Performance Analysis of Paper Packing System Using Markov Modelling

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***Abstract*- Paper finishing system is a subsystem of paper manufacturing plant. The system consists of rewinders, cutters and packing unit, arranged in series parallel combination. The system is analysed for its full availability and reduced availability. A mathematical model based on Markov death birth process is formulated for analysis. The failure and repair rates of the various components 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. Results show that availability of the system improves with increase in repair rates whereas decreases with increase in failure rates. The analysis would certainly be beneficial for the management to design and decide future strategy of production.**

I. INTRODUCTION

Process industries like sugar mill, sugar mill, thermal power plant, fertilizer industry, oil refineries, paper plant, plays an important role in fulfilling our daily requirements. The demand of product quality and system reliability is on an increase day by day. Failure of a system is a random phenomenon. The system or component deteriorates with time and leads to complete failure. This causes the decrease in production and hence decrease in profits. Therefore, maintenance and the availability of the system is a major concern. It is always desirable to have maximum availability of the system considering economic and operational points. [1] [2] [3] .Markov modelling is widely and most accepted used for reliability and availability analysis. The system arrangement may be series, parallel or combination of both. Sharma and Tewari [4], Arora and Kumar [5] carried out an analysis of coal fired power plant was done using Markov modelling. Aksu & Turan [6] presents reliability and availability valuation of pod propulsion system using failure mode and effect analysis, fault tree analysis (FTA) and Markov analysis complementarily. The steady state performance of crushing unit and ash handling unit of steam thermal plant using Markov modelling had been analysed using real time data. Khanduja et al. [7] discussed the reliability, availability and maintenance (RAM) planning of the bleaching system of paper plant. Markov birth-death process was used for transition diagram and mathematical analysis. Umemura & Dohi [8] suggested the embedded Markov Chain approach in continuous-time and discrete-time scales stochastic behaviour of an electronic system to increase its steady-state availability. Sharma and Kumar [9] used RAM analysis on a urea production process plant to minimize system failures, maintainability requirements and optimizing equipment availability. Hassan et al. [10] proposed Markov model for LNG processing plant for availability and PM.

II. SYSTEM DESCRIPTION

The finishing system comprises of three various components-Rewinder, cutters and packing unit. The function of the rewinder is to rewind the reels from one tambour to another tambour. Here, the web run can be changed, from the outer to the inner side, the reel edges may be cut and deficiencies in the paper can be removed. In a cutter, the smaller reels that have been cut to size from tambours by the slitter rewinder are cut to sheets of a specified size. Several reels can be processed simultaneously, depending on the design of the cutter and the "cutting weight" of the paper. The important thing here is to produce sheets with clean cutting edges, in other words, to prevent cutting dust from clinging to the edges, since this would cause problems in the printing process. The paper reels fed into the cutter are trimmed on both edges and separated in longitudinal direction by circular knives. The web is then cut off to the required size by the chopper knife. Finally, the paper is packaged for transport to the customer.

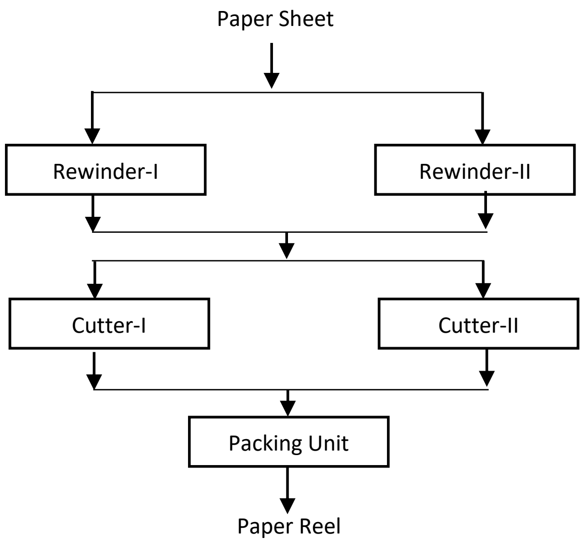

Fig.1 Various components of paper finishing process

The packing is important to avoid transport damages and to provide protection against moisture. Transport methods and means determine the type of packing. Fig. 1 shows the schematic arrangement of the various components of the paper finishing system.

