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Reliability Analysis of Screw Manufacturing Plant Using Orthogonal Matrix Method

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ABSTRACT

The paper proposes a methodology to compute reliability of the screw plant. A screw plant consists of four subsystems A, B, C, D working in series namely heading machine, slotting machine, thread rolling machine and polishing machine. Subsystem A is supported by standby units having perfect switching over device and subsystem C has two units in parallel redundancy and remaining two subsystems B and D are subjected to major failure only. For system configuration and establishment of the model we prefer Boolean algebra method and orthogonal matrix method has been used for reliability calculation. Reliability of the Screw Plant has been estimated when the failure rate expressed by weibull and exponential time distribution. Mean time to failure has also been determined for exponential time distribution, which is also a relevant characteristic of reliability.

Keywords: Boolean function, failure rate, mean time to failure, reliability

INTRODUCTION

Now a day, companies are required to place strenuous efforts . One has often heard the expression “There is no substitute for experience” and many industries today depend on this experience and skill to produce reliable products. In a progressive business surrounding, a reliable production system secures the sustainability of an enterprise. Thus, the system reliability assessment and prediction, which concerns the different stages of the operating process, has become increasingly important. In this paper, we resolve the mathematical function that explicits the system reliability in terms of the component reliabilities. Previously a lot of research work has been accomplished by many analysts on the topic reliability/availability. Agarwal (1977) discussed a method to minimize the cost and maximize the availability of the system.

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Gupta & Kumar and Singh (1989) had studied on availability of paper industry. Dhillon (1992) explained a K-Out of N component system with human error. Burns (1997) used a computer program to calculate the mean time between failures of complex system. Gupta et al. (2005) presented numerical analysis of reliability and availability of the Serial Processes in Butter-Oil Processing Plant. Agarwal and Bansal (2009) carried head of line repair discipline with environment effect to find the reliability of the system. Agarwal et al. (2010) studied on reliability with cold standby system. Garg et al. (2010) performed a study on the blackboard manufacturing system. Ekata and Singh (2011) developed various characteristics of reliability with Partial and Complete Failure. Shakuntala et al. (2011) had applied Lagrange's method to compute the reliability of polytube industry. Singh et al. (2011) studied on a different technique to determining terminal reliability. Kumar et al. (2013) evaluated the availability analysis of coal-fired power plant. Agarwal and Bansal (2015) examined the cost analysis of solar thermal electric power plant. Taj et al. (2017) proposed regenerative point method to find reliability of cable plant. There are such a significant number of existing strategies to acquire system reliability But all the methods follow by them bring on tiresome and complicated computation. So keeping all this fact in perspective, we used Boolean algebra technique to find a formulation of the system and applying matrix method to use reliability calculation which described the structure of complex system/equipments and the features of its. Fratta (1973) demonstrated an efficient algorithm for the analysis of unreliable communication network. Nakazawa (1977) focused on a decomposition strategy for analyzing the reliability by a Boolean Expression. Agarwal and Gupta (1983) proposed Boolean algebra method to find reliability. Singh et al. (2011) examined the utilization of the Boolean Truth Table demonstrating strategy in assessing the reliability parameters. Iqbal and Uduman (2016) established Boolean function with fuzzy logic technique for Reliability analysis of paper plant, which was obviously, an achievement in this context, but still needed further development. The aim of the present paper is a further augmentation of Boolean function technique by considering a contextual analysis of screw manufacturing plant. When we want need to get instant system's reliability without numerous computations, this technique is of much significance. Generally engineers and business personnel utilize this technique. In actuality, the significance of orthogonal matrix method for complex systems cannot be overlooked because of two reasons

(a) For system reliability various techniques are required in the advancement of complex system
(b) In several engineering systems, system configurations do not modify for a long period, however the reliabilities of parts modification perpetually.

