SENSITIVITY ANALYSIS OF A UREA FERTILIZER PLANT

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Abstract

Purpose – This paper presents a sensitivity analysis of a urea fertilizer manufacturing system comprising several sub-systems of differing nature. Design/methodology/approach–A mathematical model is developed for the consistent general repair and disappointment rates for every subsystem. The framework is analyzed by utilizing regenerative point graphical technique; as a result, some recommendations are made for the optimized output. A state transition diagram of the system is developed to find mean time to busy period server, system failure and system availability. Findings – The present study suggests an approach to improve the system performance. The analysis and results outlined in this paper are useful to system managers, training supervisor, engineers and reliability analysts in the manufacturing industry. Originality/ value – The manufacturing system of Urea fertilizer consists of a complex structure with the high risk of machine failure. Machine/ Production failure leads to high risks of economic & environmental loss and worker's safety. To address this challenge effectively, sensitivity analysis of the urea fertilizer plant is discussed for minimizing the risk of machine failure.

Keywords: Reliability, Availability, Server of Busy Period, RPGT

I. Introduction

The plants of urea fertilizer consist of a large number of sub-systems which are inter-connected in series/parallel or both. It is needed for various sub-systems to be remaining perpetually in the up state for the efficient working, But, in reality, they are subject to random failures and replacement take place. The processing of the sub-system depends upon the operating conditions and the repair policies, as a result, its failure are difficult to predict. For the most preferable level of system availability, behavioural analysis is a best mechanism to economize operational parameters.

The analysis of accessibility parameters like reliability, availability, maintainability etc. of different mechanical system can help in improving the quality of synthesis and increase the production. To ensure the system performance, it is necessary to utilize various strategies throughout its service life. A number of researchers [Garg et al. [10], Ram and Manglik [17], kumar et al. [9], Lin [12], Liu and Xie [13], Ni et al. [15]] analyzed the accessibility parameters of different mechanical systems utilizing various strategies. Kumar et al. [11] considered a single-unit system to study the concept of preventive maintenance for all associated variables. Mishra et al. [14] used the Markov approach to discuss the optimal availability of break drum manufacturing system. Kumar and Singh [10] performed the reliability analysis of a complex system which consists of two repairable subsystems connected in series. Kumar et al. [8] discussed the behavior analysis of a bread making system considering five distinct sub-systems consist of mixer, oven, tunnels, divider and proofer useful to the management utilizing RPGT under steady-state. Hua et al. [5] developed a mathematical modeling using the state merging method to analyses a rearranged Markov model to assess the reliability of the phased-mission system (PMS). Gao et al. [3] considered planar slider crank mechanism for two clearance joints to study the reliability sensitivity analysis and optimization design using the Monte Carlo method. Tahir et al. [18] demonstrated a model by incorporating thermal storage, heat pump and demand responses and showed that warm capacity and demand response improve the part of variable manageable force sources. Jindal et al. [6] analyzed the reliability of the plant comprises of one programmed screw-press bio-coal briquetting machine. The behavioral analysis of a washing unit in paper industry for system parameters was discussed by Kumar et al. [7] using the RPGT. Rajbala et al. [16] applied Markov birth-death process for the analysis of the EGR Air Exhaust Pipe (EAEP) manufacturing plant. Agrawal et al. [1] studied the profit analysis of a Water Treatment RO Plant is agreed out by utilizing the RPGT. Dahiya et al. [2] studied the Optimization Using Heuristic Algorithm in Pharmaceutical industry. In this paper, keeping in view the purpose of analyzing real existing industrial system model, a urea fertilizer system is considered.

In fact, Urea fertilizer manufacturing system is a complex type repairable engineering system involving high risk of machine/production failure. Machine/Production failure leads to high risks of economic & environmental loss and worker’s safety. That’s why sensitivity analysis of the same plant is discussed in the present research. The problem is solved using RPGT to analyze the system parameters. The results describing the system behavior is discussed qualitatively through graphs and tables.

II. Problem Description and Assumptions

I. System Description

The urea fertilizer manufacturing system comprise of nine subsystems connected in series named as Ammonia Making Section (A), Medium Pressure Section (B), Low Pressure Section (C), Pre-vacuum Section (D), Vacuum Section (E), Periling Section (F) and high pressure (P1), medium pressure (P2), low pressure units (P3) as shown in Figure 1.

The performance of the system is best when all units are good but it fails to work when any of the nine sub-systems fail.

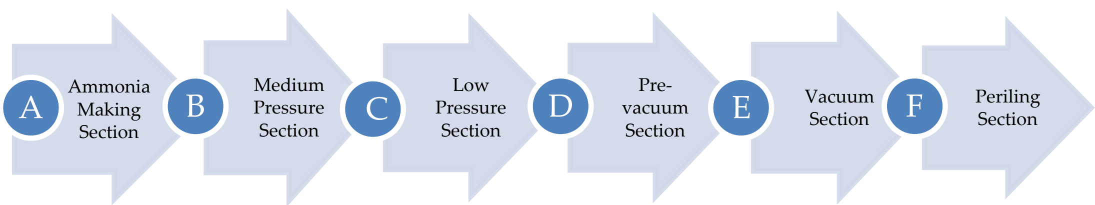

Figure 1: *Urea Fertilizer Making System Network*

II. Notations

$p_n(t)$ $(0 \le n \le 29)$	: Probability that the systems is in state S_n.at time t.
α_i $(1 \le i \le 6)$	: Subsystem's failure rates.
$\alpha_7, \alpha_8, \alpha_9$	: Failure rate of pressure unit P_1, P_2 and P_3 respectively.
α_0	: Constant failure rate of entire system from any of its operative state.
β_i $(1 \le i \le 6)$	: Subsystem's repair rates.
H	: Repair rate of system failed due to pressure unit P_3
C	: Repair rate of system failed due to common cause failed.
a, b, c, d, e, and f	: Subsystem A, B, C, D, E, and F failed.
S_0	: Initial operative state of the system
S_{21}	: System's failed state due to the failure of pressure unit P_3.
S_2	: System's failed state due to the common cause failure.

