IJournals International Journal of Software & Hardware Research in Engineering
ISSN No: 2347-4890 Volume 2 Issue 11, November-2014

Mtsf And Profit Analysis of A Three Unit System Working In An Industry With Repair Equipment Failure

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ABSTRACT
The main aim of this research study is to present a MTSF and profit analysis of a three unit system with the assumption that repair equipment may also fail during the repair. Using semi-markov process and regenerative point technique various reliability characteristics like MTSF, Availability and profit functions are obtained which are very useful to industry.

Keywords: MTSF, Availability, Profit Function, Regenerative point.

1. INTRODUCTION

Two or more-unit systems with working or failed states have been discussed under various assumptions and situations by many researchers including [1-4], they all have assumed that repair equipment can never be failed. But in real situation repair equipment may also fail during the repairing of failed unit. We had visit the sugar mill situating in Muzaffar nagar ,UP. For getting the idea of designing the model and also for collecting the data of failure and operating time of the units. From this mill we have observed that a system consists of two big similar units of one unit and one small unit , both of which are connected in series, but one big unit has two Sub units connected in Parallel one of them is in standby mode, This System is operating only if one of the big unit and small unit are in good condition .On the basis of the situation observed in this mill, we put a step towards this direction by analyzing the reliability and the profit function of a 3-unit System, evaluating various measures of system effectiveness Taking the above facts into consideration in this paper we analyze a system model assuming the possibility of repair equipment failure.

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2. SYSTEM DESCRIPTION

This System consists of two big identical units of A and one small unit B both are connected in series, but A has two Sub unit connected in Parallel one of them is in standby mode, so both units A and B are initially operating but the operation of only one sub unit of A is sufficient for operating the system with operating Unit B. There is a single repair facility. When repair equipment fails during the repair of any failed unit, repairman starts the repair of repair-equipment first so the preference has been given to repair-equipment over failed unit. Each repaired unit works as good as new.

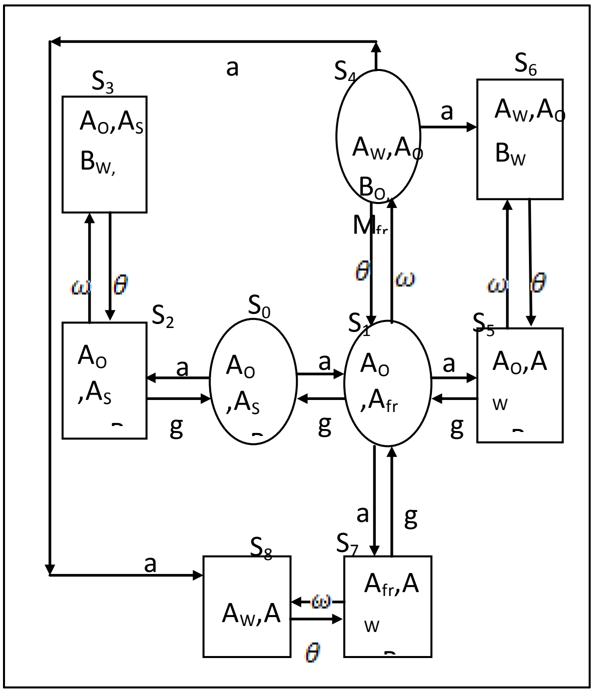

Fig.1-Transition Diagram

3. NOTATIONS

For defining the states of the system we assume the following symbols:

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ISSN No: 2347-4890 Volume 2 Issue 11, November-2014

A_0 : Unit A is in operative mode

B_0: Unit B is in operative mode

A_{fr} : Unit A is in failure mode

B_{fr} : Unit B is in failure mode

w: Constant rate of failure of repair-equipment

θ: Constant rate of repair-equipment's repair

A_w: unit A in failure mode but in waiting for repairman

B_w: unit B in failure mode but in waiting for repairman

M_{fr}: unit A in failure mode but in waiting for repairman

B_w: unit B in failure mode but in waiting for repairman

$q_{ij}(.), ($ pdf &cdf of transition time from regenerative states pdf &cdf of transition time from regenerative state S_i to S_j.

μ_i : Mean sojourn time in state S_i.