In both these circumstances, orthogonal matrix method would incredibly decrease the calculations which are required over and over to evaluate the system reliability. In this paper, we proposed a Boolean function technique to evaluate the reliability of screw manufacturing plant. Boolean function technique is simpler as compared with the other techniques to get reliability parameters. Some specific cases have also given to enhance practical utility of the model. We have compared the values of reliability function, in case of failures follow Weibull and Exponential time distributions

System Description

Screw is a tool that has been used since the dawn of time; it is one of the most important pieces you need to repair any aspect of a project you're looking for. The word "screw" now has a permanent place in the language that we use every day. The screw plant is divided into four subsystems, namely Cold Heading Machine, Slotting Machine, Thread Rolling Machine and Polishing Machine. Usually, screws are prepared from wire. Firstly the wire is cut in desire length and makes the head of the screw by Heading Machine. Slotted head screw needs a further Step to cut the slot in the head, this is succeeded with Slotting Machine then put all the pieces into the Thread Rolling machine to produce threads. Finally, polish the screw to shine the final product. The system configuration of the system is shown in Figure 1.

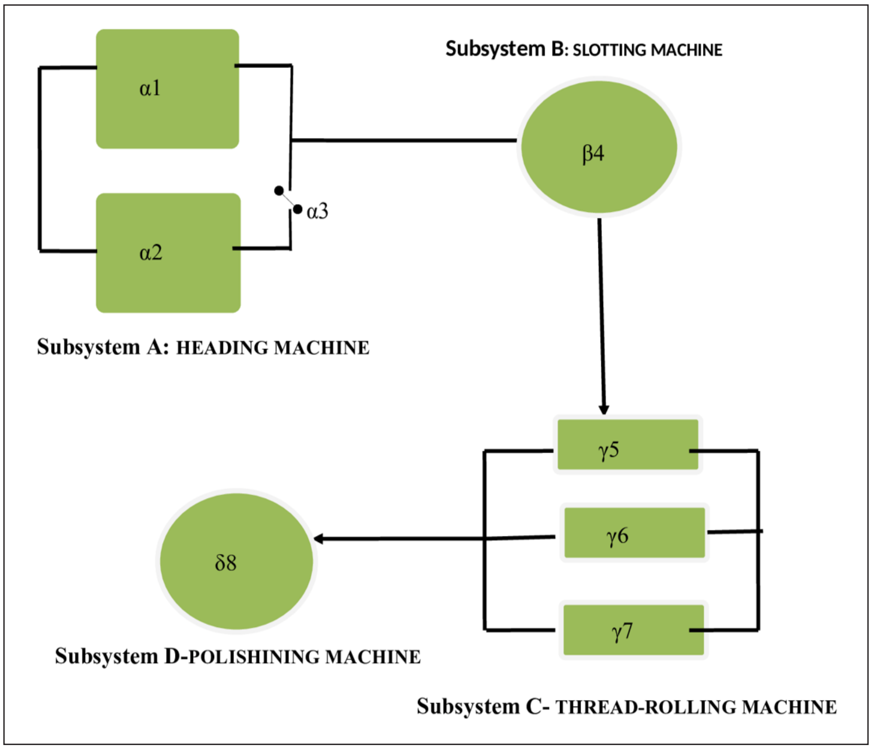

Figure 1. System configuration of screw manufacturing plant

1. Heading Machine (A) has two units; one is in operable state and second is in standby with perfect switching over device.
2. Slotting Machine (B) has a single unit.
3. Thread-Rolling Machine (C) has three units connected in parallel.
4. Polishing Machine (D) consists one unit only.

Assumptions.

1. At the beginning, all the subsystems are workable.
2. The plant has two states only i.e. Operable and failed.
3. Failure rates are arbitrary and statistically-independent.
4. The reliability of the each unit is known in advance.
5. Failure of any subsystem of the plant discontinues the functioning of the system.

Notations.

α_1, α_2	: States of Heading machine
α_3	: States of perfect Switching devices
β_4	: States of Slotting machine
$\gamma_5, \gamma_6, \gamma_7$	: States of Threading Rolling Machine
δ_8	: States of Polishing Machine
$\alpha_{i,}$ $\beta_4, \gamma_j, \delta_8$ for all i,=1,2,3 & j=5,6,7	: =1 is in operable state and = 0 is in failed state
$\neg\alpha_i, \neg\beta_4, \neg\gamma_j$ $\neg\delta_8$	: Negation of $\alpha_{i,}$ $\beta_4,$ γ_j, δ_8 for all i,=1,2,3 & j=5,6,7
$\wedge / \vee$	: Conjunction / Disjunction
$\mid \mid$	: Representation of logical matrix
$\Re_{\alpha_i}, \Re_{\beta_j}, \Re_{\gamma_k}, \Re_{\delta_m}$	: Reliability of $\alpha_i^{\hbar}, \beta_j^{\hbar}, \gamma_k^{\hbar}, \delta_l^{\hbar}$ part of the system, $\forall$ i=1,2,3, j=4, k=5,6,7, m=8
C_i	: $1-R_i$
$\Re_{\wp}$	: Reliability of the Screw Plant
$\Re_W(t) / \Re_E(t)$	: Reliability of the screw plant when failures follow Weibull time distribution / Exponential time distribution

