Breakdown and Reliability Analysis in a Process Industry

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Abstract- *The complex nature of modern equipment and systems often lead to failures and as a consequence lead to increase in machine downtime0 thus affecting production. The failures of machineries cause disruptions in production resulting in a loss of availability of the system .This further increases the cost of maintenance. TPM has been proved as a successful tool for increasing the OEE of machineries by using simple effective techniques. Initially in this study Pareto analysis was used to figure out the major contributors towards downtime losses. RCA using the Why-Why technique was done so as to explain the reasons behind equipment breakdown. This helped in developing a PM schedule for the machines. Reliability is an important parameter for any piece of equipment. In this study Weibull statistics was used to measure the reliability of the system and also explain the CDF governing the rate of failure. The fitness of the model developed using weibull distribution was further verified using the KS test which is a "distance test". The value of the shape parameter β helped to understand the current state of the machine and justify the use of the PM schedule developed.*

Keywords: *Downtime Losses, TPM, OEE, Pareto analysis, PM schedule,Weibull distribution, CDF, Distance test, K-S test.*

Abbreviations:

TPM: Total Productive Maintenance.
OEE: Overall Equipment Effectiveness.
RCA: Root cause analysis.
PM: Preventive Maintenance.
CDF: Cumulative distribution function.
K-S: Kolmogorov-Smirnov.

I. INTRODUCTION

In most cases machine operators fail to detect the actual causes behind any problem whenever a failure occurs. They are often seen treating the symptoms rather than eliminating the problem at the grass root level. This further elevates the problem to a whole new level which would have otherwise not occurred had it been treated correctly in the first place. An in depth analysis together with experience and training only prepares an individual for proper handling of failed equipments. A thorough practical knowledge of mechanical, electrical as well as electronic parts able an operator to run a complex piece of equipment like the pouch machine smoothly. Mostly operators gather the basic knowledge through experience in the field. But this has a side effect as well, till the time they had become experts in their fields they had already wasted a considerable amount of valuable production time. Analysis of root causes through brainstormingand training sessions can only give a clear picture to the operators of equipments they are handling. This study was done on the pouch machine or the vertical filling and sealing machine in a cosmetic plant. This machine has a wide variety of applications from packing liquids, semi liquids to powder products as well. Table Ishows specifications of the machine under study.

TABLE I: MACHINE SPECIFICATIONS

Speed	Up to 66 strokes per min. Depending upon product and quantity to be packed.
Max roll width	800 mm
Max roll diameter	600 mm
Max pouch length	135mm
No. Of tracks	8
Main motor	3 hp, A.C. 3 phase 440 V, induction motor
Power consumption	10 KW
Machine dimensions	3.25 m*1.6 m *2.7 m
Air required	12 cfm at 12 kg per cm
Net weight	2000 kg
Gross weight	2400 kg

II. LITERATURE REVIEW

Equipment breakdown has always contributed towards machine downtime. Industrial Engineers have always tried to reduce downtime and increase the availability of machineries. TPM plays a vital role in achieving it. **Wakjira, MelesseWorkneh. et al. (2012)** has been able to reduce downtime and increase the OEE of existing machineries by TPM implementation in boiler plant in an Ethiopian malt manufacturing unit. Through TPM, **Gupta, Amit Kumar. et al. (2012)** has been instrumental in increasing the availability of existing machinery hence reducing the need for further capital investment. The forth pillar of TPM,Planned maintenance addresses the problem of equipment breakdown. Preventive maintenance, Breakdown maintenance, Corrective maintenance and lastly Maintenance prevention are the techniques involved in Planned maintenance. Preventive maintenance checklists as prepared by **M, Manoj., et al (2014)** helped increase availability, MTBF and reduce MTTR significantly. Also the number of machine breakdowns were reduced after implementation in this case. Parameters like reliability, MTTR and MTBF are also important factors that define Equipment breakdown and help to understand equipments better. To measure the reliability of any equipment, it is of utmost importance to find out the cumulative distribution function (CDF) governing the failure rate. **Mirzai, M. et al. (2006)** uses weibull distribution to explain the failure rate of power transformers in an Iranian electric company. This paper further does a goodness of fit test on the developed mathematical model by using the KS test. **Bose, D., et al (2013)** evaluates reliability, availability and maintainability of a diesel locomotive engine and uses weibull statistics to explain the failure rate.**Wang, Hsaio-Mei., (2009)** states that for distance tests in cumulative distribution function (CDF) the KS test is a good approach. He further makes a comparison between the Chi-square test and the KS test.

