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Stochastics analysis of a polytube plant

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Abstract
The Purpose of this paper is to compute reliability parameters of polytube plant having four units using Regenerative point Graphical Technique (RPGT). A Polytube plant consists of four sub systems such as Mixture (A), Extruder (B), Die (C), and Cutter (D). These subsystems are configured in series for successful working of plant. Units A & B have subunits in series whereas units C & D have subunits arranged in parallel. If one of units fails then the system fails and if C or D units are in reduced state then the system works in reduced. Numerical examples are taken to verify the derived results. Behavior analysis of the system is done which may be useful to management in maintaining the various units of the system Tables and graphs are prepared to compare and draw the conclusion.

Keywords: reliability, availability, busy period, system parameters, RPGT

Introduction
Behavioral Analysis bouncecel benefit the transaction in order of higher potency and decline maintenance charge this can besides be successful to administration to recognize the doom of decreasing/ increasing the flaw / fix rates of a particular element on the completely system. Reliability analysis occupies increasingly more important Issues in manufacturing system, power plant system, oil plant system, soap cakes production system, engineering system, stand by system etc. The design of repairable/ failure system is a pertinent component in behavioral analysis. A location of researchers for the be more ages have with all the extras the availability parameters of at variance industrial system per offbeat methods and a zip code of scan papers have been published in this direction. Behavioral analysis of Polytube industries has been evaluated using regenerative point graphical technique (RPGT).

Literature review
Rajbala & Garg [2019] [2] discussed about the steady state and time dependent availability analysis of a manufacturing plant. Rajbala & Garg [2019] [3] discussed about the Behaviour analysis of alloy wheel plant. Rajbala & Kumar [2021] [5] discussed about an article on the system reliability and availability analysis using RPGT-A general approach. Kumar and Garg [2019] [11] have discussed the reliability technology theory and its applications. Kumar *et al.* [2018] [8] have studied behaviour analysis of a bread making system. Kumar *et al.* [2019] analyzed sensitivity analysis of a cold standby framework with priority for preventive maintenance consist two identical units with server failure utilizing RPGT. Present paper consists two units one of which is online while other is kept is cold standby mode. Online & cold standby unit are indistinguishable in nature & have just two modes one is good and other is totally failed.
Rajbala, *et al.* [2019] [3] have studied the system modeling and analysis: a case study EAEP manufacturing plant. Kumar *et al.* [2017] [10] have studied behavior analysis in the urea fertilizer industry. Kumar *et al.* [2017] [12] have examined the mathematical modeling & profit analysis of an edible oil refinery plant. Kumar *et al.* [2019] [11] studied mathematical modeling & behavioral analysis of a washing unit in paper mill.
Agrawal *et al.* [2021] [4] studied the Water Treatment Reverse Osmosis Plant using RPGT. Kumar *et al.* [2018] [9] paper analyzed sensitivity analysis of 3:4:: good system plant. Priya *et al.* [2021] [13] Vedic mathematics in derivatives and integration, differential equations and partial differential equations. Kumari *et al.* [2021] [15] studied the constrained problems using PSO. Kumari *et al.* [2021] [17] discussed the profit analysis of an agriculture thresher plant in steady state using RPGT.

Anchal *et al*. [2021] [16] discussed the SRGM model using differential equation has been proposed, in which two categories of faults: simple and hard with respect to time in which these occur for isolation and removal after their detection has been presented. Garg *et al*. [2021] [18] studied the Reliability technology theory and application. Rajbala *et al*. [2022] [19] studied the redundancy allocation problem in cylinder Manufacturing Plant using heuristic algorithm. Rajbala *et al*. [2021] [20] discussed the availability analysis of two subsystem failures simultaneously via markov modeling.
A Polytube industry consists of four sub units Mixture (A), Extruder (B), Die (C) & Cutter (D). Mixture (A) it mixes raw material such as PVC rising, calcium carbonate, wax and other chemical in appropriate proportion for manufacturing pipe. Extruder (B) is consists of a heater to heat the raw material at different temperature. Die (C) is also used to make different size of pipes. Sub units C is reduced State. Cutter (D) is used to cuts the pipe in different sizes. Problem is solved using RPGT to determine system parameters. System behavior is discussed with the help of graphs and tables. Particular cases are also taken for different repair and failure rates of the system.