Mathematical Formulation of the Model

1. There are some steps to define Boolean algebra technique
2. We discover straightforward ways between units of a plant.
3. Corresponding to the Boolean variables which are given to the diverse units, we find the Boolean expression to the paths
4. For the Boolean expression which is given in step 2, we find the disjoint expression

To get the terminal reliability, substitute the relating values of probabilities in the given disjoint Boolean expression

The Paths to refer successful activity of the screw plant by adopting the Boolean function technique, in terms of logical matrix are:

$$\Delta(\alpha_1,\alpha_2,\alpha_3,\beta_4,\gamma_5,\gamma_6,\gamma_7,\delta_8)=\begin{vmatrix}\alpha_1 & \beta_4 & \gamma_5 & \delta_8 & \\ \alpha_1 & \beta_4 & \gamma_6 & \delta_8 & \\ \alpha_1 & \beta_4 & \gamma_7 & \delta_8 & \\ \alpha_2 & \alpha_3 & \beta_4 & \delta_5 & \delta_8 \\ \alpha_2 & \alpha_3 & \beta_4 & \delta_6 & \delta_8 \\ \alpha_2 & \alpha_3 & \beta_4 & \delta_7 & \delta_8\end{vmatrix} \tag{1}$$

Solution of the Model

With the help of algebra of logic equation (1) developed as,

$$\Delta(\alpha_1,\alpha_2,\alpha_3,\beta_4,\gamma_5,\gamma_6,\gamma_7,\delta_8)=\beta_4\,\delta_8\wedge\Psi(\alpha_1,\alpha_2,\alpha_3,\gamma_5,\gamma_6,\gamma_7) \tag{2}$$

Where,

$$\Psi(\alpha_1,\alpha_2,\alpha_3,\gamma_5,\gamma_6,\gamma_7)=\begin{vmatrix}\alpha_1 & \gamma_5 & \\ \alpha_1 & \gamma_6 & \\ \alpha_1 & \gamma_7 & \\ \alpha_2 & \alpha_3 & \gamma_5 \\ \alpha_2 & \alpha_3 & \gamma_6 \\ \alpha_2 & \alpha_3 & \gamma_7\end{vmatrix}=|D_g| \tag{3}$$

Where, $|D_g|$ is a column matrix, $\forall$ g = 1, 2, 3,4,5,6

$$D_1=|\alpha_1 \quad \gamma_5| \tag{4}$$

$$D_2=|\alpha_1 \quad \gamma_6| \tag{5}$$

$$D_3=|\alpha_1 \quad \gamma_7| \tag{6}$$

$$D_4=|\alpha_2 \quad \alpha_3 \quad \gamma_5| \tag{7}$$

$$D_5 = \left| \alpha_2 \quad \alpha_3 \quad \gamma_6 \right| \tag{8}$$
$$D_6 = \left| \alpha_2 \quad \alpha_3 \quad \gamma_7 \right| \tag{9}$$

The defined logical matrix in equation (3) represents cases of parallel units. D_1 represents when α_1 and γ_5 are working. D_2 is case when α_1 and γ_6 are working and so on.

By Orthogonalization algorithm the above equation may be written as

$$\Psi(\alpha_1,\alpha_2,\alpha_3,\gamma_5,\gamma_6,\gamma_7) = \begin{vmatrix} D_1 & & & & & \\ \neg D_1 & D_2 & & & & \\ \neg D_1 & \neg D_2 & D_3 & & & \\ \neg D_1 & \neg D_2 & \neg D_3 & D_4 & & \\ \neg D_1 & \neg D_2 & \neg D_3 & \neg D_4 & D_5 & \\ \neg D_1 & \neg D_2 & \neg D_3 & \neg D_4 & \neg D_5 & D_6 \end{vmatrix} \tag{10}$$