A. Notations

The various notations used in the analysis are as following:-

Superscript 'o': the subsystem is operative
Superscript 'g': the subsystem is good but not operative.
Superscript 'qr' : the subsystem is queuing for repair.
Superscript 'qm': the subsystem is queuing for maintenance.
λ_j : failure rate of subsystem Rewinder. (j=1, 2).
μ_j :repair rate of subsystem Rewinder. (j=1, 2).
λ_k :failure rate of subsystem Cutter. (k=1, 2).
μ_k :repair rate of subsystem Cutter. (k=1, 2).
λ_3 :failure rate of subsystem packing.
μ_3 :repair rate of subsystem packing.
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'.

B. Assumptions

1. All the units are initially operating and are in good state.
2. Each unit has three states viz. good, degraded and failed.
3. Each unit is as good as new after repair.
4. Failure and repair events are statistically independent.
5. There exists only one repair facility to carryout repair in the plant which is done on priority basis, subsystem P is given first priority for repair action.
6. On failure of any one unit of subsystem C, the other unit serves the purpose of cutter and system works in reduced capacity. The system works at full capacity again when failed unit is repaired.
7. On failure of any one unit of subsystem R , the other unit serves the purpose of cutter and system works in reduced capacity. The system works at full capacity again when failed unit is repaired.

II. MATHEMATICAL ANALYSIS OF THE SYSTEM

The system starts from a particular state at time 't' and reaches failed state, PM state or remains in the operative state during the time interval Δt. The mathematical formulation of the model is carried out using first order differential – difference equations associated with the state transition diagram of the system. Various probability considerations give the following differential equations associated with the paper finishing process. These equations are solved for determining the steady state availability of the system. Fig. 2 shows the various transition states of the system .

$$P'_0(t) + Z_0P_0(t) = \mu_3P_1(t) + \mu_kP_2(t) + \mu_jP_3(t) + \mu_{3-j}P_{16}(t) + \mu_{3-k}P_{19}(t) \quad \ldots (1)$$
$$P'_1(t) + \mu_3P_1(t) = \lambda_3P_0(t) \quad \ldots (2)$$
$$P'_2(t) + Z_2P_2(t) = \lambda_kP_0(t) + \mu_3P_{10}(t) + \mu_jP_4(t) \quad \ldots (3)$$
$$P'_3(t) + Z_3P_3(t) = \lambda_kP_0(t) + \mu_3P_5(t) + \mu_kP_{14}(t) \quad \ldots (4)$$
$$P'_4(t) + Z_4P_4(t) = \lambda_kP_3(t) + \mu_3P_9(t) + \mu_{3-k}P_8(t) \quad \ldots (5)$$
$$P'_5(t) + \mu_3P_5(t) = \lambda_3P_3(t) \quad \ldots (6)$$
$$P'_6(t) + \mu_jP_6(t) = \lambda_{3-j}P_3(t) \quad \ldots (7)$$
$$P'_7(t) + \mu_jP_7(t) = \lambda_{3-j}P_4(t) \quad \ldots (8)$$
$$P'_8(t) + \mu_{3-k}P_8(t) = \lambda_{3-k}P_4(t) \quad \ldots (9)$$
$$P'_9(t) + \mu_3P_9(t) = \lambda_3P_4(t) \quad \ldots (10)$$
$$P'_{10}(t) + \mu_3P_{10}(t) = \lambda_3P_2(t) \quad \ldots (11)$$
$$P'_{11}(t) + \mu_kP_{11}(t) = \lambda_{3-k}P_2(t) \quad \ldots (12)$$
$$P'_{12}(t) + \mu_kP_{12}(t) = \lambda_{3-k}P_{14}(t) \quad \ldots (13)$$
$$P'_{13}(t) + \mu_{3-j}P_{13}(t) = \lambda_{3-j}P_{14}(t) \quad \ldots (14)$$
$$P'_{14}(t) + Z_{14}P_4(t) = \lambda_jP_2(t) + \mu_3P_{15}(t) + \mu_{3-j}P_{13}(t) \quad \ldots (15)$$
$$P'_{15}(t) + \mu_3P_{15}(t) = \lambda_3P_{14}(t) \quad \ldots (16)$$
$$P'_{16}(t) + \mu_{3-j}P_{16}(t) = \mu_jP_6(t) + \mu_kP_{17}(t) \quad \ldots (17)$$
$$P'_{17}(t) + \mu_kP_{17}(t) = \mu_jP_7(t) \quad \ldots (18)$$
$$P'_{18}(t) + \mu_jP_{18}(t) = \mu_kP_{12}(t) \quad \ldots (19)$$
$$P'_{19}(t) + \mu_{3-k}P_{19}(t) = \mu_jP_{18}(t) + \mu_kP_{11}(t) \quad \ldots (20)$$

