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MAINTENANCE MODELING AND ANALYSIS: ON A GLASS-FIBRE INDUSTRY

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ABSTRACT

This Organizational outcomes and optimal utilization of available resources is key to organization's growth, development and success, thus the productivity of output would depend on availability of the facilities meant for the business processes. There are certain fundamental setbacks in frequency with which preventive maintenance is to be performed also maintenance tasks are interrelated to other functional areas in many ways therefore maintenance policy derived should help realizing multiple goals of an organization. In maintenance engineering when we search for optimal schedule for preventive maintenance (PM) analytical tools normally fail due to the involvement of the transcendental expressions stochastic behavior. The same problem related to setbacks of preventive maintenance is faced by leading fibre glass Company and it was seen that they were totally relying on breakdown maintenance which has become the problem on hand. With the earlier maintenance record various sub systems which were prone to frequent breakdown were found and their failure data was collected, studied and analyzed. Further Probability plotting was carried out using Minitab and code was developed in MATLAB to know which distribution the equipment's follow. To this effect a mathematical model published was implemented appropriately and analyzed on the shop floor with appropriate maintenance policy. A complete comparative analysis and feasibility was carried out are presented.

KEYWORDS: Preventive Maintenance; Maintenance Policy; Maintenance Cost; Breakdown Maintenance; Weibull Analysis.

Organizational outcomes and optimal utilization of available resources is key to organization's growth, development and success, thus the productivity of output would depend on availability of the facilities meant for the business processes. There are certain fundamental setbacks in frequency with which preventive maintenance is to be performed also maintenance tasks are interrelated to other functional areas in many ways therefore maintenance policy derived should help realizing multiple goals of an organization.

In any organization the unscheduled maintenance scheme will always result in frequent breakdown of machine and deviations in their outputs. The most important criteria inorganization is to follow a proper maintenance schedule for machines and equipment's which will reduce the breakdowns of machines and increase the reliability and productivity.

Problem on Hand

The same problem related to setbacks of preventive maintenance is faced by leading fibre Glass Company and it was seen that they were totally relying on breakdown maintenance which has become the problem on hand. As it is very well known that BDM is not at all preferable every time, which will severely impede the business process of any organization. With the earlier maintenance record various sub systems which were prone to frequent breakdown were found and their failure data was collected, studied and analyzed. Further Probability plotting was carried out using Minitab and code was developed in MATLAB to know which distribution the equipment's follow. To this effect a mathematical model published was implemented appropriately and analyzed on the shop floor with appropriate maintenance policy.

LITERATURE REVIEW

Usgaonkar and Mariappan (2007) presented a new additive Weibull model which was based on adding two weibull survival functions to describe the bathtub profile. Graphical estimation technique was used for parameter estimation. Various case studies discussed in this paper illustrated the applicability of the model. From the parameter obtained, the hazard rate function can be plotted which gives bathtub shaped profile only when the straight line is ascertain in subsequent plots.

Sakhardande et al. (2011) has carried out detailed investigation on how to reduce significant loss in unloading hours and given recommendation on maintenance policy for mechanical ore handling plant in Goa. In this ore handling plant, the receiving section dealt with the unloading of ore from barge which was achieved by wire rope operated grab un-loader. Due to continuous unloading, frequent failure of wire rope was observed which caused disruption in unloading process. This results in significant loss in unloading hours. They

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had identified and applied two models which provided the optimum schedule for replacing the wire rope.

Mariappan, et al. (2012) developed a system that will investigate on the input data of a given system which decideson its maintenance polices, specifically between breakdown maintenance and preventive maintenance. The system developed has a genesis of Kay's work. A complete system was developed as an integrated graphical tool for degradable system wherein repairing or replacement as applicable, considering three important criteria. Also the system developed optimizes for optimal period in case of PM. Mechanism to resolve maintenance policies between PM and BDM was depicted graphically and therefore usability is easier.

Chen (1999) proposed a new two parameter lifetime distribution. The distribution has increasing or bathtub-shaped failure rate function, exact confidence interval and exact joint confidence regions for the parameters which were discussed based on type −II censored samples.