$\neg D_1$ Represent that D_1 is in failed state. Second row $\neg D_1 D_2$ represent that D_1 is in failed state and D_2 is working. Similarly other rows can be defined. By application of Boolean algebra of logical matrix above rows can be expanded as:

$$\neg D_1\, D_2 = \begin{vmatrix} \neg\alpha_1 & \\ \alpha_1 & \neg\gamma_5 \end{vmatrix} \wedge \left| \alpha_1 \quad \gamma_6 \right| = \left| \alpha_1 \quad \neg\gamma_5 \quad \gamma_6 \right| \tag{11}$$

Similarly,

$$\neg D_1 \neg D_2\, D_3 = \left| \alpha_1 \quad \neg\gamma_5 \quad \neg\gamma_6 \quad \gamma_7 \right| \tag{12}$$

$$\neg D_1 \neg D_2 \neg D_3\, D_4 = \left| \neg\alpha_1 \quad \alpha_2 \quad \alpha_3 \quad \gamma_5 \right| \tag{13}$$

$$\neg D_1 \neg D_2 \neg D_3 \neg D_4\, D_5 = \left| \neg\alpha_1 \quad \alpha_2 \quad \alpha_3 \quad \neg\gamma_5 \quad \gamma_6 \right| \tag{14}$$

$$\neg D_1 \neg D_2 \neg D_3 \neg D_4 \neg D_5\, D_6 = \left| \neg\alpha_1 \quad \alpha_2 \quad \alpha_3 \quad \gamma_5 \quad \neg\gamma_6 \quad \gamma_7 \right| \tag{15}$$

Inserting all these values in equation (10), we get

$$\Psi(\alpha_1,\alpha_2,\alpha_3,\gamma_5,\gamma_6,\gamma_7) = \begin{vmatrix} \alpha_1 & \gamma_5 & & & & \\ \alpha_1 & \neg\gamma_5 & \gamma_6 & & & \\ \alpha_1 & \neg\gamma_5 & \neg\gamma_6 & \gamma_7 & & \\ \neg\alpha_1 & \alpha_2 & \alpha_3 & \gamma_5 & & \\ \neg\alpha_1 & \alpha_2 & \alpha_3 & \neg\gamma_5 & \gamma_6 & \\ \neg\alpha_1 & \alpha_2 & \alpha_3 & \gamma_5 & \neg\gamma_6 & \gamma_7 \end{vmatrix} \tag{16}$$

Using (16), equation (2) becomes

$$\Delta(\alpha_1,\alpha_2,\alpha_3,\beta_4,\gamma_5,\gamma_6,\gamma_7,\delta_8)=\begin{vmatrix} \alpha_1 & \beta_4 & \gamma_5 & \delta_8 & & & & \\ \alpha_1 & \beta_4 & \neg\gamma_5 & \gamma_6 & \delta_8 & & & \\ \alpha_1 & \beta_4 & \neg\gamma_5 & \neg\gamma_6 & \gamma_7 & \delta_8 & & \\ \neg\alpha_1 & \alpha_2 & \alpha_3 & \beta_4 & \gamma_5 & \delta_8 & & \\ \neg\alpha_1 & \alpha_2 & \alpha_3 & \beta_4 & \neg\gamma_5 & \gamma_6 & \delta_8 & \\ \neg\alpha_1 & \alpha_2 & \alpha_3 & \beta_4 & \gamma_5 & \neg\gamma_6 & \gamma_7 & \delta_8 \end{vmatrix} \quad (17)$$

Hence the probability of successful operation (i.e. reliability) of the screw plant is given by

$$\Re_S = P_r\{\Delta(\alpha_1,\alpha_2,\alpha_3,\beta_4,\gamma_5,\gamma_6,\gamma_7,\delta_8)=1\}$$