Where,

$Z_0 = \lambda_k + \lambda_j + \lambda_3$
$Z_2 = \mu_k + \lambda_j + \lambda_{3-k} + \lambda_3$
$Z_3 = \mu_j + \lambda_k + \lambda_{3-j} + \lambda_3$
$Z_4 = \mu_j + \lambda_{3-k} + \lambda_{3-j} + \lambda_3$
$Z_{14} = \mu_k + \lambda_{3-k} + \lambda_{3-j} + \lambda_3$

Taking Laplace Transform of above (1-20) equations, we get

$$sP_0(s) + Z_0P_0(t) = 1 + \mu_3P_1(s) + \mu_kP_2(s) + \mu_jP_3(s) + \mu_{3-j}P_{16}(s) + \mu_{3-k}P_{19}(s), \quad \ldots (21)$$
$$sP_1(s) + \mu_3P_1(s) = \lambda_3P_0(s) \quad \ldots (22)$$
$$sP_2(s) + Z_2P_2(s) = \lambda_kP_0(s) + \mu_3P_{10}(s) + \mu_jP_4(s) \quad \ldots (23)$$

$sP_3(s) + Z_3P_3(s) = \lambda_j P_0(s) + \mu_3 P_5(s) + \mu_k P_{14}(s)$ ... (24)

$sP_4(s) + Z_4P_4(s) = \lambda_k P_3(s) + \mu_3 P_9(s) + \mu_{3-k} P_8(s)$ ... (25)

$sP_5(s) + \mu_3 P_5(s) = \lambda_3 P_3(s)$ ... (26)

$sP_6(s) + \mu_j P_6(s) = \lambda_{3-j} P_3(s)$ ... (27)

$sP_7(s) + \mu_j P_7(s) = \lambda_{3-j} P_4(s)$ ... (28)

$sP_8(s) + \mu_{3-k} P_8(s) = \lambda_{3-k} P_4(s)$ ... (29)

$sP_9(s) + \mu_3 P_9(s) = \lambda_3 P_4(s)$ ... (30)

$sP_{10}(s) + \mu_3 P_{10}(s) = \lambda_3 P_2(s)$ ... (31)

$sP_{11}(s) + \mu_k P_{11}(s) = \lambda_{3-k} P_2(s)$ ... (32)

$sP_{12}(s) + \mu_k P_{12}(s) = \lambda_{3-k} P_{14}(s)$ ... (33)

$sP_{13}(s) + \mu_{3-j} P_{13}(s) = \lambda_{3-j} P_{14}(s)$ ... (34)

$sP_{14}(s) + Z_{14}P_4(s) = \lambda_j P_2(s) + \mu_3 P_{15}(s) + \mu_{3-j} P_{13}(s)$ ... (35)

$sP_{15}(s) + \mu_3 P_{15}(s) = \lambda_3 P_{14}(s)$ ... (36)

$sP_{16}(s) + \mu_{3-j} P_{16}(s) = \mu_j P_6(t) + \mu_k P_{17}(s)$ ... (37)

$sP_{17}(s) + \mu_k P_{17}(s) = \mu_j P_7(s)$ ... (38)

$sP_{18}(s) + \mu_j P_{18}(s) = \mu_k P_{12}(s)$ ... (39)

$sP_{19}(s) + \mu_{3-k} P_{19}(s) = \mu_j P_{18}(s) + \mu_k P_{11}(s)$ ... (40)