Research gap
Earlier most of the researchers have evaluated system parameter with constant failure/repair rates various technique and a few of them discussed these system behavior analysis in steady state with respect to the change failure/repair rates of unit of the system. There may be a situation in which a particular unit in a system may need more care for maintains to have optimum value of system parameters, a very few researcher in this field give the concept of sensitivity analysis of the system. In our purpose a research work to carry out the sensitivity analysis of various processing industry and carry out the sensitivity analysis of these process industry keeping fix failure/repair rates and increasing the repair/failure of different units of process industries. Tables and graphs of all the parameters and profit function will we prepaid followed by conclusion recommendation to the management for taking care of and assigning maintenance faculty of different subsystems/ units in the industries.

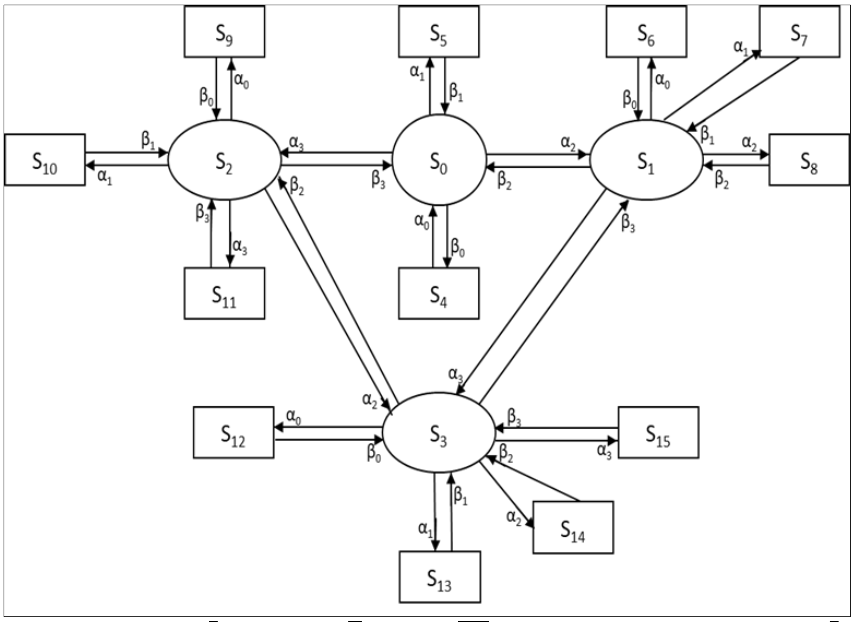
Assumptions
1. There is single repair facility which is available twenty four hours and seven days.
2. Failures and repairs are independent of each other and their unit is taken as per day.
3. Units C, D are reduced capacity also.
4. Units A, B in series capacity also.

Notations
○ : Full Capacity Working State
□ : Failed State

A, B, C, D: Denote the subsystem is working in good condition.

$\bar{C}$, $\bar{D}$: Indicate the reduced state of the subsystem 'C' and 'D'.

a, b, c, d: Denote the failed state.
$(0 \leq i \leq 3)$ α_i = Failure rate of the subsystem A, B, C, & D respectively.
$(0 \leq i \leq 3)$ β_i = Repair rate of the subsystem A, B, C, & D respectively.
By taking into consideration the above notations & assumptions, the Transition Diagram of the system is given in Figure 1.



