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Reliability Analysis of Hinges Manufacturing System considering Repairs by External Repairman and Priority given to Hardware Repair

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Abstract: The purpose of this paper is to analyze the hinges manufacturing system stochastically by assuming the concept of priority. Here, two units of hinges manufacturing machine are taken in which one unit is operative and another is kept in spare. For smoothly working, an external repairman gives the service to the system. The machine functions properly to do the assigned jobs with full efficiency after repairs. The priority is given to hardware repair over other repairs. The rate of short circuit in machine, hardware and power failure rates follow the Weibull distribution. Also, the distributions of all the repair rates are taken as Weibull. The reliability measures in steady state are determined by using of semi-Markov process and regenerative point technique. The behavior of the important measures is shown graphically for arbitrary values of parameters.

Keywords: Hinges Manufacturing System, Repairman, Hardware, Reliability Measures, Reliability Analysis, Priority.

1. Introduction

Hinges are everywhere in our daily life and they are critical in keeping our kitchen cabinets, cupboards or wardrobes working properly. Everyone makes the arrangement of necessary things such as house, health facility, electricity supply, etc. for living in society. Hinges have been in use for thousands of years and have evolved from very simplistic to extremely specialized – used in areas of aerospace, military, computing, travel and more. Cultures around the world, without exception, would never have evolved as they have if hinges had never been available – hinges are universal and worth their weight in gold. The everyday benefits from using hinges are many, varied and virtually countless. Hinges serve as unsung heroes for billions of people throughout the world, every single day. Hinges ad hinges manufacturing machine are shown in Figure 1 and Figure 2 respectively.

As, in the Hardware manufacturing business, a company can emerge as a leader with a competent workforce adapting to changing business requirements. The reliability of the hinges manufacturing systems becomes very important to make the product according to market. The cold standby redundancy technique has been used by several scholars to make the system more reliable. Sridharan and Mohanavadivu (1998) studied the stochastic behavior of two-unit standby system with two types of repairmen and patience time. A two-unit cold standby system has been described by Meng et al. (2006) with switch failure and equipment maintenance. El-Said and El-Sherbeny (2010) analyzed a two-unit cold standby system with two-stage repair and waiting time. Bao and Cui (2012) studied reliability of two-unit cold standby Markov repairable system with neglected failures. A two-unit cold standby system with arrival time of the server subject to MOT has been analyzed by Barak et al. (2013). Kumar and Baweja (2015) determined cost benefit analysis of a cold standby system with preventive maintenance. The availability and profit analysis of a two-unit cold standby system has been calculated for general distribution by Kumar and Goel (2016). Kumar et al. (2017) determined cost of an engineering system involving subsystems in series configuration. Shekhar et al. (2020) discussed a load sharing redundant repairable system. Malik and Yadav (2020) determined reliability analysis of a computer system with unit wise cold standby redundancy subject to failure of service facility during software up-gradation. Malik and Yadav (2021) described a computer system with unit wise cold standby redundancy and priority to hardware repair subject to failure of service facility. In the above literature, the hinges manufacturing systems are not investigated in term of reliability and profit/cost.

Hence the aim of this paper is to analyze the hinges manufacturing system stochastically by assuming the concept of priority. Here, two units of hinges manufacturing machine are taken in which one unit is operative and another is kept in spare. For smoothly working, an external repairman gives the service to the system. The machine functions properly to do the assigned jobs with full efficiency after repairs. The priority is given to hardware repair over other repairs. The rate of short circuit in machine, hardware and power failure rates follow the Weibull distribution. Also, the distributions of all the repair rates are taken as Weibull. The reliability measures in steady state are determined by using of semi-Markov process and regenerative point technique. The behavior of the important measures is shown graphically for arbitrary values of parameters.

