AVAILABILITY ANALYSIS OF A PART OF RUBBER TUBE PRODUCTION SYSTEM UNDER PREEMPTIVE RESUME PRIORITY REPAIR

Atul Goyal[1], S.K. Sharma[2], Pardeep Gupta[3]

[1]Department of Mechanical Engineering, Lala Lajpat Rai Institute of Engineering & Technology, Moga - 142001, India (coolatul3@rediffmail.com)
[2]Department of Mechanical Engineering, National Institute of Technology, Kurukshetra - 136119, India (sknitk@rediffmail.com)
[3]Department of Mechanical Engineering, Sant Longowal Institute of Engineering & Technology, Sangrur-148106, India (pardeepmech@yahoo.co.in)

Abstract - A mathematical model of the gradually deteriorating Rubber Preparation System, a part of a cycle rubber tube manufacturing plant is presented in this paper for improving its availability. The methodology for determining the availability of the system under preemptive resume priority repair discipline is based on Markov Modeling. The system undergoes for preventive maintenance (PM) and corrective maintenance (CM) on its transition to pending-to-failed and failed states respectively. The effect of repair error in preventive maintenance on most vulnerable items of the system is examined to realize the highest level of performance. The failure and repair rates of the different subcomponents of the system are taken as constant. Probability considerations at various stages of the system give differential equations which are solved using Laplace Transform to obtain the state probabilities. Performance analysis of the system has been carried out which helped in identifying the critical factors and assessing their impact on the system availability.

Significance – Performance analysis of a practical system is conducted in the paper with the purpose to improve its operational availability. The analysis helped in identifying the key factors and there exists good scope to improve the system availability by controlling the contributing factors. The improvement in the availability of the system is possible up to 4.16%. It is also explored that the PM of the production system must be done on reaching degraded state to enhance its availability. It is further highlighted that the availability of the system will be more in case ideal PM is carried out as compared to faulty PM.

Keywords - Preventive maintenance, productivity, availability, reliability, priority

(Received: 28 October 2008; Accepted in revised form: 17 June 2009)

1. INTRODUCTION

Maintenance actions are generally of two types: Corrective Maintenance (CM) and Preventive Maintenance (PM). The quality of maintenance actions in both CM and PM is an emerging area of research and is also vitally important when maintenance policies are being developed in practice. PM can be either perfect or imperfect and the study of their impact on the performance of the manufacturing systems after maintenance action is very important. A perfect PM is assumed to restore the equipment to be as good as new while imperfect PM brings the system to failed state. There always exist priorities to repair different failed items when limited repair facilities are available. When a lower priority item is under repair and an item of higher priority breaks down, the lower priority unit is preempted and higher priority unit is attended first for the repair. After the completion of its repair the preempted unit is repaired from the point it was interrupted. This is known as preemptive resume priority repair discipline [ref. 1, 2 & 5].

The three states of the practical system are taken into account by introducing one pending-to-failed state along with two other good and failed states. The system components exhibit two types of failures – revealed and unrevealed. The revealed failures bring the components from good state or pending-to-failed state to failed state while the unrevealed failures bring the components from good state to pending-to-failed state. The PM and CM are performed on transition to pending-to-failed and failed states of the components of the system.

Reliability/availability/maintainability analyses of production systems pertaining to process industries have assumed ever-increasing importance in the recent past. This can benefit the industry in terms of higher productivity and lower maintenance costs. Singh I.P. [1] considered a parallel and redundant complex system having preemptive repair discipline in which lower priority item joins the repair only when all units of higher priority under service or waiting for service have been served. Singh I.P. [2] studied complex system under preemptive repeat priority repair discipline and obtained results exhibiting the working of the system. Islamov [3] proposed a general method for determining the reliability of multiple repairable systems. The kolmogorov equations with a large number of differential equations are transformed into integral differential equations to obtain solutions. Microelsen [4] has described the status of the use of reliability technology in the process industry in present time and how to proceed for future. Gupta et al [5] applied Markov based methodology to study the long-run availability of repairable mechanical duplex casting system under priority repair. Gupta et al [6] derived some interesting reliability characteristics and obtained optimum number of maintainers to maintain 14 spinning cells of a 7-Out -of-14: G chemical system. Gupta et al [7] further studied availability model of gradually deteriorating carded sliver production system under faulty and perfect PM for improving its availability. Dyer [8] focused to improve reliability/availability/repairability for Markov Systems. Tsai et al [9] presented a method to study the effect of three types of PM actions – mechanical service, repair and replacement on availability of a multi-component system. In the recent past quite a good number of studies have been carried and several methods have been proposed for reliability analysis of industrial systems under preventive/predictive maintenance which can benefit the industry in a number of ways.

