Evaluation of a system for reliability and profit where stand by units functions to accommodate the required demand

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Abstract — *The present paper investigates the functioning of the system where all the standby units are able to accommodate the required demand as per requirement. The system considers the future eventualities, i.e. anytime the system comes across with increased workload; all the standby units become operative in order to accommodate this required demand. In the beginning, there is one main unit which is in operative mode and three units are in cold standby state. There is a single repairman facility. Reliability analysis and profit evaluation of the system has been made done in the paper. Various graphs such as MTSF and Profit have been plotted for the present study.*

Keywords — *Standby systems; semi Markov process; Regenerative point technique.*

I. Introduction

Innovations in the field of Science and Technology play a significant role in improving our daily lives and making our lifestyle more advanced. When we talk about Development, whether it is country's development or human development, it is directly linked to technology in many aspects. In other words, we can say that Science and Development goes hand in hand. Therefore in order to enhance economy and betterment in any field, Technology, Science and Engineering are prerequisites. Reliability is the ability of a system or a component to do its intended work under stated conditions. Reliability Engineering deals with evaluation, prevention and organization of risks of failure. The goal of reliability engineering is to enhance the ability of the system or a component to work under stress such that they operate and work for longer time period without getting failed.

Many researchers have drawn significant work in the field of reliability engineering. In 1987, Goel and Sharma discussed 2-unit standby system with two failure modes and slow switch and used regenerating point technique to analyse reliability and availability. In 2011, Mathew *et al* analysed 2-unit parallel cc plant system operative with full installed capacity. Pathak *et al* in 2013 studied the system comprising one main unit and two supporting units. Malhotra and Taneja (2015) compared two stochastic models by introducing the concept of inspection and scheduled maintenance with production depending on demand. Further in 2016, Sharma and Sharma investigated the standby system with provision of concomitant working. Fagge *et al* (2017) analysed the availability of a repairable system requiring two types of supporting device for operations.
Numerous researches have been made by various researchers considering different work disciplines of the systems. Reliability literature has plenty of researches relating to working of standby units on the failure of main unit. But there are very few researches related to systems with required demand and simultaneous working of main as well as standby units. Also, most of the studies are not based on real data. The present study deals with such problems. It is considered that, when the system comes across with the situation of ancillary demand, the main as well as all the standby units are made operative in order to meet the desired necessity. The practical situation can be seen in the power plant working at Bunge India Pvt. Ltd. situated at Rajpura, Punjab. The work has been done on real data. Previous setup of power plant consisted of three low pressure boilers. But the advancement in engineering systems, current setup consists of one main high pressure boiler and previous three low pressure boilers which act as cold standby units now. The study deals with current scenario.

Initially, there is single main unit which is in operative state and three cold standby units are available such that if main unit fails, all the standby units become operative in order to keep the system working properly. The capacity of generating power of all the standby units is equivalent to that of the single main unit. Sometimes the system deals with the circumstances where there in increased demand of power generation. In such circumstances, there is a provision in the system that all the standby units are made operative with the main unit in order to meet the requirement. Repair of main unit and standby units is done by single repairman. The repair is done on first come, first served basis. At an instance, any two of three standby units cannot fail simultaneously, i.e., failure cannot occur in more than one cold standby unit in a single state. All other standby units go to standby state on the failure of any of one cold standby unit.

II. NOTATIONS

λ Constant failure rate of main unit (Unit 1)

λ_1/ λ_2/ λ_3 Constant failure rate of cold standby units(Unit 2/3/4)

α Constant rate of Unit 2,3 and 4 (all of the three standby units) to become operative from standby state

α_1 Constant rate of Unit 2,3 and 4 (all of the three standby units) to become standby from operative state

g(t)/G(t) pdf/ cdf of repair time of the main unit at failed state (Unit 1)

$g_1(t)/G_1(t)$ pdf/ cdf of repair time of the standby unit at failed state (Unit 2)

$g_2(t)/G_2(t)$ pdf/ cdf of repair time of the standby unit at failed state (Unit 3)

$g_3(t)/G_3(t)$ pdf/ cdf of repair time of the standby unit at failed state (Unit 4)

a probability that after the repair of a unit, workload is only for one unit

b probability that after the repair of a unit, workload is for all units (main and all standby units)

