1]. Draglines are capital-intensive HEMMs, and hence their failure has a major impact on the productivity of the mine [2,3]. In order to make the dragline available for use and to optimize the operational cost, the reliability analysis of the various components of the dragline is of paramount importance to the maintenance engineers. The maintenance policy of the dragline is categorized into two types: planned maintenance and unplanned maintenance [4]. Planned maintenance includes periodic maintenance of the equipment before its failure [3]; whereas corrective maintenance is performed after the failure of the components or subsystem of the dragline and repair or replacement operations are performed to back into the functional state [4]. The corrective maintenance of the dragline can lead to major downtime losses. The goal of reliability analysis is to examine a statistical approach which fits the information best. The reliability is the operation of time, mean time to failure (MTTF) and mean time to repair (MTTR) data are employed to find the statistical lifetime disbursement of the component of the dragline. A system may have repairable and non-repairable components.Repairable frameworks can be gotten back to their employable circumstances throughcorrective maintenance [3]. The MTTF data of the repairable system are in the function time in between the failures. The reasons for in the middle between the super durable break in the framework to fill the expected role under unambiguous working circumstances [5]. After the failure of the system, the separate part of the failed component is either fixed or supplanted [6]. The failure of components data wasexamined to prove whether independent and identical distribution was given [7]. Failures in any component of the dragline and don't provide proper maintenance could cause the entire dragline systemto beterminated. It is required to study the life of a dragline or a set of draglines working under different environmental conditions to find out a pattern of its reliability curve prior to the installation of the new dragline to efficiently design a maintenance policy. Effective use of the dragline system requires a thorough knowledge of machine productivity, efficiency, and reliability. This paper discusses the reliability of a recently commissioned dragline in one of the opencast projects in Northern India. In this work, just corrective maintenance data were making use of the unavailability of planned maintenance data to determine the reliability and availability of the dragline. The failure of mechanical and electrical components of the dragline was studied and analyzed using the MTTF and MTTR data, as suggested in the literature [9, 10].

2. METHODOLOGY

The dragline components haveinstancy of an individual subsystem is recognized by considering time to failure (TTF) data collected from the logbook of the dragline. The TTF data are tried for free and indistinguishable attributes to look at whether any pattern and relationship exist between the data[11], [12]. Ifthere is no pattern and relationship exist, the data are free and indistinguishably disseminated. The data is considered to track down the best fit circulation by Kolmogorov-Smirnov (K-S) test [14,15]. The best fit distribution curve will be estimated for various components of the draglineand identified thereliability of every single subsystem. Finally, the best fit reliability curve of the overall dragline is identified [16]. The analysis of the failure of the components/subsystems and the accompanying advances have been taken on which have been addressed as:

1. **Data collection and validation**: Visit the mines to collect the maintenance data, and failure data from themaintenance logbook and also check for outliers, errors and any unpredictability in the data.
2. **Study of failure data of various components of dragline:**To investigate the failure data to which sorts of the failure modes, recognized the information in various failure types.
3. **Analyze the frequency of the component's failures:** The number of failures of the different components is After failure of the system, the separate part of the failed component is either fixed or supplanted determined from the maintenance logbook for a period of operation of the dragline.
4. **Analysis of TTF data by using K-S goodness fittest:** The data of MTBF of components is determined by the distribution values in the form of Weibull, Weibull(3p), Beta, Exponential, Gamma, Lognormal, Normal and Uniform.
5. **Identify the best-fit distribution of each component:**According to the ranking the goodness best-fit distribution is considered and place the number of failures against functional time to check the nature of the curvature.
6. **Estimate thereliability of a dragline:** Based on the results of the distribution curve of the different subsystems, the reliability of the dragline is determined.

The basic assumption of this study was the restoration of the component starts as soon as possible when a failure occurs in any component of the dragline. The methodology used for the reliability analysis consistsof three basic steps: comprehensionof the components of the dragline system and subsystem; a collection of MTTF data for each subsystem of dragline and modelling of the failure data through the probability distributions; and estimation of the reliability of each subsystem.

