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Statistical Modelling and Analysis of Vital Reliability Indices Pertaining to the Critical Components of Cement Manufacturing Plant

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Abstract : In today's industries, modern machinery is essential for profitability and market competitiveness. The production of components relies heavily on machinery, requiring tailored maintenance for effective strategies. Machine failures can disrupt operations, emphasizing the need for individualized maintenance to sustain productivity. The research paper focuses on analyzing breakdown data from Cement Industry machinery, utilizing the maximum likelihood approach and Weibull distribution modeling to estimate reliability. Statistical assessments of the Scale factor (α) and Shape factor (β) are conducted, with MINITAB 19 software targeting the least reliable components to enhance overall reliability in cement production unit.

***IndexTerms* - Downtime, reliability, scale factor (α), shape factor (β), weibull distribution modeling.**

I. INTRODUCTION

In today's industries, machinery faces breakdowns regardless of cost or size, emphasizing the need for proactive maintenance during capacity planning and activities[1].The main goal is to enhance equipment performance by implementing effective maintenance schedules[2]. Maintenance significantly impacts machine tools and their reliability[3]. The literature reviews various studies using mathematical models for maintenance plans in manufacturing[4,5].The Weibull distribution is commonly used for reliability modeling[6]. This paper focuses on the Cement industry, exploring reliability through successful operation and the absence of breakdowns[7]. The research aims to improve mechanical component performance in cement manufacturing through proactive strategies, including optimization and statistical analyses for enhanced overall plant performance. This research work focus on assessing how dependable the machine components are in a cement manufacturing plant. The components breakdown time data collected from maintenance records in the cement industry. The maintenance data have analyzed for the machinery and evaluated the reliability using the Weibull distribution, a statistical method. In real-world situations, the actual lifespan of tools often doesn't match what we predict. After analysis, many mechanical issues occur because of the least reliable components in the machines. If we can identify and address faults early on, it helps us manage or even prevent major repairs [8]. This study focuses on the Cement industry, where operational failures pose a significant risk. The examination of reliability in this paper looks at it from a manufacturer's perspective, emphasizing it as a crucial aspect in technical product production. Instead of providing a rigid definition, the paper explores reliability based on key aspects such as successful operation and the avoidance of breakdowns and failures[7]. Long-term reliability research shows a relationship between the failure rate and running time, following the "bathtub curve."[9]. This curve has three stages: Early failure due to design or production defects, random failure with a stable failure rate, and wear-out failure marked by a rapid increase in failure rate due to equipment wear and aging as shown in figure 1.[10].

Figure 1: Bath Tub Curve.

The Weibull distribution, known for modeling these stages, is used for reliability analysis in various fields, including steels, glass, metals, composite materials, wind sector applications, ceramics, and complex machine tools.[11-17] This distribution aids in understanding the reliability and failure patterns in materials science and engineering. This research underscores the significance of system reliability in improving mechanical component performance in cement manufacturing. The Objectives involve proactive measures for efficiency, statistical analysis of data, and applying the Weibull distribution model to critical components. The study aims to offer insights for maintenance engineers, aiding informed decision-making to optimize overall plant performance. This study can serve as a valuable benchmark for leading companies, helping them optimize maintenance strategies and plan schedules based on its findings.

II. Methodology

The Weibull distribution is known for its flexibility in modeling failure rates by adjusting parameters like scale, shape, and optionally, location. Shape (β) and scale (α) parameters are estimated using graphical and analytical methods. Widely recognized as a powerful tool for predicting machine or tool life, the Weibull distribution is preferred for its adaptability in representing a broad range of failure rate scenarios.[18]. The steps employed in the research methodology is shown in figure 2