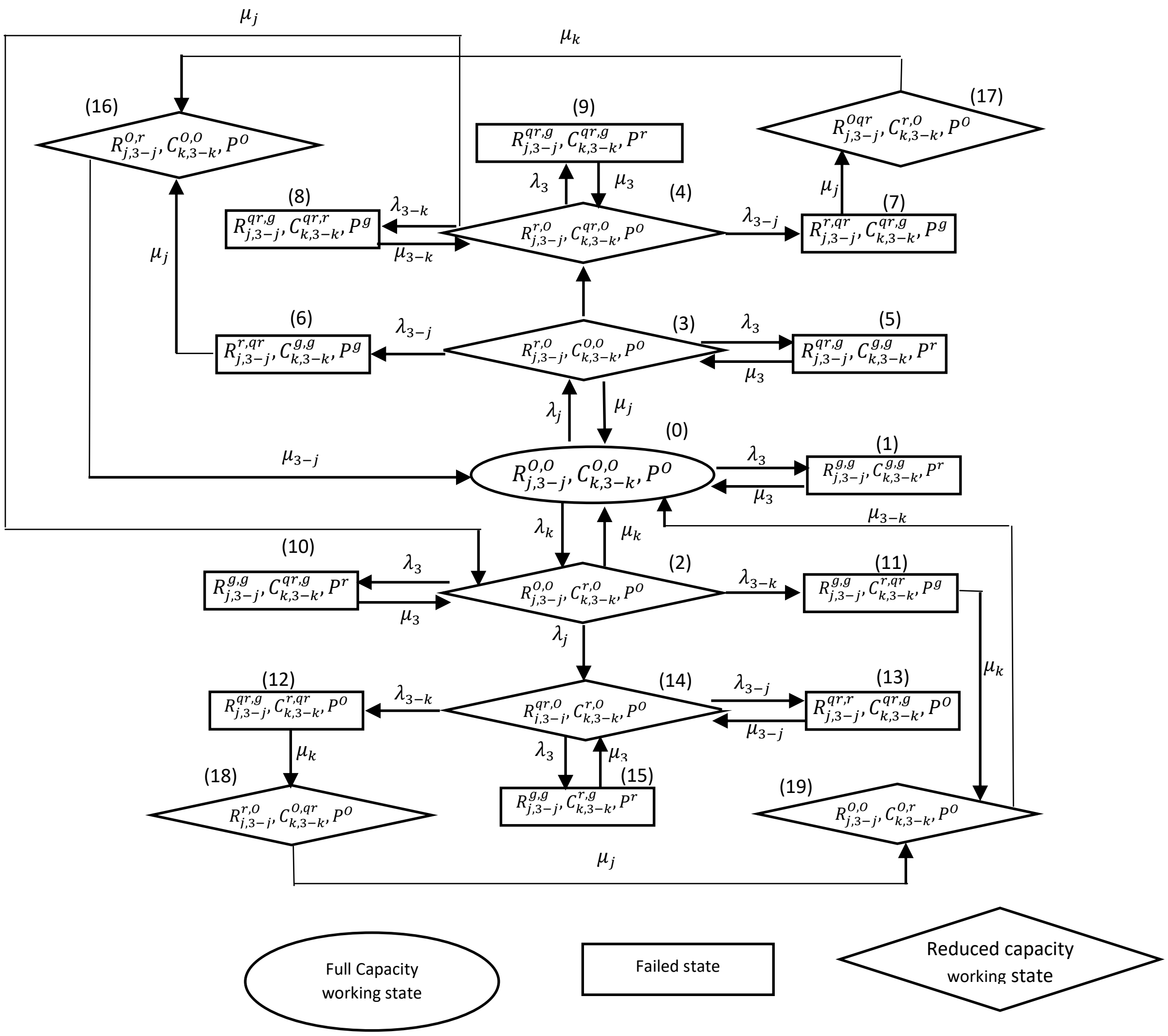

Fig. 2 Transition diagram of Paper finishing system

Solving recursively the above equations (21 to 40) we get,

$P_n(s) = K_n P_0$, where n=1,2,3 …….19

$K_1 = \frac{\lambda_3}{s+\mu_3}$ $K_2 = \frac{\mu_j A_4 D_4 + \lambda_k}{D_1}$ $K_3 = D_4$

$K_4 = B_4 K_3$ $K_5 = A_3 K_3$ $K_6 = A_6 K_3$

$K_7 = A_6 A_4 K_3$ $K_8 = A_8 A_4 K_3$ $K_9 = A_3 A_4 K_3$

$K_{10} = A_3 K_2$ $K_{11} = A_{11} K_2$ $K_{12} = A_{11} B_2 K_2$

$K_{13} = A_{13}B_2K_2$ $\quad K_{14} = B_2K_2$ $\quad K_{15} = A_3B_2K_2$

$K_{16} = B_1K_3$ $\quad K_{17} = A_{17}A_6A_4K_3$ $\quad K_{18} = A_{18}A_{11}B_2K_2$