2.1 Silent features of a dragline

The dragline consists of bucket capacity ($24m^3$), boom length (96m),boom angle was $30^0$and the operating radius of the dragline was 88m. Dragline consists of a base, rotating frame, mast, fairlead, and operator cabin.There are four mechanisms of dragline such as drag, hoist, swing and walking. The drag and hoist system of the dragline is connected to the bucket with the help of drag rope and hoist rope respectively. The bucket is a rectangular box type part with an opening on one side. It is joined to the dragline boom through a hoist rope. Two drag chains and two hoist chains are fitted with the bucket. The hoist chain is fitted with the spreaderbar. Its teeth are replaceable sort and when they wear out in abundance, they are supplanted with new teeth. The basic component of the dragline is shown in Figure 1.

2.2 Data collection

The maintenance and failure dataof the Abhimanyu dragline is collected which was deployed in an opencast coal mine belonging to Northern Coalfields Limited, India. The time to failure (TTF) data of 5 years (2014–2019) of the subsystems is recorded from the support logbook of the mine.A few data which are not kept in the logbook are likewise gathered during the conversation with upkeep individuals.

3. DATA ANALYSIS

The arrangement of statistical failure distribution of various components of dragline and analysing the pattern of each distribution and, determination of best-fit distribution and model parameter assessment of the time.