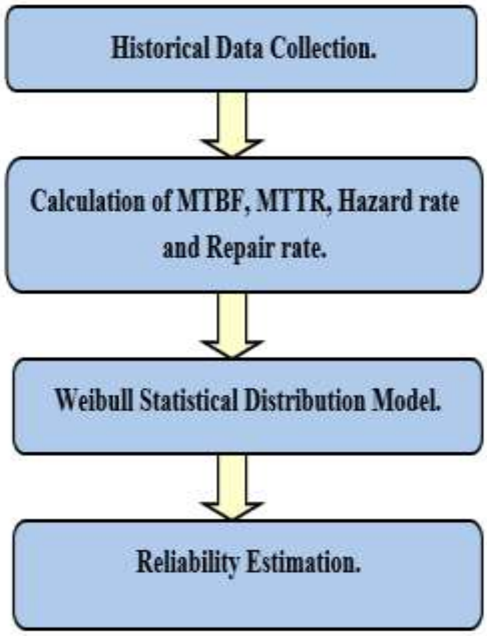

Figure 2: Methodology of the research work

2.1 Mean Time Between Failures (MTBF)

Mean Time Between Failures (MTBF) is the average time a device operates before an irreparable breakdown, indicating the expected operational duration before a failure event; changes in MTBF over time suggest variations in failure frequency.

$$MTBF = \frac{\text{Operating Time}}{\text{No. of Failures}}$$

$$= \frac{\text{Running Time} - \text{Downtime}}{\text{No. of Failures}}$$

2.2 Mean Time to Repair (MTTR)

Mean Time To Repair (MTTR) measures the average time taken to fix a failed component or system, indicating expected downtime after failures; increasing MTTR suggests longer recovery times.

$$MTTR = \frac{\text{Downtime}}{\text{No of Failures}}$$

2.3 Hazard rate.

The frequency at which a system or a component fails per unit of time is known as Hazard rate or Failure rate. It is the probability of the system or component failing in a short interval of time, given that it has survived up to that point.

$$Hazard\ Rate = \frac{\text{No. of Failures}}{\text{Running Time}}$$

2.4 Repair rate.

The frequency at which a system or component require maintenance or repairs to keep it functioning properly. It is a key metric in assessing the reliability and performance of a system over time. It is calculated by the formula

$$Repair\ rate = \frac{\text{No. of Failures}}{\text{Downtime}}$$

III. RELIABILITY ESTIMATION

The Weibull distribution is crucial in life data analysis for predicting machine reliability, characterized by two key parameters: the shape factor (β) and scale parameter (α). β captures physical failure patterns, while α represents time to failure, with $\beta < 1$ indicating infant mortality, $\beta = 1$ indicating random failures, and $\beta > 1$ suggesting wear out. The slope of β provides insights into failure behavior, offering a comprehensive understanding of machine reliability. Mean time to repair (MTTR) and mean time between failure (MTBF) are important reliability measures for identifying critical equipment. Reliability, defined as the probability of a unit performing adequately for a given duration under specified conditions, is influenced by factors like quality, workmanship, manufacturing processes, materials, storage, and testing. The paper seeks to assess system reliability through the Weibull distribution method, employing "Minitab 19" software for the computations. Reliability refers to the probability that a machine will not experience failures, making it a significant measure of quality [19]. Mean downtime is the average time a machine experiences failure or breakdowns. On the other hand, Mean Downtime Between Failures is the expected average time that passes between each breakdown [20].. Reliability prediction involves analyzing and calculating the failure rate of machines or components. To predict reliability, key parameters like Mean Time Between Failures (MTBF), Mean Time to Repair (MTTR), and Availability are assessed [21].The reliability of a system, denoted as

$$R(t) = e^{-\left[\frac{t}{\alpha}\right]^{\beta}} \quad (1)$$

Where: **R(t) :** Reliability of System , **α :** is the scale factor, **β :** is the shape factor, **t :** represents the mean time. This mathematical representation captures the time-dependent nature of reliability, providing a tool for analyzing and predicting system performance over time. According to literature, in many manufacturing units, the primary reason for reduced production is machine breakdowns. For our case study, we've chosen to focus on a cement manufacturing unit. After collected data from the maintenance department of the manufacturing unit we found that many machines face frequent failures. After reviewing the historical data, we started a case study to figure out how we can improve the reliability of these machines. Our goal is to assist the Cement Manufacturing unit's Mechanical critical component which helps in achieving its maximum productivity.