$S_0 = ABCD$, $S_1 = AB\bar{C}D$, $S_2 = ABC\bar{D}$, $S_3 = AB\overline{CD}$, $S_4 = aBCD$, $S_5 = AbCD$, $S_6 = aB\bar{C}D$, $S_7 = Ab\bar{C}D$, $S_8 = AB\bar{C}d$, $S_9 = aBC\bar{D}$, $S_{10} = AbC\bar{D}$, $S_{11} = ABc\bar{D}$, $S_{12} = aB\overline{CD}$, $S_{13} = Ab\overline{CD}$, $S_{14} = ABc\bar{D}$, $S_{15} = AB\bar{C}$

Fig 1: System of Polytube Plant

Transition Probability of system is given below table 1

$q_{i,j}(t)$ **:** Probability density function regenerative state 'i 'and 'j' , $p_{i,j}$ **:** Steady state transition probability from a regenerative state 'i' to a regenerative state 'j'

Table 1: Transition Probabilities

$q_{i,j}(t)$	$P_{ij} = q^*_{i,j}(0)$
$q_{0,1}(t) = \alpha_2 e^{-(\alpha_0+\alpha_3+\alpha_2+\alpha_1)t}$	$p_{0,1} = \alpha_0/(\alpha_0+\alpha_2+\alpha_1+\alpha_3)$
$q_{0,2}(t) = \alpha_3 e^{-(\alpha_1+\alpha_0+\alpha_3+\alpha_2)t}$	$p_{0,2} = \alpha_3/(\alpha_2+\alpha_1+\alpha_0+\alpha_3)$
$q_{0,4}(t) = \alpha_0 e^{-(\alpha_0+\alpha_2+\alpha_1+\alpha_3)t}$	$p_{0,4} = \alpha_0/(\alpha_0+\alpha_2+\alpha_1+\alpha_3)$
$q_{0,5}(t) = \alpha_1 e^{-(\alpha_2+\alpha_1+\alpha_0+\alpha_3)t}$	$p_{0,5} = \alpha_1/(\alpha_0+\alpha_3+\alpha_2+\alpha_1)$
$q_{1,0}(t) = \beta_2 e^{-(\alpha_2+\alpha_1+\alpha_0+\alpha_3+\beta_2)t}$	$p_{1,0} = \beta_2/(\alpha_0+\alpha_3+\alpha_2+\alpha_1+\beta_2)$
$q_{1,3}(t) = \alpha_3 e^{-(\alpha_0+\alpha_2+\alpha_1+\alpha_3+\beta_2)t}$	$p_{1,3} = \alpha_3/(\alpha_2+\alpha_1+\alpha_0+\alpha_3+\beta_2)$
$q_{1,6}(t) = \alpha_0 e^{-(\alpha_2+\alpha_1+\alpha_0+\alpha_3+\beta_2)t}$	$p_{1,6} = \alpha_0/(\alpha_0+\alpha_2+\alpha_1+\alpha_3+\beta_2)$
$q_{1,7}(t) = \alpha_1 e^{-(\alpha_0+\alpha_3+\alpha_2+\alpha_1+\beta_2)t}$	$p_{1,7} = \alpha_1/(\alpha_3+\alpha_2+\alpha_0+\alpha_1+\beta_2)$
$q_{1,8}(t) = \alpha_2 e^{-(\alpha_0+\alpha_2+\alpha_1+\alpha_3+\beta_2)t}$	$p_{1,8} = \alpha_2/(\alpha_0+\alpha_2+\alpha_1+\alpha_3+\beta_2)$
$q_{2,0}(t) = \beta_3 e^{-(\alpha_2+\alpha_1+\alpha_0+\alpha_3+\beta_3)t}$	$p_{2,0} = \beta_3/(\alpha_0+\alpha_3+\alpha_2+\alpha_1+\beta_3)$
