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Hazard Rate Diagnosis of Heavy Earth Moving Machinery using 2-parameter Weibull Analysis

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Abstract: **Hazard rate is a parameter of importance for understanding the machine completely. If a machine could perform to its full potential it has to go through a series of well-defined maintenance policies along with supervision and care. However, the performance of a machine alters based on the time as defined by the bath tub curve. It is a property by law. Hence a fixed way of familiarization may not hold good to access and ascertain the performance of the machine. Thus, for the machines in particular of heavy earth moving machinery are to be emphasized for the hazard rate by a meticulous and cumbersome method that can protect and prevent the machine by analyzing its condition periodically. Weibull analysis is one of the ways of such method that holds good to this purpose. Apart from the many other methods, a 2-parameter weibull analysis is an effective method to find the hazard rate of heavy earth moving machinery (HEMM). The data of HEMM is taken from the operating conditions of the machines in the field. Usually the HEMM are subjected to many number of failures, sometimes same failure may happen multiple of times. The hazard rate lies in how vulnerable is the failure, as well as what is the root cause for the failures. In practice it is also found from the investigation the major components or parts that are contributing the maximum portion for the failure of the machinery. These findings are very essential for the formulation of the suitable maintenance policy along with the vital areas of the machinery for preventive actions. And also the maintenance policies are different for the different periods of machine operation. Hence the position of the machine in bath tub curve is also found from the investigation. In order to archive that the collected data is refined as per the requirements for the assessment of the performance of HEMM, Weibull analysis is an effective method for the assessment of the reliability; availability and also the hazard rate. Machines follow different failure distributions hence it is very important to know the failure distribution of the HEMM. During the investigation of the hazard rate the failure distribution of the HEMM is calculated. In the present work the 2-parameter weibull analysis, the scale and shape parameters are found and based on the findings, the hazard rate of the HEMM is found, also the position of the machine is obtained.**

Index Terms: **Hazard rate diagnosis, heavy earth moving machinery, reliability, availability**

I. Introduction

The heavy moving machineries play an important role in the performance of plant and production. They are the key machines among all machines present in the industry. In addition to it the problems associated with these machines are more compared to any other conventional machines because of its operations in hazardous environment. HEMM are generally subjected to more number of failures hence the probability of failures for HEMM is more and there by the hazard rate. Before going to the actual assessment of the hazard rate, the term hazard rate is to be understood in a more elaborative and elucidative way to understand it role in an industry [1,2,3].

The trend of the machine is an important indicator for the machine's growth or decline. As per the bathtub curve any machine has three stages in its lifetime. They are the starting or early age, middle age and the end death declining or death stage. Based on the position of the machine the suitable maintenance policies are suggested to the operations and maintenance personnel. It is often observed in the industry about the vital few trivial many concepts; the same Perato's principle is also applied to the HEMM components. Those failures which are giving the maximum effect over the performance of the machines are assessed from that the preventive and protective measures are suggested.

Hazard rate is the statistic that defines the amount of risk present in the machine if it continues its operation on the present state. It indicates the problems associated with the machine and shows how the machine behaves against the time of operation. It is a usual experience to see that a machine often experiences less performance as the time lapses. But because of that fact the industry should not suffer any more. This is possible if and only if the machine is settled down as per its performance. Hence the performance and capability of the machine is prime concern in all the places. There is no short cut for the assessment of the performance of the machine. As described in the bath tub curve, a machine has usually three stages of life. They are the infant age, the young age and the old age. By observing the bath tub curve, the failures pattern gradually decreases and reaches a constant, after that there is an increase in the failure rate. Hence it is very difficult to identify and assess the nature of the failure distribution of HEMM. In addition to that the failures trend of the HEMM is difficult to find. This problem is solved by adopting the 2-parameter weibull analysis. Here in this analysis the 2 parameters namely shape parameter and scale parameter are used. These two parameters lay an arena to identify the failure and repair distribution based upon the reliability, availability and maintainability are found. Here in this research the impact of machine's failure rate that is hazard rate is identified and then the distribution of failures is found. By that the hazard rate is found there by the know-how analysis is made towards the action to be taken for the machine to work. The detailed methodology is given in the flow chart shown below in figure 1.