IV. DATA COLLECTION AND FAILURE ANALYSIS

To start a case study, the first important step is to gather a lot of information. If the collected data is not enough, it can be hard to analyze and might lower the quality of the research. In the present research, maintenance data spanning three years, from January 2021 to December 2023 has been meticulously collected from a Cement manufacturing unit for a strong case study. This dataset presents a comprehensive overview of machine breakdown, encompassing details on the causes of failures, the affected machinery, and the remedial actions previously implemented by maintenance teams. This detailed failure data provides insights into the frequency of failures and breakdowns across various equipment, facilitating thorough analysis and informed decision-making to optimize maintenance strategies and enhance operational efficiency.

Table 1 : Estimation of MTBF, MTTR, Hazard rate and Repair rate for Girth gear.

S.No	Month	Running Time (Hrs)	Down Time (Hrs)	No. of Failures	Operating Time (Hrs)	MTBF (Hrs)	MTTR (Hrs)	Hazard Rate	Repair Rate	Monthly Operating Time (Hrs)
1	Jan. 21	450	40	4	410	102.5	10	0.0088	0.1	450
2	Feb.	396	0	0	396	0	0	0	0	846
3	March	450	20	1	430	430	20	0.0022	0.05	1296
4	April.	432	0	0	432	0	0	0	0	1728
5	May	450	30	3	420	140	10	0.0066	0.1	2178
6	June	432	0	0	432	0	0	0	0	2610
7	July	450	0	0	450	0	0	0	0	3060
8	Aug.	450	0	0	450	0	0	0	0	3510
9	Sept.	432	20	2	412	206	10	0.0046	0.1	3942
10	Oct.	450	0	0	450	0	0	0	0	4392
11	Nov.	432	0	0	432	0	0	0	0	4824
12	Dec.	450	0	0	450	0	0	0	0	5274
13	Jan. 22	450	50	5	400	80	10	0.0111	0.1	5724
14	Feb.	396	0	0	396	0	0	0	0	6120
15	March	450	0	0	450	0	0	0	0	6570
16	April.	432	45	4	387	96.75	11.25	0.0092	0.088	7002
17	May	450	0	0	450	0	0	0	0	7454
18	June	432	0	0	432	0	0	0	0	7884
19	July	450	0	0	450	0	0	0	0	8334
20	Aug.	450	20	2	430	215	10	0.0044	0.1	8784
21	Sept.	432	0	0	432	0	0	0	0	9216
22	Oct.	450	0	0	450	0	0	0	0	9666
23	Nov.	432	0	0	432	0	0	0	0	10098
24	Dec.	450	25	3	425	141.66	8.33	0.0066	0.12	10548
25	Jan. 23	450	0	0	450	0	0	0	0	10998
26	Feb.	396	0	0	396	0	0	0	0	11394
27	March	450	0	0	450	0	0	0	0	11844
28	April	432	30	3	402	134	10	0.0069	0.1	12276
29	May	450	0	0	450	0	0	0	0	12726

30	June	432	0	0	432	0	0	0	0	13158
31	July	450	0	0	450	0	0	0	0	13608
32	Aug.	450	0	0	450	0	0	0	0	14058
33	Sept.	432	50	5	382	76.4	10	0.0115	0.1	14490
34	Oct.	450	0	0	450	0	0	0	0	14940
35	Nov.	432	18	2	414	207	9	0.0046	0.111	15372
36	Dec.	450	0	0	450	0	0	0	0	15822

Table 2: Parameters for evaluating reliability for the Critical Components in Cement Plant.