III. Assumptions

- The single repair facility is available.
- Medium and low pressure can be obtained from high pressure unit by scientific logic.
- When system fails then only the pressure units will be repair one.

IV. State transition diagram

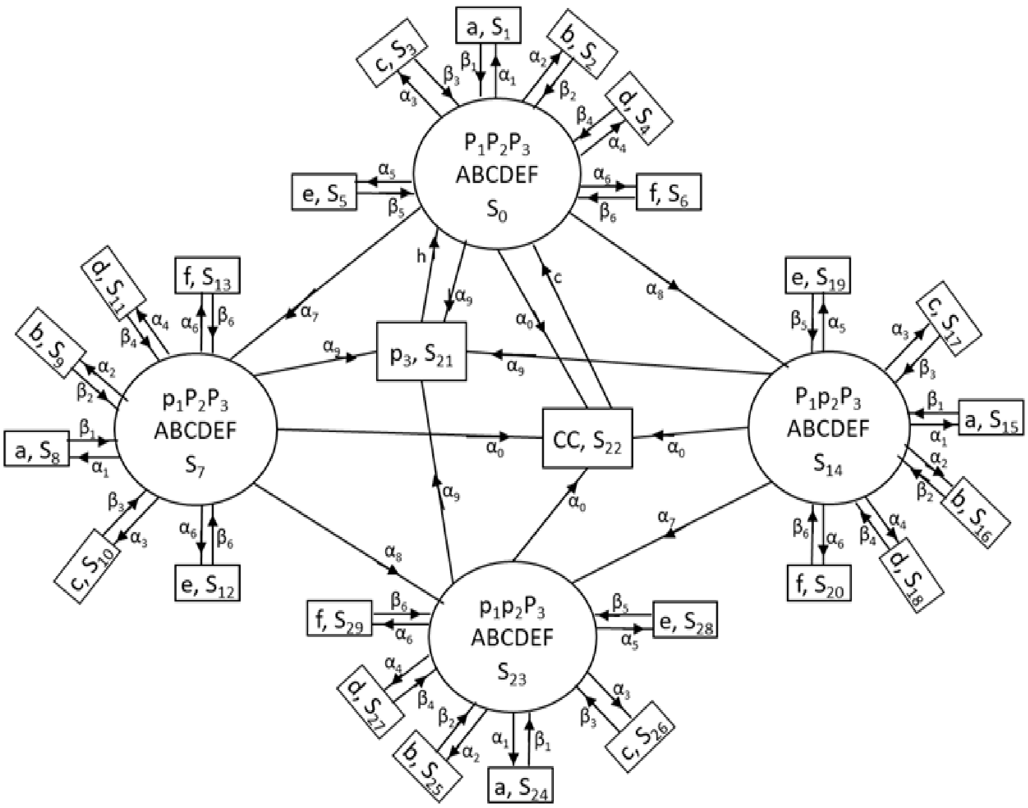

Figure 2: *Transition Diagram of System Design*

V. Transition Probabilities and Mean Sojourn Times (SMT)

Table 1 and Table 2 represents the Transition probabilities and MST for the states i, j respectively.