Heavy earth moving machinery performance is more important particularly in mining industry. Here in this research the dumpers used in coal mines of singareni collieries are considered for investigation of performance. It is a usual practice to use the dumpers in the mining industry to transport the raw materials from the mining area to the place of shipping yard. As a part of dumpers operation, the machines are often subjected to multiple numbers of failures. However the impact of failures over the performance of the industry alters from situation to situation. As a part of those failures the intensity of them are accessed by hazard rate in other terms the effect of machine failures over the system performance.

Even though there are many number of ways to find the hazard rate the weibull analysis is by default an effective and efficient method to ascertain the status of the machine in terms of its performance. This method uses two parameters viz shape parameter and scale parameter. These two parameters show the pattern of the machine failures and their distribution with time. In graphical representation the x axis denotes the time and y axis denotes the impact of failures of the machine, here in this case the dumpers. Based on the values of the shape parameter and scale parameter the intensity and nature of hazard is understood. On the other hand in addition to the hazard rate the reliability and availability of the machine (dumpers) is accessed. Here the noteworthy thing to understand is the ability of the machine to perform the intended tasks with minimum number of failures is the reliability of the machine. But the failure of the machine, which affects abruptly the entire process of the industry, is known as hazard rate. If the machine whether it is operating or not but available for work is the availability of the machine. These parameters give the complete details of the condition of the machine. By considering the wide spread applications of the heavy earth moving machinery in the field of engineering and production, the weibull analysis helps a lot.

The finding of the hazard rate, reliability, availability and maintainability alone will not constitute the solution to the problem. The application of these parameters into the wide spread performance of the machine is very important. Hence the emphasis made on the applicability of the above mentioned parameters to find the most effective and efficient solution is made. As a part of that the cause and effect diagram is made for the finding of the most critical cause that accounts to huge loss.

II. Literature Survey

The hazard rate diagnosis is the matter of interest particularly in the HEMM, because a rapid failure of such machine may result in unrecoverable loss. This is the reason many of the researches often emphasize the diagnosis mechanisms or methodologies, which certainly yields a better solution. But it is a factious thought that all the routes do not yield a same and required solution. However if the diagnosis of HEMM made through the weibull analysis makes the factious thoughts into reality. Because it is the best result oriented method that yields better results among its competitive methods. In addition to that the weibull analysis gives multiple results and they are useful for further investigation. It also evolves and describes the spread of the distribution of the failures or the outcomes of the machine [4,5,6]. This gives the foundation for the assessment of the reliability, availability and maintainability. But most of the researches have suggested about the investigation of the reliability by homogeneous or non-homogeneous processes. Out of all the methods the weibull analysis gives the best results. In spite of many other ways to access the performance of the machine hazard rate is emphasized because of its impact on the productivity. If a machine is failed because of some reason it may lead to some loss but if a machine is failed abruptly, it will create a catastrophic situation that will make the entire industry failure.

The trend of the failures of the machine is an alarming parameter that can constitute the framing of the suitable and sound measures for the betterment of the productivity. There are many methods available for the assessment of the HEMM failures trend. Out of them the following methods are used for the finding of the trend they are Eye ball test and cumulative plot test. Each test is performed for Time Between Failures (TBF) and Time To Repair (TTR). The majority of the outcomes of the above tests are considered for the decision making.

Nomenclature

α: Scale Parameter
β: Shape Parameter
γ: Location Parameter
σ: Log Mean Standard Deviation
ξ: Log Mean Value
ϕ: Standard Normal Cumulative Distribution Function
(t): Time
CDF: Cumulative Distribution Function
CTBF: Cumulative Time Between Failures
F(t): Cumulative Probability
f(t): Instantaneous Density Function
H: Hazard Rate and Hazard Function
HPP: Homogeneous Poisson Process
i.i.d: Independently Identically Distributed
MCCF: Mean Cumulative Cost Function
MCRF: Mean Cumulative Repair Function
MTBF: Mean Time Between Failures
MTTR: Mean Time To Repair
N or n: Number of Failures;
n(t): Function of Cumulative Number of Failures on time ‘t’ (general)
N(t): Cumulative Number of Failures at time ‘t’ (instantaneous)
NHPP: Non Homogeneous Poisson Process
OTBF(or OT): Ordered Time Between Failures
PDF: Probability Density Function
R(t): Reliability Function
R: Reliability function
ROCOF: Rate of Occurrence of Failures
RP: Renewable Process
S_i: Sum or Total Time on Test up to i^{th} failure
TBF: Time Between Failures