III. SYMBOLS

O_I/ O_{II}/ O_{III}/ O_{IV} Unit 1/2/3/4 is in operative state

CS_{II}/ CS_{III}/ CS_{IV} Unit 2/3/4 is in cold standby state

$F_{rI}/F_{rII}/F_{rIII}/F_{rIV}$ Unit 1/2/3/4 is under repair respectively

$F_{wrI}/F_{wrII}/F_{wrIII}/F_{wrIV}$ Unit 1/2/3/4 is waiting for repair respectively

$F_{RII}/F_{RII}/F_{RIII}/F_{RIV}$ Unit1/2/3/4 is under repair respectively from the previous state, i.e., repair is continuing from previous state

IV. TRANSITION PROBABILITIES AND MEAN SOJOURN TIMES

A state transition diagram in fig. 1 shows various transitions of the system. The epochs of entry into states 0, 1, 2, 3, 4and 5 are regenerative points and thus these are regenerative states. The states 6, 7, 8, 9, 10 and 11 are failed states.

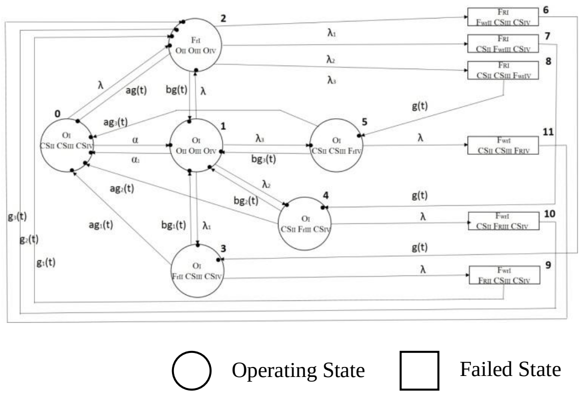

Fig. 1

The non-zero elements p_{ij}, are obtained as under:

$$p_{01}=\frac{\alpha}{\alpha+\lambda} \qquad p_{02}=\frac{\lambda}{\alpha+\lambda}$$

$$p_{10}=\frac{\alpha_1}{\lambda+\lambda_1+\lambda_2+\lambda_3+\alpha_1} \qquad p_{12}=\frac{\lambda}{\lambda+\lambda_1+\lambda_2+\lambda_3+\alpha_1}$$

$$p_{13}=\frac{\lambda_1}{\lambda+\lambda_1+\lambda_2+\lambda_3+\alpha_1} \qquad p_{14}=\frac{\lambda_2}{\lambda+\lambda_1+\lambda_2+\lambda_3+\alpha_1}$$

$$p_{15}=\frac{\lambda_3}{\lambda+\lambda_1+\lambda_2+\lambda_3+\alpha_1} \qquad p_{20}=ag^*(\lambda_1+\lambda_2+\lambda_3)$$

$$p_{21}=bg^*(\lambda_1+\lambda_2+\lambda_3) \qquad p_{26}=\frac{\lambda_1[1-g^*(\lambda_1+\lambda_2+\lambda_3)]}{\lambda_1+\lambda_2+\lambda_3}=p_{23}^{(6)}$$

$$p_{27}=\frac{\lambda_2[1-g^*(\lambda_1+\lambda_2+\lambda_3)]}{\lambda_1+\lambda_2+\lambda_3}=p_{24}^{(7)} \qquad p_{28}=\frac{\lambda_3[1-g^*(\lambda_1+\lambda_2+\lambda_3)]}{\lambda_1+\lambda_2+\lambda_3}=p_{25}^{(8)}$$

$$p_{30}=ag_1^*(\lambda) \qquad p_{31}=bg_1^*(\lambda)$$

$$p_{39}=1-g_1^*(\lambda)=p_{32}^{(9)} \qquad p_{40}=ag_2^*(\lambda)$$

$$p_{41}=bg_2^*(\lambda) \qquad p_{4,10}=1-g_2^*(\lambda)=p_{42}^{(10)}$$

$$p_{50}=ag_3^*(\lambda) \qquad p_{51}=bg_3^*(\lambda)$$

$$p_{5,11}=1-g_3^*(\lambda)=p_{52}^{(11)} \qquad p_{63}=g^*(0)=p_{74}=p_{85}$$

$$p_{92}=g_1^*(0) \qquad p_{10,2}=g_2^*(0)$$

$$p_{11,2}=g_3^*(0)$$

By these transition probabilities, it can be verified that

$$p_{01}+p_{02}=1 \qquad p_{10}+p_{12}+p_{13}+p_{14}+p_{15}=1$$

$$p_{20}+p_{21}+p_{26}+p_{27}+p_{28}=1 \qquad p_{20}+p_{21}+p_{23}^{(6)}+p_{24}^{(7)}+p_{25}^{(8)}=1$$