Figure 1: Hinges

Figure 2: Hinges Manufacturing Machine

2. Abbreviations and Notations

O	The unit is operative
Cs	The unit is in cold standby
$f_1(t)/F_1(t)$	pdf/cdf of h/w failure time
$f_2(t)/F_2(t)$	pdf/cdf of power failure time
$f_3(t)/F_3(t)$	pdf/cdf of internal short circuit time
$r_1(t)/R_1(t)$	pdf/cdf of h/w repair time
$r_2(t)/R_2(t)$	pdf/cdf of power supplier repair time
$r_3(t)/R_3(t)$	pdf/cdf of wire repair time
pdf/cdf	Probability density function/Cumulative density function
$q_{ij}(t)/Q_{ij}(t)$	pdf/cdf of passage time from regenerative state S_i to a regenerative state S_j or to a failed state S_j without visiting any other regenerative state in $(0,t]$
$q_{ij.kr}(t)/Q_{ij.kr}(t)$	pdf/cdf of direct transition time from regenerative state S_i to a regenerative state S_j or to a failed state S_j visiting states S_k and S_r once in $(0,t]$
$p_{ij}/p_{ij.kr}$	Steady state probability of transition from state S_i to state S_j directly/via states S_k and S_r once
μ_i	MST in state S_i which is given by $\mu_i = E(T_i) = \int_0^\infty \mathrm{P}(T_i > t)dt$ where T_i denotes the sojourn time in state S_i.
m_{ij}	Contribution to MST (μ_i) in state S_i when system transits directly to state S_j so that $\mu_i = \sum_j m_{ij}$ and $m_{ij} = \int t dQ_{ij}(t) = -q_{ij}^{*'}(0)$
$\emptyset_i(t)$	cdf of first passage time from regenerative state S_i to a failed state
Z_0	System revenue per unit up-time
$Z_1/Z_2/Z_3$	Repair cost per unit time due to hardware failure/short circuit/power supplier failure

3. Assumptions and State Descriptions

To describe the system the following assumptions are made:

a) There is a hinges manufacturing system in which components function independently.
b) Two identical units are taken up in which one unit is in operation mode and the other unit is in spare.
c) There is an external repairman for repairing the components of the system and power supply.
d) The h/w repairs, wiring repairs and power repairs are perfect.
e) The distributions of failure and repair rates are assumed to be Weibull.

The possible transitions of states are shown in the Figure 3 in which S_0, S_1, S_3 are up-states and $S_2, S_4 - S_9$ are failed states.

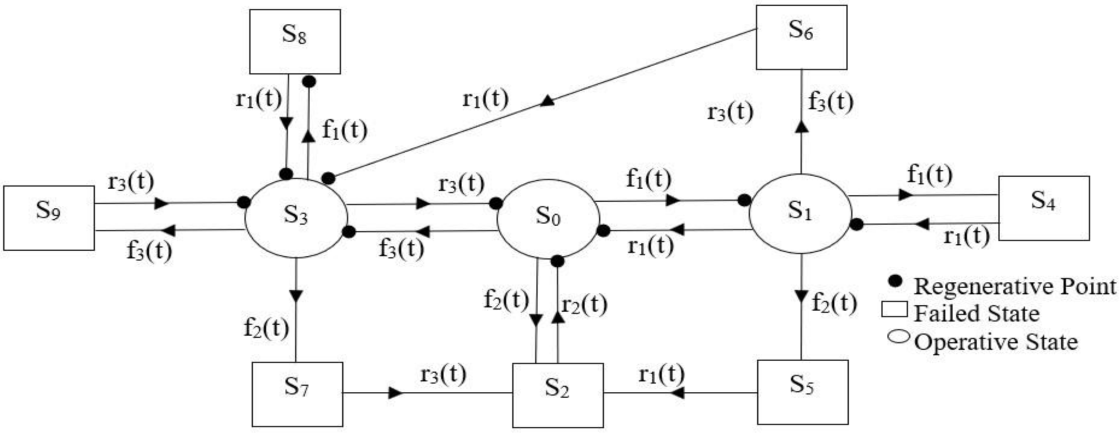

Figure 3: State Transition Probabilities

The possible states of the model are described as follows:

S_0: (O, Cs)	S_1: (HFUr, O)	S_2: (FEUr, Cs)	S_3: (FWUr, O)
S_4: (HFUR HFWr)	S_5: (HFUR, FEWr)	S_6: (HFUR, FWWr)	S_7: (FWUR, FEWr)
S_8: (FWWr, HFUr)	S_9: (FWUR, FWWr)		

4. Performance Measures

4.1Transition Probabilities

The arbitrary distributions of failure and repairs rates are considered as:

$f_1(t) = \alpha\theta t^{\theta-1}e^{-\alpha t^\theta}$, $f_2(t) = \beta\theta t^{\theta-1}e^{-\beta t^\theta}$, $f_3(t) = \gamma\theta t^{\theta-1}e^{-\gamma t^\theta}$, $r_1(t) = a\theta t^{\theta-1}e^{-at^\theta}$, $r_2(t) = b\theta t^{\theta-1}e^{-bt^\theta}$ and $r_3(t) = c\theta t^{\theta-1}e^{-ct^\theta}$

Then the differential transition probabilities for state S_0 are given by

$dQ_{01}(t) = f_1(t)\bar{F}_2(t)\bar{F}_3(t)dt$, $dQ_{02}(t) = f_2(t)\bar{F}_1(t)\bar{F}_3(t)dt$, $dQ_{03}(t) = f_3(t)\bar{F}_1(t)\bar{F}_2(t)dt$

Taking LST of above equations and using the following results

$p_{ij} = \lim_{s\to 0} \emptyset_{ij}^{**}(s) = \emptyset_{ij}^{**}(0) = \int_0^\infty dQ_{ij}(t) = \int_0^\infty q_{ij}(t)dt$, we get

$p_{01} = \frac{\alpha}{\alpha+\beta+\gamma}$, $p_{02} = \frac{\beta}{\alpha+\beta+\gamma} = p_{00.2}$, $p_{03} = \frac{\gamma}{\alpha+\beta+\gamma}$

Similarly, the other transition probabilities for remaining states are given by

$p_{10} = \frac{a}{a+\alpha+\beta+\gamma}$ $p_{14} = \frac{\alpha}{a+\alpha+\beta+\gamma} = p_{11.4}$ $p_{15} = \frac{\beta}{a+\alpha+\beta+\gamma} = p_{10.52}$ $p_{16} = \frac{\gamma}{a+\alpha+\beta+\gamma} = p_{13.6}$

$p_{20} = 1$ $p_{30} = \frac{c}{c+\alpha+\beta+\gamma}$ $p_{37} = \frac{\beta}{c+\alpha+\beta+\gamma} = p_{30.72}$ $p_{38} = \frac{\alpha}{c+\alpha+\beta+\gamma}$

$p_{39} = \frac{\gamma}{c+\alpha+\beta+\gamma} = p_{33.9}$ $p_{41} = p_{52} = p_{63} = p_{72} = p_{81} = p_{93} = 1$

From the above transition probabilities, the following relations are obtained as follows:

$p_{01}+p_{02}+p_{03}=p_{10}+p_{14}+p_{15}+p_{16}=p_{30}+p_{37}+p_{38}+p_{39}=1$

$p_{01}+p_{00.2}+p_{03}=p_{10}+p_{11.4}+p_{10.52}+p_{13.6}=p_{30}+p_{30.72}+p_{38}+p_{33.9}=1$

4.2 Mean Sojourn Times (MST)

The MST (μ_i) in state S_i are calculated by the following relations

$m_{ij}=\left|-\frac{d}{ds}Q_{ij}^{**}(s)\right|_{s=0}=-Q_{ij}^{**\prime}(0)$ and $\mu_i=\sum_j m_{ij}$ where $Q_{ij}^{**}(s)=\int_0^\infty e^{-st}dQ_{ij}(t)$. Thus, we have

$\mu_0=\frac{\Gamma\left(1+\frac{1}{\theta}\right)}{(\alpha+\beta+\gamma)^{\frac{1}{\theta}}},\ \mu_1=\frac{\Gamma\left(1+\frac{1}{\theta}\right)}{(a+\alpha+\beta+\gamma)^{\frac{1}{\theta}}},\ \mu_2=\frac{\Gamma\left(1+\frac{1}{\theta}\right)}{b^{\frac{1}{\theta}}},\ \mu_3=\frac{\Gamma\left(1+\frac{1}{\theta}\right)}{(c+\alpha+\beta+\gamma)^{\frac{1}{\theta}}},\ \mu_4=\frac{\Gamma\left(1+\frac{1}{\theta}\right)}{a^{\frac{1}{\theta}}}=\mu_5=\mu_6=\mu_8$

$\mu_7=\frac{\Gamma\left(1+\frac{1}{\theta}\right)}{c^{\frac{1}{\theta}}}=\mu_9,\ \mu_0'=\mu_0+\mu_2p_{02},\ \mu_1'=\mu_1+\mu_4(1-p_{10})+\mu_2p_{15},$