Or,

$$\Re_S = \Re_{\alpha_1}\Re_{\beta_4}\Re_{\gamma_5}\Re_{\delta_8} + \Re_{\alpha_1}\Re_{\beta_4}C_{\gamma_5}\Re_{\gamma_6}\Re_{\delta_8} + \Re_{\alpha_1}\Re_{\beta_4}C_{\gamma_5}C_{\gamma_6}\Re_{\gamma_7}\Re_{\delta_8} + C_{\alpha_1}\Re_{\alpha_2}\Re_{\alpha_3}\Re_{\beta_4}\Re_{\gamma_5}C_{\delta_8}$$
$$+ C_{\alpha_{11}}\Re_{\alpha_2}\Re_{\alpha_3}\Re_{\beta_4}C_{\gamma_5}\Re_{\gamma_6}\Re_{\delta_8} + C_{\alpha_1}\Re_{\alpha_2}\Re_{\alpha_3}\Re_{\beta_4}\Re_{\gamma_5}C_{\gamma_6}\Re_{\gamma_7}\Re_{\delta_8}$$

$$\Re_S = \Re_{\delta_8}\big[\Re_{\alpha_1}\Re_{\beta_4}\Re_{\gamma_5} + \Re_{\alpha_1}\Re_{\beta_4}\Re_{\gamma_6} - \Re_{\alpha_1}\Re_{\beta_4}\Re_{\gamma_5}\Re_{\gamma_6} + \Re_{\alpha_1}\Re_{\beta_4}\Re_{\gamma_7} - \Re_{\alpha_1}\Re_{\beta_4}\Re_{\gamma_5}\Re_{\gamma_7}$$
$$- \Re_{\alpha_1}\Re_{\gamma_5}\Re_{\gamma_6}\Re_{\gamma_7} + \Re_{\alpha_1}\Re_{\beta_4}\Re_{\gamma_5}\Re_{\gamma_6}\Re_{\gamma_7} + \Re_{\alpha_2}\Re_{\alpha_3}\Re_{\beta_4}\Re_{\gamma_5} - \Re_{\alpha_1}\Re_{\alpha_2}\Re_{\alpha_3}\Re_{\beta_4}\Re_{\gamma_5} + \Re_{\alpha_2}\Re_{\alpha_3}\Re_{\beta_4}\Re_{\gamma_6}$$
$$- \Re_{\alpha_1}\Re_{\alpha_2}\Re_{\alpha_3}\Re_{\beta_4}\Re_{\gamma_6} - \Re_{\alpha_2}\Re_{\alpha_3}\Re_{\beta_4}\Re_{\gamma_5}\Re_{\gamma_6} + \Re_{\alpha_1}\Re_{\alpha_2}\Re_{\alpha_3}\Re_{\beta_4}\Re_{\gamma_5}\Re_{\gamma_6} + \Re_{\alpha_2}\Re_{\alpha_3}\Re_{\beta_4}\Re_{\gamma_5}\Re_{\gamma_7}$$
$$- \Re_{\alpha_1}\Re_{\alpha_2}\Re_{\alpha_3}\Re_{\beta_4}\Re_{\gamma_5}\Re_{\gamma_7} - \Re_{\alpha_2}\Re_{\alpha_3}\Re_{\beta_4}\Re_{\gamma_5}\Re_{\gamma_6}\Re_{\gamma_7} + \Re_{\alpha_1}\Re_{\alpha_2}\Re_{\alpha_3}\Re_{\beta_4}\Re_{\gamma_5}\Re_{\gamma_6}\Re_{\gamma_7}\big] \quad (18)$$

Some Special Cases

Case I: If $\Re_{\alpha_i} = \Re_{\beta_4} = \Re_{\gamma_j} = \Re_{\delta_8} \quad \forall i = 1,2,3 \quad and \quad j = 5,6,7$

Then equation (18) turns into

$$\Re_{S} = \Re^8 - \Re^7 - \Re^6 - \Re^5 + 3\Re^4 \quad (19)$$

Case II: In case of weibull time distribution let h_i be the failure rate corresponding to system state $\alpha_i, \forall i = 1,2,3,\ \beta_4,\ \gamma_j\ \ \forall j = 5,6,7,\ \delta_8$ respectively, then at an instant ‘t’ the system reliability is given by

$$\Re_W(t) = \sum_{k=1}^{9} \exp.\left\{-P_k t^{\theta}\right\} - \sum_{l=1}^{8} \exp.\left\{-N_l t^{\theta}\right\} \tag{20}$$

