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Analytical and Computational Studies of Availability of Complex Industrial System

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Abstract- The paper discusses the availability analysis of rice plant under preventive maintenance assuming three states of system namely: goodstate, pending-failure and failed state. When the system is in pending failure state, preventive maintenance (PM) is employed. Thetransition rates are time dependent, the mathematical formulation has been carried out using supplementary variable technique. The system of partial differential equations thus obtained has been solved analytically by Lagrange's method. Special cases are discussed using usingRunga –Kutta forth order for various choices of transition rates.

Key Words-Lagrange's Method, Runge- Kutta forth order, MATLAB,Availability, Supplementary variable technique.

1 Introduction

Maintainability and availability are two main aspects, which are closely relatedto reliability. The use of reliability technology was discussed by singh(1983) and Michelsen (1998). A number of have been developed by researchers,Singh (2011) to determine the optimal maintenance schedule. Barlow and Hunter (1960) studied the preventive maintenance models with minimal repairs. Khan and Gupta (1985) have introduced the concept of a pending failure state in order to consider usual operating and wear out periods of engineering systems and proposed a 3-state model.

For the last thirty years, reliability analysis has been applied mainly within the areaof risk analysis and the design of safety systems. In a process industry, failure of any one machine drastically affects the performance of the whole system. Scheduled maintenance planning plays a prominent role in reliability and its objective is to maximize the availability at lowest possible cost. The system undergoes for preventive maintenance (PM) and corrective maintenance (CM) on its transitions leads to degraded and failed state respectively. Perfect and efficient PM means no damage and no error during operation. Zhao (1994) developed a generalized availability model for repairable components and series system including perfect and imperfect switch over device. Priel (1974) developed methodology for failure analysis in process plants. Osaki and Nakagava (1976) gave a detailed bibliography for reliability and availability of stochastic system. Hibi(1977) suggested methods to estimate maintenance performance.Ramakrishna and Bawa (2005) Have discussed optimization of machine design criteria for high reliability and maintainability in food processing industry.

Most of the work is related to the numerical analysis of the steady state of the various systems. The reliability and other parameters have been studied for maintained system only by taking constant failure and repair rates.Howeverseveral authors studied the behavior analysis of system under priority repair.

In this paper we made an attempt to analyze availability under priority repair and maintenance planning taking somewhat factual data.The methodology adopted in this paper provides a better understanding of the behavior of the system under varying operating conditions. Availability analysis of the rice mill presented will help the management in deciding upon the maintenance strategy to be adopted to improve the performance of the system and consequently reduce the operation and maintenance cost.

The paper is organized as follows: The section 1 is introductory in nature. In section 2, a brief introduction about system and various notations of the subsystems are presented. The basic assumptions, on which the present analysis is based, are also discussed in section 2. The mathematical formulation of the Chapman – Kolmogorov differential equation of Rice Mill, assuming transition states with two cases namely variable transition rates and constant transition rates in section 3.This section also deals with thestudy state behavior having constant failure and repair rates. The analytical solution of the differential equations is also discussed in this section with the various combination constant failure and repair rates. The system of differential equations has been solved numerically to obtain the availability of the rice mill in section 4. Certain conclusions drawn from this analysis is discussed in the section 5.

2.1 System description

2.1.1 Sub-system E (Elevator)

Elevator (or lift) is vertical transport equipment that efficiently moves people or goods between floors These are five units ($E_i, i = 1,3,5,7,9$).Failure of any one unit causes complete failure of the system.

2.1.2 Sub-system C (Cleaning)

.These are two identical units ($C_i, i = 1,2$)working in parallel.This unit can work with one unit in reduced capacity.

2.1.3 Sub-system H (Husking)

There is one unit subjected to major

failure.

2.1.4 Sub-system S (Separation)

There is one unit subjected to major failure.

2.1.5 Sub-system W (Whitening)

These are two identical units ($W_i, i = 1,2$) working in parallel. This unit can work with one unit in reduced capacity.

2.1.6 Sub-system L (Polishing)

These are two units ($L_i, i = 10,11$).Failure of any one unit causes complete failure of the system.

2.2 Notations

$-$: The Sub-system/unit is running without any failure.

g: Unit is in good state but not operative.

m: Unit is under preventive maintenance.

r: unit is under repair or repair continued.

B^z: ($B = H, S$) indicate the working state of husking separation machine w.r.t z,(z=-,g, m ,r).

E_{ij}^{xy} : indicates the working state of the sub-system E_i and E_jw.r.t , $y, (x, y = -, g, r) :: \quad i = 1,3,5,7,9 :: j = i + 2, i + 4, i + 6 if i = 1; j = i - 2, i + 2, i + 4 : if i = 3; j = i - 2, i - 4, i + 2, i + 4 if i = 5; j = i - 2, i - 4, i - 6, i + 2 if i = 7;$

P_{kl}^{xy} : indicates the working state of the sub-system P_k and P_l w.r.t $x, y, (x, y = -, g, r) :: k = 10,11 :: l = 11\ if k = 10; l = 10\ if k = 11.$

$L_{u\ 3-u}^{tn}$: indicates the working states of the subsystem L the ordered pair $\binom{t}{u}$ and $\binom{t}{3-u}$ represents the functioning of the sub-system L w. r. t to "t" and "n"$(u = 1,2; t, = -, r)$.

$W_{v\ 3-v}^{tn}$: indicates the working states of the subsystem W the ordered pair $\binom{t}{v}$ and $\binom{t}{3-v}$ represents the functioning of the sub-system W w. r. t to "t" and "n"$(v = 1,2; t, = -, r)$.

$\lambda_i(y)$: refers failure rate of the sub-system $E_1, E_3, E_5, E_7, E_9, L_{10}, L_{11}, H, S$and W from normal to failed state $(i = 1,3,5,7,9,10,11,12,13)$.

$\lambda_k(y)$: refers failure rate of the sub-system C and W from normal to reduced state $(k = 2,4)$.

λ_l: refers constant transition state of the subsystem H and Swhich transits the system into the 6 and 7 respectively on reaching to these state preventing maintenance of H and S states start immediately, $(l = 6,8)$.

$\mu_i(x)$: Time dependent repair rates of the subsystem$E_1, E_2, E_3, E_5, E_7, E_9, P_{10}, P_{11}, H, S$and W to return it from failed to normal state and elapsed repair time is x,$(i = 1,3,5,7,9,10,11,12,13)$

$\mu_k(x)$: Time dependent repair rates of the subsystem $C$and W to return it from reduced to normal state and elapsed repair time "x"$(k = 2,4)$.

b_i: Probability the PM of H and S is carried out satisfactorily and this makes the system operative$(i = 6,8)$.

$1 - b_i$: Probability the PM of H and S is carried out unsatisfactory and this makes the system to failed state thereafter $(i = 6,8)$.