III. OBJECTIVE

The objectives of this work are to study the root causes behind equipment breakdown. Secondly, to develop a PM schedule based on the findings of the RCA analysis. Thirdly, to find out the cumulative distribution function governing the rate of failure and lastly to measure the reliability of the machine based on the model parameters.

IV. METHODOLOGY

At first, a Pareto analysis of machine downtime losses showed that equipment breakdown was the greatest contributor. To understand Equipment breakdown better, a RCA using the Why-Why technique was done with the help of machine operators and maintenance personnel. This was followed by the development of a PM schedule based on common industrial practices.

As for determining the cumulative distribution function governing the failure rate the weibull distribution was adopted as a model. The loading time was expressed in terms of minutes and arranged in an ascending order. In order to convert the weibull equation into a linear one log normal function was used twice and after plotting these points the weibull parameters β (shape parameter) and η_o(slope parameter) were estimated from the graph itself. The values of the distribution function were compared with the original cumulative failure rate to verify the correctness of the model using the Kolmogorov-Smirnovcriteria.

To measure the reliability of the machine using the weibull parameters β and η_o, the formula $R(t) = \exp[-(t/\eta_o)^{\beta}]$was used. The time period taken was the average loading time for a period of six months.

V. ANALYSIS & DISCUSSION

A. Downtime Analysis.

There are a total of fifteen major downtime losses which are recorded by the production department. In order to narrow down the study only to the important ones, the individual loss percentage and cumulative loss percentage were calculated. Downtime data is provided in details in Table II.

TABLE II: MACHINE DOWNTIME DATA

Downtime losses	Total loss (mins.)	Cumalative loss (mins.)	Individual loss percentage	Cumulative loss percentage
Equipment failure	1675	1675	34	34
Minor stoppages	1460	3135	30	64
Shift change	297	3432	6	70
Change over	285	3717	6	76
Utility failure	280	3997	6	81
Others	921	4918	19	100

Pareto analysis of downtime losses in Fig. 1 gives a better picture of the situation. The various types of downtime losses are plotted along the primary horizontal axis. The individual loss in minutes is plotted along the primary vertical axis, while the cumulative loss percentage is plotted against the secondary vertical axis.

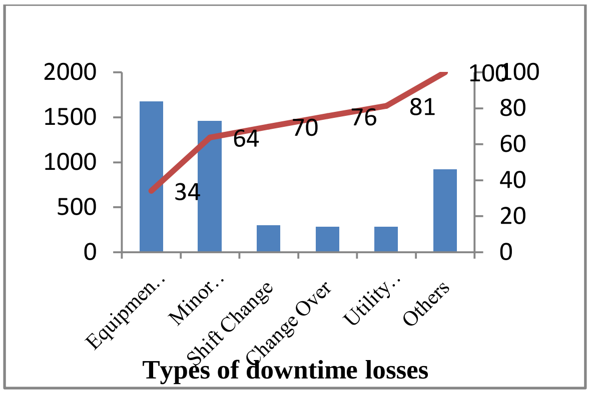

Fig.1: Pareto Analysis of Machine Downtime.