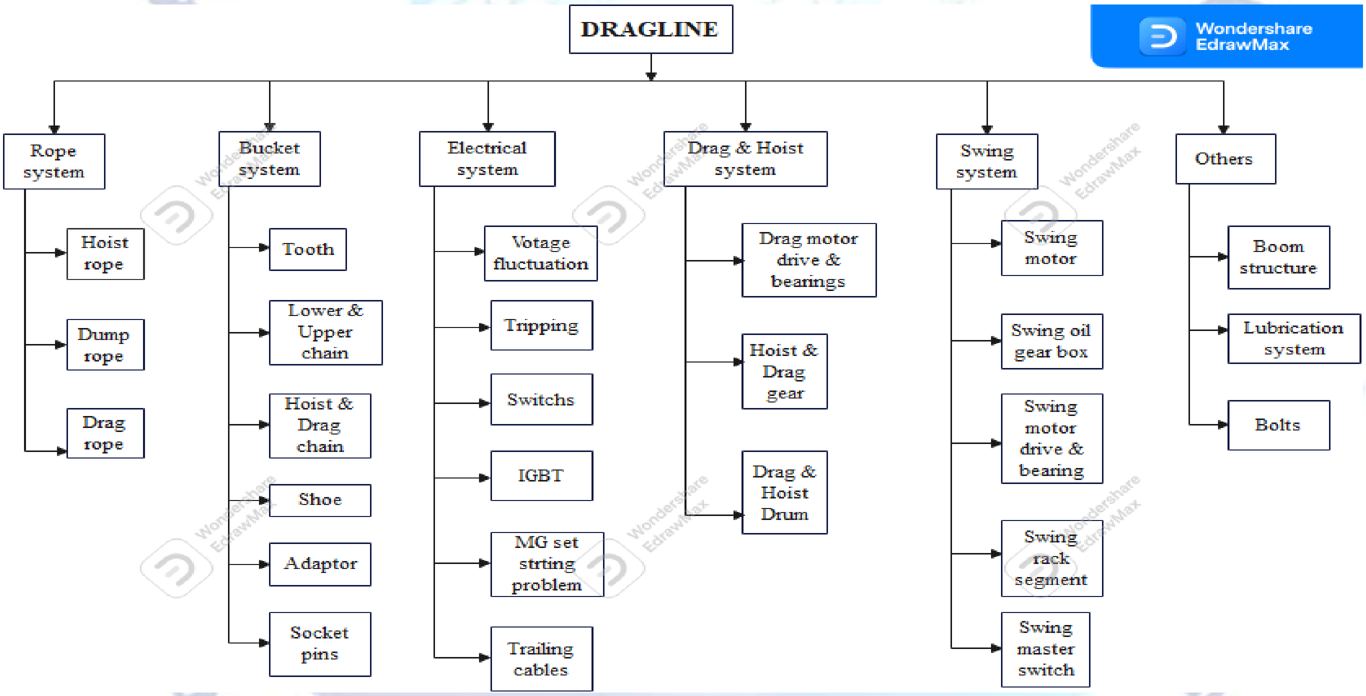

***Figure 1:** Failure of Major Components of Dragline*

After completing the data possessing, identifying the distribution parameter of various distributions such as Normal, Lognormal, Gamma, Weibull, Weibull (3p), Beta, Uniform and Exponential have been examined. Among all these,the best fit distribution is viewed as the Weibull distribution for various subsystems.To find the best fit distribution, K-S test has been utilized. Bring down the worth in K-S test, better is the fitment. After knowing the best fit distribution of the failure data for various subsystems, the meantime to failure (MTTF) is calculated.MTTFs are then compared to the failure of the subsystems to derive the reliability of each sub-system.System or subsystems/ components failure occurs due to non-operating behaviour under specific conditions. By using the MTTF data failure time distribution and probability density function of each component are analyzed to know the best-fit distribution using Kolmogorov-Smirnov's (K-S) goodness of fit test. The best-fit distributions of the reliability curve of each component of the dragline are presented shown in Figures 2 to Figure 27.

4. RESULT AND DISCUSSION

The dragline and its subsystem's reliabilityhave been estimated for various components of the dragline using probability distributions. This technique will allow determining the reliability of a component or system with the goal that the component or a system will fill the expected role during a particular timeframe under the expressed circumstances.

The goodness of fit test for the overall breakdown of the dragline is presented. The K-S goodness of best fit test for MTTF of dragline proved Weibull distribution as the best-fit distribution. The lognormal distribution is represented by two parameters: α is the location parameter, and β is the shape parameter. The modelling and analysis of the failuredata were done by EASYFIT software.

Table 1: *Analysis of MTTF Data of Components of rope system of a Dragline Using K-S Goodness of Fit Test*

System	System Components	Test Statistics								Best - Fit	Parameters
		W	**W (3p)**	**B**	**Ex**	**G**	**LN**	**N**	**U**		
Rope	Hoist rope	0.113	0.185	0.196	0.292	0.179	0.143	0.357	0.328	W	α=0.568 β=396.2
	Dump rope	0.102	0.123	0.133	0.097	0.110	0.153	0.159	0.198	Ex	λ=0.008
	Drag rope	0.080	0.070	0.200	0.154	0.145	0.102	0.226	0.279	W(3p)	α=0.811 β=86.6 γ=0.25

W = Weibull distribution, W(3p) = Weibull (3P) distribution, B = Beta, E= Exponential, G = Gamma, LN = lognormal, N = Normal, U = Uniform

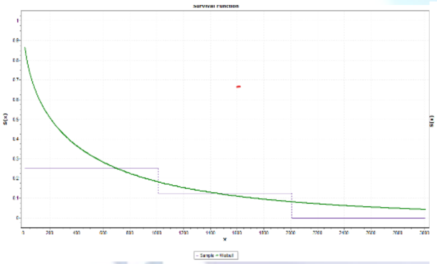

Fig 2. Hoist rope

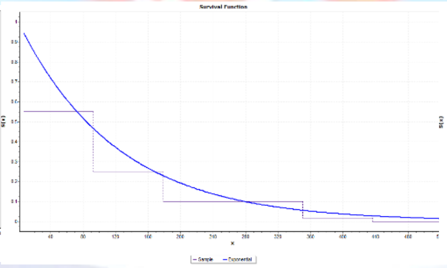

Fig 3. Dump rope

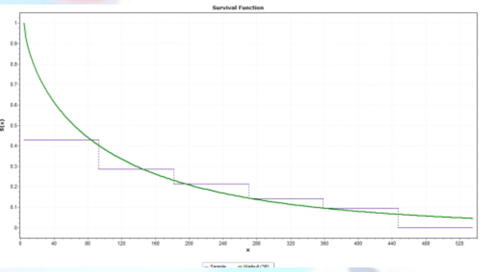

Fig 4. Drag rope

Table 2: *Analysis of MTTF Data of Components of bucket system of a Dragline Using K-S Goodness of Fit Test*