Xie et al. (2002) presented a new model which was useful for modeling lifetime of system with a bathtub shape failure rate function. The traditional Weibull distribution function is however unable to model the complete life time of system with a bathtub shape failure rate function. The presented model can be seen as generalization Weibull distribution. In this paper, parameter estimation methods are discussed for new distribution. The new model was much flexible as it contained only three parameters and was related to Weibull and exponential distribution in asymptotic manner. From numerical examples it was seen that new method was easy to use and also achieved higher accuracy as compared to other models. Hence it served a good alternative when model for bathtub shape failure rate function are needed.

Notations

A: Availability in case of BDM

As: availability in case of PM

BDM :Breakdown maintenance

β : Shape parameter of two-parameter Weibull distribution

c: Maintenance cost per unit time for BDM

c_S :Maintenance cost per unit time for PM

C :Average effective maintenance cost rate for BDM

C_S: Average effective maintenance cost rate for PM

f(t) : probability density function (pdf) of time to failure

F(t) : Distribution function of time to failure

h(t) :Hazard rate function

m :Mean Time To Repair (MTTR) or Mean maintenance time, in case of BDM

m_S : MTTR, Mean maintenance time of PM

MTBF :Mean Time Between Failures (MTBF)

PM :Preventive maintenance

R(t): Reliability function

T* :Optimal schedule

$\overline{T}$: Mean time between preventive maintenances

θ : Scale parameter of Weibull distribution

WPP : Weibull Probability Plot

CASE DESCRIPTION

The Binani Industries Ltd. is the leading manufacturer of fiberglass in the state of Goa. Various types of products are manufactured in this company which is produced throughout the year. The problems faced by a large fibreglass company as a result of frequent breakdown in machines and equipment has lowered the productivity along with higher rejection level, as breakdown maintenance is very tedious and time consuming. Higher rejection level not only causes huge loss to the company but also causes customer dissatisfaction and delay in the product produce. The main objective is to reduce the likelihood or frequency of failure of equipment's. These frequent breakdowns of equipment's can be reduced by determining optimum maintenance schedule by arriving at an appropriate policy.

MAINTENANCE POLICY MODELING

The model developed by Kay (1976) offers considerable scope to derive collaborative maintenance decisions. The schedule maintenance is to mitigate the failure of machinery, during its assigned operating time by means of scheduled maintenance. It has long been accepted that a reasonable criterion by which the effectiveness of PM can be addressed via availability and maintenance cost. This is so because the relative increase in availability that can be obtained by PM compared to BDM is rather limited. Equations for availability and maintenance cost rate have been derived in respect of PM and BDM. Availability under BDM is

$$A = M/(M+m) = 1/(1+\mu) \qquad (1)$$

and under PM is

$$A_S = \frac{\overline{T}}{\overline{T} + m_S R(T) + m\left[1 - R(T)\right]} \qquad (2)$$

Maintenance cost rate under BDM is

$$C = \frac{c.m}{M + m} \qquad (3)$$

And under PM is

$$C_S = \frac{[1 - R(T)]mc + R(T)m_S C_S}{\overline{T} + m_S R(T) + m[1 - R(T)]} \qquad (4)$$

Hence the criteria for preventive maintenance to be attractive are: A_s-A > 0 or C_s-C < 0 The following conditions have been derived using the above criteria, to ensure that the preventive maintenance scheduled in time T offers maximum benefit than the corrective maintenance.

$$\alpha = \frac{1}{M}\int_0^T R(t)dt \qquad (5)$$

$\alpha > 1\text{-}kR(T)$

where $k = k_1 = 1-\gamma$ for maximizing availability and $k = k_2 \approx (1-\delta\gamma)$ for minimizing maintenance cost. As failure processes can be safely modeled as Weibull distribution, "(7)," can be evaluated after carrying out Weibull analysis. The integrand in "(7)," is transcendental but real valued analytic function. Therefore, a graphical approach would be more feasible. "(8)," resolves into α-curve and a straight line [1-k.R(T)]. It is proposed to obtain optimal schedule corresponding to the max gap between α-curve and criterion line under consideration as shown in Fig. 2.