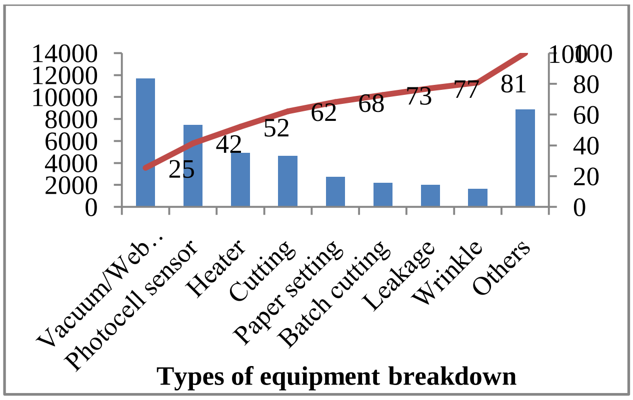

Fig. 2: Pareto Analysis of Equipment Breakdown

From the Pareto analysis the factors contributing roughly eighty percent towards downtime were found to beEquipment breakdown, Minor stoppages, Shift change, Change Over, Utility failure.Out of these five major losses equipment breakdown was further studied. Table III shows equipment breakdown in details.

TABLE III: EQUIPMENT BREAKDOWN DATA.

Equipment breakdown / failure statement	Total loss (mins.)	Cumulative loss (mins.)	Individual loss percentage	Cumulative loss percentage
Vacuum pump	11695	11695	25	25
Photocell sensor	7460	19155	16	42
Heater	4910	24065	11	52
Cutting	4660	28725	10	62
Paper setting	2720	31445	6	68
Batch cutting	2195	33640	5	73
Leakage	2010	35650	4	77
Wrinkle	1655	37305	4	81
Others	8845	46150	19	100

A second Pareto Analysis as in Fig. 2 was done so as to figure out the primary causes of equipment breakdown. Various causes related to equipment breakdown are plotted along the primary horizontal axis. The primary vertical axis shows loss in minutes and the secondary vertical gives the loss percentage.

Thus, from the Downtime analysis, the major equipment breakdown causes were found to be Vacuum pump failure , Photocell sensor failure, heater failure, Cutting failure, paper setting problem, batch cutting failure and the occurrence of leakage and wrinkle(fold marks) on the pouches. Vacuum pump, heater and photocell are essentially machine components while cutting failure, paper setting problem, batch cutting failure, leakage and wrinkle are undesirable effects caused during machine operation.

B. Root Cause Analysis.

Root Cause Analysis is a method to understand the actual reasons behind any undesirable effect, so as to address the problem at the grass root level. A typical example of RCA using the why-why technique in case of vacuum pump is shown Fig. 3.

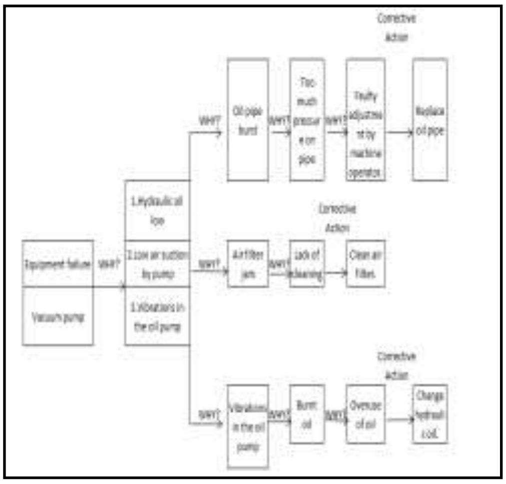

Fig. 3: Why-Why Analysis Of Vacuum Pump failure.

C. Preventive Maintenance Schedule.

Based on the RCA, PM checklists were prepared keeping in mind common industrial practices. Table IV gives an idea on the monthly PM schedule.

TABLE IV: MONTHLY PM CHECKLIST.