Table 1: *Transition Probabilities*

$q_{i,j}(t)$	$p_{ij} = q^*_{i,j}(0)$
$q_{0,i}(t) = \alpha_i e^{-(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_7+\alpha_9+\alpha_8+\alpha_0)t}$	$p_{0,i}= \alpha_i/(\alpha_1+\alpha_5+\alpha_0+\alpha_4+\alpha_7+\alpha_8+\alpha_2+\alpha_9+\alpha_3+\alpha_6)$
$q_{0,14}(t) = \alpha_8 e^{-(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_7+\alpha_8+\alpha_9+\alpha_0)t}$	$p_{0,14}= \alpha_8/(\alpha_3+\alpha_5+\alpha_0+\alpha_4+\alpha_6+\alpha_8+\alpha_7+\alpha_9+\alpha_2+\alpha_1)$
$q_{0,21}(t) = \alpha_9 e^{-(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_7+\alpha_8+\alpha_9+\alpha_0)t}$	$p_{0,21}= \alpha_9/(\alpha_1+\alpha_5+\alpha_0+\alpha_4+\alpha_2+\alpha_8+\alpha_7+\alpha_9+\alpha_6+\alpha_3)$
$q_{0,22}(t) = \alpha_0 e^{-(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_7+\alpha_8+\alpha_9+\alpha_0)t}$	$p_{0,22}= \alpha_0/(\alpha_1+\alpha_5+\alpha_0+\alpha_4+\alpha_2+\alpha_8+\alpha_7+\alpha_9+\alpha_6+\alpha_3)$
Where i = 1 to 7	
$q_{i,0}(t)= \beta_i e^{-\beta_i t}$, $q_{7+i}(t)= \beta_{7+i} e^{-\beta_i t}$	$p_{7+i}= 1$, $p_{14+i}= 1$, $p_{21+i}= 1$
$q_{14+i}(t)= \beta_{14+i} e^{-\beta_i t}$, $q_{21+i}(t)= \beta_{21+i} e^{-\beta_i t}$	$p_{i,0}= 1$, where $1 \le i \le 6$
$q_{7,7+i}(t) = \alpha_i e^{-(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_0+\alpha_8+\alpha_9)t}$	$p_{7,7+i}= \alpha_i/(\alpha_0+\alpha_9+\alpha_3+\alpha_8+\alpha_6+\alpha_5+\alpha_2+\alpha_4+\alpha_1)$
$q_{7,23}(t) = \alpha_8 e^{-(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_0+\alpha_8+\alpha_9)t}$	$p_{7,23}= \alpha_8/(\alpha_0+\alpha_9+\alpha_2+\alpha_4+\alpha_6+\alpha_5+\alpha_1+\alpha_8+\alpha_3)$
$q_{7,21}(t) = \alpha_9 e^{-(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_0+\alpha_8+\alpha_9)t}$	$p_{7,21}= \alpha_9/(\alpha_0+\alpha_9+\alpha_4+\alpha_8+\alpha_6+\alpha_5+\alpha_1+\alpha_3+\alpha_2)$
$q_{7,22}(t) = \alpha_0 e^{-(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_0+\alpha_8+\alpha_9)t}$	$p_{7,22}= \alpha_0/(\alpha_0+\alpha_9+\alpha_2+\alpha_1+\alpha_6+\alpha_5+\alpha_8+\alpha_4+\alpha_3)$
$q_{7+i,7}(t)= \beta_1 e^{-\beta_1 t}$	$p_{7+i,7}= 1$, where $1 \le i \le 6$
$q_{14,14+i}(t) = \alpha_i e^{-(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_7+\alpha_9+\alpha_0)t}$	$p_{14,14+i}= \alpha_i/(\alpha_6+\alpha_2+\alpha_5+\alpha_4+\alpha_9+\alpha_1+\alpha_7+\alpha_0+\alpha_3)$
$q_{14,22}(t) = \alpha_0 e^{-(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_7+\alpha_9+\alpha_0)t}$	$p_{14,22}= \alpha_0/(\alpha_5+\alpha_2+\alpha_0+\alpha_4+\alpha_9+\alpha_3+\alpha_7+\alpha_6+\alpha_1)$
$q_{14,23}(t) = \alpha_7 e^{-(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_7+\alpha_9+\alpha_0)t}$	$p_{14,23}= \alpha_7/(\alpha_6+\alpha_2+\alpha_0+\alpha_5+\alpha_9+\alpha_1+\alpha_7+\alpha_4+\alpha_3)$
$q_{14,21}(t) = \alpha_9 e^{-(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_7+\alpha_9+\alpha_0)t}$	$p_{14,21}= \alpha_9/(\alpha_5+\alpha_2+\alpha_0+\alpha_4+\alpha_9+\alpha_1+\alpha_7+\alpha_6+\alpha_3)$
$q_{14+i,14}(t)= \beta_1 e^{-\beta_1 t}$, $q_{23+i,23}(t)= \beta_i e^{-\beta_i t}$	$p_{14+i,14}= 1$, $p_{23+i,23}= 1$, where $1 \le i \le 6$
$q_{21,0}(t)= \text{h}e^{-ht}$, $q_{22,0}(t)= \text{c}e^{-ct}$	$p_{21,0}= 1$, $p_{22,0}= 1$
$q_{23,22}(t) = \alpha_0 e^{-(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_0+\alpha_9)t}$	$p_{23,22}= \alpha_0/(\alpha_6+\alpha_2+\alpha_9+\alpha_4+\alpha_1+\alpha_3+\alpha_0+\alpha_6)$
$q_{23,23+i}(t) = \alpha_i e^{-(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_0+\alpha_9)t}$	$p_{23,23+i}= \alpha_i/(\alpha_5+\alpha_2+\alpha_9+\alpha_1+\alpha_4+\alpha_6+\alpha_0+\alpha_3)$
$q_{23,21}(t) = \alpha_9 e^{-(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_0+\alpha_9)t}$	$p_{23,21}= \alpha_9/(\alpha_6+\alpha_2+\alpha_9+\alpha_4+\alpha_1+\alpha_6+\alpha_0+\alpha_3)$

Table 2: *Mean Sojourn Times*

$R_i(t)$	$\mu_i=R_i^*(0)$
$R_0(t)= e^{-(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_7+\alpha_8+\alpha_9+\alpha_0)t}$	$\mu_0 = 1/(\alpha_3+\alpha_2+\alpha_8+\alpha_1+\alpha_9+\alpha_6+\alpha_4+\alpha_7+\alpha_5+\alpha_0)$
$R_{k+i}(t)= e^{-\beta_i t}$ where $1 \le i \le 6$,	$\mu_i = 1/\beta_i$, where $1 \le i \le 6$
$R_j(t)= e^{-(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_0+\alpha_8+\alpha_9)t}$	$\mu_j = 1/(\alpha_3+\alpha_2+\alpha_1+\alpha_6+\alpha_5+\alpha_4+\alpha_8+\alpha_0+\alpha_9)$
where j = 7, 14, 23	where j = 7, 14, 23
$R_{21}(t)= e^{-ht}$, $R_{22}(t)= e^{-ct}$	$\mu_{21} = 1/h$, $\mu_{22} = 1/c$

The following paragraphs outline meaning of parameters assessment, Availability of system, Expected fractional no. of inspection by repairman and busy period of server.