System	System Components	Test Statistics								Best - Fit	Parameters
		W	**W (3p)**	**B**	**Ex**	**G**	**LN**	**N**	**U**		
Bucket	Tooth	0.158	0.120	0.305	0.234	0.309	0.115	0.301	0.325	LN	σ=1.097 μ=4.104
	Lower & Upper chain	0.093	0.099	0.192	0.254	0.127	0.114	0.215	0.257	W	α=0.542 β=257.2
	Hoist &Drag chain	0.056	0.060	0.145	0.130	0.101	0.072	0.191	0.205	W	α=0.774 β=166.3
	Shoe	0.264	0.218	0.240	0.573	0.493	0.338	0.367	0.310	W(3p)	α=0.325 β=89.7 γ=5.75

	Adopter	0.111	0.194	0.269	0.346	0.168	0.194	0.403	0.402	W	α=0.522 β=262.3
	Socket pins	0.116	0.073	0.131	0.130	0.114	0.077	0.206	0.249	W(3p)	α=0.721 β=71.1 γ=9.75

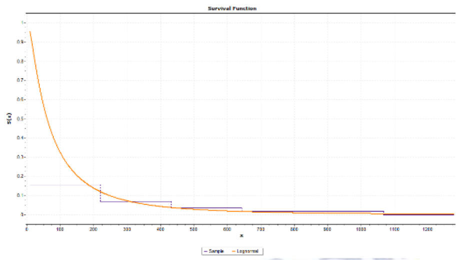
Fig. 5. Tooth

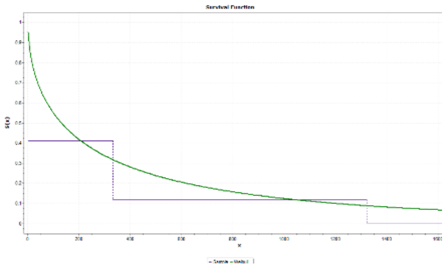
Fig 6. Lower & Upper chain

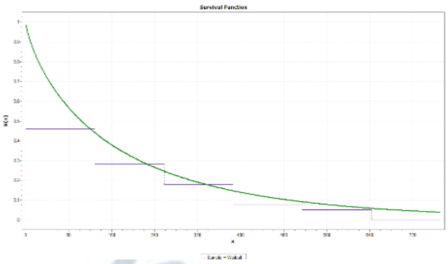
Fig 7. Hoist & Drag chain

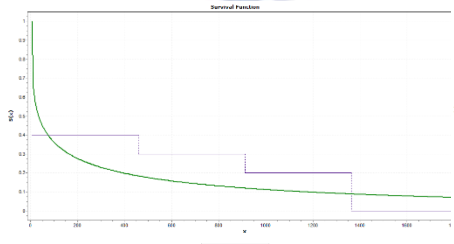
Fig 8. Shoe

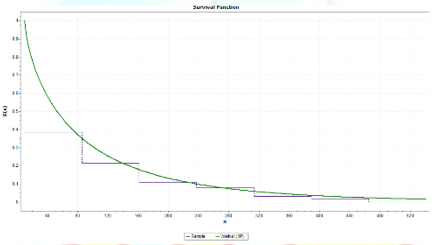
Fig 9. Adopter

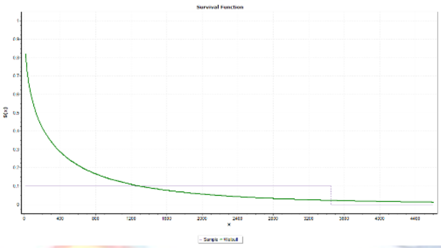
Fig 10. Socket pins

Table 3: *Analysis of MTTF Data of Components of Electrical system of a Dragline Using K-S Goodness of Fit Test.*

System	**System Components**	**Test Statistics**								**Best - Fit**	**Parameters**
		W	**W (3p)**	**B**	**Ex**	**G**	**LN**	**N**	**U**		
Electrical system	Voltage fluctuation	0.136	0.111	0.272	0.263	0.183	0.131	0.271	0.278	W(3p)	α=0.646 β=193.8 γ=15.0
	Tripping	0.105	0.110	0.097	0.108	0.139	0.122	0.189	0.136	B	α_1=0.620 α_2=1.409 a = 26.25 b = 830.0
	Switches	0.134	0.108	0.203	0.450	0.272	0.199	0.295	0.245	W(3p)	α=0.311 β=237.3 γ=5.5
	IGBT	0.086	0.142	0.285	0.425	0.196	0.175	0.348	0.313	W	α=0.384 β=94.1
	MG set starting problem	0.114	0.114	0.267	0.226	0.145	0.111	0.265	0.302	LN	α=1.312 μ=4.574
	Trailing cables	0.102	0.172	0.274	0.320	0.152	0.191	0.349	0.322	W	α=0.563 β=205.5