$\oplus$: Symbol of ordinary Convolution

$$A(t) \oplus$$

$$B(t) = \int_0^t A(t-u)B(u$$

$$B(t) = \int_0^t A(t-u)dB($$

3.1 Transition Probability and Sojourn Times

The steady state transition probability can be as follows

$P_{01} = \frac{a_1}{\varphi}$ $P_{32}=1$

$P_{02} = \frac{a_2}{\varphi}$ $P_{41} = \frac{\theta}{\phi}$

$P_{10} = \frac{\beta}{\beta + \omega + \varphi}$ $P_{46} = P_{45.6} = \frac{a_1}{\theta + \varphi}$

$P_{14} = \frac{\omega}{\beta + \omega + \varphi}$ $P_{48} = P_{47.8} = \frac{a_2}{\theta + \varphi}$

$P_{15} = \frac{a_2}{\beta + \omega + \varphi}$ $P_{51} = \frac{\beta_2}{\omega + \beta_2}$

$P_{17} = \frac{a_1}{\beta + \omega + \varphi}$ $P_{56} = \frac{\omega}{\omega + \beta_2}$

$P_{20} = \frac{\beta_2}{\beta_2 + \omega}$ $P_{71} = \frac{\beta_1}{\omega + \beta_1}$

$P_{23} = \frac{\omega}{\beta_2 + \omega}$ $P_{78} = \frac{\omega}{\omega + \beta_1}$

$P_{01}+P_{02}=1$ $P_{41}+P_{47.8}+P_{45.6}=1$

$P_{10}+P_{14}+P_{15}+P_{17}=1$ $P_{20}+P_{23}=1$

$P_{41}+P_{46}+P_{48}=1$ $P_{71}+P_{78}=1$

$P_{32}=1$, $P_{87}=1$, $P_{65}=1$ $P_{56}+P_{51}=1$ **(1-26)**

Mean sojourn times:

$$\mu_0 = \frac{1}{\phi} \qquad \frac{1}{\omega + \varphi}$$

$$\mu_4 = \frac{1}{\theta + \phi}$$

4. ANALYSIS OF CHARACTERISTICS

4.1 MTSF (Mean Time to System Failure)

To determine the MTSF of the system, we regard the failed state of the system as absorbing state, by probabilistic arguments, we get

$$\phi_0(t) = Q_{01} \otimes \phi_1(t) + Q_{02}$$

$$\phi_1(t) = Q_{10} \otimes \phi_0(t) + Q_{14} \otimes \phi_4(t) + Q_{15} + Q_{17}$$

$$\phi_4(t) = Q_{41} \otimes \phi_1(t) + Q_{48} + Q_{46}$$

Taking Laplace Stieltjes transforms of these relations and solving for $\phi_0^{**}(s)$,

$$\phi_0^{**}(s) = \frac{N(s)}{D(s)}$$

$$N = \mu_0(1 - P_{14}P_{41}) + \mu_1(P_{01} + P_{02}P_{41}) + \mu_2(P_{01}P_{14} + P_{02})$$

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$$D = (1 - P_{14}P_{41}) - P_{01}P_{10} + P_{02}P_{41}P_{10}$$

4.2 Availability Analysis

Let $A_i(t)$ be the probability that the system is in up-state at instant t given that the system entered regenerative state i at t=0.using the arguments of the theory of a regenerative process the point wise availability $A_i(t)$ is seen to satisfy the following recursive relations

$$A_0(t) = M_0(t) + q_{01} \oplus A_1(t) + q_{02} \oplus A_2(t)$$
$$A_1(t) = M_1 + q_{10} \oplus A_0(t) + q_{14} \oplus A_4(t) + q_{15} \oplus A_5(t) + q_{17.7} \oplus A_1(t) + q_{18.7} \oplus A_8(t)$$
$$A_2(t) = q_{20} \oplus A_0(t) + q_{23} \oplus A_3(t)$$
$$A_3(t) = q_{32} \oplus A_2(t)$$
$$A_4(t) = M_4 + q_{41} \oplus A_1(t) + q_{45.6} \oplus A_5(t) + q_{47.8} \oplus A_7(t)$$
$$A_5(t) = q_{51} \oplus A_1(t) + q_{56} \oplus A_6(t)$$
$$A_6(t) = q_{65} \oplus A_5(t)$$
$$A_7(t) = q_{71} \oplus A_1(t) + q_{78} \oplus A_8(t)$$
$$A_8(t) = q_{87} \oplus A_7(t)$$