$P_k(x, y, t)$: Probability that the system is in state k at time t and has an elapsed failure time 'y' and elapsed repair time 'x'$(k = 12,3,4,5,7,9,10,11,12,13)$.

$P_z(x, t)$:Probability that the system is in state z at time t and has an elapsed repair time 'x'$(z = 6,8)$.

2.3 Assumptions

The assumptions, on which the present analysis is based on, are as follows:

(i) Repair and failure rates are independent of each other and their unit is taken as per day.

(ii) Failure and Repair rates of the subsystems are taken as variable.
(iii) Performance wise, a repaired unit is as good as new one for a specified duration..
(iv) Sufficient repair facilities are provided.
(v) Service of the subsystem includes repair and/or replacement.
(vi) System may work at reduced capacity also.

3 Mathematical modeling of the system in transient state

Mathematical modeling has been developed for the prediction of time dependent availability of the individual components as well as entire system. The failure and repair rates of different subsystem available from the maintenance sheets of rice plant, are used us standard input information for Kumar et al (1999)The state of the system defines the condition at any instant of time and the information is useful in analyzing the current state and in the prediction of the failure state of the system. If the state of the is probability based,the model is a non markovian model.Non markovian models is defined by a set of probabilities P_{ij},where P_{ij} is the probability of transition from any state i to any state j,One of most important features of the Non Markovian process is that the transition probability P_{ij},depends on past completely.

3.1 When both failure and repair rates are variable

In this section we develop the Chapman-Kolmogorov differential equation assuming variable failure and repair rates of the subsystems by applying supplementary variable technique. In the transient state, Probability considerations give the following system of differential difference equation associated with the state transition diagram (fig. 1) of the system at time $(t+\Delta t)$. Using mnemonic rule, we have

$P_0(t+\Delta t) = [1-(\int \sum_{i=1}^{R} \lambda_i(y)dy\Delta t - \lambda_6\Delta t - \lambda_8\Delta t]P_0(t) + \int \sum_{i=1}^{R} \mu_i(x)\, P_i(x,y,t)dxdy\, \Delta t + \int b_6\mu_6 P_6(x,t)dx\, \Delta t + \int b_8\mu_8 P_8(x,t)dx\, \Delta t$Dividing both sides by$\Delta t$, we get$\frac{P_0(t+\Delta t)-P_0(t)}{\Delta t} = -[(\int \sum_{i=1}^{R} \lambda_i(y)dy) - \lambda_6 - \lambda_8]P_0(t) \quad + \int \sum_{i=1}^{R} \mu_i(x)\, P_i(x,y,t)dxdy + \int b_6\mu_6 P_6(x,t)dx + \int b_8\mu_8 P_8(x,t)dx$

$$\left[\frac{d}{dt} + \int \sum_{i=1}^{R} \lambda_i(y)dy + \lambda_6 + \lambda_8\right] P_0(t) = + \int b_6\mu_6 P_6(x,t)dx + \int b_8\mu_8 P_8(x,t)dx \quad (1)$$

Similarly, for the other states, we can write the differential equation as:

$$\left[\frac{\partial}{\partial t} + \frac{\partial}{\partial x} + \frac{\partial}{\partial y} + \lambda_4(y) + \mu_2(x)\right] P_2(x,y,t) = \lambda_2(y)P_0(t) + \mu_4(x)P_{14}(x,y,t) \quad (2)$$

$$\left[\frac{\partial}{\partial t} + \frac{\partial}{\partial x} + \frac{\partial}{\partial y} + \lambda_2(y) + \mu_4(x)\right] P_4(x,y,t) = \lambda_4(y)P_0(t) + \mu_2(x)P_{14}(x,y,t) \quad (3)$$

$$\left[\frac{\partial}{\partial t} + \frac{\partial}{\partial x} + \frac{\partial}{\partial y} + \mu_i(x)\right] P_i(x,y,t) = \lambda_i(y)P_0(t)\ i = 1,3,5,7,9,10,11. \quad (4)$$

$$\left[\frac{\partial}{\partial t} + \frac{\partial}{\partial x} + \frac{\partial}{\partial y} + \mu_6(x)\right] P_6(x,t) = \lambda_6 P_0(t) \quad (5)$$

$$\left[\frac{\partial}{\partial t} + \frac{\partial}{\partial x} + \frac{\partial}{\partial y} + \mu_8(x)\right] P_8(x,t) = \lambda_8 P_0(t) \quad (6)$$

$$\left[\frac{\partial}{\partial t} + \frac{\partial}{\partial x} + \frac{\partial}{\partial y} + \mu_{12}(x)\right] P_{12}(x,y,t) = \lambda_{12}(y)P_0(t) + (1-b_6)\mu_6(x)P_6(x,t) \quad (7)$$

$$\left[\frac{\partial}{\partial t} + \frac{\partial}{\partial x} + \frac{\partial}{\partial y} + \mu_{13}(x)\right] P_{13}(x,y,t) = \lambda_{13}(y)P_0(t) + (1-b_8)\mu_8(x)P_8(x,t) \quad (8)$$

$$\left[\frac{\partial}{\partial t} + \frac{\partial}{\partial x} + \frac{\partial}{\partial y} + \mu_4(x) + \mu_2(x)\right] P_{14}(x,y,t) = \lambda_2(y)P_4(x,y,t) + \lambda_4(y)P_2(x,y,t) \quad (9)$$

Boundary Condition:

$$P_i(0,y,t) = \lambda_i(y)P_0(t)\ ;\ i = 1,2,3,4,5,7,9,10,11,12,13 \quad (10)$$

$$P_i(0,t) = \int \lambda_i(y)P_0(t)dy\, ; i = 6,8 \quad (11)$$

$$P_{14}(0,y,t) = \int \lambda_2(y)P_2(x,y,t)dx + \int \lambda_4(y)P_4(x,y,t)\, dx \quad (12)$$

Initial Conditions

$$P_0(0) = 1 \quad (13)$$

$P_i(x,0) = 0$; $i = 6,8$; $P_i(x,y,0) = 0$; $i = 1,2,3,4,5,7,9,10,11,12,13,14$ (14)