Integrated Graphical Model

Since the procedure mentioned above is iterative in nature, one may find it cumbersome and time consuming. Owing to the computational skills involved, some practitioners may find it difficult to implement this approach practically. Keeping this in mind, a graphical approach involving an evaluation sheet in a graphical form is developed; running the iterative mechanism in the backend. The details of the approach are as follows:

It is clear that a decision and hence optimal schedule in case of PM are dependent upon failure density parameters of Weibull, which are normally shape parameter, β and decision parameter k. The computational efforts can be reduced if a functional relationship between distribution function of failure density, shape parameter of Weibull distribution and decision parameter is established, i.e. F(T) = G(β,k). However, evaluating the function G is quite difficult, as the function is transcendental and closed form integration is difficult. But the functional relationship can be mapped by physically rotating the decision line [1-kR(T)] from the lowest segment of k = 1 to a higher segment closer to k =0, through a step of say 0.05, necessarily keeping the point (1, 1) as pivot as presented pictorially in Fig. 4.2. As k is less than 1 and positive, this rotation covers practically all possible values of k. Here, it is noteworthy that each line segment represents the decision parameter, k as it intercepts (1-k) on the ordinate and passes through (1, 1). In the case of PM is preferred, the iterative procedure developed can be used for evaluating optimal period.

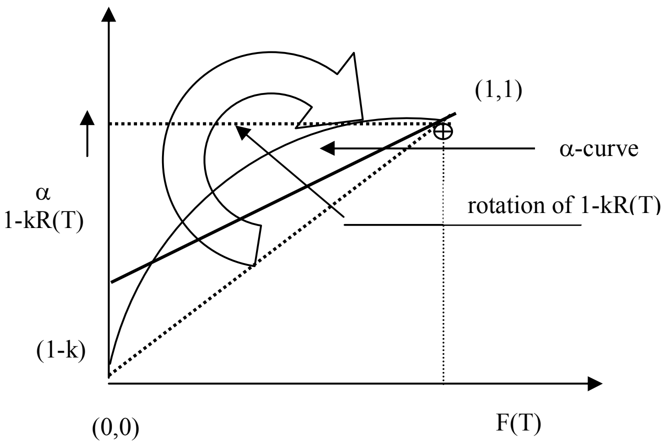

Figure 1: Evaluation of graphical model

The numerator of the third factor of Eqn. (36) is decision line and the denominator is α-curve for the givenβ, k and T. The optimal T* obtained from the iterative mechanism expressed in Eqn. (36) if put in F(T*)= G (β, k) the required functional relation can be mapped. This is done by developing an algorithm. That is, for the given β, each segmented k value will yield a point F(T).If the same is repeated for other values of k, for selected β, we will get a curve as shown in Fig. 4.3. The same procedure is repeated for different values of β and the corresponding family of curves obtained will give the map of the required functional relation as shown in Fig. 4.3. This map is referred as integrated graphical model. This can be effectively used in maintenance decisions. Following algorithm presents a structured approach for effectively using this for maintenance decision.

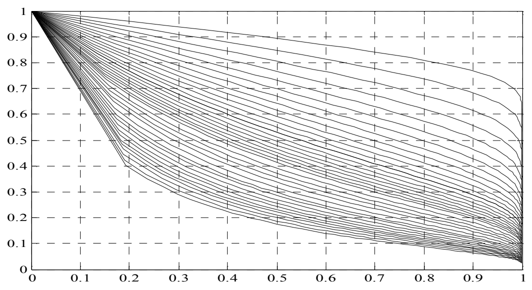

Figure 2: Graphical aid for maintenance policy

Procedure

A systematic procedure involving a number of steps has been evolved to evaluate the maintenance policies for degradable systems.

Step 1: Identify a system or subsystem of interest.

Step 2: Collect the data of failure time, down time and cost for the system under consideration.

Step 3: Perform Weibull analysis on the time to failure data and obtain Weibull parameters β and θ.

Step 4: Fix curve in the integrated model given in Fig. 4.3 for the value of β obtained in Step 3.

Step 5: Select the criterion.

Step 6: Compute value of k as per the criterion selected.

Step 7: Obtain the point of intersection of curve selected in Step 4 and decision parameter k calculated in Step 6.

Step 8: Check if the point of intersection falls in Phase-1.

If yes, go to Step 9, else go to Step 10.

Step 9: The decision is “BDM is preferable” for the criterion under consideration.

Step 10: Check if the point of intersection falls in Phase-2.

If yes, go to Step 12.If no, go to Step 11.

Step11: The decision is “the system needs further investigation”. No immediate decision is drawn. Go to Step 15.