$$p_{30}+p_{31}+p_{39}=1 \qquad p_{30}+p_{31}+p_{32}^{(9)}=1$$

$$p_{40}+p_{41}+p_{4,10}=1 \qquad p_{40}+p_{41}+p_{42}^{(10)}=1$$

$$p_{50}+p_{51}+p_{5,11}=1 \qquad p_{50}+p_{51}+p_{52}^{(11)}=1$$

$$p_{63}=1=p_{74}=p_{85} \qquad p_{92}=p_{10,2}=p_{11,2}=1$$

The unconditional mean time taken by the system to transit for any regenerative state j, when it is counted from epoch of entrance into that state i, is mathematically stated as –

$$m_{ij}=\int_0^\infty t\,dQ_{ij}(t)=-q_{ij}^{*'}(0), Thus -$$

$$m_{01}+m_{02}=\mu_0 \qquad m_{10}+m_{12}+m_{13}+m_{14}+m_{15}=\mu_1$$

$$m_{20}+m_{21}+m_{26}+m_{27}+m_{28}=\mu_2 \qquad m_{20}+m_{21}+m_{23}^{(6)}+m_{24}^{(7)}+m_{25}^{(8)}=k$$

$$m_{30}+m_{31}+m_{39}=\mu_3 \qquad m_{30}+m_{31}+m_{32}^{(9)}=k_1$$

$$m_{40}+m_{41}+m_{4,10}=\mu_4 \qquad m_{40}+m_{41}+m_{42}^{(10)}=k_2$$

$$m_{50}+m_{51}+m_{5,11}=\mu_5 \qquad m_{50}+m_{51}+m_{52}^{(11)}=k_3$$

where,

$$k=\int_0^\infty \bar{G}(t)dt \qquad k_1=\int_0^\infty \bar{G}_1(t)dt$$

$$k_2=\int_0^\infty \bar{G}_2(t)dt \qquad k_3=\int_0^\infty \bar{G}_3(t)dt$$

The mean sojourn time in the regenerative state i (μ_i) is defined as the time of stay in that state before transition to any other state, then we have -

$$\mu_0=\frac{1}{\lambda+\alpha} \qquad \mu_1=\frac{1}{\lambda+\lambda_1+\lambda_2+\lambda_3+\alpha_1}$$

$$\mu_2=\frac{1-g^*(\lambda_1+\lambda_2+\lambda_3)}{\lambda_1+\lambda_2+\lambda_3} \qquad \mu_3=\frac{1-g_1^*(\lambda)}{\lambda}$$

$$\mu_4=\frac{1-g_2^*(\lambda)}{\lambda} \qquad \mu_5=\frac{1-g_3^*(\lambda)}{\lambda}$$

$$\mu_6=-g^{*\prime}(0)=\mu_7=\mu_8 \qquad \mu_9=-g_1^{*\prime}(0)$$

$$\mu_{10}=-g_2^{*\prime}(0) \qquad \mu_{11}=-g_3^{*\prime}(0)$$

V. MEAN TIME TO SYSTEM FAILURE

The mean time to system failure when the system starts from the state 0, is

$$T_0 = \frac{N}{D}$$

Where

$$\begin{aligned} N = {} & \mu_0[1-p_{12}p_{21}-p_{13}p_{31}-p_{14}p_{41}-p_{15}p_{51}]+\mu_1[p_{01}+p_{02}p_{21}]+\mu_2[p_{02}+p_{01}p_{12} \\ & -p_{02}p_{13}p_{31}-p_{02}p_{14}p_{41}-p_{02}p_{15}p_{51}]+\mu_3[p_{01}p_{13}+p_{02}p_{13}p_{21}]+\mu_4[p_{01}p_{14}+p_{02}p_{14}p_{21}] \\ & +\mu_5[p_{01}p_{15}+p_{02}p_{15}p_{21}] \end{aligned}$$