Solving these equations (1-9) together with initial and boundary conditions (10-14) using Lagrange's method, we get the state probabilities as given below:

$$P_0(t) = e^{-T_0 t}[1 + \int S_0(t) e^{T_0 t} dt] \quad (15)$$

$$P_i(x,y,t) = e^{-\int \mu_i(x)dx}[\lambda_i(y-x)P_0(t-x) + \int \lambda_i(y)P_0(t)e^{\int \mu_i(x)dx}dx] \; i = 1,3,5,7,9,10,11 \quad (16)$$

$$P_2(x,y,t) = e^{-\int T_1(x,y)dx}[\lambda_2(y-x)P_0(t-x) + \int S_1(x,y,t)e^{\int T_1(x,y)dx}dx] \quad (17)$$

$$P_4(x,y,t) = e^{-\int T_2(x,y)dx}[\lambda_4(y-x)P_0(t-x) + \int S_2(x,y,t)e^{\int T_2(x,y)dx}dx] \quad (18)$$

$$P_6(x,t) = e^{-\int T_3(x)dx}[\lambda_6 P_0(t-x) + \int \lambda_6 P_0(t)e^{\int T_3(x)dx}dx] \quad (19)$$

$$P_8(x,t) = e^{-\int T_4(x)dx}[\lambda_8 P_0(t-x) + \int \lambda_6 P_0(t)e^{\int T_4(x)dx}dx] \quad (20)$$

$$P_{12}(x,y,t) = e^{-\int \mu_{12}(x)dx}[\lambda_{12}(y-x)P_0(t-x) + \int S_3(x,y,t)e^{\int \mu_{12}(x)dx}dx] \quad (21)$$

$$P_{13}(x,y,t) = e^{-\int \mu_{13}(x)dx}[\lambda_{13}(y-x)P_0(t-x) + \int S_4(x,y,t)e^{\int \mu_{13}(x)dx}dx] \quad (22)$$

$P_{14}(x,y,t) = e^{-\int T_5(x)dx} \int [\,\lambda_4(y-x)P_2(x,y-$ *x,t−x+λ2y−xP4x,y−x,t−x+S5x,y,teT5xdx]dx* (23)

Where

$$T_0 = \int \sum_{i=1}^{R} \lambda_i(y)dy + \lambda_6 + \lambda_8$$

$T_1(x,y) = \lambda_4(y) + \mu_2(x)$; $T_2(x,y) = \lambda_2(y) + \mu_4(x)$; $T_3(x) = (1-b_6)\mu_6(x) + b_6\mu_6(x)$

$T_4(x) = (1-b_8)\mu_8(x) + b_8\mu_8(x)$; $T_5(x) = \mu_4(x) + \mu_2(x)$

$$S_0(t) = \int \sum_{i=1}^{R} \mu_i(x)\, P_i(x,y,t)dxdy + \int b_6\mu_6 P_6(x,t)dx + \int b_8\mu_8 P_8(x,t)dx$$

$S_1(x,y,t) = \lambda_2(y)P_0(t) + \mu_4(x)P_{14}(x,y,t)$; $S_2(x,y,t) = \lambda_4(y)P_0(t) + \mu_2(x)P_{14}(x,y,t)$

; $S_3(x,y,t) = \lambda_{12}(y)P_0(t) + (1-b_6)\mu_6(x)P_6(x,t)$

$S_4(x,y,t) = \lambda_{13}(y)P_0(t) + (1-b_8)\mu_8(x)P_8(x,t)$

$S_5(x,y,t) = \lambda_2(y)P_2(x,y,t) + \lambda_4(y)P_4(x,y,t)$ (24)

$b_i = 1 \; for \; Idealized \; maitenance$

$0 \; for \; faulty \; maintenance \; (i = 6,8)$ (25)

If the industry provide the failure and repair rates, one can calculate the availability $A_v(t)$ in term of the probability$P_0(t)$, which is shown in equitation (1), thus, the time dependent availability $A_v(t)$ of the system is given by

$$A_v(t) = P_0(t) + \int \sum_{i=2}^{2,4,14} P_i(x,y,t)\,dxdy + \int \sum_{i=6,8} P_i(x,t)\,dx \quad (26)$$

3.2 When both failure and repair rates are constant

To find the availability of the system, when both failure and repair rates are constant, system of equations (1-9) reduces to more simplified form, as follows:

$$\left[\frac{d}{dt} + \sum_{i=1}^{13} \lambda_i\right] P_0(t) = \sum_{i=1}^{5,7,9,10,11,12,13} \mu_i P_i(t) + b_6\mu_6 P_6(t) + b_8\mu_8 P_8(t) \quad (27)$$

$$\left[\frac{d}{dt}+\lambda_4+\mu_2\right]P_2(t)=\lambda_2 P_0(t)+\mu_4 P_{14}(t) \quad (28)$$

$$\left[\frac{d}{dt}+\lambda_2+\mu_4\right]P_4(t)=\lambda_4 P_0(t)+\mu_2 P_{14}(t) \quad (29)$$

$$\left[\frac{d}{dt}+\mu_i(x)\right]P_i(t)=\lambda_i P_0(t)$$

$i = 1,3,5,6,7,8,9,10,11$ (30)

$$\left[\frac{d}{dt}+\mu_{12}\right]P_{12}(t)=\lambda_{12} P_0(t)+(1-b_6)\mu_6 P_6(t) \quad (31)$$

$$\left[\frac{d}{dt}+\mu_{13}\right]P_{13}(t)=\lambda_{13} P_0(t)+(1-b_8)\mu_8 P_8(t) \quad (32)$$

$$\left[\frac{d}{dt}+\mu_4+\mu_2\right]P_{14}(t)=\lambda_2 P_4(t)+\lambda_4 P_2(t) \quad (33)$$

Initial conditions

$$P_i(0)=\begin{Bmatrix} 1, for\ i=0 \\ 0,\ \ otherwise \end{Bmatrix} \quad (34)$$

Most of the authors have used Laplace transformation for simple systems and matrix method to solve the reliability function. But in this case it is difficult to find Laplace inverses, since expressions for probability transforms are in very complicated form and the complexity increase with the increase in number of equation. To overcome such type of problems the system of differential equation (27-33) with initial conditions (34) has been solved numerically following the approach adopted by Gupta et. al. (2007).Vaderperre and Makhanov(2005) used a numerical method to find the long run availability of a priority system.The numerical computation has been carried out starting from $t=0$ to$t=360$ days assuming $t=0.005$as equivalent to one day. The availability of rice mill has been obtained by taking different combinations of the constant failure and repair rates of the subsystems collected from the concerned industry. It is evident that availability$A_v(t)$of the system can be computed as,

$$A_v(t)=\sum_{i=0,2,4,6,8,14} P_i(t) \quad (35)$$

3.3 Steady state availability when failure and repair rates are constant under idealized preventive maintenance

In the process industry, management remains interested in long run availability of the system.. This can be achieved by taking $\frac{d}{dt}\to 0$ and$\frac{\partial}{\partial t}\to 0$, as$t\to\infty$. Then the equations (1-9) reduce to linear algebraic equations when transitions rates are constant.