$\mu_3'=\mu_3+\mu_7(p_{37}+p_{39})+\mu_2p_{37}$

4.3 Reliability and Mean Time to System Failure (MTSF)

Let $\emptyset_i(t)$ be the c.d.f. of first passage time from regenerative state S_i to a failed state. Regarding the failed state as absorbing state, we have following recursive relations for $\emptyset_i(t)$:

$\emptyset_i(t)=\sum_j Q_{ij}(t)Ⓢ\emptyset_j(t)+\sum_k Q_{ik}(t)$

where S_j is an un-failed regenerative state to which the given regenerative state S_i can transit and S_k is a failed state to which the state S_i can transit directly. Thus, the following equations are obtained as:

$\emptyset_0(t)=Q_{01}(t)Ⓢ\emptyset_1(t)+Q_{02}(t)+Q_{03}(t)Ⓢ\emptyset_3(t)$

$\emptyset_1(t)=Q_{10}(t)Ⓢ\emptyset_0(t)+Q_{14}(t)+Q_{15}(t)+Q_{16}(t)$

$\emptyset_3(t)=Q_{30}(t)Ⓢ\emptyset_0(t)+Q_{37}(t)+Q_{38}(t)+Q_{39}(t)$

Taking Laplace Stieltjes Transform of above equations, we get

$\emptyset_0^{**}(s)=Q_{01}^{**}(s)\emptyset_1^{**}(s)+Q_{02}^{**}(s)+Q_{03}^{**}(s)\emptyset_3^{**}(s)$

$\emptyset_1^{**}(s)=Q_{10}^{**}(s)\emptyset_0^{**}(s)+Q_{14}^{**}(s)+Q_{15}^{**}(s)+Q_{16}^{**}(s)$

$\emptyset_3^{**}(s)=Q_{30}^{**}(s)\emptyset_0^{**}(s)+Q_{37}^{**}(s)+Q_{38}^{**}(s)+Q_{39}^{**}(s)$

Solving for $\emptyset_0^{**}(s)$ by Cramer Rule, we have

$\emptyset_0^{**}(s)=\frac{\Delta_1}{\Delta}$

Where $\Delta=\begin{vmatrix}1 & -Q_{01}^{**}(s) & -Q_{03}^{**}(s)\\ -Q_{10}^{**}(s) & 1 & 0\\ -Q_{30}^{**}(s) & 0 & 1\end{vmatrix}$ and

$\Delta_1=\begin{vmatrix}Q_{02}^{**}(s) & -Q_{01}^{**}(s) & -Q_{02}^{**}(s)\\ Q_{14}^{**}(s)+Q_{15}^{**}(s)+Q_{16}^{**}(s) & 1 & 0\\ Q_{37}^{**}(s)+Q_{38}^{**}(s)+Q_{39}^{**}(s) & 0 & 1\end{vmatrix}$

Now, we have $R^*(s)=\frac{1-\emptyset_0^{**}(s)}{s}$

The reliability of the system model can be obtained by

$$R(t)=L^{-1}[R^*(s)]$$

The mean time to system failure (MTSF) is given by

$MTSF=\lim_{s\to 0}R^*(s)=R^*(0)=\frac{N_1}{D_1}$, where $N_1=\mu_0+p_{01}\mu_1+p_{03}\mu_3$ and

$D_1=1-p_{01}p_{10}-p_{03}p_{30}$

4.4 Availability

Let $A_i(t)$ be the probability that the system is in up-state at epoch 't' given that the system entered regenerative state S_i at $t=0$. The recursive relations for $A_i(t)$ are given as

$A_i(t)=M_i(t)+\sum_j q_{ij}^{(n)}(t)©A_j(t)$

where S_j is any successive regenerative state to which the regenerative state S_i can transit through n transitions. Thus, the following equations are obtained as:

$$A_0(t) = M_0(t) + q_{00.2}(t)©A_0(t) + q_{01}(t)©A_1(t) + q_{03}(t)©A_3(t)$$
$$A_1(t) = M_1(t) + [q_{10}(t) + q_{10.52}(t)]©A_0(t) + q_{11.4}(t)©A_1(t) + q_{13.6}(t)©A_3(t)$$
$$A_3(t) = M_3(t) + [q_{30}(t) + q_{30.72}(t)]©A_0(t) + q_{33.9}(t)©A_3(t) + q_{38}(t)©A_8(t)$$
$$A_8(t) = q_{83}(t)©A_3(t)$$