**IGBT: Insulated- Gate Bipolar Transistor **MG: Motor Generator*

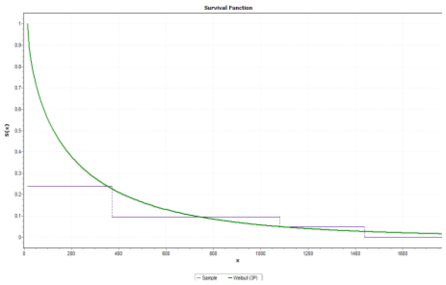

Fig 11. Voltage fluctuation

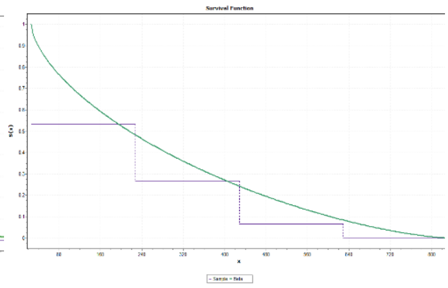

Fig 12. Tripping

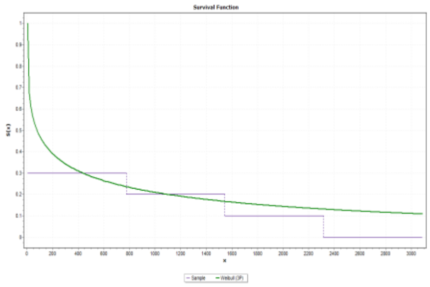

Fig 13. Switches

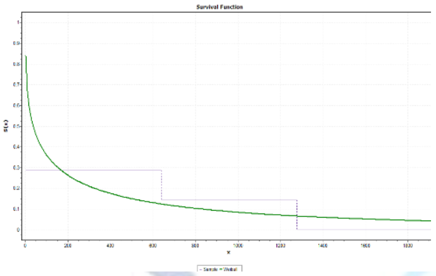

Fig 14. IGBT

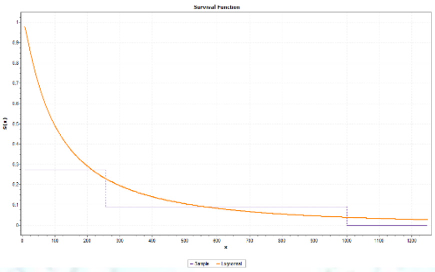

Fig 15. MG set starting problem

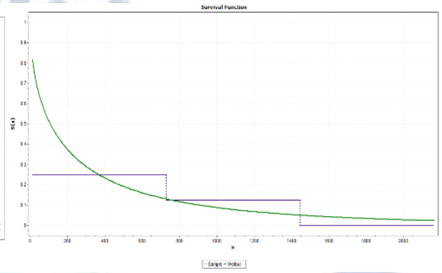

Fig 16. Trailing cables

***Table 4:** Analysis of MTTF Data of Components of Drag & Hoist system of a Dragline Using K-S Goodness of Fit Test*

System	**System Components**	**Test Statistics**								**Best - Fit**	**Parameters**
		W	**W (3p)**	**B**	**Ex**	**G**	**LN**	**N**	**U**		
Drag and hoist	Drag motor drive & bearing	0.054	0.216	0.317	0.367	0.210	0.193	0.406	0.377	W	α=0.960 β=5.0
	Hoist & Drag gear	0.103	0.169	0.329	0.484	0.153	0.118	0.326	0.301	W	α=0.466 β=145.8
	Hoist &Drag drum	0.109	0.211	0.303	0.460	0.220	0.211	0.319	0.323	W	α=0.414 β=80.6