Where,

$$P_1 = h_{\alpha_1} + h_{\beta_4} + h_{\delta_8} + h_{\delta_8}$$
$$P_2 = h_{\alpha_1} + h_{\beta_4} + h_{\gamma_6} + h_{\delta_8}$$
$$P_3 = h_{\alpha_1} + h_{\beta_4} + h_{\gamma_7} + P_4$$
$$P_4 = h_{\alpha_1} + h_{\alpha_2} + h_{\beta_4} + h_{\gamma_5} + h_{\delta_8}$$
$$P_5 = h_{\alpha_1} + h_{\alpha_2} + h_{\beta_4} + h_{\delta_8} + h_{\delta_8}$$
$$P_6 = h_{\alpha_1} + h_{\beta_4} + h_{\gamma_5} + h_{\gamma_6} + h_{\gamma_7} + h_{\delta_8}$$
$$P_7 = h_{\alpha_2} + h_{\alpha_3} + h_{\beta_4} + h_{\gamma_5} + h_{\gamma_7} + h_{\delta_8}$$
$$P_8 = h_{\alpha_1} + h_{\alpha_2} + h_{\alpha_3} + h_{\beta_4} + h_{\gamma_6} + h_{\gamma_6} + h_{\delta_8}$$
$$P_9 = h_{\alpha_1} + h_{\alpha_2} + h_{\alpha_3} + h_{\beta_4} + h_{\gamma_5} + h_{\gamma_6} + h_{\gamma_7} + h_{\delta_8}$$

and

$$N_1 = h_{\alpha_1} + h_{\beta_4} + h_{\gamma_5} + h_{\gamma_6} + h_{\delta_8}$$
$$N_2 = h_{\alpha_1} + h_{\beta_4} + h_{\gamma_5} + h_{\gamma_7} + h_{\delta_8}$$
$$N_3 = h_{\alpha_1} + h_{\beta_4} + h_{\gamma_6} + h_{\gamma_7} + h_{\delta_8}$$
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$$N_5 = h_{\alpha_1} + h_{\alpha_2} + h_{\alpha_3} + h_{\beta_4} + h_{\gamma_6} + h_{\delta_8}$$
$$N_6 = h_{\alpha_2} + h_{\alpha_3} + h_{\beta_4} + h_{\gamma_5} + h_{\gamma_6} + h_{\delta_8}$$
$$N_7 = h_{\alpha_1} + h_{\alpha_2} + h_{\alpha_3} + h_{\beta_4} + h_{\gamma_7} + h_{\gamma_7} + h_{\delta_8}$$
$$N_8 = h_{\alpha_2} + h_{\alpha_3} + h_{\beta_4} + h_{\gamma_5} + h_{\gamma_6} + h_{\gamma_7} + h_{\delta_8}$$

Case III: Consider $\theta = 1$, in the case of exponential time distribution. It is a special case of the weibull distribution. At an instant't' the reliability of considered system is given by:

$$\Re_E(t) = \sum_{k=1}^{9} \exp.\left\{-P_k t\right\} - \sum_{l=1}^{8} \exp.\left\{-N_l t\right\} \tag{21}$$

Where, P_k and N_l 's have previously described.

Also mean time to failure of the screw plant in case of exponential time distribution is given by

$$\text{M.T.T.F} = \int_0^{\infty} \Re_E(t)\, d$$

$$= \sum_{k=1}^{9}\left(\frac{1}{P_k}\right) - \sum_{l=1}^{8}\left(\frac{1}{N_l}\right) \tag{22}$$

Numerical Calculation

For justification of above calculate expression we have to set some appropriate numerical data and result will be given below. The relationship can be seen by tabular and graphical representation.

(A) $\alpha_i\left(i=1,2,3\right), \beta_4, \gamma_{\text{j}}\left(j=5,6,7\right), \delta_8 = 0.001,\ \ \theta = 2\ and\ \ \text{t} = 0,1,2\text{ - -}$ in equation (20)

(B) $\alpha_i\left(i=1,2,3\right), \beta_4, \gamma_{\text{j}}\left(j=5,6,7\right), \delta_8 = 0.001,\ \ and\ \ \text{t} = 0,1,2\text{ - -}$ in equation (21)

(C) $\alpha_i\left(i=1,2,3\right), \beta_4, \gamma_{\text{j}}\left(j=5,6,7\right), \delta_8 = 0,0.1......1.0$ in equation (22)

With the help of above data, we figure out the Table 1 and Table 2 .The analogous graph has been shown in Figure 2 and Figure 3 respectively.