Now taking Laplace transform of these equations and solving them for $A_0^*(s)$, we get

$$A_0^*(s) = \frac{N_1(s)}{D_1(s)}$$

The steady state availability is

$$A_0 = \lim_{s \to 0}(sA_0^*(s)) = \frac{N_1}{D_1}$$

$$N_1 = \mu_0(1-P_{23})[P_{71}P_{18.7}(1-P_{56}P_{65}) + P_{78}P_{65}P_{56}(1-P_{11.7}-P_{14}P_{41})] + (1-P_{23})P_{78}P_{01}[(\mu_1+\mu_4P_{14}) + P_{56}P_{65}(\mu_1+\mu_4P_{14})]$$

$$D_1 = \mu_0P_{78}P_{10}P_{20}P_{51} - \mu_1P_{78}P_{01}P_{20}P_{51} + \mu_2(P_{78}P_{51}(1-P_{14}P_{47.8}-P_{02}P_{10}) - P_{18.7}P_{51} - P_{78}P_{11.7}) + \mu_3P_{51}(1-P_{11.7}-P_{71}P_{14}P_{47.8})$$
$$\mu_4(P_{01}P_{51}P_{14}P_{20}P_{78}P_{51}) + (\mu_6+\mu_5)[(P_{20}P_{01}P_{78}(P_{15}P_{45.6}+P_{51})] + \mu_7P_{01}P_{51}P_{20}(P_{14}P_{18.7} + P_{51}P_{14}(1-P_{47.8}))]$$
$$+\mu_8P_{02}P_{20}P_{51}[P_{78}(P_{10}-P_{14}P_{47.8}) + P_{18.7}]$$

4.3 Busy Period Analysis Of The Repairman

Let $B_i(t)$ be the probability that the repairman is busy at instant t, given that the system entered regenerative state I at t=0.By probabilistic arguments we have the following recursive relations for $B_i(t)$ **(34-35)**

$$B_0(t) = q_{01} \oplus B_1(t) + q_{02} \oplus B_2(t)$$
$$B_1(t) = W_1 + q_{10} \oplus B_0(t) + q_{14} \oplus B_4(t) + q_{15} \oplus B_5(t) + q_{17.7} \oplus B_1(t) + q_{18.7} \oplus B_8(t)$$
$$B_2(t) = W_2 + q_{20} \oplus B_0(t) + q_{23} \oplus B_3(t)$$
$$B_3(t) = W_3 + q_{32} \oplus B_2(t)$$
$$B_4(t) = W_4 + q_{41} \oplus B_1(t) + q_{45.6} \oplus B_5(t) + q_{47.8} \oplus B_7(t)$$
$$B_5(t) = W_5 + q_{51} \oplus B_1(t) + q_{56} \oplus B_6(t)$$
$$B_6(t) = W_6 + q_{65} \oplus B_5(t)$$
$$B_7(t) = q_{71} \oplus B_1(t) + q_{78} \oplus B_8(t)$$
$$B_8(t) = W_8 + q_{87} \oplus B_7(t)$$

Taking Laplace transform of the equations of busy period analysis and solving them for $B_0^*(s)$,we get

$$B_0^*(s) = \frac{N_2(s)}{D_1(s)}$$

In the steady state

$$B_0 = \lim_{s \to 0}(sB_0^*(s)) = \frac{N_2}{D_1} \qquad \textbf{(36-44)}$$

Where

$$N_2 = \mu_0(1-P_{23})[P_{71}P_{18.7}(1-P_{56}P_{65}) + P_{78}P_{51}(P_{45.6}P_{14} + P_{15})]$$

D_1 is already specified.

4.4 Expected Number of Visits by the Repairman

We defined as the expected number of visits by the repairman in (0,t],given that the system initially starts from regenerative state S_i
By probabilistic arguments we have the following recursive relations for $V_i(t)$

$$V_0(t) = q_{01} \oplus (1 + V_1(t)) + q_{02} \oplus (1 + V_2(t))$$
$$V_1(t) = q_{10} \oplus V_0(t) + q_{14} \oplus V_4(t) + q_{15} \oplus V_5(t) + q_{17.7} \oplus V_1(t) + q_{18.7} \oplus V_8(t)$$
$$V_2(t) = q_{20} \oplus V_0(t) + q_{23} \oplus V_3(t)$$
$$V_3(t) = q_{32} \oplus V_2(t)$$
$$V_4(t) = q_{41} \oplus V_1(t) + q_{45.6} \oplus V_5(t) + q_{47.8} \oplus V_7(t)$$
$$V_5(t) = q_{51} \oplus V_1(t) + q_{56} \oplus V_6(t)$$
$$V_6(t) = q_{65} \oplus V_5(t)$$
$$V_7(t) = q_{71} \oplus V_1(t) + q_{78} \oplus V_8(t)$$
$$V_8(t) = q_{87} \oplus V_7(t)$$