$$\left[\sum_{i=1}^{13}\lambda_i\right]P_0=\left[\sum_{i=1}^{13}\mu_i\right]P_i \quad (36)$$

$$\mu_i P_i=\lambda_i P_0 i=1,3,5,6,7,8,9,10,11,12,13 \quad (37)$$

$$[\lambda_4+\mu_2]\,P_2=\lambda_2 P_0+\mu_4 P_{14} \quad (38)$$

$$[\lambda_2+\mu_4]P_4=\lambda_4 P_0+\mu_2 P_{14} \quad (39)$$

$$[\mu_4+\mu_2]P_{14}=\lambda_2 P_4+\lambda_4 P_2 \quad (40)$$

Solving recursively the above system of equations (36-40), we get

$$P_2=M_1 P_0 \quad (41)$$

$$P_4=M_2 P_0 \quad (42)$$

$$P_{14}=M_3 P_0 \quad (43)$$

Now using normalizing condition

$$\sum_{i=0}^{14} P_i=1 \quad (44)$$

$$P_0=\left[1+\frac{\lambda_1}{\mu_1}+M_1+\frac{\lambda_3}{\mu_3}+M_2+\frac{\lambda_5}{\mu_5}+\frac{\lambda_6}{\mu_6}+\frac{\lambda_7}{\mu_7}+\frac{\lambda_8}{\mu_8}+\right.$$

λ9μ9+λ10μ10+λ11μ11+λ12μ12+λ13μ13+M3−1

(45)

and, the availability is ,

$$A_v = \left[1 + M_1 + M_2 + M_3 + \frac{\lambda_6}{\mu_6} + \frac{\lambda_8}{\mu_8}\right] P_0 \quad (46)$$

Where

$P_2 = M_1 P_0$: $P_4 = M_2 P_0$:$P_{14} = M_3 P_0$

$M_1 = \frac{\lambda_2}{S_4 S_5} + \frac{\mu_4 \lambda_4 \lambda_2}{S_1 S_4 S_2 S_5 S_3}$:$M_2 = \frac{\lambda_4}{S_2 S_3} + \frac{\mu_2 \lambda_4}{S_1 S_2 S_3} M_1$:$M_3 = \frac{\lambda_2}{S_1} M_2 + \frac{\lambda_4}{S_1} M_1$

$S_1 = \mu_4 + \mu_2$: $S_2 = \lambda_2 + \mu_4$:$S_3 = 1 - \frac{\mu_2 \lambda_2}{S_1 S_2}$: $S_4 = \lambda_4 + \mu_2$:$S_5 = 1 - \frac{\lambda_4 \mu_2}{S_1 S_2} - \frac{\mu_4 \lambda_4 \mu_2 \mu_2}{S_1 S_4 S_2 S_1 S_3}$

4 Performance Analyses

4.1 When Rates are Constant

Figure $3(a)$ shows the availability of the system with failure rateλ_1 of the Elevator for a period 360days divided over an interval of 30days. It seems that increase in failure rate (λ_1) of elevator from .005 (once in 200 hrs.) to .010 (once in 100 hrs.) affect the availability of the system by (2.4% to 3.6%) whereas it affect (6.6% to 7.8%)with the increase in time from (30 $daysto$ 360 $days$)respectively

Figure $3(b)$ showsthat the availability decreases (6.7% to 19.1%) with the increase in the values of failure rate (λ_{11})of polishing machine from .003 (once in 333 days) to .014 (once in 7hrs.)respectively. Further we also find that when the time increase from (30 $daysto$ 360 $days$)the availability decrease by (6.7% t0 19.0%) respectively.

Figure $3(c)$ shows that availability of the system is affected by $.26\%$ $t0$ $.15\%$ with the increase in failure rate (λ_{12}) of husking machine (once in 19hrs. to once in 16 hrs.) whereas increase in time affect it by app. (6.6% to 6.4%)from 30 days to 360 days respectively

Figure $3(d)$ shows that the availability decreases($.25\%$ to $.13\%$) with the increase in the failure rate of separating machine (λ_{13}) from($.057$ to $.087$)respectively . Further we also find that when the time increase from 30 days to 360 days the availability decrease by (6.6% to 6.5%) respectively.

Figure 4(a) shows that the affect of repair rate of elevator on availability of the system. One can see that increase in time from 30 days to 360 days decrease the availability of the system decreases (8.4% to 4.4%) however increase in repair rate (μ_1) of elevator from .029(Once in 35hrs.)to$.04$(once in 25hrs.) increase it app. ($.68\%$ to 2.1%)

Figure 4(b) shows that the increase in repair rate (μ_{11}) of polishing machine from .011 (once in 90 hrs.) to .10(once in 10hrs.) increase the availability of the system by (1.8% to 7.4%) and when the time increase from 30 days to 360days the availability decrease (8.4% to 3.3%).

Figure 4(c) shows that increase (1.1% t0 .97%) respectively with the increase in repair rate (μ_{12}) of husking machine from (1.10 to 4.10) .Further we also find that when the time increase from 30 days to 360 days the availability of the system decrease by app. (8.4% to 8.5% respectively.

Figure 4(d) shows that the availability increases($.39\%$ to $.35\%$) with the increase in repair rate (μ_{13}) of separating machine from2.5 to 3.5. respectively Further we also find that by an increase in time from 30 days to 360 days the availability of the system decrease by app. 8.4% respectively.

4.2 Steady State Behavior

Figure 5(a) shows that behavior of availability of the system. Failure rate of elevator from different values of repair rate (μ_1) of theelevator. It is included that increase in failure rate(λ_1) from (.005 to .010) reduce the system availability by (3.6%) and the when repair rate (b1) of elevator is increasedfrom .029 to .119 the availability increase by (2.9%).

Figure 5(b) shows that the availability decrease in the by (23.1% and 9.5%) with the increase in the failure rate λ_{11} of polishing machine from (.003 to .018)respectively. Further we also see that when repair rate (μ_{11}) of polishing machine is increased from (.011 to .10) the availability of the system increase by (5.7% to 50.5%) respectively.

Figure 5(c) shows that the increase in failure rate (λ_{12}). Husking machine from (.57% to 0.16%) decrease availability of the system (.39%) and when repair rate μ_{12} of slicing machine increase from (1.10 to 4.10) the availability increase by .78%.

Figure 5(d) shows that the availability decreases by (.78% and .36%) with the increase in the failure rate λ_{13} of separating machine from($.057$ to $.147$respectively). Further we also see that when repair rate (μ_{13}) of separating machine is increased from (2.2 to 5.5) the availability of the system increase by ($.29\%$ to $.71\%$) respectively.

5 Conclusions

The reliability management of complex industrial system is highly difficult for reliability analysis due to difficulties in modeling and evaluating the performance of the system, especially during strategic maintenance planning. Through rigorous efforts have been made by researchers to evolve methods to study the effect of subsystem conditions and maintenance policies on system performance, these methods involve complex computations and the computations grow tremendously with further growth in number of subsystems.

Thus the above study shows that the availability tables and graphs provides us information about the system to be cared more and sequence of subsystem in which we should care. Thus the system will work satisfactory for long time giving maximum output and also will improve the quality.