$$\begin{aligned} D = {} & 1-p_{10}p_{10}-p_{02}p_{20}-p_{12}p_{21}-p_{13}p_{31}-p_{14}p_{41}-p_{15}p_{51}-p_{02}p_{10}p_{21}-p_{01}p_{12}p_{20}-p_{01}p_{13}p_{30} \\ & -p_{01}p_{14}p_{40}-p_{01}p_{15}p_{50}-p_{02}p_{13}p_{21}p_{30}-p_{02}p_{14}p_{21}p_{40}-p_{02}p_{15}p_{21}p_{50}+p_{02}p_{13}p_{31}p_{20} \\ & +p_{02}p_{14}p_{41}p_{20}+p_{02}p_{15}p_{51}p_{20} \end{aligned}$$

VI. EXPECTED UP-TIME OF THE SYSTEM

The steady state availability of the system is given by

$$A_0 = \frac{N_1}{D_1}$$

Where

$$\begin{aligned} N_1 = {} & \mu_0[1-p_{13}p_{31}-p_{14}p_{41}-p_{15}p_{51}-p_{21}(p_{12}+p_{13}p_{32}^{(9)}+p_{14}p_{42}^{(10)}+p_{15}p_{52}^{(11)}) \\ & -p_{23}^{(6)}\{p_{32}^{(9)}(1-p_{14}p_{41}-p_{15}p_{51})+p_{31}(p_{12}+p_{14}p_{42}^{(10)}+p_{15}p_{52}^{(11)})\} \\ & -p_{24}^{(7)}\{p_{42}^{(10)}(1-p_{13}p_{31}-p_{15}p_{51})+p_{41}(p_{12}+p_{13}p_{32}^{(9)}+p_{15}p_{52}^{(11)})\} \\ & -p_{25}^{(8)}\{p_{52}^{(11)}(1-p_{13}p_{31}-p_{14}p_{41})+p_{51}(p_{12}+p_{13}p_{32}^{(9)}+p_{14}p_{42}^{(10)})\}] \\ & +\mu_1[p_{01}(1-p_{23}^{(6)}p_{32}^{(9)}-p_{24}^{(7)}p_{42}^{(10)}-p_{25}^{(8)}p_{52}^{(11)})+p_{02}(p_{21}+p_{31}p_{23}^{(6)}+p_{41}p_{24}^{(7)}+p_{51}p_{25}^{(8)})] \\ & +\mu_2[p_{01}(p_{12}+p_{13}p_{32}^{(9)}+p_{14}p_{42}^{(10)}+p_{15}p_{52}^{(11)})+p_{02}(1-p_{13}p_{31}-p_{14}p_{41}-p_{15}p_{51})] \\ & +\mu_3[p_{01}\{p_{13}(1-p_{24}^{(7)}p_{42}^{(10)}-p_{25}^{(8)}p_{52}^{(11)})+p_{23}^{(6)}(p_{12}+p_{14}p_{42}^{(10)}+p_{15}p_{52}^{(11)})\} \\ & \quad +p_{02}\{p_{13}(p_{21}+p_{41}p_{24}^{(7)}+p_{51}p_{25}^{(8)})+p_{23}^{(6)}(1-p_{14}p_{41}-p_{15}p_{51})\}] \\ & +\mu_4[p_{01}\{p_{14}(1-p_{23}^{(6)}p_{32}^{(9)}-p_{25}^{(8)}p_{52}^{(11)})+p_{24}^{(7)}(p_{12}+p_{13}p_{32}^{(9)}+p_{15}p_{52}^{(11)})\} \\ & \quad +p_{02}\{p_{14}(p_{21}+p_{31}p_{23}^{(6)}+p_{51}p_{25}^{(8)})+p_{24}^{(7)}(1-p_{13}p_{31}-p_{15}p_{51})\}] \\ & +\mu_5[p_{01}\{p_{15}(1-p_{23}^{(6)}p_{32}^{(9)}-p_{24}^{(7)}p_{42}^{(10)})+p_{25}^{(8)}(p_{12}+p_{13}p_{32}^{(9)}+p_{14}p_{42}^{(10)})\} \\ & \quad +p_{02}\{p_{15}(p_{21}+p_{31}p_{23}^{(6)}+p_{41}p_{24}^{(7)})+p_{25}^{(8)}(1-p_{13}p_{31}-p_{14}p_{41})\}] \end{aligned}$$