t_j : Failure time at j^{th} failure
TTR: Time To Repair
TTT: Total Time to Test

III. Methodology

The detailed methodology is shown in the below figure no 1. The complete procedure of hazard rate diagnosis is given in the flow chart. Even though there are many number of earth moving machines available in the company the emphasis is made on the dumpers because of their importance. At first the trend analysis is carried out then the trend of the HEMM found. After finding the trend of the machines using the 2 parameters weibull analysis is performed for the finding of the hazard rate, reliability, availability. There are some assumptions for the analysis of the HEMM, they are the effects of the weather changes during the machines working is neglected. The human working hours are not considered for the assessment of the machines. Emotions and attitudes of the persons operating the HEMM are also neglected. A maximum of 20 hours per day is considered for the HEMM operations.

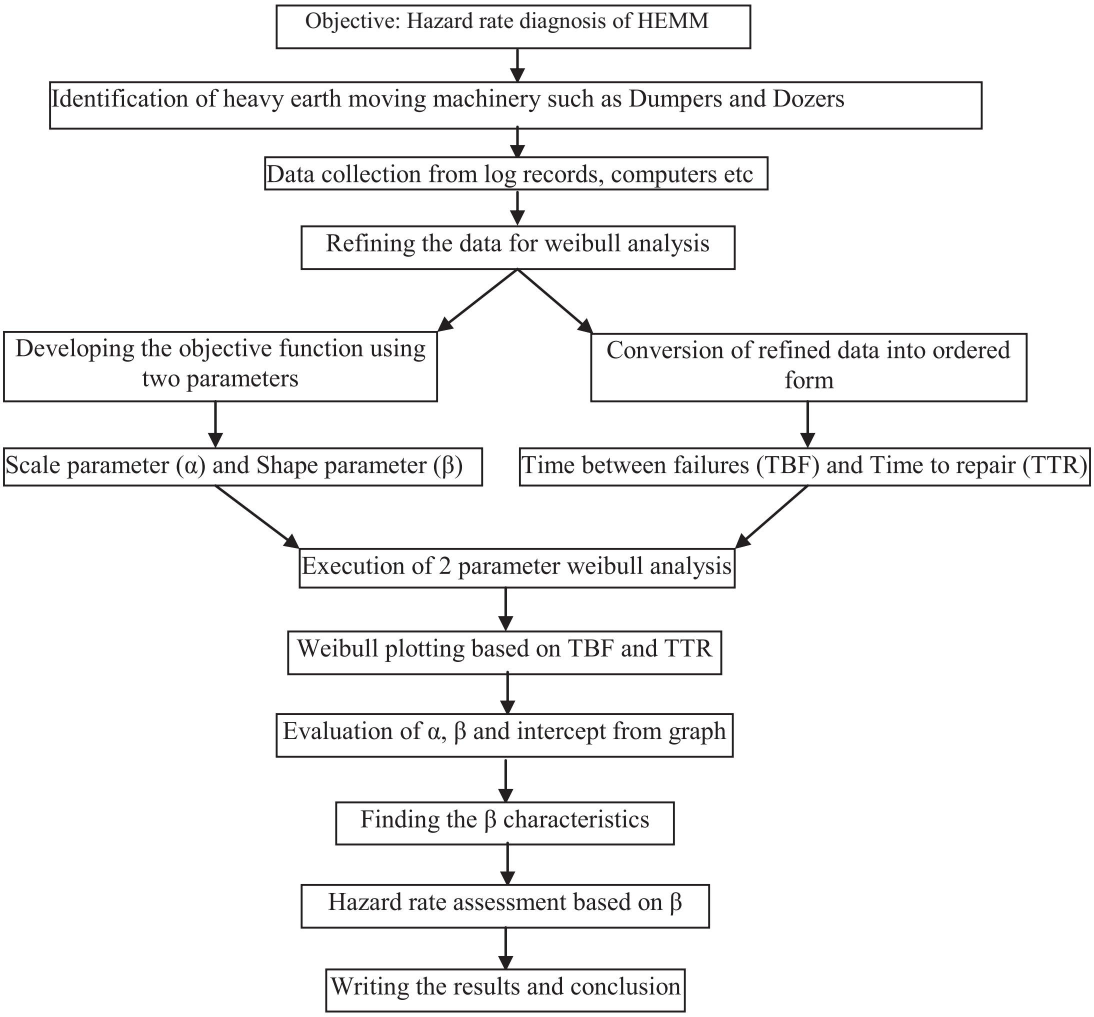

Figure 1. Methodology of 2-parameter weibull analysis for hazard rate diagnosis

As briefed above in the figure 1 it is made in such a way that the hazard rate is analyzed by the weibull analysis with two parameters scale (α) and shape parameters (β). Out of all, the collection of data is a cumbersome task because of the heavy and difficult climatic conditions of the working environment. There is a maintenance period of 5 days for every 100 days of dumper operation for the maintenance apart from the intermittent failures.

IV. Analysis

The results of the trend tests are given below the table no. I. Based on the outcomes of the two tests the below results are obtained. In some cases two tests have resulted two different outcomes. Yet the most appropriate outcome is selected for the decision. There are three possible outcomes for the trend analysis namely positive trend, negative trend and no trend. There were two ways in which the machine's performance with respect to trend analysis is calculated one