III. Evaluation of Path Probabilities

The change likelihood of all reachable states from base state 'ξ' = '0' are: Probabilities from state '0' to various vertices are given as

$V_{0,0} = 1$, (1)

$V_{0,j} = (0,j) = p_{0,j}$; where $1 \le j \le 6$, (2)

$V_{0,7} = (0,7)/\{(1-L_1)(1-L_2)(1-L_3)(1-L_4)(1-L_5)(1-L_6)\}$ (3)

$V_{0,j} = (0,7,j)/\{(1-L_1)(1-L_2)(1-L_3)(1-L_4)(1-L_5)(1-L_6)(1-L_i)\}$; where $8 \le j \le 13$; $7 \le i \le 12$, (4)

$V_{0,14} = (0,14)/\{(1-L_{13})(1-L_{14})(1-L_{15})(1-L_{16})(1-L_{17})(1-L_{18})\}$ (5)

$V_{0,j} = (0,14,j)/\{(1-L_{13})(1-L_{14})(1-L_{15})(1-L_{16})(1-L_{17})(1-L_{18})(1-L_i)\}$; where $15 \le j \le 20$; $19 \le i \le 24$, (6)

$V_{0,21} = (0,21)+\{(0,14,21)/(1-L_{13})(1-L_{14})(1-L_{15})(1-L_{16})(1-L_{17})(1-L_{18})\}+\{(0,7,21)$

$$/(1-L_1)(1-L_2)(1-L_3)(1-L_4)(1-L_5)(1-L_6)\}\ )\}+\{(0,7,23,21)/(1-L_1)(1-L_2)(1-L_3)(1-L_4)(1-L_5)(1-L_6)(1-L_{25})(1-L_{26})(1-L_{27})(1-L_{28})(1-L_{29})(1-L_{30})\}+\{(0,14,23,21)/(1-L_{13})(1-L_{14})(1-L_{15})(1-L_{16})(1-L_{17})(1-L_{18})(1-L_{25})(1-L_{26})(1-L_{27})(1-L_{28})(1-L_{29})(1-L_{30})\} \quad (7)$$

$$V_{0,22} = (0,22)+\{(0,14,22)/(1-L_{13})(1-L_{14})(1-L_{15})(1-L_{16})(1-L_{17})(1-L_{18})\}+\{(0,7,22)/(1-L_1)(1-L_2)(1-L_3)(1-L_4)(1-L_5)(1-L_6)\}+\{(0,7,23,22)/(1-L_1)(1-L_2)(1-L_3)(1-L_4)(1-L_5)(1-L_6)(1-L_{25})(1-L_{26})(1-L_{27})(1-L_{28})(1-L_{29})(1-L_{30})\} \quad (8)$$

$$V_{0,23} = \{(0,7,23)/ (1-L_1)(1-L_2)(1-L_3)(1-L_4)(1-L_5)(1-L_6)(1-L_{25})(1-L_{26})(1-L_{27})(1-L_{28})(1-L_{29})(1-L_{30})\}+\{(0,14,23)/(1-L_{13})(1-L_{14})(1-L_{15})(1-L_{16})(1-L_{17})(1-L_{18})(1-L_{25})(1-L_{26})(1-L_{27})(1-L_{28})(1-L_{29})(1-L_{30})\} \quad (9)$$

$$V_{0,j} = \{(0,14,23,j)/ (1-L_{13})(1-L_{14})(1-L_{15})(1-L_{16})(1-L_{17})(1-L_{18})(1-L_{25})(1-L_{26})(1-L_{27})(1-L_{28})(1-L_{29})(1-L_{30})(1-L_i)\}+\{(0,7,23,24)//(1-L_1)(1-L_2)(1-L_3)(1-L_4)(1-L_5)(1-L_6)(1-L_{25})(1-L_{26})(1-L_{27})(1-L_{28})(1-L_{29})(1-L_{30})(1-L_i)\}; \text{ where } 24 \le j \le 29;\ 31\le i \le 36, \quad (10)$$

Where L_i are cycles of level 1 and

$(1-L_j) = \{1-(7,i,7)\} = (1-p_{7,i}p_{i,7})$, where $1 \le j \le 6$; $8 \le i \le 13$, (11)
$(1-L_7) = \{1-(8,7,8)\} = (1-p_{8,7}p_{7,8})$ (12)
$(1-L_8) = \{1-(9,7,9)\} = (1-p_{9,7}p_{7,9})$ (13)
$(1-L_9) = \{1-(10,7,10)\} = (1-p_{10,7}p_{7,10})$ (14)
$(1-L_{10}) = \{1-(11,7,11)\} = (1-p_{11,7}p_{7,11})$ (15)
$(1-L_{11}) = \{1-(12,7,12)\} = (1-p_{12,7}p_{7,12})$ (16)
$(1-L_{12}) = \{1-(13,7,13)\} = (1-p_{13,7}p_{7,13})$ (17)
$(1-L_j) = \{1-(14,i,14)\} = (1-p_{14,i}p_{i,14})$; where $13 \le j \le 18$; $15 \le i \le 20$, (18)
$(1-L_{19}) = \{1-(15,14,15)\} = (1-p_{15,14}p_{14,15})$ (19)
$(1-L_{20}) = \{1-(16,14,16)\} = (1-p_{16,14}p_{14,16})$ (20)
$(1-L_{21}) = \{1-(17,14,17)\} = (1-p_{17,14}p_{14,17})$ (21)
$(1-L_{22}) = \{1-(18,14,18)\} = (1-p_{18,14}p_{14,18})$ (22)
$(1-L_{23}) = \{1-(19,14,19)\} = (1-p_{19,14}p_{14,19})$ (23)
$(1-L_{24}) = \{1-(20,14,20)\} = (1-p_{20,14}p_{14,20})$ (24)
$(1-L_j) = \{1-(23,i,23)\} = (1-p_{23,i}p_{i,23})$; where $25 \le j \le 30$; $24 \le i \le 29$, (25)
$(1-L_{31}) = \{1-(24,23,24)\} = (1-p_{24,23}p_{23,24})$ (26)
$(1-L_{32}) = \{1-(25,23,25)\} = (1-p_{25,23}p_{23,25})$ (27)
$(1-L_{33}) = \{1-(26,23,26)\} = (1-p_{26,23}p_{23,26})$ (28)
$(1-L_{34}) = \{1-(27,23,27)\} = (1-p_{27,23}p_{23,27})$ (29)
$(1-L_{35}) = \{1-(28,23,28)\} = (1-p_{28,23}p_{23,28})$ (30)
$(1-L_{36}) = \{1-(29,23,29)\} = (1-p_{29,23}p_{23,29})$ (31)

IV. Evaluation of System Parameters

The MTSF and other parameters are evaluated under steady-state conditions by using S_1 as the base state.