In this paper a subsystem of the plant which is a continuous production system is considered and the availability analysis of the system under preemptive resume priority repair is carried out. A cycle rubber tube production plant situated in Ludhiana, India is chosen for study. Laplace transform is used for solving differential equations to obtain state probabilities. Numerical results based upon the true data collected from industry are presented to illustrate the steady state behavior of the system under different plant conditions. The results obtained are very informative and can also help in improving the performance of the system.

2. SYSTEM DESCRIPTION

The process flow diagram presenting the process of the rubber preparation multiple component system is shown in Fig. -1. The system is an automatic continuous production system. Two banburies (B_1, B_2) of capacity 240 kg each working in parallel are used for the mixing of raw rubber with additives, oils, various fillers and activators. This subsystem can work with one item in reduced capacity if one of the two banburies comes under PM/CM. After proper mixing of the raw ingredients and attaining temperature of 160^0C, the master batch of the rubber goes to mixing mill (M) through a hopper. The function of the mixing mill is to produce rubber sheets of 10 to 12 mm thickness from the rubber mixture. This mixing mill is located below the banbury section. In this mill the rubber mixture is forced to pass through blades for sheet formation. The accumulating mill (A) serves the purpose of accumulating the rubber sheets coming out from the mixing mill to vacate it for next batch. The process flow diagram representing the working of the system under study is shown in Figure-1.

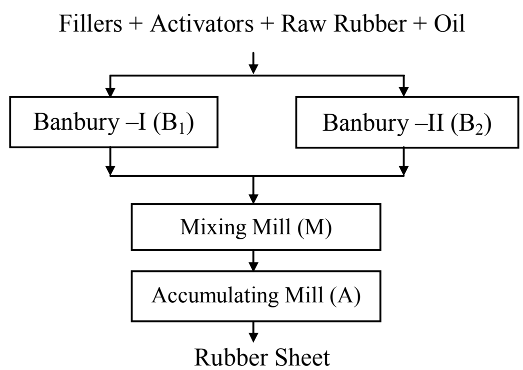

Figure 1. Process Flow Diagram

3. NOTATIONS AND ASSUMPTIONS

3.1 Notations

Subsystem B: Consists of two identical banburies (B_i , i =1,2) subjected to both revealed and unrevealed failures.
Subsystem M: Mixing Mill is subjected to both revealed and unrevealed failures.
Subsystem A: Accumulating Mill is subjected to both revealed and unrevealed failures.
Superscript ‘o’: the subsystem is operative
Superscript ‘g’: the subsystem is good but not operative.
Superscript ‘r’: the subsystem is under repair.
Superscript ‘qr’: the subsystem is queuing for repair.
Superscript ‘m’: the subsystem is under PM
Superscript ‘qm’: the subsystem is queuing for PM.

α, β, γ :constant transition rates causing the subsystems B, M & A respectively to go from normal state to degraded state.

b : constant probability that PM is carried out unsatisfactorily and this leads the system to failed state immediately thereafter.

(1-b) : constant probability that PM is carried out satisfactorily and this makes the system operate immediately thereafter.

ϕ, η, ξ : refer the respective PM rate of a banbury, mixing mill and accumulating mill.

λ_i : refer respective failure rates of B_1, B_2, A & M (i=1,2, 3, 4).

μ_i : refer respective repair rates of B_1, B_2, A & M (i=1,2, 3, 4).

$P_i(t)$: state probability that the system is in i^{th} state at time t.

s : Laplace transform variable
Dash (') : represent derivatives w.r.t. 't'

3.2 Assumptions

1. All the units are initially operating and are in good state.
2. Each unit has three states viz. good, pending-to-be-failed and failed.
3. Each unit is as good as new after repair.
4. Failure and repair events are statistically independent.
5. The failure, repair and preventive maintenance rates are taken as constant.
6. The plant employs a single maintenance team to handle both PM and CM. The repair is performed on priority basis if the failed items are more. Both M & A are the first priority items for the repair purpose. The unit B_1 and B_2 are second priority items for CM purpose. If B_i is under PM and thereafter B_{3-i} comes under failed state, PM of B_i will be completed first before the initiation of repair of B_{3-i} ($i = 1,2$).
7. At a time preventive maintenance of only one of the subsystem is performed.
8. If any unit of the system will be under repair, preventive maintenance of the other units will not be initiated.