$q_{2,3}(t) = \alpha_2 e^{-(\alpha_0+\alpha_2+\alpha_1+\alpha_3+\beta_3)t}$	$p_{2,3} = \alpha_2/(\alpha_1+\alpha_2+\alpha_0+\alpha_3+\beta_3)$
$q_{2,9}(t) = \alpha_0 e^{-(\alpha_1+\alpha_2+\alpha_0+\alpha_3+\beta_3)t}$	$p_{2,9} = \alpha_0/(\alpha_3+\alpha_1+\alpha_2+\alpha_0+\beta_3)$
$q_{2,10}(t) = \alpha_1 e^{-(\alpha_2+\alpha_1+\alpha_0+\alpha_3+\beta_3)t}$	$p_{2,10} = \alpha_1/(\alpha_1+\alpha_1+\alpha_0+\alpha_3+\beta_3)$
$q_{2,11}(t) = \alpha_3 e^{-(\alpha_1+\alpha_3+\alpha_2+\alpha_0+\beta_3)t}$	$p_{2,11} = \alpha_3/(\alpha_0+\alpha_2+\alpha_1+\alpha_3+\beta_3)$
$q_{3,1}(t) = \beta_3 e^{-(\alpha_0+\alpha_2+\alpha_1+\alpha_3+\beta_2+\beta_3)t}$	$p_{3,1} = \beta_3/(\alpha_2+\alpha_3+\alpha_0+\alpha_1+\beta_2+\beta_3)$
$q_{3,2}(t) = \beta_2 e^{-(\alpha_2+\alpha_1+\alpha_0+\alpha_3+\beta_2+\beta_3)t}$	$p_{3,2} = \beta_2/(\alpha_0+\alpha_2+\alpha_1+\alpha_3+\beta_2+\beta_3)$
$q_{3,12}(t) = \alpha_0 e^{-(\alpha_0+\alpha_2+\alpha_1+\alpha_3+\beta_2+\beta_3)t}$	$p_{3,12} = \alpha_0/(\alpha_0+\alpha_3+\alpha_2+\alpha_1+\beta_2+\beta_3)$
$q_{3,13}(t) = \alpha_1 e^{-(\alpha_3+\alpha_1+\alpha_2+\alpha_0+\beta_2+\beta_3)t}$	$p_{3,13} = \alpha_1/(\alpha_3+\alpha_2+\alpha_1+\alpha_0+\beta_2+\beta_3)$
$q_{3,14}(t) = \alpha_2 e^{-(\alpha_0+\alpha_3+\alpha_2+\alpha_1+\beta_2+\beta_3)t}$	$p_{3,14} = \alpha_2/(\alpha_0+\alpha_2+\alpha_1+\alpha_3+\beta_2+\beta_3)$
$q_{3,15}(t) = \alpha_3 e^{-(\alpha_2+\alpha_1+\alpha_0+\alpha_3+\beta_2+\beta_3)t}$	$p_{3,15} = \alpha_3/(\alpha_2+\alpha_1+\alpha_0+\alpha_3+\beta_2+\beta_3)$
$q_{4,0}(t) = \beta_0 e^{-\beta_0 t}$	$p_{4,0} = 1$
$q_{5,0}(t) = \beta_1 e^{-\beta_1 t}$	$p_{5,1} = 1$
$q_{6,1}(t) = \beta_0 e^{-\beta_0 t}$	$p_{6,1} = 1$
$q_{7,1}(t) = \beta_1 e^{-\beta_1 t}$	$p_{7,1} = 1$
$q_{8,1}(t) = \beta_2 e^{-\beta_2 t}$	$p_{8,1} = 1$
$q_{9,2}(t) = \beta_0 e^{-\beta_0 t}$	$p_{9,2} = 1$
$q_{10,2}(t) = \beta_1 e^{-\beta_1 t}$	$p_{10,2} = 1$
$q_{11,2}(t) = \beta_3 e^{-\beta_3 t}$	$p_{11,2} = 1$
$q_{12,3}(t) = \beta_0 e^{-\beta_0 t}$	$p_{12,3} = 1$
$q_{13,3}(t) = \beta_1 e^{-\beta_1 t}$	$p_{13,3} = 1$
$q_{14,3}(t) = \beta_2 e^{-\beta_2 t}$	$p_{14,3} = 1$
$q_{15,3}(t) = \beta_3 e^{-\beta_3 t}$	$p_{15,3} = 1$