The performance analysis of rice mill help in increasing the production and quality of rice. Detailed study reveals that the polishing subsystem is critical part of the system and needs utmost care of management. Thus, the concerned managers can plan and adapt suitable maintenance practices/strategies for improving the system performance. Apart from these advantages the system performance analysis may help to conduct cost benefit analysis, operational capability studies, inventory spare parts management and replacement decisions.

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Figure Captions
Figure 1 Flow diagram of Rice plant.
Figure 2 Transition diagram of rice plant
Figure 3 Effect of failure rates on availability of rice plant.
Figure 4Effect of repair rates on availability of rice plant.
Figure 5 Effect of failure and repair rates on steady state availability of rice plant.

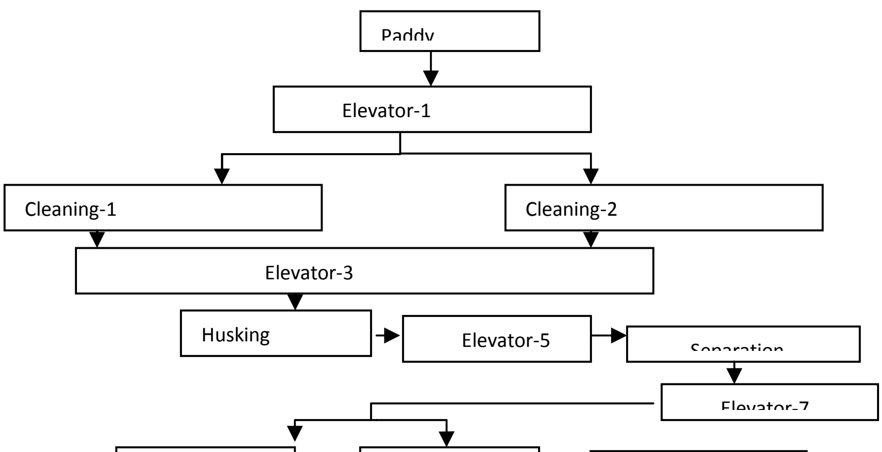


Figure 1

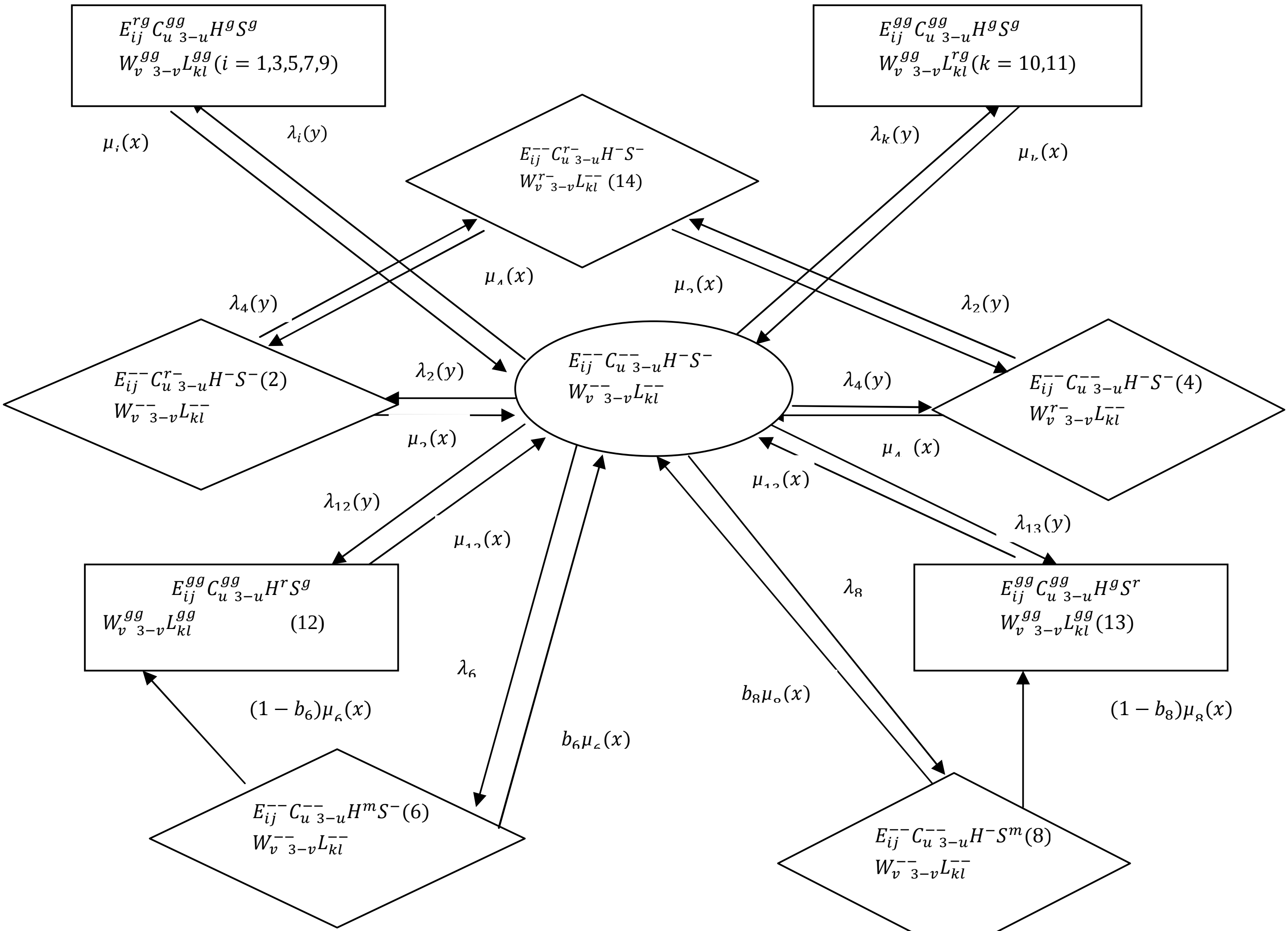


Figure 2