$$\begin{aligned} D_1 = {} & \mu_0[p_{10}(1-p_{23}^{(6)}p_{32}^{(9)}-p_{24}^{(7)}p_{42}^{(10)}-p_{25}^{(8)}p_{52}^{(11)})+p_{12}(p_{20}+p_{30}p_{23}^{(6)}+p_{40}p_{24}^{(7)}+p_{50}p_{25}^{(8)}) \\ & +p_{13}\{p_{30}+p_{20}p_{32}^{(9)}-p_{24}^{(7)}(p_{30}p_{42}^{(10)}-p_{40}p_{32}^{(9)})-p_{25}^{(8)}(p_{30}p_{52}^{(11)}-p_{50}p_{32}^{(9)})\} \\ & +p_{14}\{p_{40}+p_{20}p_{42}^{(10)}-p_{23}^{(6)}(p_{30}p_{42}^{(10)}-p_{40}p_{32}^{(9)})-p_{25}^{(8)}(p_{40}p_{52}^{(11)}-p_{50}p_{42}^{(10)})\} \\ & +p_{15}\{p_{50}+p_{20}p_{52}^{(11)}-p_{23}^{(6)}(p_{30}p_{52}^{(11)}-p_{50}p_{32}^{(9)})-p_{24}^{(7)}(p_{40}p_{52}^{(11)}-p_{50}p_{42}^{(10)})\}] \\ & +\mu_1[p_{01}(1-p_{23}^{(6)}p_{32}^{(9)}-p_{24}^{(7)}p_{42}^{(10)}-p_{25}^{(8)}p_{52}^{(11)})+p_{02}(p_{21}+p_{31}p_{23}^{(6)}+p_{41}p_{24}^{(7)}+p_{51}p_{25}^{(8)})] \\ & +k[1-p_{13}p_{31}-p_{14}p_{41}-p_{15}p_{51}-p_{01}(p_{10}+p_{13}p_{30}+p_{14}p_{40}+p_{15}p_{50})] \\ & +k_1[p_{01}(p_{13}+p_{12}p_{23}^{(6)}-p_{13}p_{24}^{(7)}p_{42}^{(10)}-p_{13}p_{25}^{(8)}p_{52}^{(11)}+p_{14}p_{23}^{(6)}p_{42}^{(10)}+p_{15}p_{23}^{(6)}p_{52}^{(11)}) \\ & \quad +p_{02}(p_{23}^{(6)}+p_{13}p_{21}+p_{13}p_{41}p_{24}^{(7)}+p_{13}p_{51}p_{25}^{(8)}-p_{14}p_{41}p_{23}^{(6)}-p_{15}p_{51}p_{23}^{(6)})] \\ & +k_2[p_{01}(p_{14}+p_{12}p_{24}^{(7)}+p_{13}p_{24}^{(7)}p_{32}^{(9)}-p_{14}p_{23}^{(6)}p_{32}^{(9)}-p_{14}p_{25}^{(8)}p_{52}^{(11)}+p_{15}p_{24}^{(7)}p_{42}^{(10)}) \\ & \quad +p_{02}(p_{24}^{(7)}+p_{14}p_{21}-p_{13}p_{31}p_{24}^{(7)}+p_{14}p_{31}p_{23}^{(6)}+p_{14}p_{51}p_{25}^{(8)}-p_{15}p_{51}p_{24}^{(7)})] \\ & +k_3[p_{01}(p_{15}+p_{12}p_{25}^{(8)}+p_{13}p_{25}^{(8)}p_{32}^{(9)}+p_{14}p_{25}^{(8)}p_{42}^{(10)}-p_{15}p_{23}^{(6)}p_{32}^{(9)}-p_{15}p_{24}^{(7)}p_{42}^{(10)}) \\ & \quad +p_{02}(p_{25}^{(8)}+p_{15}p_{21}-p_{13}p_{31}p_{25}^{(8)}-p_{14}p_{41}p_{25}^{(8)}+p_{15}p_{31}p_{23}^{(6)}+p_{15}p_{41}p_{24}^{(7)})] \end{aligned}$$