- Mean time to system failure (T0): Regenerative un-failed states to which the framework can travel (starting state '0'), Preceding entering any bombed state are: 'j' = 7, 0, 14, 23 taking 'ξ' = '0'.

$$T_0=(V_{0,0}\mu_0+V_{0,7}\mu_7+V_{0,14}\mu_{14}+V_{0,23}\mu_{23})/(1-p_{0,7}p_{7,21}p_{21,0}-p_{0,7}p_{7,23}p_{23,21}p_{21,0}-p_{0,7}p_{7,23}p_{23,22}p_{22,0}-p_{0,14}p_{14,21}p_{21,0}-p_{0,14}p_{14,22}p_{22,0}-p_{0,14}p_{14,23}p_{23,21}p_{21,0}-p_{0,14}p_{14,23}p_{23,22}p_{22,0}) \quad (32)$$

- Availability of System (A_0): The states at which the framework is accessible are 'j' = 0, 14, 7, 23 taking 'ξ' = '0' the all-out division of time for which framework is accessible is given by

$$A_0 = \left[\sum_j V_{\xi,j}\,, f_j, \mu_j\right] \div \left[\sum_i V_{\xi,i}\,, f_j, \mu_i^1\right] = (V_{0,0}\mu_0+V_{0,7}\mu_7+V_{0,14}\mu_{14}+V_{0,23}\mu_{23})/D \quad (33)$$

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

$\mu_{13}+V_{0,12}\mu_{12}+V_{0,11}\mu_{11}+V_{0,14}\mu_{14}+V_{0,17}\mu_{17}+V_{0,16}\mu_{16}+V_{0,15}\mu_{15}+V_{0,18}\mu_{18}+V_{0,21}\mu_{21}+V_{0,20}\mu_{20}+V_{0,19}\mu_{19}+V_{0,22}\mu_{22}+V_{0,25}\mu_{25}+V_{0,24}\mu_{24}+V_{0,23}\mu_{23}+V_{0,26}\mu_{26}+V_{0,29}\mu_{29}+V_{0,28}\mu_{28}+V_{0,27}\mu_{27})$

- Busy Period of Server: States where server is busy are S_i, S_{7+i}, S_{14+i}, S_{23+i}, where $1 \le i \le 6$, S_{21}, S_{22} taking ξ = '0', the time server remains busy is

$$B_0=(V_{0,9}\mu_9+V_{0,4}\mu_4+V_{0,3}\mu_3+V_{0,11}\mu_{11}+V_{0,10}\mu_{10}+V_{0,1}\mu_1+V_{0,8}\mu_8+V_{0,6}\mu_6+V_{0,5}\mu_5+V_{0,13}\mu_{13}+V_{0,12}\mu_{12}+V_{0,2}\mu_2+V_{0,15}\mu_{15}+V_{0,18}\mu_{18}+V_{0,17}\mu_{17}+V_{0,16}\mu_{16}+V_{0,19}\mu_{19}+V_{0,22}\mu_{22}+V_{0,21}\mu_{21}+V_{0,20}\mu_{20}+V_{0,24}\mu_{24}+V_{0,27}\mu_{27}+V_{0,26}\mu_{26}+V_{0,25}\mu_{25}+V_{0,28}\mu_{28}+V_{0,29}\mu_{29})/D \quad (34)$$

- Expected Fractional Number of server visits by repairman: States where repairman do visit's a fresh are j =7, 14, 23 and S_i, S_{7+i}, S_{14+i}, S_{23+i}, where $1 \le i \le 6$, S_{21}, S_{23} taking 'ξ' = '0',

$$V_0 = (V_{0,7} +V_{0,14}+V_{0,21})/ (V_{0,1}\mu_2+V_{0,4}\mu_4+V_{0,3}\mu_3+V_{0,25}\mu_{25}+V_{0,10}\mu_{10}+V_{0,9}\mu_9+V_{0,8}\mu_8+V_{0,6}\mu_6+V_{0,5}\mu_5+V_{0,21}\mu_{21}+V_{0,24}\mu_{24}+V_{0,27}\mu_7+V_{0,15}\mu_{15}+V_{0,18}\mu_{18}+V_{0,17}\mu_{17}+V_{0,16}\mu_{16}+V_{0,29}\mu_{29}+V_{0,22}\mu_{22}+V_{0,12}\mu_{13}+V_{0,20}\mu_{20}+V_{0,14}\mu_{14}+V_{0,2}\mu_2+V_{0,26}\mu_{26}+V_{0,11}\mu_{11}+V_{0,28}\mu_{28}+V_{0,19}\mu_{19}) \quad (35)$$

V. Results

Particular cases of Sensitivity Analysis: Furthermore, the following paragraphs describe two Sensitivity Analysis cases and corresponding results in tabular and graphical forms.

Case 1: Sensitivity Analysis w. r. t. change in repair rates**.** Taking α_i = 0.1 ($0 \le i \le \alpha$) and varying β_1, β_2, β_3, β_4, β_5, β_6 one by one respectively at 0.75, 0.80, 0.85, 0.90, 0.95, 1.00.