The state transition diagram shown in Fig. 2 is derived using the above notations and assumptions

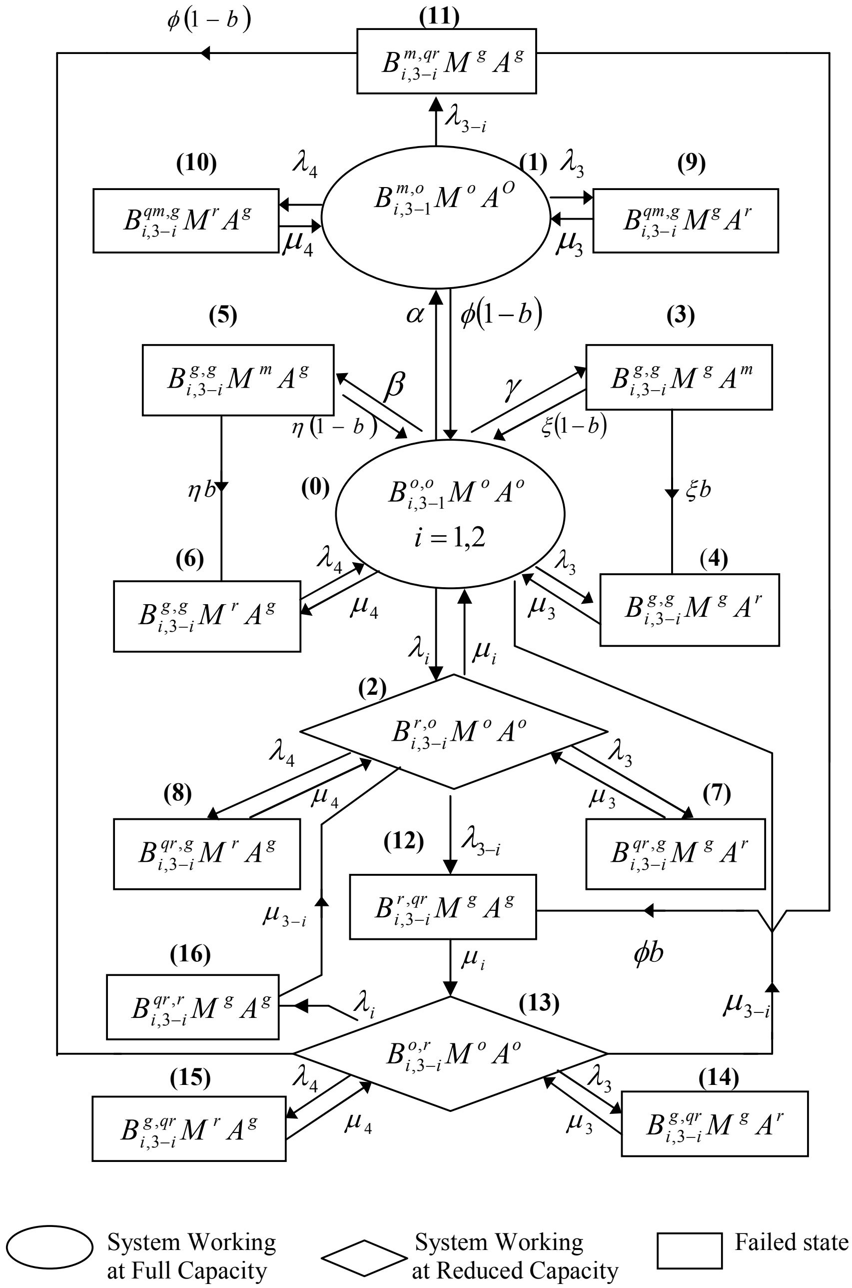

Figure 2. State Transition Diagram

4. MATHEMATICAL ANALYSIS OF THE SYSTEM

Probability consideration gives the following first order differential equations associated with the state transition diagram.

$$P_0'(t)+T_0P_0(t)=\mu_iP_2(t)+\phi(1-b)P_1(t)+\xi(1-b)P_3(t)+\mu_3P_4(t)+\eta(1-b)P_5(t)+\mu_4P_6(t)+\mu_{3-i}P_{13}(t)$$

Where $T_0=\alpha+\beta+\gamma+\lambda_i+\lambda_3+\lambda_4$ … 1

$$P_1'(t)+T_1P_1(t)=\alpha P_0(t)+\mu_3P_9(t)+\mu_4P_{10}(t)$$

Where $T_1=\phi+\lambda_{3-i}+\lambda_3+\lambda_4$ … 2

$$P_2'(t)+T_2P_2(t)=\lambda_iP_0(t)+\phi bP_1(t)+\mu_3P_7(t)+\mu_4P_8(t)+\mu_{3-i}P_{16}(t)$$