VII. BUSY PERIOD OF A REPAIRMAN

The steady state busy period of the system is given by:

$$B_R = \frac{N_2}{D_1}$$

Where

$$\begin{aligned} N_2 = {} & W_2[p_{01}(p_{12}+p_{13}p_{32}^{(9)}+p_{14}p_{42}^{(10)}+p_{15}p_{52}^{(11)})+p_{02}(1-p_{13}p_{31}-p_{14}p_{41}-p_{15}p_{51})] \\ & +W_3[p_{01}\{p_{13}(1-p_{24}^{(7)}p_{42}^{(10)}-p_{25}^{(8)}p_{52}^{(11)})+p_{23}^{(6)}(p_{12}+p_{14}p_{42}^{(10)}+p_{15}p_{52}^{(11)})\} \\ & \quad +p_{02}\{p_{13}(p_{21}+p_{41}p_{24}^{(7)}+p_{51}p_{25}^{(8)})+p_{23}^{(6)}(1-p_{14}p_{41}-p_{15}p_{51})\}] \\ & +W_4[p_{01}\{p_{14}(1-p_{23}^{(6)}p_{32}^{(9)}-p_{25}^{(8)}p_{52}^{(11)})+p_{24}^{(7)}(p_{12}+p_{13}p_{32}^{(9)}+p_{15}p_{52}^{(11)})\} \\ & \quad +p_{02}\{p_{14}(p_{21}+p_{31}p_{23}^{(6)}+p_{51}p_{25}^{(8)})+p_{24}^{(7)}(1-p_{13}p_{31}-p_{15}p_{51})\}] \\ & +W_5[p_{01}\{p_{15}(1-p_{23}^{(6)}p_{32}^{(9)}-p_{24}^{(7)}p_{42}^{(10)})+p_{25}^{(8)}(p_{12}+p_{13}p_{32}^{(9)}+p_{14}p_{42}^{(10)})\} \\ & \quad +p_{02}\{p_{15}(p_{21}+p_{31}p_{23}^{(6)}+p_{41}p_{24}^{(7)})+p_{25}^{(8)}(1-p_{13}p_{31}-p_{14}p_{41})\}] \end{aligned}$$

and D_1 is already specified.

VIII. EXPECTED NO. OF VISITS OF REPAIRMAN

The steady state expected no. of visits of the repairman is given by:

$$V_R = \frac{N_3}{D_1}$$

Where

$$\begin{aligned} N_3 = {} & [1-p_{01}p_{10}][1-p_{23}^{(6)}p_{32}^{(9)}-p_{24}^{(7)}p_{42}^{(10)}-p_{25}^{(8)}p_{52}^{(11)}] \\ & +p_{02}[-p_{13}p_{31}(1-p_{23}^{(6)}-p_{24}^{(7)}p_{42}^{(10)}-p_{25}^{(8)}p_{52}^{(11)})-p_{14}p_{41}(1-p_{24}^{(7)}-p_{23}^{(6)}p_{32}^{(9)}-p_{25}^{(8)}p_{52}^{(11)}) \\ & \quad -p_{15}p_{51}(1-p_{25}^{(8)}-p_{23}^{(6)}p_{32}^{(9)}-p_{24}^{(7)}p_{42}^{(10)}) \\ & \quad +(1-p_{32}^{(9)})(p_{21}p_{13}+p_{13}p_{41}p_{24}^{(7)}+p_{13}p_{51}p_{25}^{(8)}) \\ & \quad +(1-p_{42}^{(10)})(p_{21}p_{14}+p_{14}p_{31}p_{23}^{(6)}+p_{14}p_{51}p_{25}^{(8)}) \\ & \quad +(1-p_{52}^{(11)})(p_{21}p_{15}+p_{15}p_{31}p_{23}^{(6)}+p_{15}p_{41}p_{24}^{(7)})] \end{aligned}$$

IX. PROFIT ANALYSIS

The expected profit incurred of the system is -

$$P = C_0A_0 - C_1B_R - C_2V_R$$

C_0 = Revenue per unit up time of the system
C_1 = Cost per unit up time for which the repairman is busy in repair
C_2 = Cost per visit of the repairman