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ISSN No: 2347-4890 Volume 2 Issue 11, November-2014

Taking Laplace stieltjes transform of the equations of expected number of visits

And solving them for $V_0^{**}(s)$, we get

$$V_0^{**}(s) = \frac{N_3(s)}{D_1(s)}$$

(70)

In steady state

$$V_0 = \lim_{s \to 0}(sV_0^*(s)) = \frac{N_3}{D_1}$$

(71)

Where

$$N_3 = \mu_0(1-P_{23})P_{47.8} + \mu_2(P_{02}+P_{51}P_{18.7}+P_{02}P_{41}P_{48}) + (\mu_4)P_{02}P$$

(72)

D_1 is already specified

5. PROFIT ANALYSIS

The expected total profit incurred to the system in steady state is given by

$$P = C_0A_0 - C_1B_0 - C_2V_0$$

(73)

Where

C_0 =Revenue/unit up time of the system

C_1 =Cost/unit time for which repairman is busy

C_2 =Cost/visit for the repairman

6. CONCLUSION

For a more clear view of the system characteristics w.r.t. the various parameters involved, we plot curves for MTSF and profit function in figure-2 and figure-3 w.r.t the failure parameter (a) of unit A for three different values of failure rate of B , while the other parameters are kept fixed as

$$\beta_1 = .002, \beta_2 = 0.006, \theta = 0.004, C_0 = 1000, C_1 = 500, C_2 = 80, \alpha = .008$$

From the fig.-2 it is observed that MTSF decreases as failure rate increases irrespective of other parameters. the curves also indicates that for the same value of failure rate,MTSF is higher for lower values of failure rate of unit B,so here we conclude that the low value of failure rate of unit B tends to increase the expected life time of the system. From the fig.-3 it is clear that profit decreases linearly as failure rate of unit A increases. Also for the fixed value of failure rate, the profit is higher for low rate of failure of Unit B.

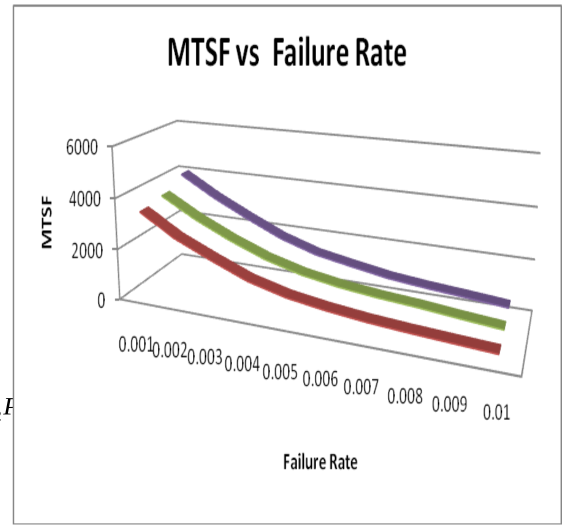

Fig. 2:MTSF vs Failure Rate of Unit A

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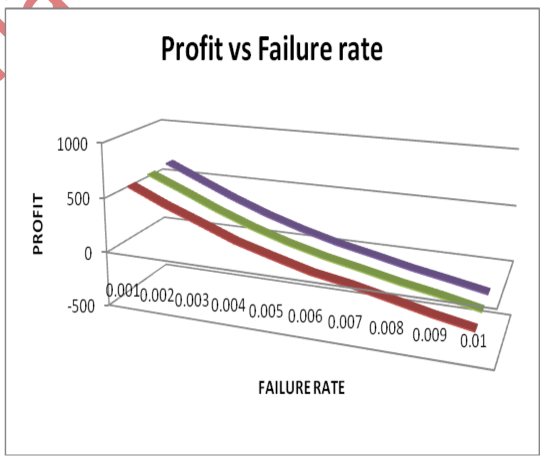

Fig. 3:Profit vs Failure Rate of Unit A

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