where $M_0(t) = \bar{F}_1(t)\bar{F}_2(t)\bar{F}_3(t)$, $M_1(t) = \bar{R}_1(t)\bar{F}_1(t)\bar{F}_2(t)\bar{F}_3(t)$ and
$M_3(t) = \bar{R}_3(t)\bar{F}_1(t)\bar{F}_2(t)\bar{F}_3(t)$
Taking LT of above equations and solving for $A_0^*(s)$, the steady state availability is calculated by

$$A_0(\infty) = \lim_{s\to 0} sA_0^*(s) = \frac{N_2}{D_2}$$

where
$N_2 = [\mu_0(1-p_{14}) + \mu_1 p_{01}](1-p_{39}-p_{38}) + \mu_3[p_{03}(1-p_{14}) + p_{13}p_{01}]$,
$D_2 = [\mu_0^{'}(1-p_{14}) + \mu_1^{'} p_{01}](1-p_{39}-p_{38}) + (\mu_3^{'} + \mu_8 p_{38})[p_{03}(1-p_{14}) + p_{13}p_{01}]$ and
$\mu_i = M_i^*(0), i = 0,1,3$

4.5 Expected Number of Hardware Repairs

Let $HR_i(t)$ be the expected number of the hardware repairs by the server in the interval $(0, t]$ given that the system entered regenerative state S_i at $t = 0$. The expected number of the hardware repairs is given by

$$HR_0(\infty) = \lim_{s\to 0} sHR_0^{**}(s)$$

The recursive relations for $HR_i(t)$ are given as:
$HR_i(t) = \sum_j Q_{ij}^{(n)}(t)Ⓢ[\delta_j + HR_j(t)]$
Where S_j is any regenerative state to which the regenerative state S_i can transit through n transitions and $\delta_j = 1$, if S_j is the regenerative state where server does job afresh, otherwise $\delta_j = 0$. Thus, the following equations are obtained as:

$$HR_0(t) = Q_{00.2}(t)ⓈHR_0(t) + Q_{01}(t)ⓈHR_1(t) + Q_{03}(t)ⓈHR_3(t)$$
$$HR_1(t) = [Q_{10}(t) + Q_{10.52}(t)]Ⓢ[1 + HR_0(t)] + Q_{11.4}(t)Ⓢ[1 + HR_1(t)] + Q_{13.6}(t)Ⓢ[1 + HR_3(t)]$$
$$HR_3(t) = [Q_{30}(t) + Q_{30.72}(t)]ⓈHR_0(t) + Q_{33.9}(t)ⓈHR_3(t) + Q_{38}(t)ⓈHR_8(t)$$
$$HR_8(t) = Q_{83}(t)Ⓢ[1 + HR_3(t)]$$

Taking LST of above relation and solving for $HR_0^{**}(s)$, the expected number of the hardware repairs are given by

$$HR_0(\infty) = \lim_{s\to 0} sHR_0^{**}(s) = \frac{N_3}{D_2}$$

where
$N_3 = p_{01}(1-p_{39}-p_{38}) + p_{38}[p_{03}(1-p_{14}) + p_{13}p_{01}]$ and
$D_2 = [\mu_0^{'}(1-p_{14}) + \mu_1^{'} p_{01}](1-p_{39}-p_{38}) + (\mu_3^{'} + \mu_8 p_{38})[p_{03}(1-p_{14}) + p_{13}p_{01}]$

4.6 Expected Number of Wire Repairs

Let $WR_i(t)$ be the expected number of the wires repaired by the server in the interval $(0, t]$ given that the system entered regenerative state S_i at $t = 0$. The expected number of the wire repairs is given by

$$WR_0(\infty) = \lim_{s\to 0} sWR_0^{**}(s)$$

The recursive relations for $WR_i(t)$ are given as:
$WR_i(t) = \sum_j Q_{ij}^{(n)}(t)Ⓢ[\delta_j + WR_j(t)]$

Where S_j is any regenerative state to which the regenerative state S_i can transit through n transitions and $\delta_j = 1$, if S_j is the regenerative state where server does job afresh, otherwise $\delta_j = 0$. Thus, the following equations are obtained as:

$WR_0(t) = Q_{00.2}(t)Ⓢ WR_0(t) + Q_{01}(t)Ⓢ WR_1(t) + Q_{03}(t)Ⓢ WR_3(t)$
$WR_1(t) = [Q_{10}(t) + Q_{10.52}(t)]Ⓢ WR_0(t) + Q_{11.4}(t)Ⓢ WR_1(t) + Q_{13.6}(t)Ⓢ WR_3(t)$
$WR_3(t) = [Q_{30}(t) + Q_{30.72}(t)]Ⓢ[1 + WR_0(t)] + Q_{33.9}(t)Ⓢ[1 + WR_3(t)] + Q_{38}(t)Ⓢ WR_8(t)$
$WR_8(t) = Q_{83}(t)Ⓢ WR_3(t)$

Taking LST of above relation and solving for $HR_0^{**}(s)$, the expected number of the wire repairs are given by

$$WR_0(\infty) = \lim_{s\to 0} sWR_0^{**}(s) = \frac{N_4}{D_2}$$

where
$N_4 = (1 - p_{38})[p_{03}(1 - p_{14}) + p_{13}p_{01}]$ and
$D_2 = [\mu_0'(1 - p_{14}) + \mu_1' p_{01}](1 - p_{39} - p_{38}) + (\mu_3' + \mu_8 p_{38})[p_{03}(1 - p_{14}) + p_{13}p_{01}]$

4.7 Expected Number of Power Supplier Repairs

Let $SR_i(t)$ be the expected number of the power supplier repairs in the interval $(0, t]$ given that the system entered regenerative state S_i at $t = 0$. The expected number of the power supplier repairs is given by

$$SR_0(\infty) = \lim_{s\to 0} sSR_0^{**}(s)$$

The recursive relations for $U_i(t)$ are given as:
$SR_i(t) = \sum_j Q_{ij}^{(n)}(t)Ⓢ[\delta_j + SR_j(t)]$
Where S_j is any regenerative state to which the regenerative state S_i can transit through n transitions and $\delta_j = 1$, if S_j is the regenerative state where server does job afresh, otherwise $\delta_j = 0$. Thus, the following equations are obtained as:

$SR_0(t) = Q_{00.2}(t)Ⓢ[SR_0(t) + 1] + Q_{01}(t)Ⓢ SR_1(t) + Q_{03}(t)Ⓢ SR_3(t)$
$SR_1(t) = Q_{10}(t)Ⓢ SR_0(t) + Q_{10.52}(t)Ⓢ[SR_0(t) + 1] + Q_{11.4}(t)Ⓢ SR_1(t) + Q_{13.6}(t)Ⓢ SR_3(t)$
$SR_3(t) = Q_{30}(t)Ⓢ SR_0(t) + Q_{30.72}(t)Ⓢ[SR_0(t) + 1] + Q_{33.9}(t)Ⓢ SR_3(t) + Q_{38}(t)Ⓢ SR_8(t)$
$SR_8(t) = Q_{83}(t)Ⓢ SR_3(t)$

Taking LST of above relation and solving for $SR_0^{**}(s)$, the expected number of the power supplier repairs are given by

$$SR_0(\infty) = \lim_{s\to 0} sSR_0^{**}(s) = \frac{N_4}{D_2}$$

where
$N_5 = p_{01}p_{15}(1 - p_{39} - p_{38}) + p_{37}[p_{03}(1 - p_{14}) + p_{13}p_{01}] + p_{02}(1 - p_{14})(1 - p_{39})$ and
$D_2 = [\mu_0'(1 - p_{14}) + \mu_1' p_{01}](1 - p_{39} - p_{38}) + (\mu_3' + \mu_8 p_{38})[p_{03}(1 - p_{14}) + p_{13}p_{01}]$

5. Profit Analysis

The profit function in the time t is given by
P (t) = Expected revenue in (0, t] – expected total cost in (0, t]
In steady state, the profit of the system model can be obtained by the following formula:
$P = Z_0A_0(\infty) - Z_1HR_0(\infty) - Z_2WR_0(\infty) - Z_3SR_0(\infty)$

6. Graphical Presentation of Reliability Measures

By taking the particular values of shape parameter as $\theta = 1$, the graphical behavior of reliability measures such as MTSF, availability and profit function are shown in the following figures: Figure 4, Figure 5 and Figure 6 respectively.