X. GRAPHICAL INTERPRETATION AND CONCLUSION

For graphical analysis following particular cases are considered:

$$g(t)=\beta e^{-\beta t} \qquad g_1(t)=\beta_1 e^{-\beta_1 t}$$

$$g_2(t)=\beta_2 e^{-\beta_2 t} \qquad g_3(t)=\beta_3 e^{-\beta_3 t}$$

Graphical study has been made for the MTSF and the profit with respect to failure rate of main unit (λ), revenue per unit uptime of the system (C_0) for different values of rate of failure rate of main unit (λ) , cost of repairman for busy in doing repair (C_1)for different values for different values of rate of failure rate of main unit (λ) and repair rate of main unit (β) for different values of rate of failure rate of main unit (λ).

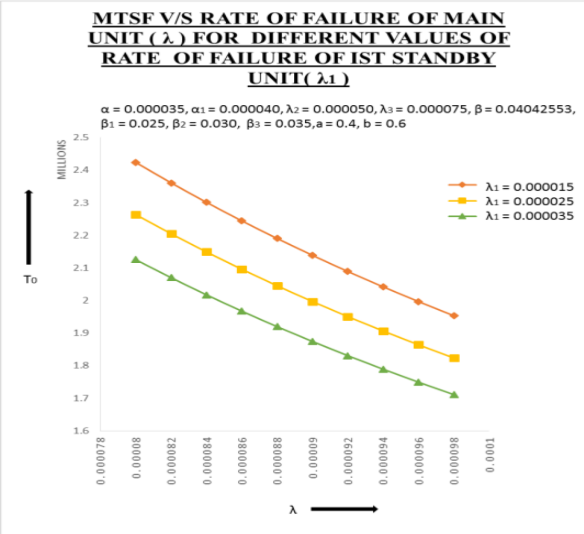

Fig. 2

The behaviour of MTSF w.r.t. failure rate of main unit (λ) for different values of rate of failure of Ist standby unit (λ_1) is shown in Fig. 2. It is clear from the graph that MTSF gets decreased with the increase in the values of the failure rate of main unit (λ). Also, the MTSF decreases as failure rate of Ist standby unit (λ_1) increases.

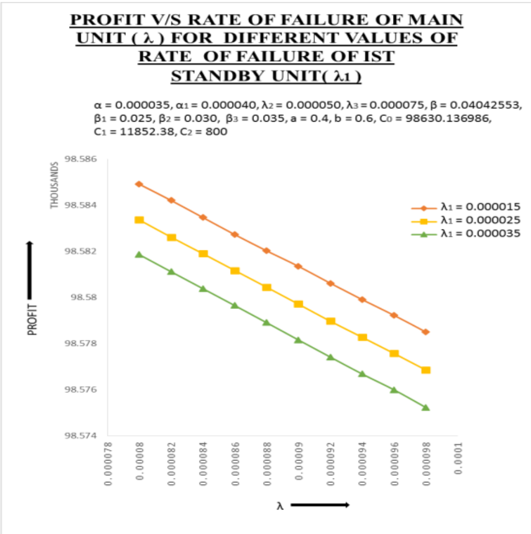

Fig. 3

It is interpreted by Fig. 3 the behaviour of profit w.r.t. to failure rate of main unit (λ) for different values of failure rate of Ist standby unit (λ_1). As the values of failure rate of main unit (λ) increases, the profit decreases. Also, the profit decreases as failure rate of Ist standby unit (λ_1) increases.