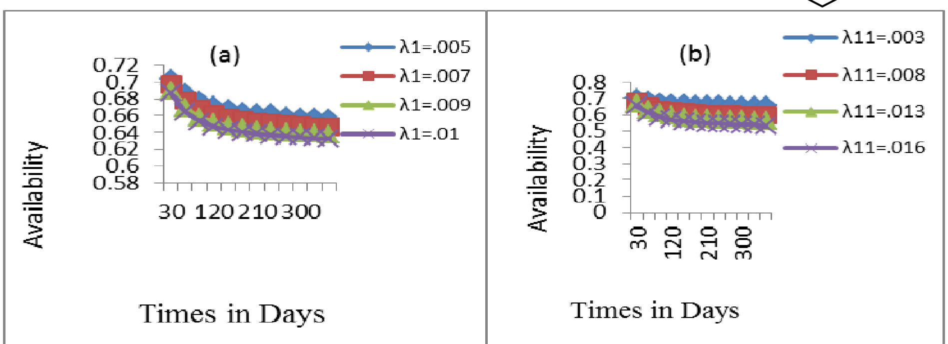
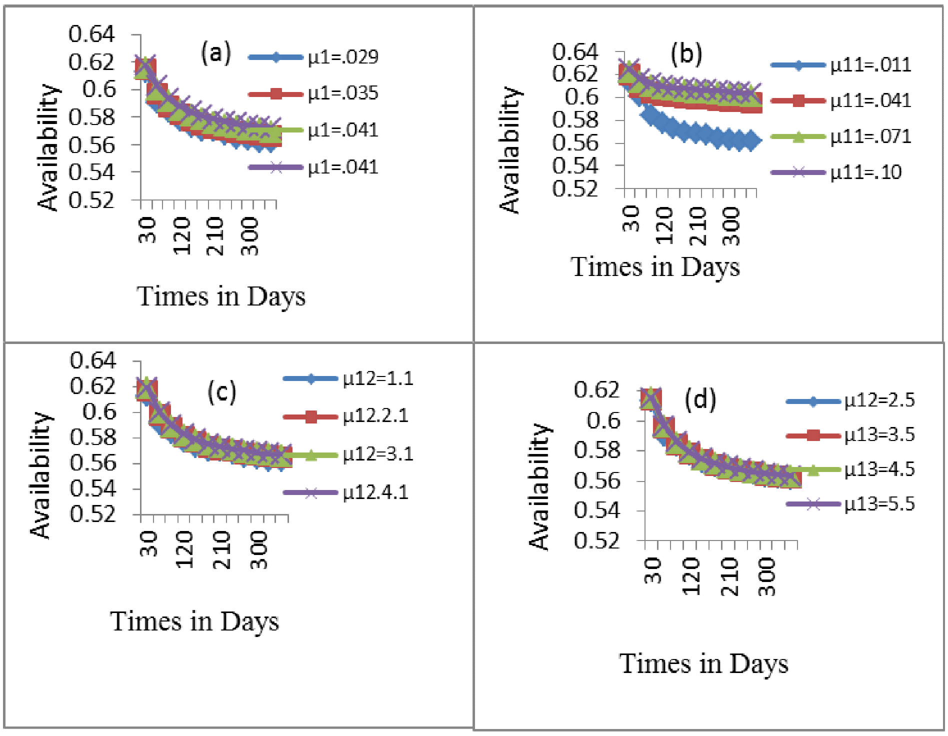
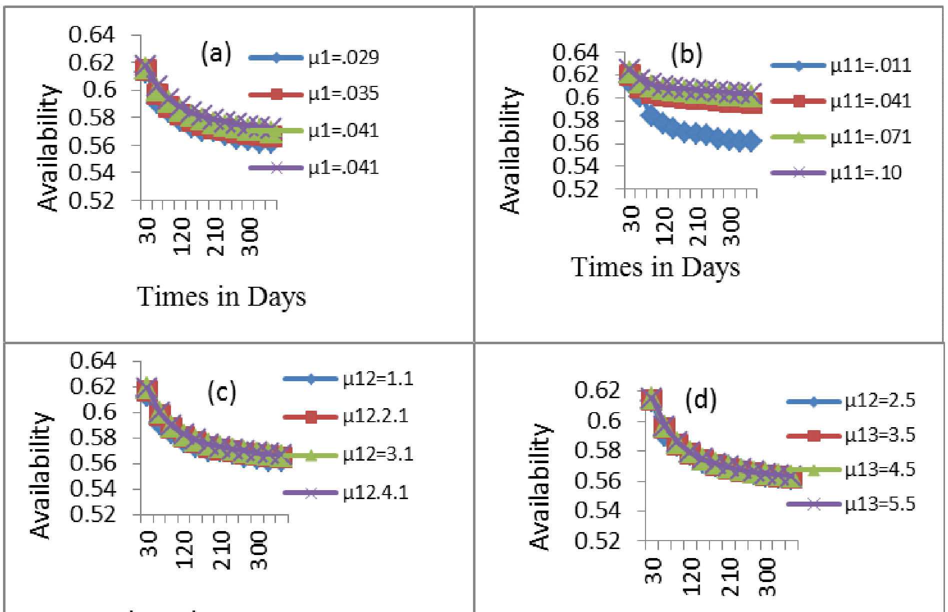


Figure:3


(a)
Availability
0.64
0.62
0.6
0.58
0.56
0.54
0.52
30
120
210
300
Times in Days
μ1=.029
μ1=.035
μ1=.041
μ1=.041
(b)
Availability
0.64
0.62
0.6
0.58
0.56
0.54
0.52
30
120
210
300
Times in Days
μ11=.011
μ11=.041
μ11=.071
μ11=.10
(c)
Availability
0.64
0.62
0.6
0.58
0.56
0.54
0.52
30
120
210
300
Times in Days
μ12=1.1
μ12.2.1
μ12=3.1
μ12.4.1
(d)
Availability
0.62
0.6
0.58
0.56
0.54
0.52
30
120
210
300
Times in Days
μ12=2.5
μ13=3.5
μ13=4.5
μ13=5.5


(a)
Availability
0.64
0.62
0.6
0.58
0.56
0.54
0.52
30
120
210
300
Times in Days
μ1=.029
μ1=.035
μ1=.041
μ1=.041
(b)
Availability
0.64
0.62
0.6
0.58
0.56
0.54
0.52
30
120
210
300
Times in Days
μ11=.011
μ11=.041
μ11=.071
μ11=.10
(c)
Availability
0.64
0.62
0.6
0.58
0.56
0.54
0.52
30
120
210
300
μ12=1.1
μ12.2.1
μ12=3.1
μ12.4.1
(d)
Availability
0.62
0.6
0.58
0.56
0.54
0.52
30
120
210
300
μ12=2.5
μ13=3.5
μ13=4.5
μ13=5.5