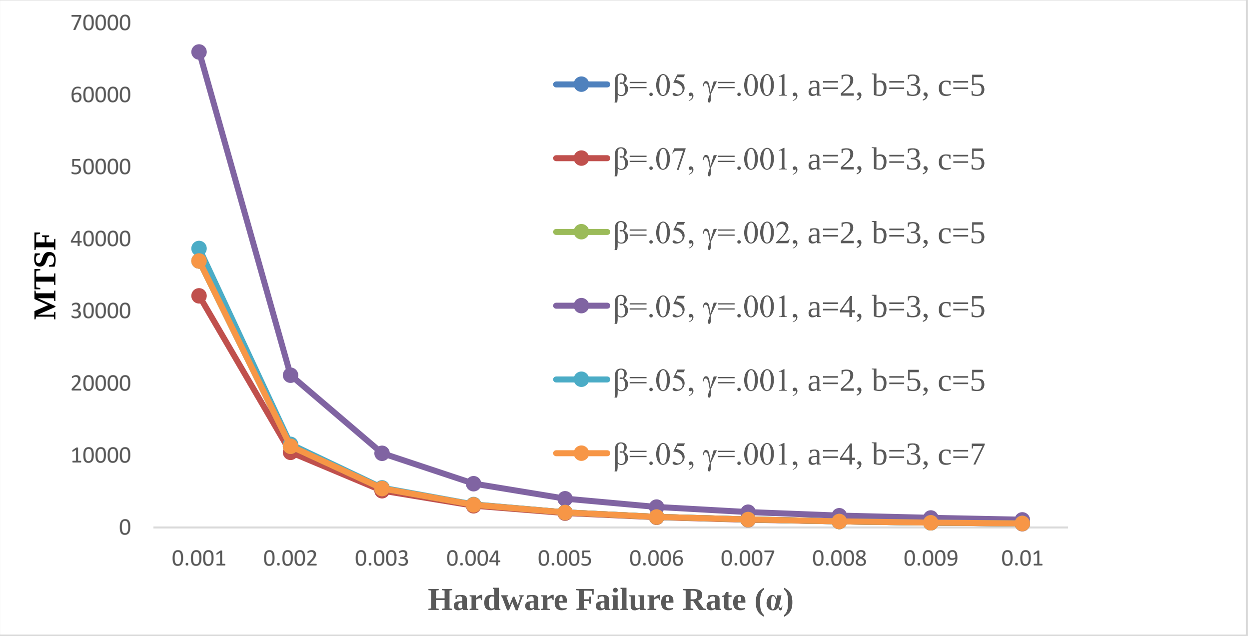

Figure 4: MTSF Vs Hardware Failure Rate (α)