Table 3: *MTSF (T_0)*

β_i	β_1	β_2	β_3	β_4	β_5	β_6	H	C
0.75	1.63964	1.63961	1.63963	1.63961	1.63960	1.63963	1.63964	1.63965
0.80	1.63965	1.63962	1.63964	1.63962	1.63961	1.63964	1.63965	1.63965
0.85	1.63966	1.63963	1.63965	1.63963	1.63962	1.63965	1.63966	1.63966
0.90	1.63967	1.63964	1.63967	1.63964	1.63963	1.63966	1.63966	1.63966
0.95	1.63968	1.63965	1.63968	1.63965	1.63964	1.63967	1.63967	1.63967
1.00	1.63969	1.63966	1.63969	1.63966	1.63965	1.63968	1.63967	1.63968

Table 4: *Availability of System (A_0)*

β_i	β_1	β_2	β_3	β_4	β_5	β_6	H	C
0.75	0.52072	0.51837	0.51631	0.51449	0.51288	0.51143	0.50065	0.50099
0.80	0.52309	0.52072	0.51865	0.51681	0.51516	0.51372	0.50284	0.50310
0.85	0.52521	0.52282	0.52072	0.51887	0.51723	0.51576	0.50479	0.50497
0.90	0.52710	0.52469	0.52258	0.52072	0.51907	0.51759	0.50654	0.50665
0.95	0.52881	0.52638	0.52426	0.52239	0.52072	0.51923	0.50811	0.50816
1	**0.53035**	0.52791	0.52578	0.52389	0.52222	0.52072	0.50953	0.50953

Table 5: *Busy Period of Server Visits (B_0)*

β_i	β_1	β_2	β_3	β_4	β_5	β_6	H	C
0.75	0.66957	0.67107	0.67237	0.67353	0.67455	**0.67547**	0.66773	0.66750
0.80	0.66807	0.66957	0.67089	0.67206	0.67310	0.67402	0.66628	0.66610
0.85	0.66673	0.66825	0.66957	0.67075	0.67179	0.67272	0.66498	0.66486
0.90	0.66553	0.66705	0.66839	0.66957	0.67063	0.67156	0.66382	0.66374
0.95	0.66444	0.66598	0.66733	0.66852	0.66957	0.67052	0.66278	0.66274
1	0.66346	0.66501	0.66637	0.66756	0.66862	0.66957	**0.66183**	**0.66183**

Table 6: *Expected Fractional Number of server visits by Repairman (V_0)*

β_i	β_1	β_2	β_3	β_4	β_5	β_6	H	C
0.75	0.49049	0.48823	0.48624	0.48449	0.48293	**0.48154**	0.48194	0.48327
0.80	0.49278	0.49049	0.48849	0.48672	0.48515	0.48375	0.48405	0.48531
0.85	0.49482	0.49252	0.49049	0.48719	0.48713	0.49572	0.48593	0.48712
0.90	0.49665	0.49432	0.49228	0.49049	0.48890	0.48747	0.48761	0.48875
0.95	0.49829	0.49595	0.49390	0.49210	0.49049	0.48906	0.48912	0.49021
1	0.49978	0.49743	0.49536	0.49355	0.49193	0.49040	0.49049	0.49153