S No.	Name of the Components.	Shape parameters from Weibull plot (β)	Scale Factor from Weibull plot (α)	Mean Operating time (t) in Hrs	Reliability R(t) in %
1.	Crusher Hammer.	1.62103	11334.6	10150.4	43.36 %
2.	Girth Gear.	1.18035	9056.62	8556.37	39.25 %
3.	Screw Conveyor Belt.	1.45267	10643.2	9647.95	42.01 %
4.	Wear plates and Cooler plates.	1.50081	11003.4	9932.60	42.41 %
5.	Cooler Hydraulic System.	1.29731	9212.57	8512.08	40.55 %
6.	Heat Exchanger.	1.51886	10136.0	9136.70	42.56 %
7.	Nozzles.	1.61639	11827.2	10594.3	43.30 %

The critical components were analyzed by a questionnaire survey from the maintenance department of the Cement Industry. After conducting a comprehensive statistical examination and data evaluation using "MINITAB 19" Software, the determined shape factor (β) and scale factor(α) for the critical component i.e Crusher Hammer-(1.62103, 11334.6), Girth Gear-(1.18035, 9056.62), Screw Conveyor Belt-(1.45267, 10643.2), Wear and Cooler plates-(1.50081, 11003.4), Cooler Hydraulic System-(1.29731, 9212.57), Heat Exchanger-(1.51886, 10136.0) Nozzles-(1.61639,11827.2) in the cement industry. It is noteworthy that shape factor values (β) > 1 signify a pronounced susceptibility to failure which is considered unacceptable. The reliability estimation, rooted in the shape factor values, focuses on diverse components within the cement industry that frequently encounter breakdowns. This analytical approach is primarily centered on evaluating the performance of Crusher Hammer, Heat Exchanger and Nozzles during the timeframe extending from January 2021 to December 2023. The data obtained from the industry is used to evaluate MTBF and MTTR for the reliability estimation and is tabulated in the table 1 and table 2. From the Distribution overview graph for Monthly operating Time (Hrs) for Maximum likelihood, the Probability Density Function, Weibull distribution, survival and hazard function for Girth gear is estimated independently.

$$\mathbf{R(t)} = e^{-\left[\frac{t}{\alpha}\right]^{\beta}}$$

$$R(t)= e^{-[0.9447]^{1.18035}}$$

$$R(t)= 0.392533 = 39.25\%$$

In Girth Gear, β = shape factor=1.18035, α = scale parameter =9056.62, t = mean time = 8556.37, The shape factors (β) having values greater than 1 indicate that the components are at a high risk of failure.Accordingly, graphs were plotted in the form of figures 3,4,5,6,7,8 and 9 shown below:

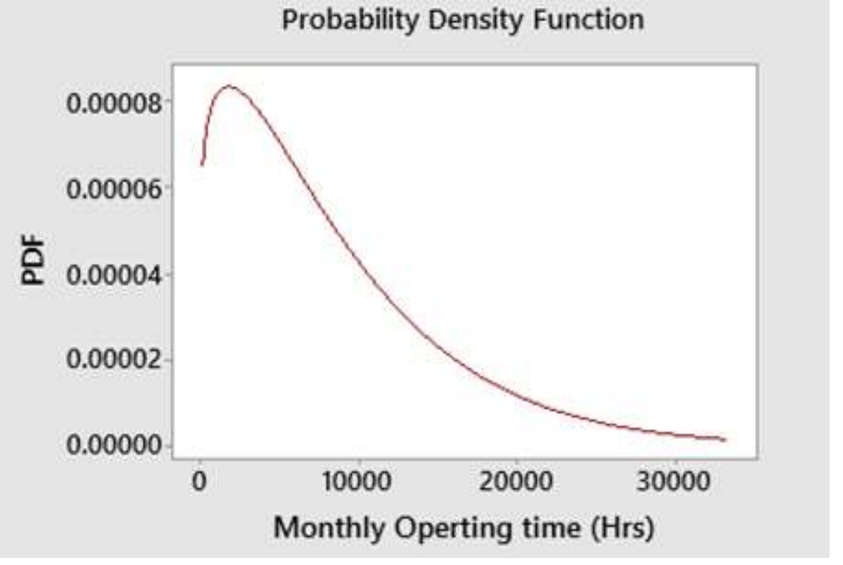

Fig. 3 Graph showing pdf of monthly operating hours

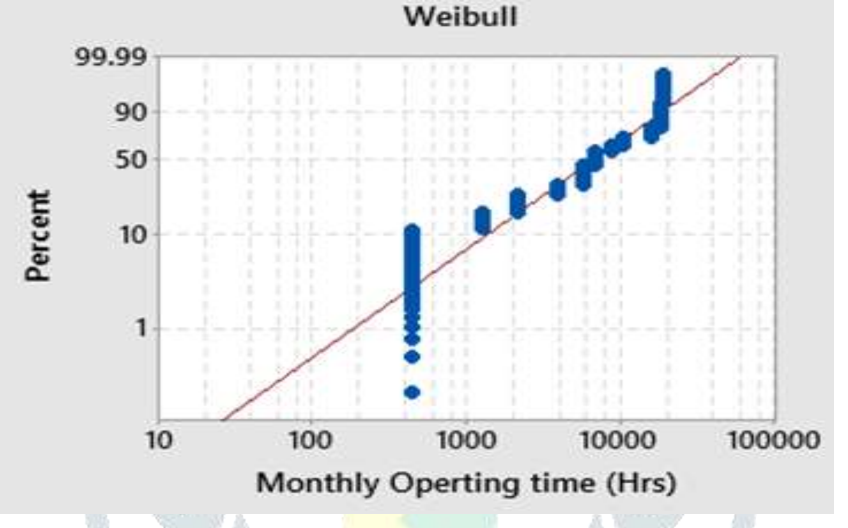

Fig.4 Graph showing Weibull pdf of monthly operating hours

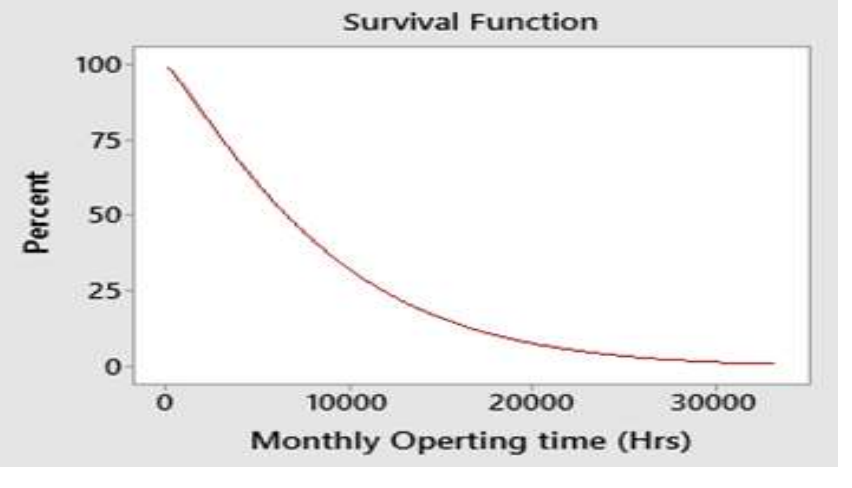

Fig.5 Graph showing survival function variation with monthly operating hours

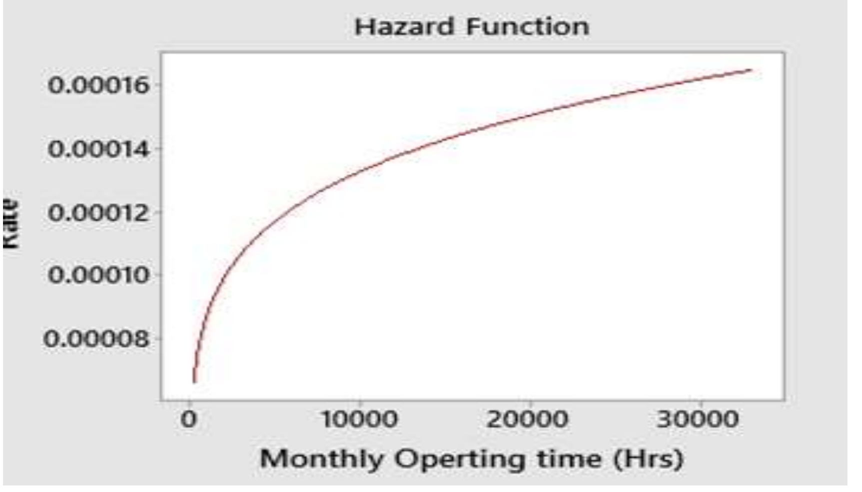

Fig.6 Graph showing hazard function variation with monthly operating hours

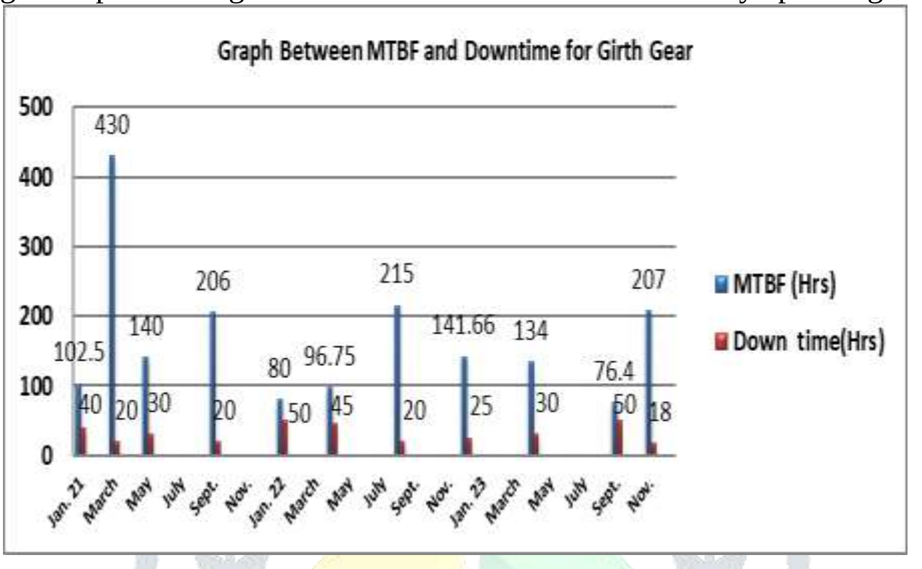

Fig. 7 Graph showing MTBF variation with downtime in hours

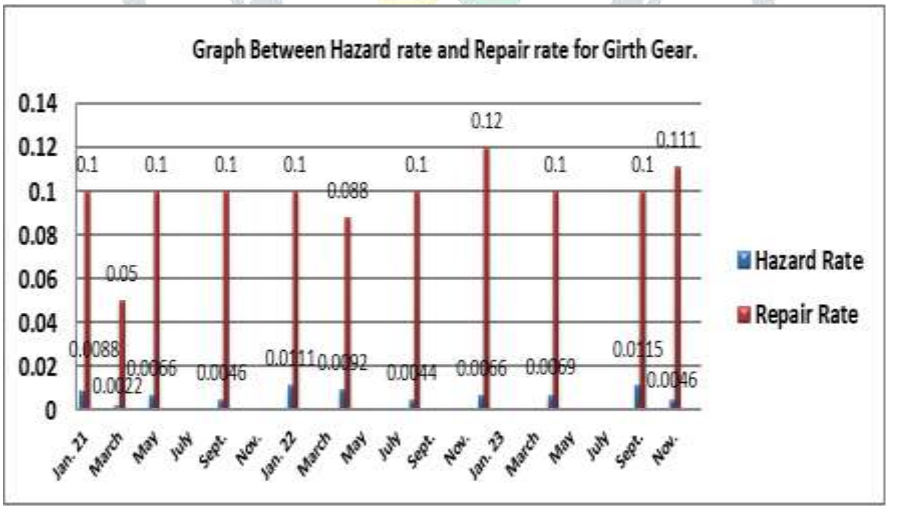

Figure 8 Graph showing hazard rate variation with repair rate in hours

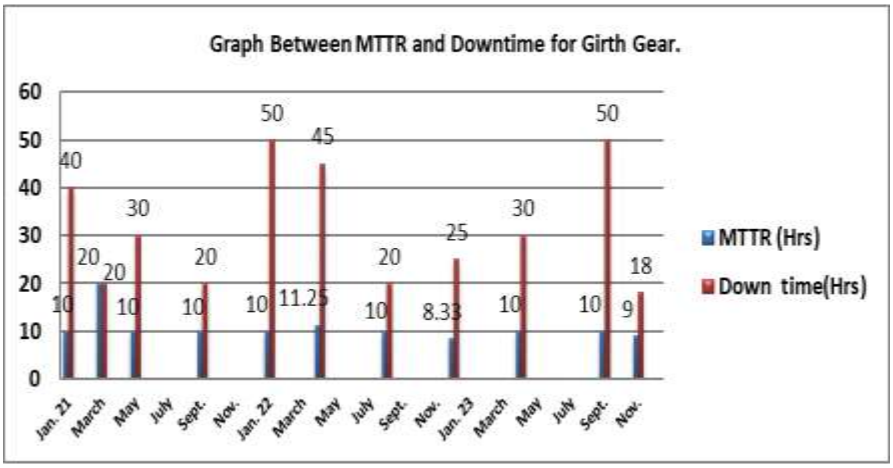

Fig. 9 Graph showing MTTR variation with download in hours

Observations

From the graphs, it was revealed that

[1] Probability density function graph so obtained is bell shaped with left end kurtosis.