Mean Sojourn times of system given below table 2

Table 2: Mean Sojourn Times

$R_i(t)$	$\mu_i = R_i^*(0)$
$R_0(t) = e^{-(\alpha_0+\alpha_2+\alpha_1+\alpha_3)t}$	$\mu_0 = 1/(\alpha_0+\alpha_2+\alpha_1+\alpha_3)$
$R_1(t) = e^{-(\alpha_2+\alpha_1+\alpha_0+\alpha_3+\beta_2)t}$	$\mu_1 = 1/(\alpha_3+\alpha_1+\alpha_2+\alpha_0+\beta_2)$
$R_2(t) = e^{-(\alpha_2+\alpha_1+\alpha_0+\alpha_3+\beta_3)t}$	$\mu_2 = 1/(\alpha_3+\alpha_1+\alpha_0+\alpha_3 2\beta_3)$
$R_3(t) = e^{-((\alpha_0+\alpha_3+\alpha_2+\alpha_1+\beta_2+\beta_3))t}$	$\mu_3 = 1/(\alpha_0+\alpha_2+\alpha_1+\alpha_3+\beta_2+\beta_3)$
$R_4(t) = e^{-\beta_0 t}$	$\mu_4 = 1/\beta_0$
$R_5(t) = e^{-\beta_1 t}$	$\mu_5 = 1/\beta_1$
$R_6(t) = e^{-\beta_0 t}$	$\mu_6 = 1/\beta_0$
$R_7(t) = e^{-\beta_1 t}$	$\mu_7 = 1/\beta_1$
$R_8(t) = e^{-\beta_2 t}$	$\mu_8 = 1/\beta_2$
$R_9(t) = e^{-\beta_0 t}$	$\mu_9 = 1/\beta_0$
$R_{10}(t) = e^{-\beta_1 t}$	$\mu_{10} = 1/\beta_1$
$R_{11}(t) = e^{-\beta_3 t}$	$\mu_{11} = 1/\beta_3$
$R_{12}(t) = e^{-\beta_0 t}$	$\mu_{12} = 1/\beta_0$
$R_{13}(t) = e^{-\beta_1 t}$	$\mu_{13} = 1/\beta_1$
$R_{14}(t) = e^{-\beta_2 t}$	$\mu_{14} = 1/\beta_2$
$R_{15}(t) = e^{-\beta_3 t}$	$\mu_{15} = 1/\beta_3$

Path Probabilities

Probabilities from state '0' to different vertices are given as

$V_{0,0} = 1$

$V_{0,1}$ = (0,1)/(1-W_3)(1-W_2)(1-W_1)[(1-W_6)/(1-W_5)(1-W_4)(1-W_9)(1-W_8){(1-W_7)/(1-W_{12})(1-W_{11})(1-W_{10})}]+(0,2,3,1)/(1-W_3)(1-W_2)(1-W_1)[(1-W_6)/(1-W_5)(1-W_4)(1-W_9)(1-W_8){(1-W_7)/(1-W_{12})(1-W_{11})(1-W_{10})}](1-W_{12})(1-W_{11})(1-W_{10})[(1-W_{13})/(1-W_5)(1-W_8)(1-W_7)(1-W_6){(1-W_{14})/(1-W_3)(1-W_2)(1-W_1)}](1-W_7)(1-W_6)(1-W_5)(1-W_8){(1-W_9)[(1-W_{14})/(1-W_3)(1-W_2)(1-W_1)][(1-W_{11})/(1-W_{10})(1-W_9)(1-W_{12})]……etc..