Activity description	Tools	Frequency	Time	Std.
Lubrication of Join Bracket	Grease gun/oil can	Monthly	30 sec	10 gm/10 ml
Lubrication of motor wheel sprocket bearing bolt	Grease gun/oil can	Monthly	30 sec	10 gm/10 ml
Lubrication of Pull Roller bolt	Grease gun/oil can	Monthly	30 sec	10 gm/10 ml
Lubrication of Guide shaft bearing	Grease gun/oil can	Monthly	30 sec	10 gm/10 ml

DailyPreventive maintenance activities like cleaning, inspection and tightening prove necessary in the long run. Activities like cleaning and tightening are normally assigned to be completed within one minute, while around thirty seconds are available for inspection activities. Cleaning is normally done with dry cloth since most of the machines have electrical components in them. Compressed air also provide a faster way of cleaning. Compressed air for cleaning do not require any special set up since most of the machines in the process industry have pneumatic cylinders in them which are operated through compressed air.The supply pipes for compressed air can be easily used for spraying purpose. Steel brushes are used while cleaning hard surfaces or electrical wires where carbon accumulation makes it almost impossible to be cleaned with cloth or air. Carbon accumulation causes heating of wires which ultimately lead to tearing. As for tightening Allen keys and spanners are very much popular. Tightening of nuts, bolts or parts subjected to repeated vibrations can prevent a major type of breakdown in the future. Table V provides details about the daily and weekly PM activities.

TABLE V: DAILY CUM WEEKLY PM CHECKLIST.

Sl. No.	Activity Description	Tools/ Procedure	Frequency	Time
1	Cleaning of Vacuum pump air filter	Compressed air	D	5 min.
2	Cleaning of Clutch/Brake assembly	Dry cloth	D	1 min.
3	Cleaning of Sealer jaws	Dry cloth	D	1 min.
4	Cleaning of Transformer wire junction.	Steel brush	D	1 min.
5	Inspection of Hydraulic oil in vacuum pump	Visual	D	30 sec.
6	Inspection of Clutch/Brake bolt.	Visual	D	30 sec.
7	Inspection of Thermocouple Thimble	Visual	D	30 sec.
8	Inspection of Sealer surface	Visual	D	30 sec.
9	Inspection of Thermocouple wire	Visual	D	30 sec.
10	Inspection of Sealer aligning bolt	Visual	D	30 sec.
11	Inspection of Rotary blade	Visual	D	30 sec.
12	Inspection of Pull rollers	Visual	D	30 sec.
13	Tightening of Clutch/Brake bolt	Spanner	W	1 min.
14	Tightening of Thimble	Allen key	W	1 min.
15	Tightening of Transformer wire junction	Spanner	W	1 min.
16	Tightening of Sealer aligning bolt	Spanner	W	1 min.
17	Tightening of Rotary blade aligning bolt	Spanner	W	1 min.
18	Tightening of Gauge bolt of pull rollers	Spanner	W	1 min.
19	Tightening of Motor wheel sprocket bearing	Spanner	W	1 min.
D = Daily, W = Weekly				

Table VI below provides details about the preventive action.**TABLE VI: PM & CM ACTION CHECKLIST.**

Sl. No.	Failure statement	Causes	Corrective action	Preventive action
1	Vacuum pump oil pipe burst	Too much pressure .	Replacement	Pressure adjustment to be done slowly
2	Photocell sensor malfunctioning	Overheat due to lengthy adjustment.	Allow photocell to cool down for some time.	Eye mark detection to be done within one minute.
3	PLC malfunctioning.	Use of negative value(-) as input	Installation of new programs.	Avoid Negative value as input.
4	Loose Pouches.	Low Sealing Pressure	Pressure adjustment by stopping m/c.	Use of Carbon papers to estimate the pressure Before hand.
5	Leakage from pouches.	Crack on sealer surface.	Replacement	Keep Sealers in cases.
6	Faulty batch cutting operation.	Blade stuck in between the sealers.	Re fitting of blade.	Operational trial before m/c running.
7	Wrinkle or fold marks on pouches.	Jaw-nozzle touch during sealing.	Aligning of nozzle.	Check nozzle alignment before m/c operation. .

D. Reliability Analysis.

1. The cumulative distribution function: The first step in reliability analysis is to find the distribution function governing the rate of failure.In order to better understand equipment failure, it is of utmost importance to know the CDF governing the rate of failure. This section attempts in finding out the CDF governing the failure rate of the machines. We first introduce the weibull distribution which defines a number of failures. Therefore, we use current data to obtain the specific distribution.