[2] Survival function of component falls exponentially with increase in number of operating hours.
[3] Hazard associated with component increases with time of operation of the component.
[4] From Table 2, the reliability of these components was found to be 43.36%, 39.25%, 42.01%, 42.41%, 40.55%, 42.56%, and 43.30%, respectively
[5] The Most Critical component is Girth Gear on the basis of reliability as compared to other critical components.
[6] The distribution employed for mathematical modeling of the survival and repair rate is Weibull distribution.

V. CONCLUSION

In this research, the primary objective is to estimate the reliability of critical components in a Cement manufacturing plant. By considering all aspects of the unit's performance, particularly machine breakdowns, it is crucial to formulate an accurate maintenance policy. This policy aims to reduce breakdowns, minimize downtime, and increase the productivity of the manufacturing plant. Initially, past breakdown data of critical components such as crusher hammer, girth gear, screw conveyor belt, wear plates and cooler plates, cooler hydraulic system, heat exchanger, nozzles were analyzed. It was found that most critical of all component was girth gear and its failure is observed to cause breakdowns, thereby decreasing both the reliability and productivity of the unit. Regular maintenance ensures that critical components function effectively, reducing unexpected breakdowns. To remain competitive and achieve maximum production goals, ongoing monitoring of maintenance technology is necessary. Implementing a proper maintenance schedule and optimizing the use of maintenance employees in the production process can lead to significant improvements. Thus, continuous improvement in maintenance practices is essential for achieving operational excellence in cement manufacturing.

VI. ACKNOWLEDGMENT

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