Research and Methodology

Path Modeling

MTSF (T_0): The regenerative un-failed states to which the system can transit from initial state '0', before entering any failed state are: 'i' = 0 using RPGT

$$\text{MTSF }(T_0) = \left[\sum_{i,sr}\left\{\frac{\left\{pr\left(\xi\xrightarrow{sr(sff)}i\right)\right\}\mu i}{\prod_{m_1\neq\xi}\{1\text{-}V_{\overline{m_1 m_1}}\}}\right\}\right] \div \left[1\text{-}\sum_{sr}\left\{\frac{\left\{pr\left(\xi\xrightarrow{sr(sff)}\xi\right)\right\}}{\prod_{m_2\neq\xi}\{1\text{-}V_{\overline{m_2 m_2}}\}}\right\}\right]$$

$T_0 = V_{0,0}\mu_0 = [1/(\alpha_0+\alpha_1+\alpha_2+\alpha_3)]$

Availability of the System (A_0): The states at which the system is available are 'j' = 0, 1, 2, 3 & i = 0, 1, 2….15, taking 'ξ' = '0' the total fraction of time for which the system is available is given by

$$A_0 = \left[\sum_{j,sr}\left\{\frac{\{pr(\xi^{sr\to}j)\}fj,\mu j}{\prod_{m_1\neq\xi}\{1\text{-}V_{\overline{m_1 m_1}}\}}\right\}\right] \div \left[\sum_{i,sr}\left\{\frac{\{pr(\xi^{sr\to}i)\}\mu_i^1}{\prod_{m_2\neq\xi}\{1\text{-}V_{\overline{m_2 m_2}}\}}\right\}\right]$$

$$A_0 = \left[\sum_j V_{\xi,j}, f_j, \mu_j\right] \div \left[\sum_i V_{\xi,i}, f_j, \mu_i^1\right]$$

= ($V_{0,0}\mu_0+V_{0,1}\mu_1+V_{0,2}\mu_2+V_{0,3}\mu_3$)/D

Where D = ($V_{0,0}\mu_0+V_{0,1}\mu_1+V_{0,2}\mu_2+V_{0,3}\mu_3+V_{0,4}\mu_4+V_{0,5}\mu_5+V_{0,6}\mu_6+V_{0,7}\mu_7+V_{0,8}\mu_8$ $+V_{0,9}\mu_9+V_{0,10}\mu_{10}+V_{0,11}\mu_{11}+V_{0,12}\mu_{12}+V_{0,13}\mu_{13}+V_{0,14}\mu_{14}+V_{0,15}\mu_{15}$)

Busy Period of the Server: The states where the server is busy are j= 1,2,3…..15 and i= 0,1,2……15 taking ξ = '0', the total fraction of time for which the server remains busy is

$$B_0 = \left[\sum_{j,sr}\left\{\frac{\{pr(\xi^{sr\to}j)\},nj}{\prod_{m_1\neq\xi}\{1\text{-}V_{\overline{m_1 m_1}}\}}\right\}\right] \div \left[\sum_{i,sr}\left\{\frac{\{pr(\xi^{sr\to}i)\}\mu_i^1}{\prod_{m_2\neq\xi}\{1\text{-}V_{\overline{m_2 m_2}}\}}\right\}\right]$$

$$B_0 = \left[\sum_j V_{\xi,j}, n_j\right] \div \left[\sum_i V_{\xi,i}, \mu_i^1\right]$$

B_0 = ($V_{0,1}\mu_1+V_{0,2}\mu_2+V_{0,3}\mu_3+V_{0,4}\mu_4+V_{0,5}\mu_5+V_{0,6}\mu_6+V_{0,7}\mu_7+V_{0,8}\mu_8+V_{0,9}\mu_9+V_{0,10}\mu_{10}$ $+V_{0,11}\mu_{11}+V_{0,12}\mu_{12}+V_{0,13}\mu_{13}+V_{0,14}\mu_{14}+V_{0,15}\mu_{15}$)/D