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is TBF and the other is TTR. Positive trend indicates the machine is increasing in its performance. Negative trend indicates the machine is decreasing in performance and no trend indicates that the machine has constant performance.

TABLE I.
TREND TESTS RESUTS

S. No	HEMM No	Cumulative Trend Test	Eye Ball Trend Test	Trend
1	C-3611	+Ve Trend	+Ve Trend	+Ve Trend
2	C-3690	No Trend	Weak -Ve Trend	No Trend
3	C-3752	+Ve Trend	Strong +Ve Trend	+Ve Trend

The analysis is made based on the performance of the heavy earth moving machinery used in Singreni collieries company limited Godavarikhani during the year 2019. The heavy earth moving machinery here in this research used is the dumper. A dumper is heavy earth moving machinery used in the company for the transportation of the coal from the mines to the dump yard and or to the supply station. The analysis started with the collection of the failure data from the site [7,8,9]. Basically the failure data is recorded in three modes. They are number of failures, frequency of failures and the third one the cost of failures. Here in this analysis, the number and frequency of failures are considered. After reefing the data, the classification of the data into required form such as TBF and TTR is made. From that data the weibull analysis is done as shown in table 1 below for the assessment of the dumpers stage in bath tub curve and also the ability and capability of the machine. Here in this analysis two parameters scale parameter (α) and shape parameter (β) are used. Hence the method named as two parameter weibull analysis [10,11,12].

GRAPHS OF EYE BALL TEST
(Time Between Failures Vs Cumulative Failure No)