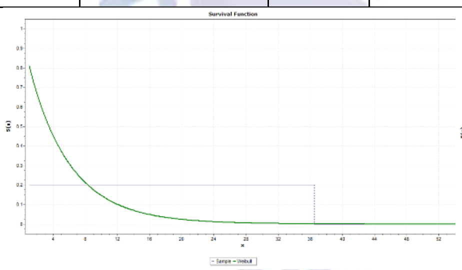

Fig 17. Drag motor drive & bearings

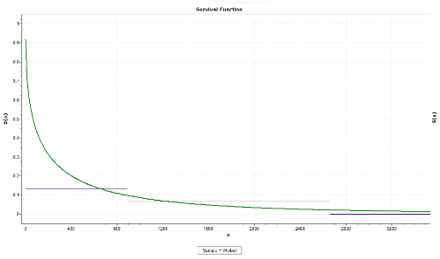

Fig 18. Hoist & Drag gear

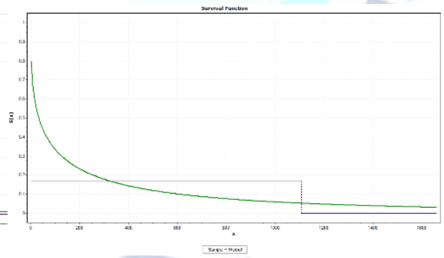

Fig 19. Hoist & Drag drum

***Table 5:** Analysis of MTTF Data of Components of Swing system of a Dragline Using K-S Goodness of Fit Test*

System	**System Components**	**Test Statistics**								**Best - Fit**	**Parameters**
		W	**W (3p)**	**B**	**Ex**	**G**	**LN**	**N**	**U**		
Swing system	Swing motor	0.137	0.116	0.160	0.213	0.160	0.1569	0.200	0.236	W(3p)	α=0.651 β=104.0 γ=6.5

	Swing oil gear box	0.123	0.098	0.149	0.207	0.147	0.133	0.232	0.233	W(3p)	α=0.682 β=101.3 γ=4.5
	Swing motor drive & bearing	0.086	0.129	0.127	0.253	0.165	0.117	0.271	0.243	W	α=0.556 β=398.0
	Swing rack segment	0.163	0.203	0.504	0.534	0.276	0.244	0.399	0.367	W	α=0.543 β=117.2
	Swing master switch	0.236	0.232	0.346	0.598	0.312	0.322	0.417	0.374	W(3p)	α=0.302 β=124.6 γ=10.75

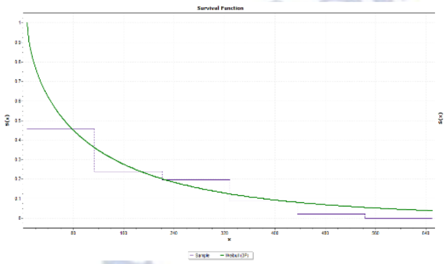
Fig 20. Swing motor

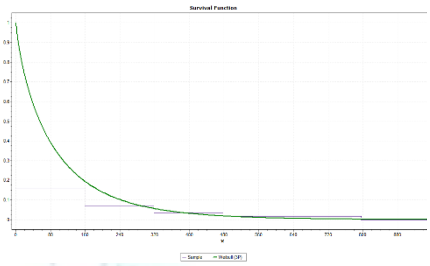
Fig 21. Swing oil gear box

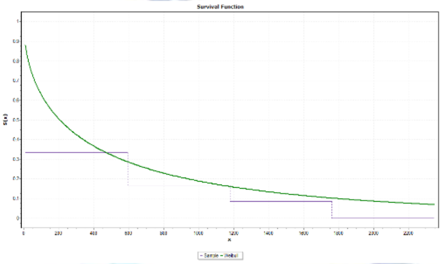
Fig 22. Swing motor drive & bearing

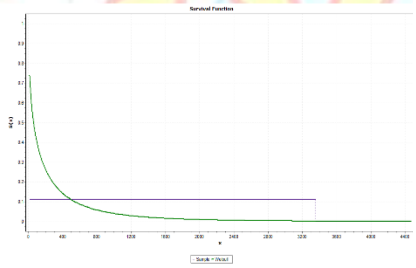
Fig 23. Swing rack segment

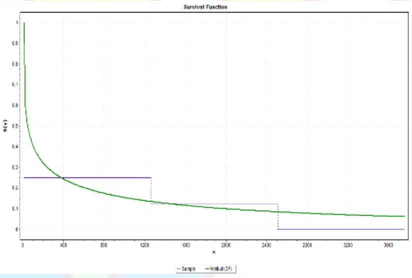
Fig 24. Swing master switch

Table 6: *Analysis of MTTF Data of Other Components of a Dragline Using K-S Goodness of Fit Test.*