Where $T_2=\mu_i+\lambda_{3-i}+\lambda_3+\lambda_4$ … 3

$$P_3'(t)+\xi P_3(t)=\gamma_iP_0(t) \quad \ldots 4$$

$$P_9'(t)+\mu_3P_9(t)=\lambda_3P_1(t)\; P_4'(t)+\mu_3P_4(t)=\lambda_3P_0(t)+b\xi P_3(t) \quad \ldots 5$$

$$P_5'(t)+\eta P_5(t)=\beta P_0(t) \quad \ldots 6$$

$$P_6'(t)+\mu_4P_6(t)=\lambda_4P_0(t)+b\eta P_5(t) \quad \ldots 7$$

$$P_7'(t)+\mu_3P_7(t)=\lambda_3P_2(t) \quad \ldots 8$$

$$P_8'(t)+\mu_4P_8(t)=\lambda_4P_2(t) \quad \ldots 9$$

$$P_9'(t)+\mu_3P_9(t)=\lambda_3P_1(t) \quad \ldots 10$$

$$P_{10}'(t)+\mu_4P_{10}(t)=\lambda_4P_1(t) \quad \ldots 11$$

$$P_{11}'(t)+\phi P_{11}(t)=\lambda_{3-i}P_1(t) \quad \ldots 12$$

$$P_{12}'(t)+\mu_iP_{12}(t)=\lambda_{3-i}P_2(t)+b\phi P_{11}(t) \quad \ldots 13$$

$$P_{13}'(t)+T_3P_{13}(t)=\phi(1-b)P_{11}(t)+\mu_iP_{12}(t)+\mu_3P_{14}(t)+\mu_4P_{15}(t)$$

Where $T_3=\mu_{3-i}+\lambda_i+\lambda_3+\lambda_4$ … 14

$$P_{14}'(t)+\mu_3P_{14}(t)=\lambda_3P_{13}(t) \quad \ldots 15$$

$$P_{15}'(t)+\mu_4P_{15}(t)=\lambda_4P_{13}(t) \quad \ldots 16$$

$$P_{16}'(t)+\mu_{3-i}P_{16}(t)=\lambda_iP_{13}(t) \quad \ldots 17$$

$i=1,2$

With initial conditions at time t = 0:

$P_i(0)=1$ When $i=0$; $P_i(0)=0$ When $i\neq 0$

Taking Laplace transform of above equations, the probability transforms are:

$$P_0(s)=\frac{1}{A_4-\mu_iK_2} \quad \ldots 18$$

$$P_i(s)=K_iP_0(s) \quad \text{For } i=1 \text{ to } 16 \quad \ldots 19$$

Where

$$K_1=\frac{\alpha}{A_2} \qquad K_2=\frac{M_3}{A_3} \qquad K_3=\frac{\gamma}{s+\xi}$$

$$K_4=\frac{\lambda_3+b\xi K_3}{s+\mu_3} \qquad K_5=\frac{\beta}{s+\eta} \qquad K_6=\frac{\lambda_4+b\eta K_5}{s+\mu_4}$$

$K_{4+l}=C_lK_2$ *For* $l=3,4$

$$K_{6+l} = C_l K_1 \quad For\ l = 3,4$$

$$K_{11} = M_1 K_1 \qquad K_{12} = \frac{\lambda_{3-i} K_2 + b\phi M_1 K_1}{s + \mu_i}$$

$$K_{13} = \frac{\phi(1-b)M_1 K_1}{A_1} + \frac{\mu_i K_{12}}{A_1}$$

$$K_{11+l} = C_l K_{13} \ \ For\ l = 3,4 \qquad K_{16} = M_2 K_{13}$$

$$A_1 = s + T_3 - \mu_3 C_3 - \mu_4 C_4$$

$$A_2 = s + T_1 - \mu_3 C_3 - \mu_4 C_4$$

$$A_3 = s + T_2 - \mu_3 C_3 - \mu_4 C_4 - \mu_{3-i} M_2 \frac{\mu_i \lambda_{3-i}}{A_1(s + \mu_i)}$$

$$A_4 = s + T_0 - \phi(1-b)K_1 - \xi(1-b)K_3 - \mu_3 K_4 - \eta(1-B)K_5 - \mu_4 K_6 - \mu_{3-i} K_{13}$$

$$C_3 = \frac{\lambda_3}{s + \mu_3},\ C_4 = \frac{\lambda_4}{s + \mu_4},\ M_1 = \frac{\lambda_{3-i}}{s + \phi},\ M_2 = \frac{\lambda_i}{s + \mu_{3-i}}$$

$$M_3 = \lambda_i + \mu_{3-i} M_2 \frac{\mu_i b\phi M_1 K_1}{A_1(s + \mu_i)} + \mu_{3-i} M_2 \phi(1-b)\frac{M_1 K_1}{A_1} + b\phi K_1$$