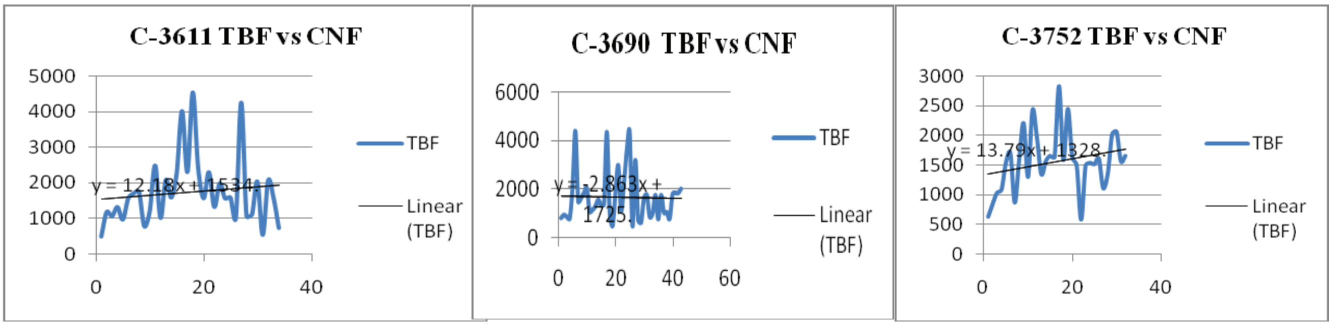

Figure 2. Graphs showing the cumulative plot test

GRAPHS OF CUMULATIVE PLOT TEST
(Cumulative Time Between Failures Vs Cumulative Failure No)

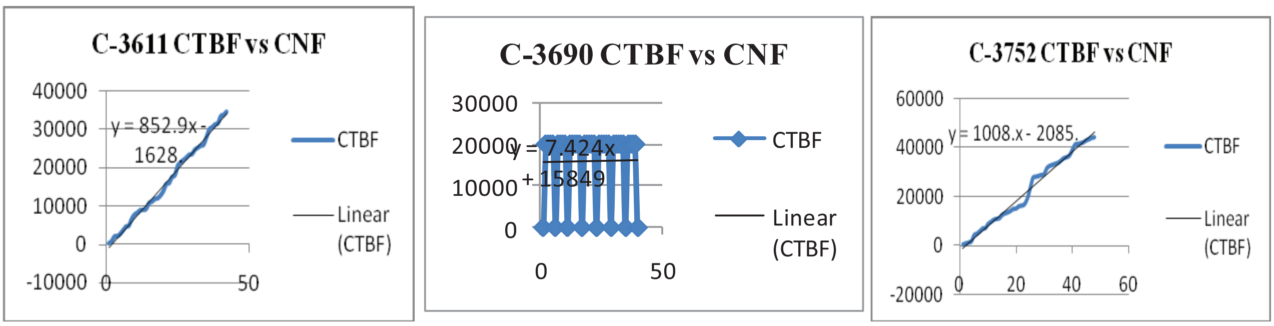

Figure 3. Graphs of eye ball test

In the above figure no 3 the graph shows the results of eye ball test. In the each graph the x axis is taken as cumulative failure numbers and on y axis the cumulative time between failures. For the HEMM no C-3611, the graph indicates the positive trend. For the HEMM no C-3690 the graph indicates no trend. For the HEMM no C-3752 the graph indicates the positive trend. In the above figure no 2 the graphs indicate the results of eye ball test. In the each graph the x axis is taken as cumulative failure numbers and on y axis the time between failures. For the HEMM no C-3611 the graph indicates the positive trend. For the HEMM no C-3690 the graph indicates weak negative trend. For the HEMM no C-3752 the graph indicates the strong positive trend.