$K_{19} = B_3K_2$

Where,

$A_3 = \frac{\lambda_3}{s+\mu_3}$ $\quad A_4 = \frac{\lambda_k}{s+Z_4-\mu_3A_3-\mu_{3-k}A_8}$

$A_8 = \frac{\lambda_{3-k}}{s+\mu_{3-k}}$ $\quad A_{11} = \frac{\lambda_{3-k}}{s+\mu_k}$ $\quad A_{13} = \frac{\lambda_{3-j}}{s+\mu_{3-j}}$

$A_{17} = \frac{\mu_j}{s+\mu_k}$ $\quad A_{18} = \frac{\mu_k}{s+\mu_j}$ $\quad B_1 = \frac{\mu_jA_6+\mu_kA_{17}A_6A_4}{s+\mu_{3-j}}$

$B_2 = \frac{\lambda_j}{s+Z_{14}-\mu_3A_3-\mu_{3-j}A_{13}}$ $\quad B_3 = \frac{\mu_jA_{18}A_{11}B_2+\mu_kA_{11}}{s+\mu_{3-k}}$

$B_4 = \frac{\lambda_k+\mu_3A_3A_4+\mu_{3-k}A_8A_4}{s+Z_4}$ $\quad D_1 = s+Z_2-\mu_3A_3$

$D_2 = \mu_kB_2\lambda_k + D_1\lambda_j$ $\quad D_3 = D_1D_5 - \mu_j\mu_kB_2A_4$

$D_4 = \frac{D_2}{D_3}$ $\quad D_5 = s+Z_3-\mu_3A_3$

Full Availability function A_{OC} (t) for the system is given as,

$A_{FC}(s) = P_0(s)$,

Inversion of $A_{FC}(s)$ gives the full availability function A(t)

Reduced Availability function A_{RC} (t) for the system is given as,

$A_{RC}(s) = P_0(s) + P_2(s) + P_3(s) + P_4(s) + P_{14}(s) + P_{16}(s) + P_{17}(s) + P_{18}(s) + P_{19}(s)$,

OR

$A_{RC}(s) = P_0(s)(1 + K_2 + K_3 + K_4 + K_{14} + K_{16} + K_{17} + K_{18} + K_{19})$

Inversion of $A_{RC}(s)$ gives the reduced availability function A(t)

$Z_0P_0 = 1 + \mu_3P_1 + \mu_kP_2 + \mu_jP_3 + \mu_{3-j}P_{16} + \mu_{3-k}P_{19}$, …(41)

$\mu_3P_1 = \lambda_3P_0$ … (42)

$Z_2P_2 = \lambda_kP_0 + \mu_3P_{10} + \mu_jP_4$ … (43)

$Z_3P_3 = \lambda_jP_0 + \mu_3P_5 + \mu_kP_{14}$ … (44)

$Z_4P_4 = \lambda_kP_3 + \mu_3P_9 + \mu_{3-k}P_8$ … (45)

$\mu_3P_5 = \lambda_3P_3$ … (46)

$\mu_jP_6 = \lambda_{3-j}P_3$ … (47)

$\mu_jP_7 = \lambda_{3-j}P_4$ … (48)

$\mu_{3-k}P_8 = \lambda_{3-k}P_4$ … (49)

$\mu_3P_9 = \lambda_3P_4$ … (50)

$\mu_3P_{10} = \lambda_3P_2$ … (51)

$\mu_kP_{11} = \lambda_{3-k}P_2$ … (52)

$\mu_kP_{12} = \lambda_{3-k}P_{14}$ … (53)

$\mu_{3-j}P_{13} = \lambda_{3-j}P_{14}$ … (54)

$Z_{14}P_4 = \lambda_jP_2 + \mu_3P_{15} + \mu_{3-j}P_{13}$ … (55)

$\mu_3P_{15} = \lambda_3P_{14}$ … (56)

$\mu_{3-j}P_{16} = \mu_jP_6 + \mu_kP_{17}$ … (57)

$\mu_kP_{17} = \mu_jP_7$ … (58)