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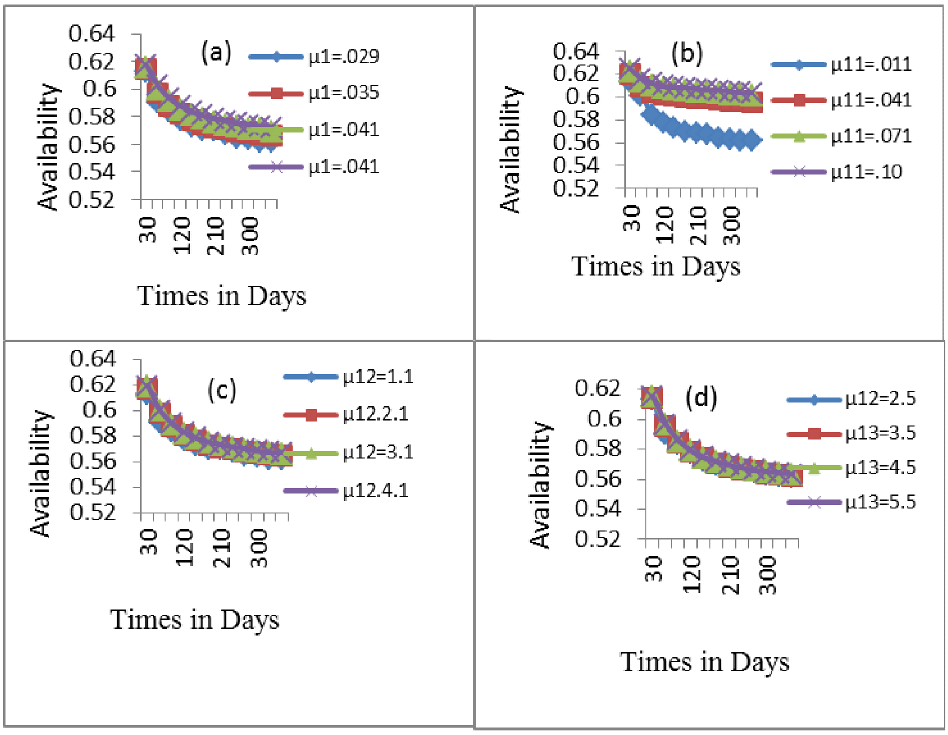
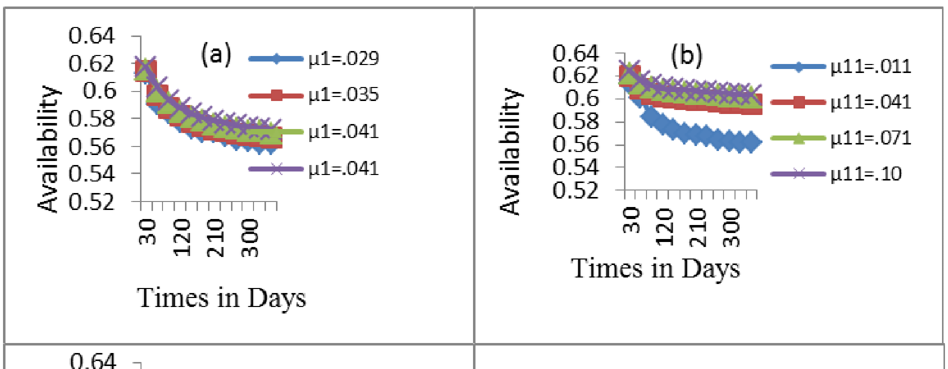
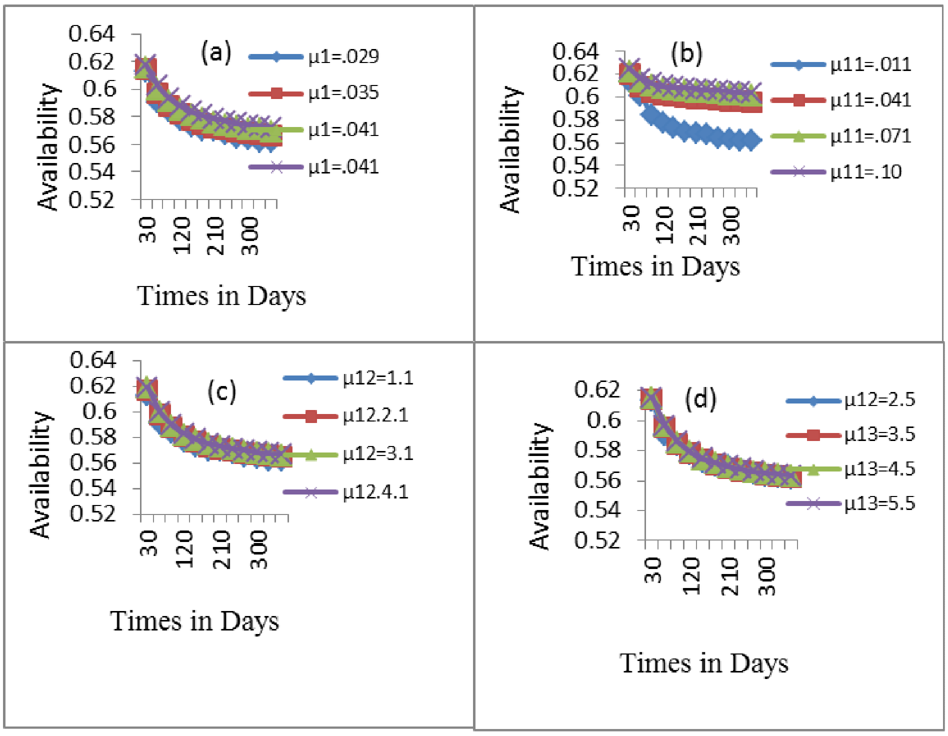
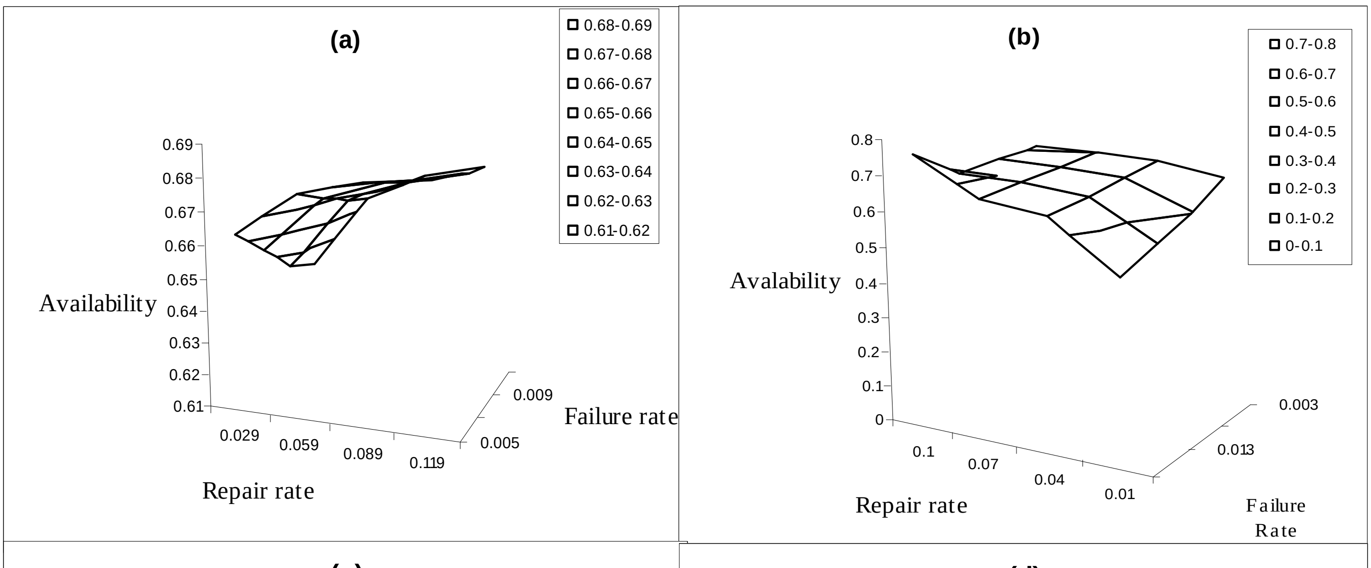