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TABLE II.
WEIBULL ANALYSIS

S No	TBF	f(t)	1 / (1-f(t))	(x) = ln(t)	(y) = ln ln (1 / (1-f(t)))
1	2	0.017677	1.017995	4.276666	-4.0266
2	6	0.042929	1.044855	4.564348	-3.12634
3	92	0.068182	1.073171	5.257495	-2.65048
4	92	0.093434	1.103064	5.257495	-2.32185
5	40	0.118687	1.13467	5.480639	-2.06876
6	40	0.143939	1.168142	5.480639	-1.86166
7	64	0.169192	1.203647	5.575949	-1.68547
8	88	0.194444	1.241379	5.66296	-1.53144
9	12	0.219697	1.281553	5.743003	-1.39403
10	84	0.244949	1.324415	5.950643	-1.26951
11	84	0.270202	1.370242	5.950643	-1.15522
12	80	0.295455	1.419355	6.173786	-1.04924
13	80	0.320707	1.472119	6.173786	-0.9501
14	04	0.34596	1.528958	6.222576	-0.85664
15	28	0.371212	1.590361	6.269096	-0.76795
16	576	0.396465	1.656904	6.356108	-0.68329
17	576	0.421717	1.729258	6.356108	-0.60204
18	600	0.44697	1.808219	6.39693	-0.52367
19	600	0.472222	1.894737	6.39693	-0.44773
20	672	0.497475	1.98995	6.510258	-0.37381
21	672	0.522727	2.095238	6.510258	-0.30155
22	696	0.54798	2.212291	6.54535	-0.23064
23	720	0.573232	2.343195	6.579251	-0.16074
24	744	0.598485	2.490566	6.612041	-0.09156
25	768	0.623737	2.657718	6.64379	-0.02279
26	888	0.64899	2.848921	6.788972	0.045872
27	912	0.674242	3.069767	6.81564	0.114758
28	984	0.699495	3.327731	6.891626	0.184229
29	1104	0.724747	3.633028	7.006695	0.254694
30	1152	0.75	4	7.049255	0.326634
31	1152	0.775253	4.449438	7.049255	0.400639
32	1224	0.800505	5.012658	7.109879	0.477455
33	1512	0.825758	5.73913	7.321189	0.558076
34	1560	0.85101	6.711864	7.352441	0.643892
35	1776	0.876263	8.081633	7.482119	0.73697
36	1848	0.901515	10.15385	7.521859	0.840641
37	1848	0.926768	13.65517	7.521859	0.960927
38	1944	0.95202	20.84211	7.572503	1.110862
39	2064	0.977273	44	7.632401	1.330832

The failure data of the HEMM is collected based on TBF and TTR and then that data is transformed into the Ordered Time Between Failure (OTBF). Based on the two parameter weibull analysis is done and from the above derived table as per the methodology of the weibull analysis the ordinate values are obtained and they are further formulated into the distribution graph along with the trend as shown in figure no. 8. Based upon the trend of the distribution the equation of weibull analysis obtained as y = 1.98x – 7.583. From that equation beta value (shape parameter) is found as 1.98 and the scale parameter (α) = 46.05.

In the same way the weibull analysis is done with the failure data of the time to repair (TTR), the result of the analysis is given below in the figure no 7. Based upon the trend of the distribution the equation of weibull analysis obtained as y = 1.345x – 5.960. From that equation beta value (shape parameter) is found as 1.745 and the scale parameter (α) = 30.43. Similarly, for the HEMM 2 and 3 the α and β values based on the TBF and TTR are listed below in table no 2.

TABLE III.
A AND B VALUES FOR DUMPER 2 AND 3

Parameter	TBF		TTR	
	α	B	A	β
Dumper 2	32	1.584	44.60	1.745
Dumper 3	90	1.555	39.34	1.476

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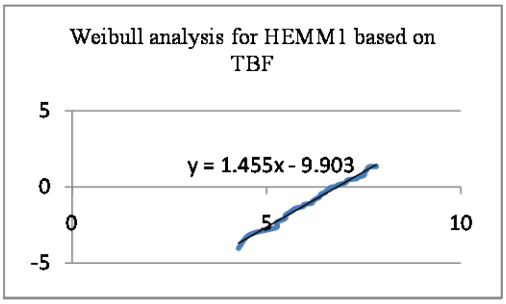

Figure 4. Weibull plot for dumper 1 based on TTR

Above figure no 4 shows the weibull analysis of dumper3 based on the time between failure (TBF) with the trend of y = 1.455x – 9.903. From the above figure it is understood that the dumper is showing a positive trend with time.

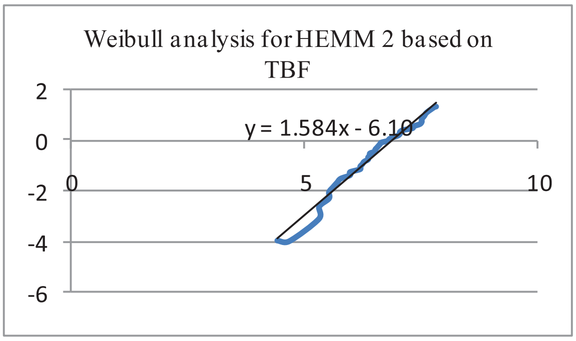

Figure 5. Weibull analysis for HEMM2- TBF

Above figure no 5 shows the weibull analysis of dumper based on the time between failure (TBF) with the trend of y = 1.548x – 6.10. From the above figure it is understood that the dumper is showing a positive trend with time.