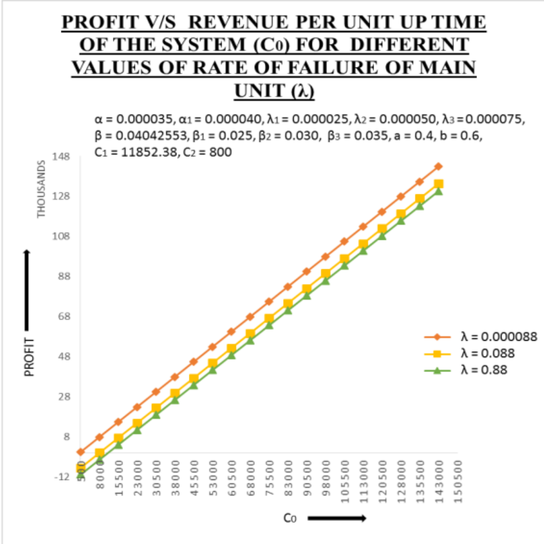

Fig. 4

Fig. 4 depicts the behaviour of the profit w.r.t. revenue per unit uptime of the system (C_0) for different values of rate of failure of main unit (λ). It can be interpreted that the profit increases with increase in the values of C_0. Following conclusions can be drawn from the graph:

1. For λ = 0.000088, profit is positive according as C_0 i.e. revenue per unit uptime of the system increases.
2. For λ = 0.088, profit is > or = or < according as C_0 > or = or < 7911.30 , i.e. the revenue per unit uptime of the system in such a way so as to give C_0 not less than 7911.30 to get positive profit.
3. For λ = 0.88, profit is > or = or < according as C_0 > or = or < 11315, i.e. , i.e. the revenue per unit uptime of the system in such a way so as to give C_0 not less than 11315 to get positive profit.

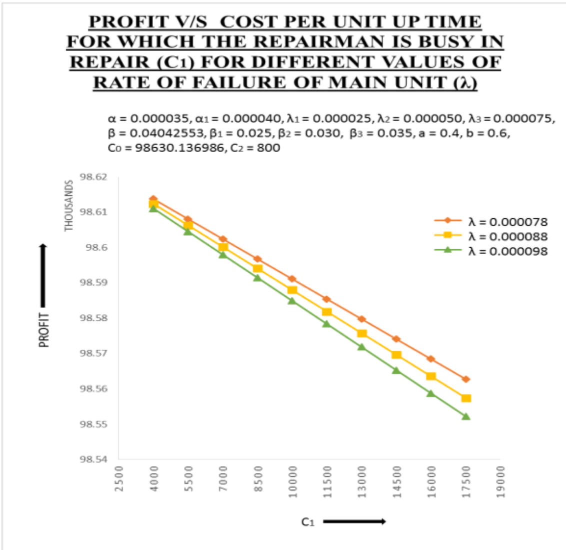

Fig. 5

Fig. 5 shows the behaviour of profit w.r.t. to Cost per unit uptime for which the repairman is busy in Repair (C_1) for different values of rate of failure of main unit (λ). As the value of Cost per unit uptime for which the repairman is busy in Repair (C_1) increases, the profit decreases. Also, the profit decreases as failure of main unit (λ) increases.

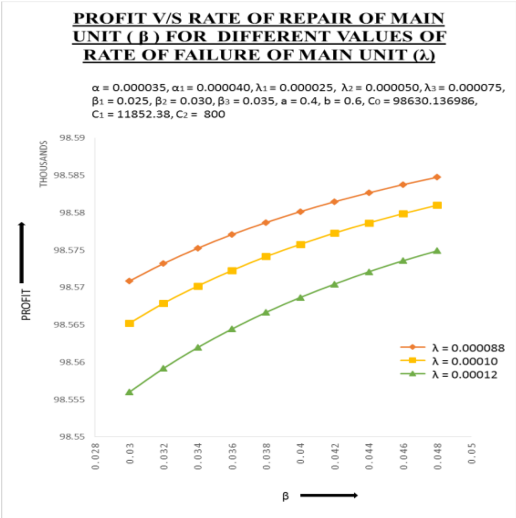

Fig. 6

Fig. 6 interprets the behaviour of profit w.r.t. to rate of repair of main unit (β) for different values of rate of failure of main unit (λ). As the values of rate of repair of main unit (β) increases, the profit increases. And, the profit decreases as failure rate of main unit (λ) increases.

XI. Conclusions

It can be concluded from various graphs that MTSF and Profit gets decreased with increase in the values of failure rates. Also, the cut off points for various rates/costs which are obtained in the above graphical study helps the user to determine appropriate values of rates/costs such that the economy of the company remains profitable. By plotting other graphs, various suggestions can be given to the company using such model. Any company, industry or other user utilizing such systems can adopt exactly the same manner by taking the numerical values of various rates, costs, etc as existing there for such systems.

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