Step12: The decision is “PM is preferable”. Compute the optimal schedule for the preferred PM either by using Eqn. (36) or by using the following steps for the criterion under consideration.

- Select the ordinate value of the point of intersection i.e. F(T*)
- Find the value of T*.

Step 13: Check if all the criteria are accounted.

If no, go to Step 14.

Otherwise, go to Step 15.

Step 14: Select a criterion among the remaining criteria and go to Step 6.

Step 15: Analyze output data obtained using different managerial implications. The flow chart depicted in Fig. 4.5 explains the logical sequence in which the tool has to be used. Actually, the model has three major parts namely Weibull analysis, maintenance decision and optimization. The input to Weibull analysis part is the results of the preliminary analysis carried out on the data collected. The output is the values of Weibull parameters. These parameters become the input to the maintenance decision part, wherein the output would be the choice between PM and BDM for the equipment under consideration. Thirdly if the output of the maintenance decision part is PM then third part will assess the optimal schedule.

Applicability

Applied the procedure on three subsystems and the results obtained are as given below:

Table 1: Failure Data of Batch Charger-1

Sr. no	Downtime (hrs.)	TTF
1	0.3	3359.7
2	0.3	6455.7
3	0.3	5543.7
4	0.45	3215.7
5	1	407.55
6	0.3	12551
7	0.3	144
8	0.3	5183.7
9	0.3	4127.7
10	0.3	3047.7

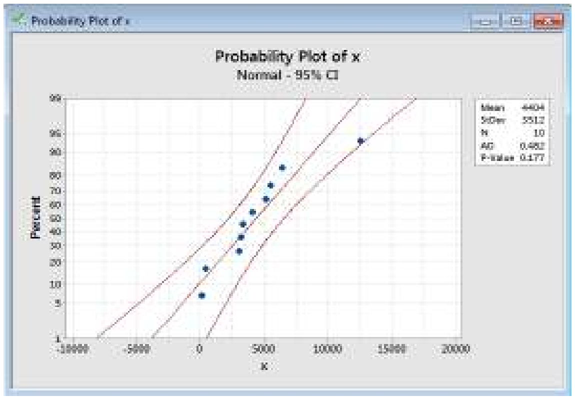

Figure 3: Probability plot for Batch Charger 1

From Weibull analysis: mean = 4404 hours, Standard deviation= 3512 hours, shape parameter = 4,ms = 6 hours, m = 6.25 hours, $\gamma = 0.96$, $k = 1-\gamma = 0.04$.

As can be seen from the graph F(T) lies in phase 1. Therefore, breakdown maintenance is preferred.

For minimizing maintenance cost: $\delta = 0.809524$, $k = 0.223117$.$F(T^*) = 0.69$, which gives $T^* = 6160$ hours

Using Equations (3) and (4), the percentage gain is obtained in maintenance cost 2% decreasing.

RESULTS AND DISCUSSION

After applying the model on the three subsystems of the plant, the results obtained are presented in the form of a table as shown in Table 2.

Table 2: Resuls and Discussion

Subsystem	**Subsystem-1: Furnace**	
Component	**Batch Charger 1**	
Criteria	**Availability**	**Maintenance cost**
T*	phase1	6160
% Change	Go for BDM	2.0144%↓
Decision	BDM	PM
Component	**Batch Charger 2**	
Criteria	**Availability**	**Maintenance cost**
T*	5514.6	2910.9
% Change	0.0027%↑	23.10%↓
Decision	PM	PM
Component	**Electric Boost System**	
Criteria	**Availability**	**Maintenance cost**
T*	phase1	–
% Change	Go for BDM	–
Decision	BDM	–
Component	**Silo 2**	
Criteria	**Availability**	
T*	phase1	1698.66
% Change	Go for BDM	21.966%↓
Decision	BDM	PM
Subsystem	**Subsystem-2: HAVC**	
Component	**HAVC chiller 1**	
Criteria	**Availability**	**Maintenance cost**
T*	377.63	147.277
% Change	Investigate further	Investigate further
Decision	No PM	No PM
Subsystem	**Subsystem-3: Autocake**	
Component	**Autocake-1**	
Criteria	**Availability**	**Maintenance cost**
T*	phase1	phase1
% Change	Go for BDM	Go for BDM
Decision	BDM	BDM
Component	**Autocake-2**	
Criteria	**Availability**	**Maintenance cost**
T*	phase1	2560.41
% Change	Go for BDM	0.5032%↓
Decision	BDM	PM
Component	**Autocake-6**	
Criteria	**Availability**	**Maintenance cost**
T*	phase1	1904.1088
% Change	Go for BDM	0.1573%↓
Decision	BDM	PM