Expected Fractional Number of Inspections by the repair man: The states where the repairman do visit's a fresh are j=4,5….15 & i= 0,1….15 is given by

$$V_0 = \left[\sum_{j,sr}\left\{\frac{\{pr(\xi^{sr\to}j)\}}{\prod_{k_1\neq\xi}\{1\text{-}V_{\overline{k_1 k_1}}\}}\right\}\right] \div \left[\sum_{i,sr}\left\{\frac{\{pr(\xi^{sr\to}i)\}\mu_i^1}{\prod_{k_2\neq\xi}\{1\text{-}V_{\overline{k_2 k_2}}\}}\right\}\right]$$

$$V_0 = \left[\sum_j V_{\xi,j}\right] \div \left[\sum_i V_{\xi,i}, \mu_i^1\right]$$

V_0 = ($V_{0,4}+V_{0,5}+V_{0,6}+V_{0,7}+V_{0,8}+V_{0,9}+V_{0,10}+V_{0,11}+V_{0,12}+V_{0,13}+V_{0,14}+V_{0,15}$)/D

Results and Conclusion

Particular cases

Behavior Analysis: - $\beta_i = \beta$ $(0 \leq i \leq 3)$ $\alpha_i = \alpha$ $(0 \leq i \leq 3)$

MTSF

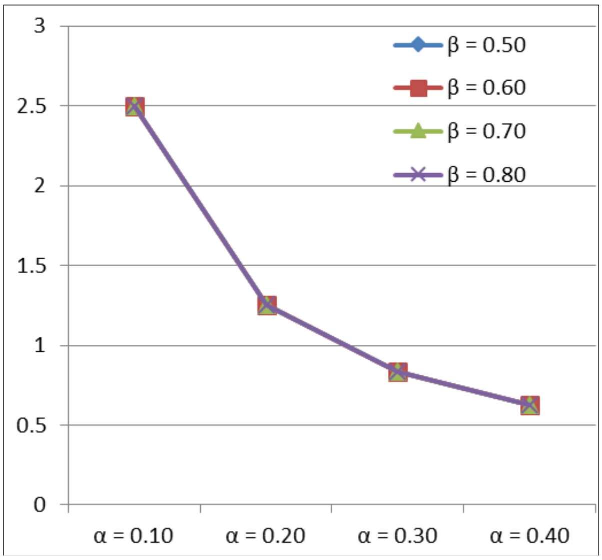


Fig 2: MTSF Graph

Availability of the System (A_0)

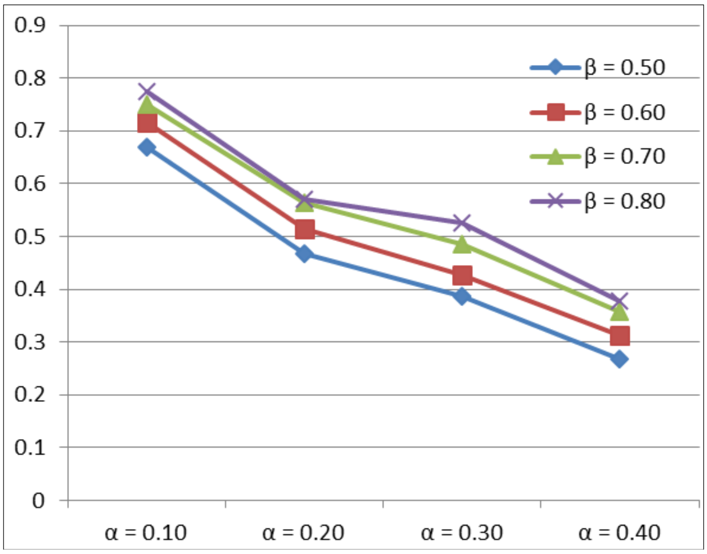


Fig 3: Availability of the System (A_0) Graph

Busy Period of the Server (B_0)