Laplace transform of the Availability Function $A(t)$ for the system is obtained as:

$$A(s) = (1 + K_1 + K_2 + K_{13})P_0(s) \qquad \ldots \qquad 20$$

Where $P_0(s)$ is given by equation-18

Inversion of $A(s)$ gives the availability function $A(t)$

4.1 Steady State Availability of the system

When $t \to \infty$, $d/dt \to 0$ and $\partial/\partial t \to 0$ the state probabilities are:

$$P_0 = \frac{1}{B_4 - \mu_i G_2} \qquad \ldots \qquad 21$$

$$P_i = G_i P_0 \ \text{For}\ i = 1 \text{ to } 16 \qquad \ldots \qquad 22$$

Where $G_1 = \frac{\alpha}{B_2} \qquad G_2 = \frac{N_3}{B_3} \qquad G_3 = \frac{\gamma}{\xi}$

$$G_4 = \frac{\lambda_3 + b\xi G_3}{\mu_3} \qquad G_5 = \frac{\beta}{\eta} \qquad G_6 = \frac{\lambda_4 + b\eta G_5}{\mu_4}$$

$$G_{4+l} = D_l G_2 \quad For\ l = 3,4$$

$$G_{6+l} = D_l G_1 \quad For\ l = 3,4$$

$$G_{11} = N_1 G_1$$

$$G_{12} = \frac{\lambda_{3-i} G_2 + b\phi N_1 G_1}{\mu_i}$$

$$G_{13} = \frac{\phi(1-b)N_1 G_1}{B_1} + \frac{\mu_i G_{12}}{B_1}$$

$$G_{11+l} = D_l G_{13} \quad For\ l = 3,4$$

$$G_{16} = N_2 G_{13}$$

$$B_1 = T_3 - \mu_3 D_3 - \mu_4 D_4$$

$$B_2 = T_1 - \mu_3 D_3 - \mu_4 D_4$$

$$B_3 = T_2 - \mu_3 D_3 - \mu_4 D_4 - \mu_{3-i} N_2 \frac{\lambda_{3-i}}{B_1}$$

$$B_4 = T_0 - \phi(1-b)G_1 - \xi(1-b)G_3 - \mu_3 G_4 \quad - \eta(1-b)G_5 - \mu_4 G_6 - \mu_{3-i} G_{13}$$

$$D_3 = \frac{\lambda_3}{\mu_3} \qquad D_4 = \frac{\lambda_4}{\mu_4}$$

$$N_1 = \frac{\lambda_{3-i}}{\phi} \qquad N_2 = \frac{\lambda_i}{\mu_{3-i}}$$

$$N_3 = \lambda_i + \mu_{3-i} N_2 \frac{b\phi N_1 G_1}{B_1} + \mu_{3-i} N_2 \phi(1-b)\frac{N_1 G_1}{B_1} + b\phi G_1$$

Using normalizing condition $\sum_{i=0}^{16} P_i = 1$, we get

$$P_0 = \left(1 + \sum_{i=1}^{16} G_i\right)^{-1} \qquad \ldots \qquad 23$$

4.2 Expressions of steady state availabilities under different field conditions are obtained as:
The Overall steady state availability of the system running with either full capacity or reduced capacity is given by:

$$\begin{aligned} A_{OC} &= P_0 + P_1 + P_2 + P_{13} \\ &= P_0\left(1 + G_1 + G_2 + G_{13}\right) \\ &= \frac{1 + G_1 + G_2 + G_{13}}{1 + \sum_{i=1}^{16} G_i} \end{aligned} \qquad \ldots \qquad 24$$

The steady state availability of the system running with full capacity is given by:

$$\begin{aligned} A_{FC} &= P_0 + P_1 \\ &= P_0\left(1 + G_1\right) \\ &= \frac{1 + G_1}{1 + \sum_{i=1}^{16} G_i} \end{aligned} \qquad \ldots \qquad 25$$

4.3 Numerical results
The Overall steady state availability of the system in case perfect preventive maintenance is performed (A_I) taking $\lambda_1 = \lambda_2 = 0.02$, $\lambda_3 = 0.015$, $\lambda_4 = 0.01$, $\alpha = 0.25$, $\beta = 0.02$, $\gamma = 0.01$, $\phi = 0.16$, $\xi = 0.02$, $\eta = 0.1$, $\mu_1 = \mu_2 = 0.125$, $\mu_3 = 0.2$, and $\mu_4 = 0.25$ is evaluated as (Here b = 0):

$$\begin{aligned} A_I &= P_0 + P_1 + P_2 + P_{13} \\ &= P_0\left(1 + G_1 + G_2 + G_{13}\right) = \mathbf{0.7752} \end{aligned}$$