Weibull cumulative distribution function is shown below

$$F`(t) = 1 - e^{-\left(\frac{t}{\eta_o}\right)^{\beta}}$$

In which β and η_o must be determined, where β and η_o are the shape parameter and scale parameter respectively. To achieve a linear equation, we use log normal function twice. Now, the equation has the form lnln $\left(\frac{1}{1-F`(t)}\right)$ =βln(t)–βln($\eta_o$) whichis also asimple linear equation Y = mX – A , Where, Y = lnln$\left(\frac{1}{1-F`(t)}\right)$; X = ln(t) and A = βln(η_o). To calculate the values of X and Y we use the failure data against loading time. Table VII shows loading time, the number of failures and the values of X and Y.

TABLE VII: CALCULATED X & Y FROM FAILURE DATA.

Loading time (min.)	No. Of failures	Cumulative failures	Cumulative frequency	X	Y
15120	47	47	0.155629	9.623774	-1.77689
32400	39	86	0.284768	10.38591	-1.09318
49800	46	132	0.437086	10.81577	-0.55403
70920	50	182	0.602649	11.16931	-0.0802
98040	65	247	0.817881	11.49313	0.532446
129660	55	302	1	11.77267	1.52718

The points X and Y are plotted on graph as in Fig. 4.

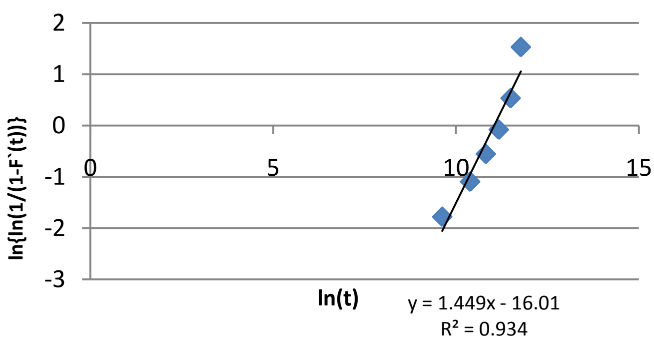

Fig. 4: Relative Cumulative Function Graph.

After plotting the values of X and Y, we get the equation y = 1.449x-16.01. This equation when compared with the standard linear equation gives us the values of β and η_o. Thus, we get β =16.01 and η_o= 62881. From the model the theoretical cumulative distribution function has the form:

$$F`(t) = 1 - e^{-(\frac{t}{62881})^{1.449}}$$

2. The Goodness of fit test: Now we use a goodness of fit test so as to measure accuracy or closeness of our values with standard ones. We use the Kolmogorov-Smirnov test for evaluation. The maximum difference between F(t) and F`(t) is the measure of how good fit the model is. Table VIII shows the difference between actual and calculated values. The maximum difference between the values is denoted by:

$$D_n = \max | F(t) - F`(t) |$$

TABLE VIII: DIFFERENCE BETWEEN ACTUAL & CALCULATED CUMULATIVE FAILURE RATE.

Loading time (mins.)	No. of failures	Cumulative No. Of failures	Actual cumulative frequency	Calculated cumulative frequency	Absolute difference.
15120	47	47	0.155629	0.119089	0.03654
32400	39	86	0.284768	0.3179	0.033132
49800	46	132	0.437086	0.5099	0.072814
70920	50	182	0.602649	0.6959	0.093251
98040	65	247	0.817881	0.85091	0.033029
129660	55	302	1	0.9424	0.0576

Therefore, D_n= 0.093251 at sample size, n = 182.

This difference, which is a random variable varies with the sample selected, this value is then compared with the critical value D_n^α using the Kolmogorov-Smirnov criteria, which measures the goodness of fit. Table IX shows various levels of significance against the sample size. In this case, the sample size is more than fifty.