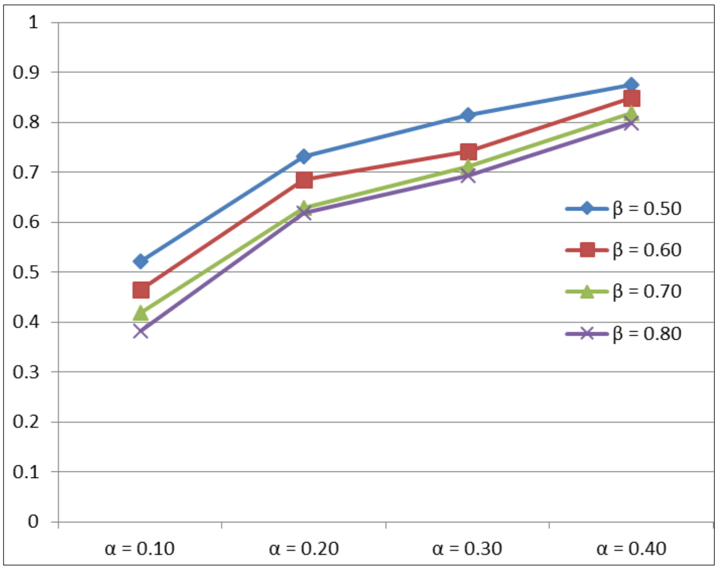


Fig 4: Busy Period of the server (B_0) Graph

Expected Fractional Number of Inspection by the Repairman (V_0)

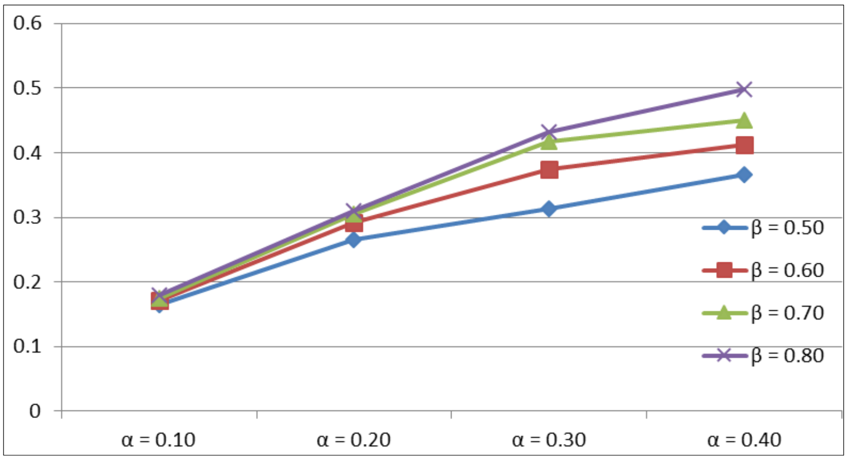


Fig 5: Expected Fractional Number of Inspection by the Repairman Graph

Conclusion

From figure 2, it is conclude that MTSF decreases more speedily with increase of failure rates of units i.e. Mixture, Extruder, Die, and Cutter. MTSF is not established with the increase in repair rate and a failure rate is same. From figure 3, the value of Ao increasing with the increase in repair rates of unit and decrease with the increase in failure rates of unit. Ao is highest when repair value is highest and lowest when failure value is highest.

From figure 4, Bo decrease as the repair rates of units increase and we see that a first row last column is the lowest value of the units. First row is lowest and last row is highest. We see that Bo increase on increase in failure rates. We see that last rows of the busy period of the server increase more speedily in equivalence of other row. From figure 5, it is conclude that, expected fractional number of inspection by repair man we see that with the increase in repair rates and also increase speedily with the increase in failure rates.

Conflict of interest

The authors declare that there is no conflict of interest of any sort on this research

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