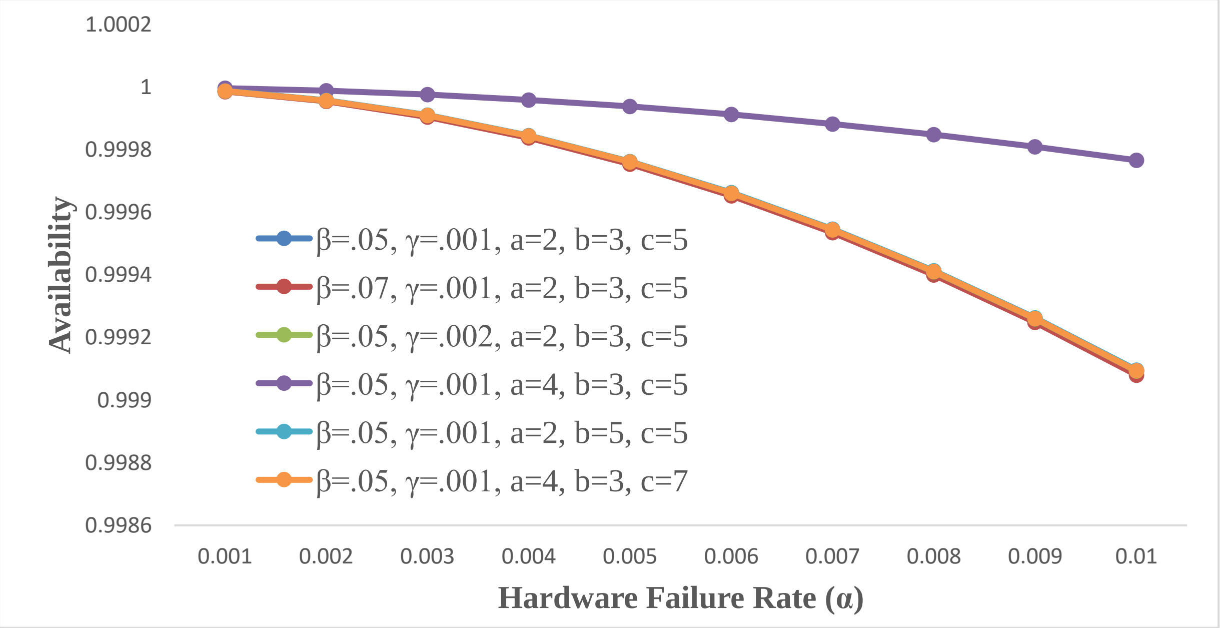

Figure 5: Availability Vs Hardware Failure Rate (α)

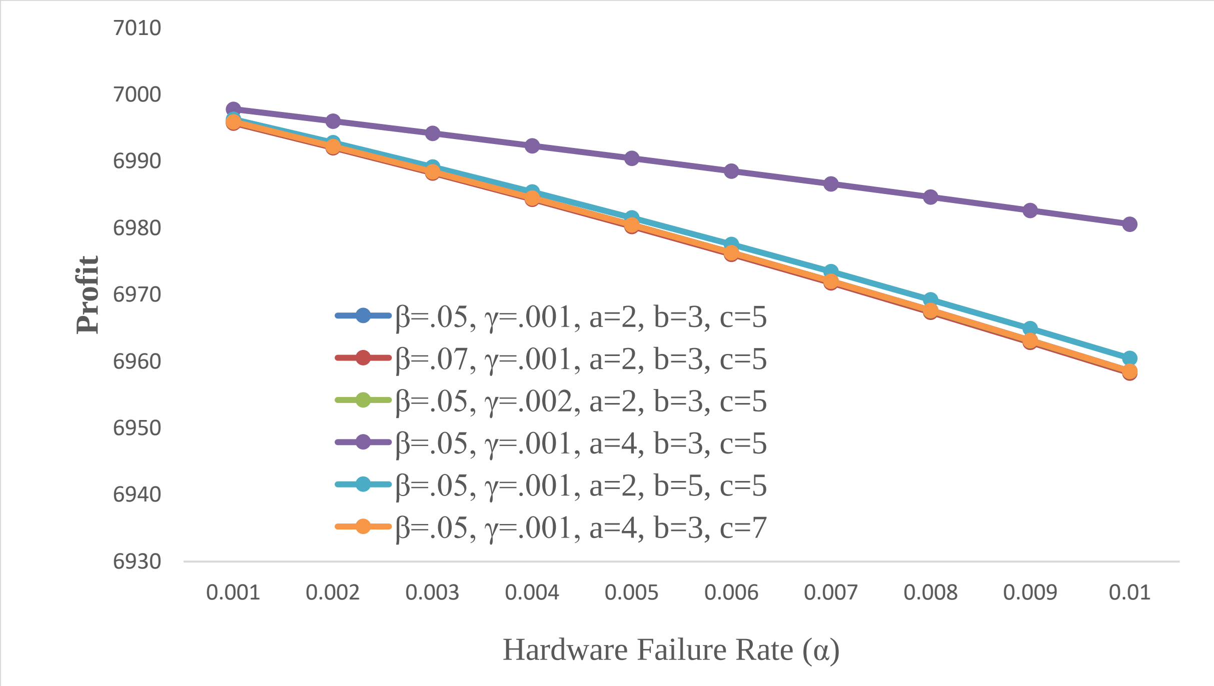

Figure 6: Profit (P) Vs Hardware Failure Rate (α)

7. Conclusion

In this research paper, the reliability measures of the hinges manufacturing system are obtained by using semi-Markov processes and regenerative point techniques. The graphs of MTSF, availability and profit function are drawn w.r.t. h/w failure rate (α) as shown in Figure 4, Figure 5 and Figure 6 respectively. Figure 3 indicates that the values of MTSF increases with increase in repair rates of hardware, wiring and power supply while it declines with increase in failure rates of the same. From Figure 5 and 6, it is observed that availability and profit function decrease with increase in component and power supply failure rates and incline with increase in component and power supply repair rates.

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