RESULT AND DISCUSSION

In the compiled work of this paper, the reliability of the screw manufacturing plant has been carried out. The reliability which depict the performance of the plant, when failure rates follow exponential and Weibull time distribution with respect to the time is shown by tabular and graphical representation in the Tables 1 and 2 and Figures 2 and 3 respectively. Figure 1 i.e. ‘Reliability Vs Time” highlight that when failure rate follows an exponential time distribution, the reliability of the screw plant decreases approximately at a uniform rate, but in case of weibull time distribution it decreases speedily. The study of Table 2 and Figure 2 “MTTF V/S Failure Rate” explores that the mean time to failure of the plant decreases catastrophically in the starting but later it decreases approximately at a uniform rate.

Table 1
Comparison of reliability when failures follow Weibull and Exponential time distribution

Time t (in days)	RW(t)	RE(t)
0	1	1
1	0.998001	0.998001
2	0.992016	0.996004
3	0.982079	0.994009
4	0.968244	0.992016
5	0.950581	0.990025
6	0.929175	0.988035
7	0.904122	0.986048
8	0.875537	0.984062
9	0.843558	0.982079
10	0.808362	0.980097

Table 2
Mean Time to Failure (MTTF) corresponding to failure rate

Failure, f_i	MTTF
0.01	36.54762
0.02	18.27381
0.03	12.18254
0.04	9.136905
0.05	7.309524
0.06	6.09127
0.07	5.221088
0.08	4.568452
0.09	4.060847
0.1	3.654762

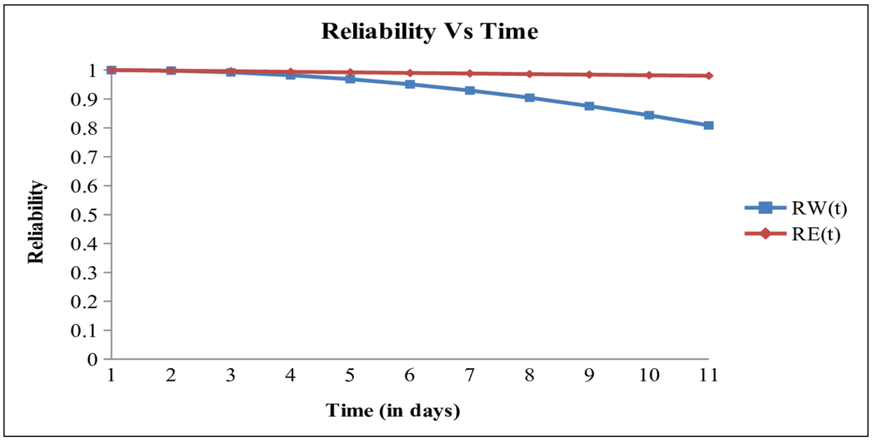

Figure 2. MTTF vs. failure rate

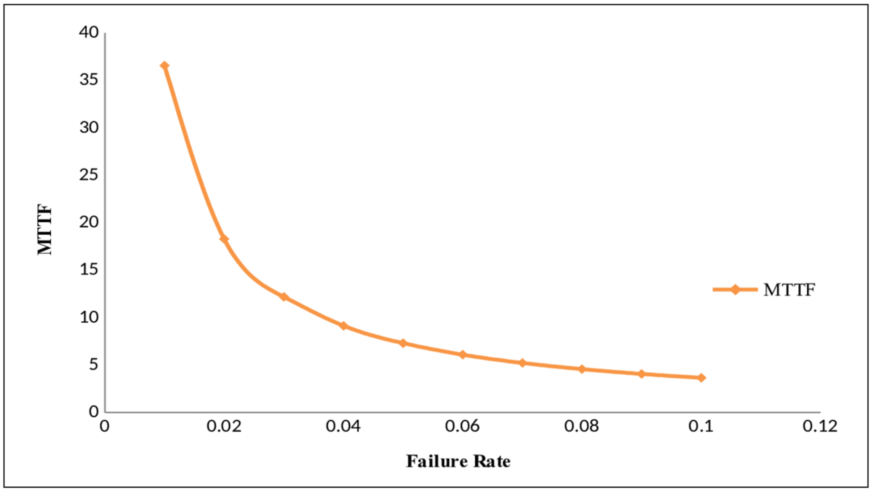

Figure 2. MTTF vs. failure rate

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