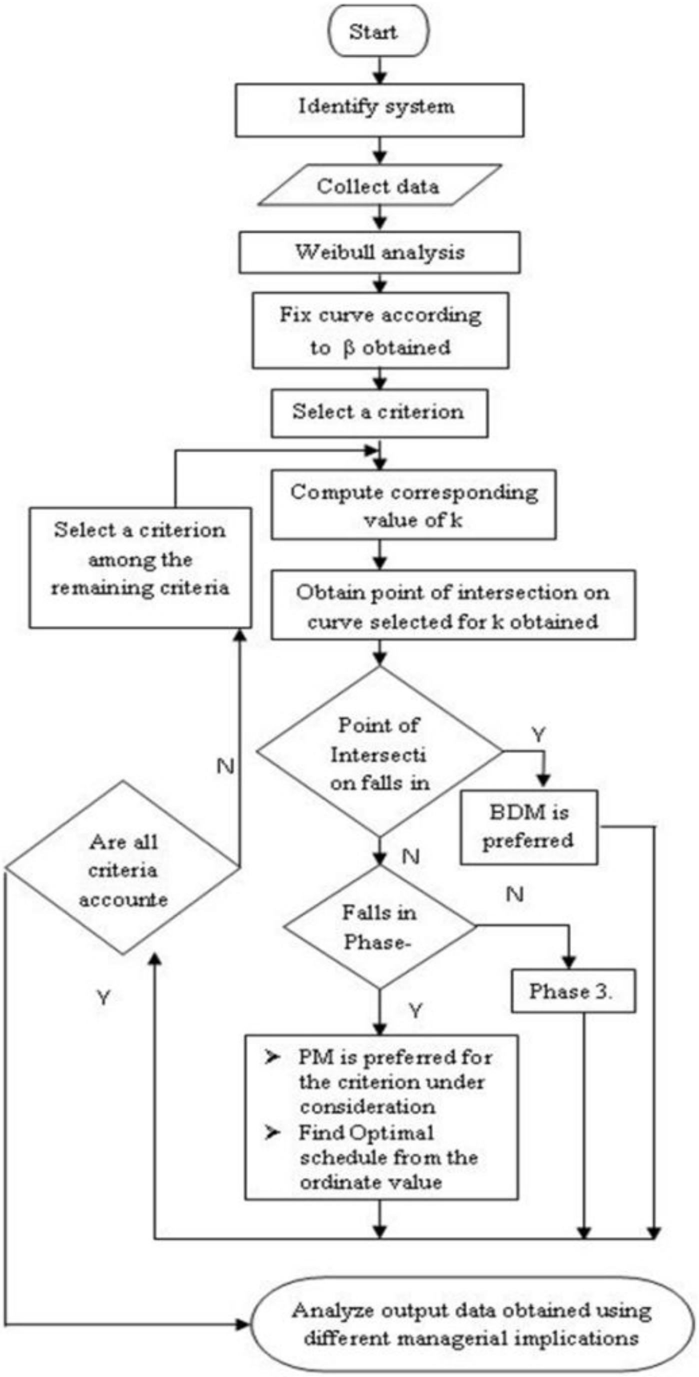

Figure 4: Fow chart for the graphical model

CONCLUSION

The integrated graphical model has successfully been able to overcome the limitation of kay's model. This has been achieved on platform of powerful mathematical software MATLAB. Tool is easy to use and interactive in nature. It being a graphical aid has a very simple procedure involved. It does not require any highly specialized personal to carry out this procedure. The tool is very versatile and can be effectively used on every shop floor with ease, thus making very useful for maintenance engineer.

The technique proposed in this work, does piecewise analysis on the obtained data. It also involves a bit of manual computing work which is subjected to human error. Another limitation of this thesis is that the tool could have been applied to some more real life cases which would have further proved its credibility.

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