Below figure no 6 shows the weibull analysis of dumper3 based on the time between failure (TBF) with the trend of y = 1.555x –7.70. From the above figure it is understood that the dumper is showing a positive trend with time.

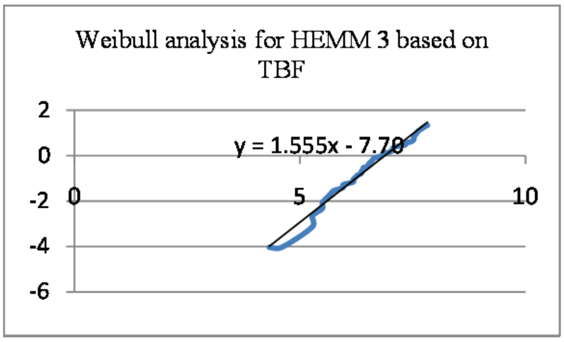

Figure 6. Weibull analysis for HEMM3- TBF

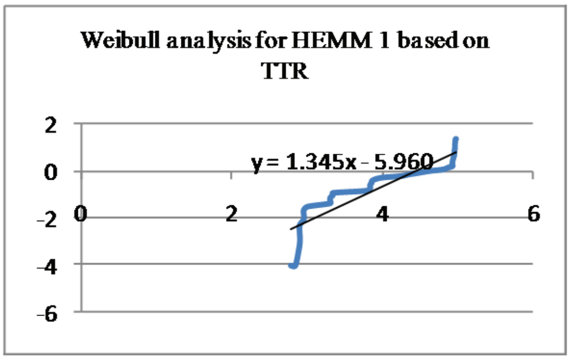

Figure 7. Weibull analysis for HEMM1- TTR

Above figure no 7 shows the weibull analysis of dumper3 based on the time to repair (TTR) with the trend of y = 1.345x –5.960. From the above figure it is understood that the dumper is showing a positive trend with time.

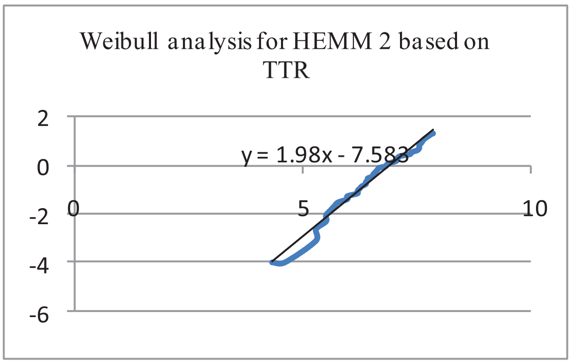

Figure 8. Weibull analysis for HEMM2- TTR

Above figure no 8 shows the weibull analysis of dumper3 based on the time to repair (TTR) with the trend of y = 1.98x – 7.583. From the above figure it is understood that the dumper is showing a positive trend with time.

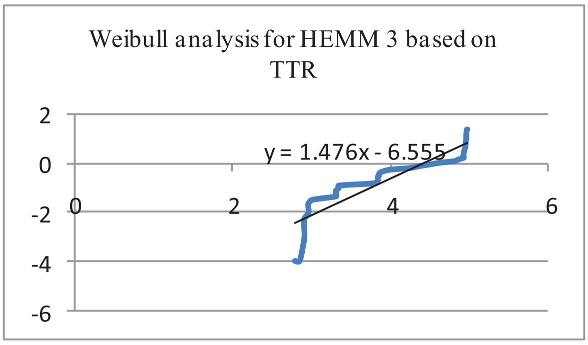

Figure 9. Weibull analysis for HEMM3- TTR

Above figure no 9 shows the weibull analysis of dumper3 based on the time to repair (TTR) with the trend of y = 1.476x – 6.555. From the above figure it is understood that the dumper is showing a positive trend with time.