The Overall steady state availability of the system in case imperfect preventive maintenance is performed (A_F) is evaluated as (Here b = 1):

$$\begin{aligned} A_F &= P_0 + P_1 + P_2 + P_{13} \\ &= P_0\left(1 + G_1 + G_2 + G_{13}\right) = \mathbf{0.7345} \end{aligned}$$

4.4 Availability analysis
The effect of failure/repair rates of different units comprising the system on its availability (under perfect PM - A_I) is studied and the results are shown as following:

4.4.1 Effect of failure rate of a banbury on availability A_I:

Taking $\lambda_2 = 0.02$, $\lambda_3 = 0.015$, $\lambda_4 = 0.01$, $\alpha = 0.25$, $\beta = 0.02$, $\gamma = 0.01$, $\phi = 0.16$, $\xi = 0.02$, $\eta = 0.1$, $\mu_1 = \mu_2 = 0.125$, $\mu_3 = 0.2$, and $\mu_4 = 0.25$.

Table 1. Steady state availability under ideal & faulty PM vs. failure rate of a banbury

λ_1	0.02	0.04	0.06	0.08
A_I	0.7752	0.7236	0.6736	0.6270
A_F	0.7345	0.6594	0.6004	0.5523

4.4.2 Effect of failure rate of an accumulating mill on availability A_I:

Taking $\lambda_1 = \lambda_2 = 0.02$, $\lambda_4 = 0.01$, $\alpha = 0.25$, $\beta = 0.02$, $\gamma = 0.01$, $\phi = 0.16$, $\xi = 0.02$, $\eta = 0.1$, $\mu_1 = \mu_2 = 0.125$, $\mu_3 = 0.2$, and $\mu_4 = 0.25$

Table 2. Steady state availability under ideal PM vs. failure rate of an accumulating mill

λ_3	0.015	0.03	0.06	0.12
A_I	0.7752	0.7326	0.6601	0.5510

4.4.3 Effect of failure rate of mixing mill on availability A_I:

Taking $\lambda_1 = \lambda_2 = 0.02$, $\lambda_3 = 0.015$, $\alpha = 0.25$, $\beta = 0.02$, $\gamma = 0.01$, $\phi = 0.16$, $\xi = 0.02$, $\eta = 0.1$, $\mu_1 = \mu_2 = 0.125$, $\mu_3 = 0.2$, and $\mu_4 = 0.25$.

Table 3. Steady state availability under ideal PM vs. failure rate of mixing mill

λ_4	0.01	0.02	0.04	0.08
A_I	0.7752	0.7519	0.7093	0.6370

4.4.4 Effect of corrective repair rate of a banbury on availability A_I:

Taking $\lambda_1 = \lambda_2 = 0.02$, $\lambda_3 = 0.015$, $\lambda_4 = 0.01$, $\alpha = 0.25$, $\beta = 0.02$, $\gamma = 0.01$, $\xi = 0.02$, $\phi = 0.16$, $\eta = 0.1$, $\mu_2 = 0.125$, and $\mu_4 = 0.25$

Table 4. Steady state availability under ideal PM vs. repair rate of a banbury

μ_1	0.125	0.150	0.175	0.200
A_I	0.7752	0.7769	0.7777	0.7780

4.4.5 Effect of corrective repair rate of an accumulating mill on availability A_I:

Taking $\lambda_1 = \lambda_2 = 0.02$, $\lambda_3 = 0.015$, $\lambda_4 = 0.01$, $\alpha = 0.25$, $\beta = 0.02$, $\gamma = 0.01$, $\xi = 0.02$, $\phi = 0.16$, $\eta = 0.1$, $\mu_1 = \mu_2 = 0.125$, and $\mu_4 = 0.25$.

Table 5. Steady state availability under ideal PM vs. repair rate of an accumulating mill

μ_3	0.2	0.4	0.8	1.6
A_I	0.7752	0.7984	0.8106	0.8168

4.4.6 Effect of corrective repair rate of mixing mill on availability A_I:

Taking $\lambda_1 = \lambda_2 = 0.02$, $\lambda_3 = 0.015$, $\lambda_4 = 0.01$, $\alpha = 0.25$, $\beta = 0.02$, $\gamma = 0.01$, $\xi = 0.02$, $\phi = 0.16$, $\eta = 0.1$, $\mu_1 = \mu_2 = 0.125$, and $\mu_3 = 0.02$