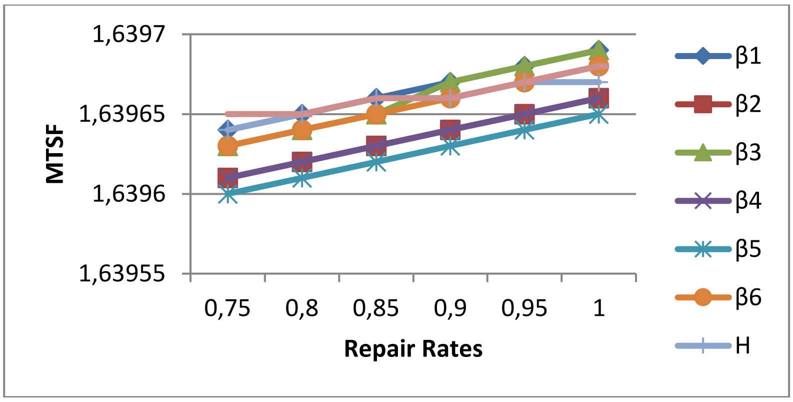

Figure 3: *Mean Time to System Failure*

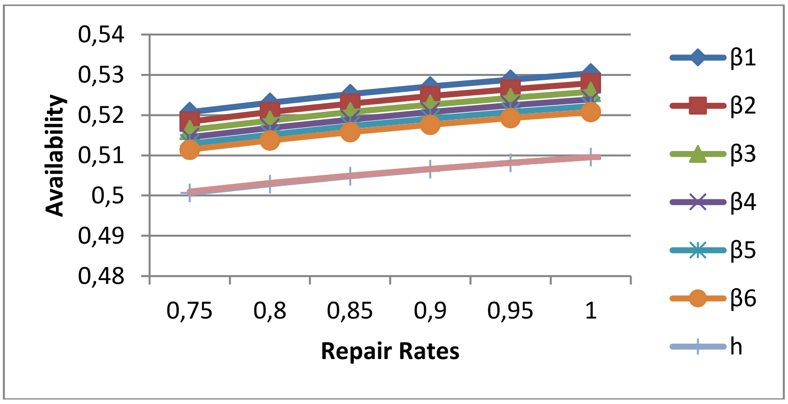

Figure 4: *Availability of System*

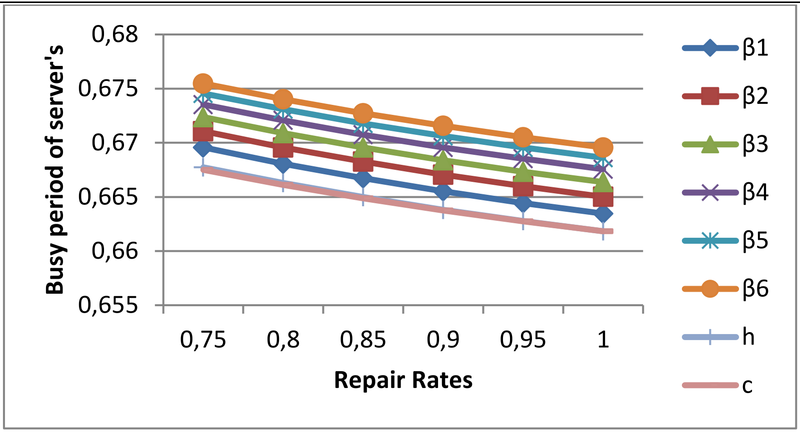

Figure 5: *Busy Period of the Server Visits*

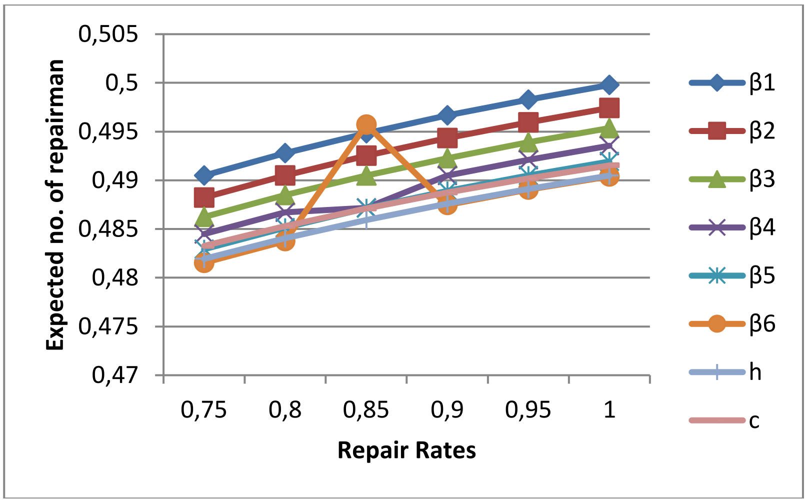

Figure 6: *Expected Fractional Number of server visits by Repairman*

Case 2: Now we consider Sensitivity Analysis case 2 with respect to change in failure rates: Fixing $\beta_i = 0.80$ ($0 \le i \le 6$) h = 1, c = 1, $\alpha_1 = \alpha_6 = \alpha_5 = \alpha_4 = \alpha_3 = \alpha_2 = 0.01$; Taking α_i = 0.1, 0.2, 0.3, 0.4 for i = 0, 7, 8, 9, we have

Table 7: *MTSF (T_0)*

α_i	α_0	α_6	α_7	α_8	α_9
0.1	2.88127	1.90761	3.26806	3.15184	**17.21485**
0.2	1.39829	1.35175	2.88127	3.02860	8.28176
0.3	1.32028	1.00665	2.59215	2.88127	4.64494
0.4	**0.86355**	0.74855	2.36740	2.62535	2.61925

Table 8: *Availability of System (A_0)*

α_i	α_0	α_6	α_7	α_8	α_9
0.1	0.63513	0.54051	0.77387	0.63730	**0.80021**
0.2	0.59134	0.47740	0.63513	0.63650	0.73625
0.3	0.56749	0.43190	0.62720	0.63513	0.64462
0.4	0.53866	**0.40780**	0.61278	0.63408	0.63513

Table 9: *Busy Period of Server Visits (B_0)*

α_i	α_0	α_6	α_7	α_8	α_9
0.1	0.67607	0.63074	0.57091	0.60098	**0.52002**
0.2	0.67782	0.67748	0.67607	0.65413	0.53951
0.3	0.67862	0.77832	0.71482	0.67607	0.61785
0.4	0.67980	**0.89412**	0.73151	0.70882	0.67607

Table 10: *Expected Fractional Number of Server visits by Repairman (V_0)*

α_i	α_0	α_6	α_7	α_8	α_9
0.1	0.25385	**0.13536**	0.23051	0.15806	0.20995
0.2	0.25412	0.21479	0.25385	0.17688	0.22616
0.3	0.26083	0.21648	0.25593	0.25385	0.22749
0.4	0.26222	0.21902	0.28552	0.25786	0.25385