A. Reliability

Reliability: It is the ability of a machine to work with minimum or zero number of failures and it is indicated as a probability value. Its value is directly proportional to the life of a machine with minimum or zero number of failures. It can be calculated using the equation

$$R(t) = e^{-\lambda t} \quad (1)$$

For dumper 1

$$R(t) = e^{-(1/781.2)*1032} = 26.6\ \%$$

For dumper 2

$$R(t) = e^{-(1/678.3)*1046} = 21.39\ \%$$

For dumper 3

$$R(t) = e^{-(1/803.2)*1055} = 26.88\ \%$$

B. Availability

Availability: It is the ability of a machine to work with minimum or zero number of failures and it is indicated as a probability value. Its value is directly proportional to the life of a machine with minimum or zero number of failures. It can be calculated using the equation

$$A(t) = e^{-\lambda t} \quad (2)$$

For dumper 1

$$A(t) = e^{-(1/942.2)*1060} = 32.46\ \%$$

For dumper 2

$$A(t) = e^{-(1/932.4)*1039} = 32.81\ \%$$

For dumper 3

$$A(t) = e^{-(1/951.2)*1090} = 31.79\ \%$$

C. Hazard rate

Hazard rate: It is the failure rate at an instance is expressed on conditional basis that a machine performs its functions needs to function as well in the next instance too without failure.

$$\lambda(t) = \frac{f(t)}{1-F(t)} \quad (3)$$

For dumper 1

$$\lambda(t) = \frac{f(t)}{R(t)} = \frac{0.674}{0.266} = 2.53$$

For dumper 2

$$\lambda(t) = \frac{f(t)}{R(t)} = 0.7861/0.2139 = 3.67$$

For dumper 3

$$\lambda(t) = \frac{f(t)}{R(t)} = 0.7312/.2688 = 3.16$$

The hazard rate is in between 2-3 for dumper 1 it indicates that the risk of failure is more and hence the machine is to be monitored frequently as well as replacement is to be scheduled as soon as possible. And for dumper 2 and dumper 3 the value is furthermore and is in between 3 and 4. That indicates that these two dumpers are in old age too and are for replacement.

V. Results

The 2-parameter weibull analysis of the HEMM (dumpers) has given the following results. As the β value for the TBF (reliability) and TTR (availability) analysis have came in between 1 and 2.

TABLE IV.
LIST OF RESULTS

Parameter		Dumper 1	Dumper 2	Dumper 3
TBF	A	46.05	32	90
	B	1.98	1.584	1.555
TTR	A	30.43	44.60	39.34
	B	1.745	1.745	1.476
Reliability		26.6	21.39	26.88
Availability		32.46	32.81	31.79
Hazard rate		2.53	3.67	3.16
Dumper position in life cycle		Old stage	Old stage	Old stage

Hence it is the clear indication that the machine has increasing failure rate. And the distribution follows the concave shape. And this indicates that the machine is in the old age as per the bath tub curve. Hence the machine is towards the replacement and or changing condition. And the scale parameter shows that the availability of the HEMM is more than that of reliability as detailed in table no III.

It is because of the fact that the machine has more amount of time to repair. It happens because there are certainly many number of associated and or dependent problems existed in the dumper. And also it is to be understood that the machine often experiences the repairs in the old age.

Therefore, it is resulted that the dumpers are in the old or death stage and it is further understood that the replacement to be done accordingly.

VI. Conclusions

The hazard rate diagnosis is performed based on the 2 parameter weibull analysis; the two parameters are scale parameter (α) and shape parameter (β). The HEMM (dumpers) are identified that, they are in the death stage and hence the dumpers does not require any further maintenance except the replacement. This analysis is very useful for the assessment of the machine (dumper) performance.

As there are many other ways to assess the position of the machine in the bath tub curve. The weibull analysis is an efficient and effective tool for the understanding of the exactness of the machine performance. And it is not an easy task to understand the HEMM (dumper) condition but with this method the exactness of the machine is found. In the mining industry this analysis is very useful.

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