Table 6. Steady state availability under ideal PM vs. repair rate of mixing mill

μ_4	0.25	0.50	1.0	2.0
A_I	0.7752	0.7874	0.7937	0.7969

4.4.7 Effect of preventive maintenance rate of a banbury on availability (A_I & A_F):

Taking $\lambda_1 = \lambda_2 = 0.02$, $\lambda_3 = 0.015$, $\lambda_4 = 0.01$, $\alpha = 0.25$, $\beta = 0.02$, $\gamma = 0.01$, $\xi = 0.02$, $\eta = 0.1$, $\mu_1 = \mu_2 = 0.125$, $\mu_3 = 0.2$ and $\mu_4 = 0.25$, b = 0 for perfect PM & b = 1 for imperfect PM

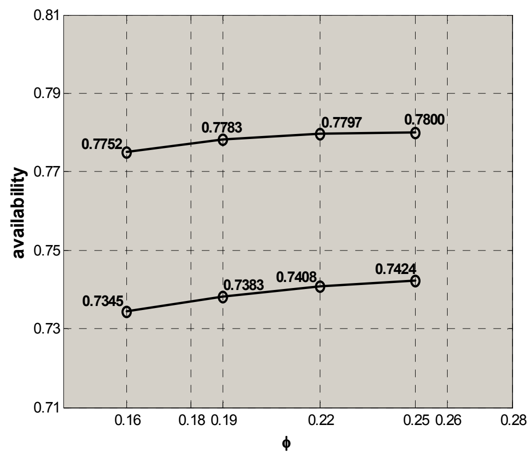

Figure 3. Steady state availability vs. PMR (Preventive Maintenance Rate) of Banbury

4.4.8 Effect of preventive maintenance rate of accumulating mill on availability (A_I & A_F):
Taking $\lambda_1 = \lambda_2 = 0.02$, $\lambda_3 = 0.015$, $\lambda_4 = 0.01$, $\alpha = 0.25$, $\beta = 0.02$, $\gamma = 0.01$, $\phi = 0.16$, $\eta = 0.1$, $\mu_1 = \mu_2 = 0.125$, $\mu_3 = 0.2$, $\mu_4 = 0.25$, b = 0 for perfect PM & b = 1 for imperfect PM

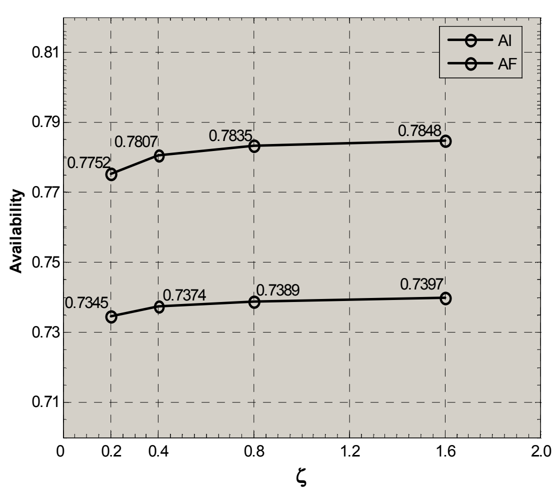

Figure 4. Steady state availability vs. PMR (Preventive maintenance rate) of accumulating mill

4.4.9 Effect of preventive maintenance rate of mixing mill on availability (A_I & A_F):

Taking $\lambda_1 = \lambda_2 = 0.02$, $\lambda_3 = 0.015$, $\lambda_4 = 0.01$, $\alpha = 0.25$, $\beta = 0.02$, $\gamma = 0.01$, $\phi = 0.16$, $\xi = 0.02$, $\mu_1 = \mu_2 = 0.125$, $\mu_3 = 0.2$, $\mu_4 = 0.25$, b = 0 for perfect PM & b = 1 for imperfect PM

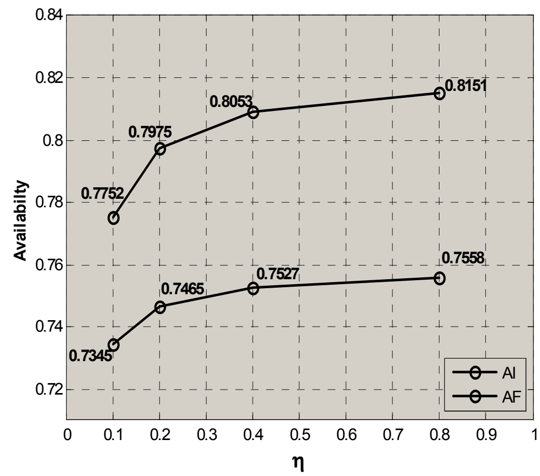

Figure 5. Steady state availability vs. PMR (Preventive maintenance rate) of mixing mill