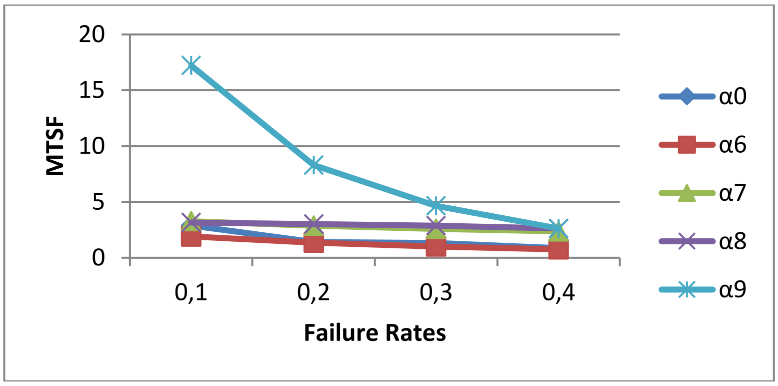

Figure 7: *MTSF*

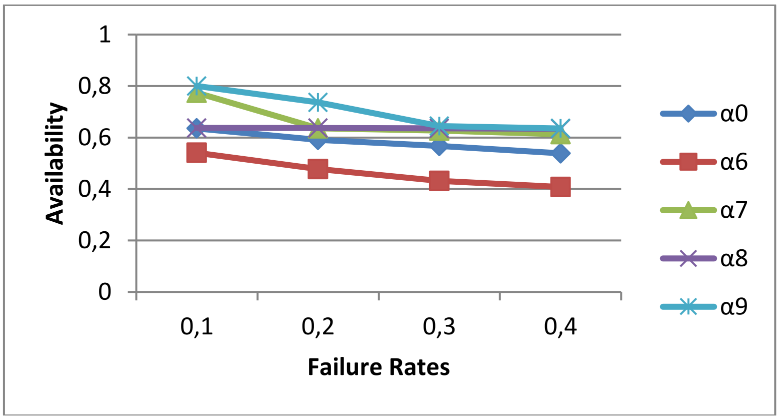

Figure 8: *Availability of System*

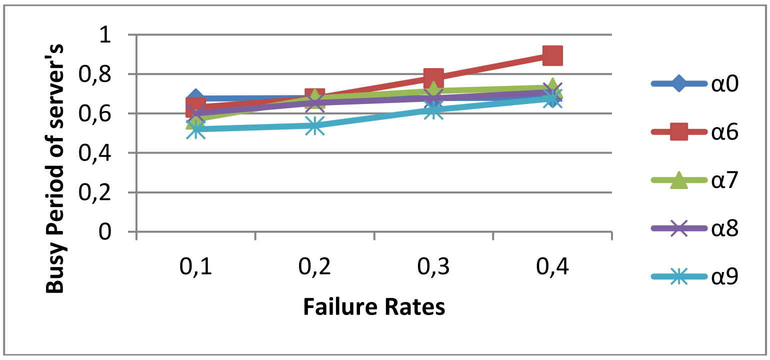

Figure 9: *Busy Period of Server Visits*

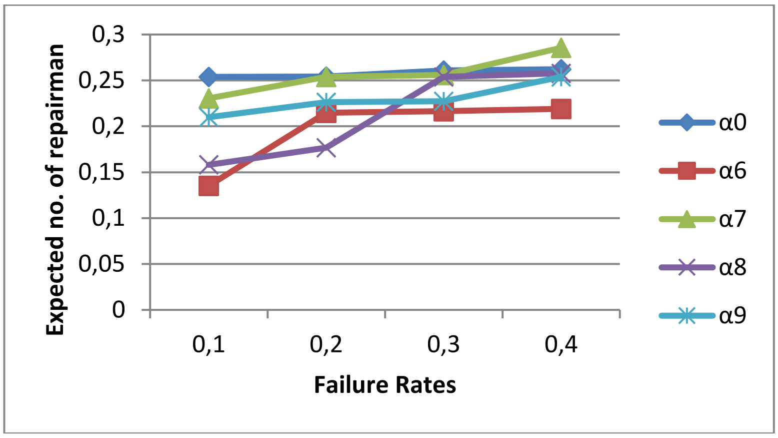

Figure 10: *Expected Fractional Number of server visits by Repairman*

VI. Discussion

Parameters related to sensitivity analysis for urea fertilizer plant are analyzed using RPGT. Effect of failure and repair rates on MTSF, availability of the system, busy period of the server, expected fractional number of server visit are discussed with the help of tables and graphs. Further from table 3 and figure 3, it observed that MTSF is independent of repair rates of various sub-units. From table 4 and figure 4, it is seen that availability increases with respect to repair rates. But there is no significance change in the value of availability of system while changing the value of repair rates. It is seen that for achieving the maximum value of A_0 repair rate of server should be maximum. For an operational system one has to minimize the busy period of the server to attain optimal level of production. It is seen from table 5 and figure 5, maximum value of repair rate of subunits leads to optimum value of the busy period. Moreover effect of repair rate of unit 'F' on the busy period of the server is more significance than other units. From table 6 and figure 6, it is seen that there is no significant change in the value of expected fraction number of server visits by repairman with the increase in repair rates of the subunits. From the table 7 and figure 7, MTSF is maximized when failure rate of higher pressure unit is minimum. MTSF is minimized when common cause failure rate is maximized. For optimum value of MTSF, failure rate of high pressure unit and common cause failure should be minimum. It is observed that availability is maximum when failure rates of high pressures unit and common cause failure rate is minimum. For an efficient system, availability should be highest, from above table 8 and Figure 8. From table 9 and figure 9, it is seen that busy period of the server increases by 62.36 % when failure rates of busy period increase from 0.1 to 0.4. From table 10 and figure 10, it is observed that the value of expected number of server's visits by repairman increased by 20.13 % when failure rates of the same and varying from 0.1 to 0.4.

VII. Conclusion

For urea fertilizer plant, In order to accomplish the ideal value of system parameters, administration may control the values of repair and failure rates of sub units. For the plant under consideration, the following conclusions are made from above research.

Case 1: Sensitivity Analysis with respect to change in repair rates (keeping failure rates constant).

- MTSF is independent of repair rates of all sub-units.
- Increase in repair rates does not have significant increase in the value of availability of system.
- In case of busy period of the server, effect of repair rate of unit 'F' is more significant as compared to other units. So repairman should be efficient in repairing the unit 'F' to minimize

the value of busy period of the server. Value of busy period is minimum when repair rate of pressure unit and common cause failure is maximum.
- No significant change in the value of expected fraction number of server visits by the repairman with change in value of repair rates of sub-units.

Case 2: Sensitivity Analysis with respect to change in failure rates (keeping repair rates constant).
- In order to have optimum value of MTSF, failure rate of high-pressure unit and common cause should be minimum.
- System availability is maximum when failure rate of high pressures unit and common cause failure rate are minimum. Availability is minimum when failure rate of sub- units are maximum.
- The optimum value of busy period is 0.52002 when the failure rate of high-pressure unit is minimum.
- The value of expected fraction number of server visits by the repairman with the increase in failure rates of the subunits.

The results obtain from above research are valuable for management to optimized the availability of plant, productions, and safety of workers. Last but not least, mathematical modeling utilizing in this paper is applicable to another manufacturing industries as well with suitable assumptions, and limitations.

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