(a)
μ1=.029
μ1=.035
μ1=.041
μ1=.041
Availability
Times in Days
(b)
μ11=.011
μ11=.041
μ11=.071
μ11=.10
Availability
Times in Days
(c)
μ12=1.1
μ12.2.1
μ12=3.1
μ12.4.1
Availability
Times in Days
(d)
μ12=2.5
μ13=3.5
μ13=4.5
μ13=5.5
Availability
Times in Days


(a)
0.68-0.69
0.67-0.68
0.66-0.67
0.65-0.66
0.64-0.65
0.63-0.64
0.62-0.63
0.61-0.62
Availability
Failure rate
Repair rate
(b)
0.7-0.8
0.6-0.7
0.5-0.6
0.4-0.5
0.3-0.4
0.2-0.3
0.1-0.2
0-0.1
Avalability
Repair rate
Failure Rate

Figur:5

Figure5

Name of subsystem	Failure rate (per hour)	Repair rate(per hour)
Elevator1	$\lambda_1 = .005 - .010$	$\mu_1 = .029 - 0.04$
Cleaning Machine	$\lambda_2 = .0003 - .0009$	$\mu_2 = 1.5 - 1.9$
Elevator-3	$\lambda_3 = .023 - .076$	$\mu_3 = 1.001 - 1.007$
Whitening Machine	$\lambda_4 = .056 - .086$	$\mu_4 = .90 - 1.5$
Elevator-5	$\lambda_5 = .002 - .006$	$\mu_5 = .90 - 1.9$
Husking Machine to normal to maintenance	$\lambda_6 = 1.004 - 1.008$	$\mu_6 = 1.08 - 2.05$
Elevator-7	$\lambda_7 = .001 - .008$	$\mu_7 = 1.3 - 1.9$
Separation Machine normal To maintenance	λ_8=1.002-1.006	μ_8=1.03-1.09
Elevator -9	$\lambda_9 = 1.005 - 1.009$	$\mu_9 = 1.03 - 1.56$
Polishing -10	λ_{10} = .00045-.00085	$\mu_{10} = .51 - .92$
Polishing -11	$\lambda_{11} = .003 - .016$	$\mu_{11} = .011 - .10$
Husking Machine to normal to failed	$\square_{12} = .052 - .061$	$\mu_{12} = 1.10 - 4.10$
Separation Machine normal to failed	$\square_{13} = .057 - .087$	$\mu_{13} = 2.5 - 5.5$

Table I Failure and Repair rates of the subsystems of rice plant.

Subsystem	Variation In Failure Rates (days)	Availability	Transition Rates
Elevator	.005(30) to .010(30) .005(360)to.010(360)	.7038 .6867 .6567 .6327	$\square_2 = .0003$ $\square_3 = .023$ $\square_4 = .056$ $\square_5 = .006$ $\square_6 = 1.004$ $\square_7 = .001$ $\square_8 = 1.002$ $\square_9 = 1.005$ $\square_{10} = .00045$ $\mu_2 = 1.9$ $\mu_3 = 1.007$ $\mu_4 = 1.5$ $\mu_5 = 1.90$ $\mu_6 = 2.05$ $\mu_7 = 1.9$ μ_8=1.09 $\mu_9 = 1.56$ $\mu_{10} = .92$
Polishing	.003(30) to .015(30) .003(360)to.015(360)	.7038 .6561 .6567 .5310	
Husking	.052(30) to .061(30) .052(360)to.061(360)	.7038 .7019 .6567 .6558	
Separation	.057(30) to .087(30) .057(360)to.087(360)	.7038 .7020 .6567 .6568	

Table-II Variation in the data of failure rates of some important subsystem .The value inside the bract's denotes days

Subsystem	Variation In Repair Rates (days)	Availability	Transition Rates
Elevator	.0 29(30) to .04(30) .029(360) to .04(360)	.6129 .6171 .5613 .5723	$\square_2 = .0009$ $\square_3 = .076$ $\square_4 = .086$ $\square_5 = .006$ $\square_6 = 1.008$ $\square_7 = .008$ $\square_8 = 1.006$ $\square_9 = 1.009$ $\square_{10} = .00085$ $\mu_2 = 1.5$ $\mu_3 = 1.005$ $\mu_4 = .90$ $\mu_5 = .90$ $\mu_6 = 1.9$ $\mu_7 = 1.3$
Polishing	.011(30) to .10(30) .011(360) to .10(360)	.6129 .6244 .5613 .6032	
Husking	1.10(30) to 4.10(30) 1.10(360) to 4.10(360)	.6129 .6195 .5613 .5668	

Separation	2.5(30) to 5.5(30) 2.5(360)to5.5(360)	.6129 .6153 .5613 .5633	μ_8=1.03 $\mu_9 = 1.03$ $\mu_{10} = .51$

Table IIIVariation in the data of failure rates of the subsystem .The value inside the bract's denotes days

Subsystem	Variation In Failure Rate .(Repair Rate)	Availability	Transition Rates
Elevator	.005 .010 .029 .119	.6644 .6401 .6644 .6777	$\square_2 = .0003$ $\square_3 = .023$ $\square_4 = .056$ $\square_5 = .006$ $\square_6 = 1.004$ $\square_7 = .001$ $\square_8 = 1.002$ $\square_9 = 1.005$ $\square_{10} = .00045$ $\mu_2 = 1.9$ $\mu_3 = 1.007$ $\mu_4 = 1.5$ $\mu_5 = 1.90$ $\mu_6 = 2.05$ $\mu_7 = 1.9$ μ_8=1.09 $\mu_9 = 1.56$ $\mu_{10} = .92$
Polishing	.003 .018 .011 .101	.6644 .5105 .6644 .7686	
Husking	.052 .082 1.10 4.10	.6644 .7686 .6644 .6685	
Separation	.057 .147 2.5 5.5	.6644 .6592 .6644 .6639	

Table IVVariation in the data of failure and repair rates of some important subsystem when both rates are constant.