System	**System Components**	**Test Statistics**								**Best - Fit**	**Parameters**
		W	**W (3p)**	**B**	**Ex**	**G**	**LN**	**N**	**U**		
Other	Boom Structure	0.175	0.203	0.243	0.490	0.286	0.307	0.316	0.282	W	α=0.547 β=76.9
	Lubrication system	0.098	0.109	0.255	0.270	0.108	0.085	0.258	0.269	LN	σ=1.659 μ=4.602
	Bolts	0.141	0.102	0.116	0.246	0.224	0.216	0.215	0.199	W(3p)	α=0.549 β=371.7 γ=63.25

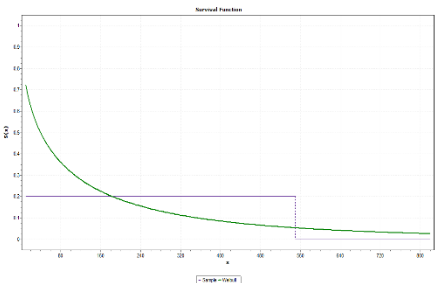

Fig 25. Boom structure

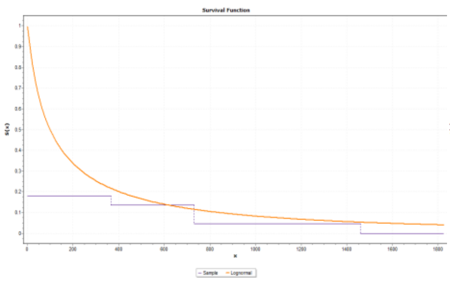

Fig 26. Lubrication system

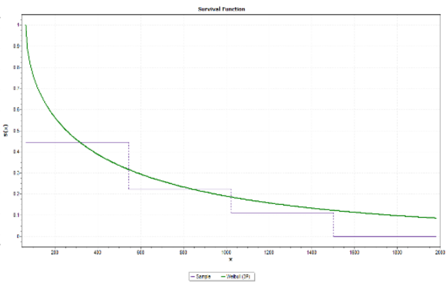

Fig 27. Bolts

Table 7:*Preventive maintainance interval for a dragline system based on the reliavbility level(%)*

Sl.no	**Reliability level (%)**	**Rope system**	**Bucket system**	**Electrical system**	**Drag & Hoist system**	**Swing system**	**Others**
1.	90	14.6h	9.6h	12.1h	3.3h	7.2h	11h
2.	80	29.6h	22.4h	32.6h	10.3h	14.8h	34.6h
3.	70	47.3h	38.8h	46.3h	16.3h	28.4h	55.3h
4.	60	76.3h	59.6h	71.1h	26.6h	50.2h	86h
5.	50	116.3h	93.4h	117.5h	40h	80.8h	132.6h

This study represents that reliability analysis plays an indispensable part in deciding the maintenance time frames. The resultant availability of subsystems can be useful for the usage, time overseeing and capital cost control in the dragline framework. For better usage element of a dragline, it very well may be prescribed that free time because of administrator expertise and maintenance faculty and so on can be thought of.

5. CONCLUSION

Reliability investigations are one of the best approaches to improve the availability, and maintainability of draglines as well as other sophisticated HEMM used in mining industries. Reliability analysis of dragline can prevent it from unwanted failure and unwanted preventive maintenance of various components and its subsequent economic loss. Effective maintenance policy, on the other hand, objectively reduces the frequency of breakdown failures and minimizes the repair time. Time to failure data of different subsystems of a dragline was found Independent and Identically (iid) distributed. The K–S best-fit test confirmed that the Weibull distributiongave the best fit to various subsystems of the dragline. In this paper, it was observed that the reliability analysis on the different systems is Bucket system, rope system, swing system, electric system and others. The reliability level of a dragline at 90% of the preventive maintenance interval is 46.7 hours. When the reliability level decreases the maintenance interval time increases.

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Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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