5. DISCUSSION AND CONCLUSIONS

Expressions to determine the reliability characteristics of the complex Rubber Preparation System are derived. The numerical results (Tables – 1, 2 and 3) highlight that increase in the failure rates of a banbury/ mixing mill/ accumulating mill reduces the availability of the system. The failure rate of the accumulating mill (λ_3) has maximum impact on the availability of the system that can be controlled/reduced using suitable maintenance measures. On the other hand Tables - 4, 5, and 6 demonstrate that improved maintenance or repair rates of the constituent components enhance the availability of the system considerably. The variation in failure rates, repair rates and maintenance rates of the subcomponents of the system affect its availability, which is needed to be controlled. The improvement in the availability of the system is possible up to 4.16% and 2.17% on increasing the repair rate of the accumulating mill and mixing mill from 0.2 to 1.6 and 0.25 to 2.0 repairs per hour respectively (Tables – 5 and 6). Planned and effective maintenance system in the plant makes it possible to improve the repair rates. It is also explored that the availability of 3-state model is higher than 2-state model having same failure and repair rates (Table-1). This governs that PM of the production systems must be done on reaching degraded state to enhance its availability. It is further shown that the availability of the system will be more in case ideal PM is carried out as compared to faulty PM (Figures – 3, 4 & 5). This information proves to be a blueprint to the maintenance management for improving the overall reliability/availability of the system utilizing perfect PM.

6. REFERENCES

[1] Singh I.P., ‘‘A Complex System having Four Types of Components with Preventive Repeat Priority Repairs’’, Micron reliability, 1989, Vol. 29, No. 6, pp. 959-962.
[2] I. P. Singh, ‘‘Preemptive repeat priority repairs and failures of non-failed components during system failure of a complex system’’, Micron reliability, 1991, pp. 216-221.
[3] R.T. Islamov, ‘‘Using Markov Reliability Modeling for Multiple Repairable Systems’’, Reliability engineering and system safety, 1994, pp. 113 - 118
[4] Q. Microelsen, ‘‘Use of Reliability technology in the process industry’’, Reliability engineering and system safety, 1998, pp. 179 - 181
[5] Gupta P., Singh J., and Singh I.P., ‘‘Behavioral Analysis of Duplex Casting System under Preventive Resume Priority Repair Discipline a Case Study’’, Industrial Engineering Journal Vol. XXXIII No.12, December 2004.
[6] P. Gupta, J. Singh, and I. P. Singh, ‘‘Maintenance Planning based on Performance Analysis of 7-out-of-14: G Chemical-system: a Case Study,’’, International Journal of Industrial Engineering, 2005, pp. 264-274.
[7] P. Gupta, A. Gupta, ‘‘Availability improvement of a production system under preventive maintenance’’, Industrial Engineering Journal, India, 2006. Vol. XXXV No.8, pp. 21-26.

[8] D. Dyer, "Unification of Reliability / Availability / Repairability Model for Markov Systems" , *IEEE Transactions on Reliability, 1985, Vol. 38.*
[9] Y. Tsai, K. Wang, L. Tsai, ''A study of availability centered preventive maintenance for multi component system'', Reliability Engineering and System Safety 84 (2004), pp. 261-270.

BIOGRAPHICAL SKETCH

Atul Goyal is a Research Scholar in the Department of Mechanical Engineering, National Institute of Technology, Kurukshetra, India. He obtained his B.Tech. and M.Tech. Degrees from Punjab Technical University, Jalandhar, Punjab, India in 2002 & 2004 respectively. He published about 10 research papers in national/international journals and conferences. His primary research interest is performance improvement, especially the modeling and analysis of operations through reliability engineering.

Dr. S.K.Sharma is presently working as Professor in Mechanical Engineering Department of NIT Kurukshetra, India. He has a rich experience of teaching of about 33 years. Dr. Sharma has already guided 24 M.Tech students and 09 PhD Scholars in various areas of Industrial Engineering and 06 research scholars are presently working with him. Dr. Sharma served various administrative posts; presently he is working as dean estate, Chairman of admission committee and member of board of studies, NIT Kurukshetra. He has published and presented 120-research paper at national and international level.

Dr. Pardeep Gupta is presently working as Professor in Mechanical engineering Department of Sant Longowal Institute of Engineering and Technology (Deemed-to-be-University and established by Government of India), Longowal, Punjab. He joined this institute as Lecturer in February 1991, became Assistant Professor in March 1999 and got promoted to the post of professor in March 2007. He obtained his B.E. and M.E. degrees from PEC, Chandigarh in 1989 & 1997 respectively and PhD. degree form NIT, Kurukshetra in 2004. He guided five Masters in engineering thesis and four research scholars are pursuing PhD. with him. He published about 20 research papers in national/international journals and conferences. He is working in the areas of reliability and quality engineering, CAD/CAM, metal machining and manufacturing engineering. He is also heading the department of training and placement of the institute for the last three years.