TABLE IX:
CRITICAL VALUES, $CV(\alpha, n)$ OF THE KS TESTWITH SAMPLE SIZE n AT DIFFERENT SIGNIFICANT LEVELS (α).

Sample size, (n)	Level of significance (α)					
	0.40	0.20	0.10	0.05	0.04	0.01
5	0.369	0.447	0.509	0.562	0.580	0.667
10	0.268	0.322	0.368	0.409	0.422	0.487
20	0.192	0.232	0.264	0.294	0.304	0.352
30	0.158	0.190	0.217	0.242	0.250	0.290
50	0.123	0.149	0.169	0.189	0.194	0.225
>50	$\frac{0.87}{\sqrt{n}}$	$\frac{1.07}{\sqrt{n}}$	$\frac{1.22}{\sqrt{n}}$	$\frac{1.36}{\sqrt{n}}$	$\frac{1.37}{\sqrt{n}}$	$\frac{1.63}{\sqrt{n}}$

For α = 0.05 and n > 50, from the above table; we have

$$D_n^\alpha = \frac{1.36}{\sqrt{n}}$$

In this case, n=182, so D_n^α = 0.10081 and $D_n^\alpha > D_n (D_n$= 0.093251).

Therefore, the Weibull distribution is verified. Thus the studied machines are in conformity with the weibull distribution for the mathematical failure model.

3. Reliability measurement using weibull parameters: Reliability using weibull parameters is given by$R(t) = \exp[-(t/\eta_o)^\beta]$.Putting t = 21610 minutes, η_o = 62881 & β = 1.449, we get, R(t) = 0.80836 or 80.8%.

Table X summarises our model parameters along with the measured value of reliability.

TABLE X: Reliability and probability of failure.

Valueof Shape Parameter	Probable Failure Mechanism	Possible Cause Of Failure
β >2	Age Related Pattern	Accelerated wear & tear of components
β ≈ 1	Time independent pattern	Process error, design fault , maloperation
β < 1	Early failure	Manufacturing Failure and reconditioning fault

The value of the shape parameter β is of special importance, as it gives us an idea about the current state of machines. Table XI summarises machine condition for different values of β.

TABLE XI: CLASSIFICATION OF SHAPE PARAMETER

Avg. Loading time (mins)	Shape parameter(β)	Scale parameter(η_o)	Reliability	Failure probability
21610	1.449	62881	80.8%	19.2%

From the model the value of the shape parameter β was found to be 1.449.

VI. CONCLUSION

In order to increase the uptime of any piece of equipment or machinery, a deep knowledge behind equipment breakdown is essential. A good number of our day to day products like liquids, semi-liquids and powder products in the form of pouches and sachets comes from the pouch machine. Like any other equipment this machine also is subjected to equipment breakdown during operational hours. Apart from causing production loss, equipment breakdown causes various other losses in the form of maintenance cost, overtime cost, defect, rework etc. A lot of factors contribute towards equipment breakdown. Root cause analysis using why-why technique was used in this regard to better explain the reasons behind breakdowns. Based on the root cause analysis, a new preventive maintenance checklist was prepared for the pouch machine.

Reliability of any equipment is a vital piece of information to the maintenance engineers. Thus, in order to measure reliability one must know the CDF governing the rate of failure. In this study, weibull distribution was adopted to explain the failure rate, later it was also verified through the KS test that the model can be represented by the selected distribution. The level of significance for the model was found to be 0.05. Reliability using the weibull parameters was found to be 80.8% for a mean operating time of 21610 minutes in normal operationg conditions. Thus for β value equal to 1.449, we can say that the machines are subjected to a time independent failure and its causes are process error, design fault and maloperation.

The present condition of the machine can be improved if the proposed PM schedules are strictly followed This might help in improving the reliability of the machines in the future.

ACKNOWLEDGEMENT.

I would like to acknowledge the support of EMAMI Ltd. Ghy, Amingaon Unit and all the faculty members of Mechanical Engineering Department, Jorhat Engineering College (Assam).

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