$\mu_jP_{18} = \mu_kP_{12}$ … (59)

$\mu_{3-k}P_{19} = \mu_jP_{18} + \mu_kP_{11}$ … (60)

Solving recursively the equations 42 to 60, we get

$P_n(s) = R_tP_0$, where t=1, 2, 3 …….19

$R_1 = \frac{\lambda_3}{\mu_3}$ $\quad R_2 = \frac{\mu_jF_4H_4+\lambda_k}{D_1}$ $\quad R_3 = H_4$ $\quad R_4 = G_4R_3$

$R_5 = F_3R_3$ $\quad R_6 = F_6R_3$ $\quad R_7 = F_6F_4R_3$ $\quad R_8 = F_8F_4R_3$

$R_9 = F_3F_4R_3$ $\quad R_{10} = F_3R_2$ $\quad R_{11} = F_{11}R_2$

$R_{12} = F_{11}G_2R_2$ $\quad R_{13} = F_{13}G_2R_2$ $\quad R_{14} = G_2R_2$

$R_{15} = F_3G_2R_2$ $\quad R_{16} = B_1R_3$ $\quad R_{17} = F_{17}F_6F_4R_3$

$R_{18} = F_{18}F_{11}G_2R_2$ $\quad R_{19} = G_3R_2$

Where,

$F_3 = \frac{\lambda_3}{\mu_3}$ $\quad F_4 = \frac{\lambda_k}{Z_4-\mu_3F_3-\mu_{3-k}F_8}$ $\quad F_8 = \frac{\lambda_{3-k}}{\mu_{3-k}}$

$F_{11} = \frac{\lambda_{3-k}}{\mu_k}$ $\quad F_{13} = \frac{\lambda_{3-j}}{\mu_{3-j}}$ $\quad F_{17} = \frac{\mu_j}{\mu_k}$

$F_{18} = \frac{\mu_k}{\mu_j}$

$G_1 = \frac{\mu_jF_6+\mu_kF_{17}F_6F_4}{\mu_{3-j}}$ $\quad G_2 = \frac{\lambda_j}{Z_{14}-\mu_3F_3-\mu_{3-j}F_{13}}$ $\quad G_3 = \frac{\mu_jF_{18}F_{11}G_2+\mu_kF_{11}}{\mu_{3-k}}$ $\quad G_4 = \frac{\lambda_k+\mu_3F_3F_4+\mu_{3-k}F_8F_4}{Z_4}$

$H_1 = Z_2 - \mu_3F_3$ $\quad H_2 = \mu_kG_2\lambda_k + H_1\lambda_j$

$H_3 = H_1H_5 - \mu_j\mu_kG_2F_4$ $\quad H_4 = \frac{H_2}{H_3}$ $\quad H_5 = Z_3-\mu_3F_3$

Using normalizing condition,

$\sum_{i=1}^{19} P_t = 1, we\ get$ … (61)

$P_0 = (1 + \sum_{t=1}^{19} P_t)^{-1}$ … (62)

$A_{FC} = P_0$ … (63)

$A_{RC} = P_0(1 + R_2 + R_3 + R_4 + R_{14} + R_{16} + R_{17} + R_{18} + R_{19})$ … (64)

TABLE I Values of repair rate and failure rate of different components

$\lambda_j = \lambda_{3-j}$	0.02	$\mu_j = \mu_{3-j}$	0.13
$\lambda_k = \lambda_{3-k}$	0.03	$\mu_k = \mu_{3-k}$	0.2
λ_3	0.01	μ_3	0.25

Solving equations 61-64 we get, A_{FC} =0.6868, A_{RC} =0.9235

III. AVAILABILITY ANALYSIS

The effect of failure and repair rates of different units comprising the finishing system on its availability is studied using markov modelling. The outcome of analysis has been shown below:-

(a) Effect of increasing failure rate of Rewinder:-
Taking $\lambda_k = \lambda_{3-k}$ =0.03, λ_3 =0.001, $\mu_j = \mu_{3-j}$ =0.13, $\mu_k = \mu_{3-k}$ =0.2, μ_3 =0.25 and varying the value of $\lambda_j = \lambda_{3-j}$ from 0.02 to 0.06, A_{FC} and A_{RC} has been evaluated and the variation shown in Fig. 3.

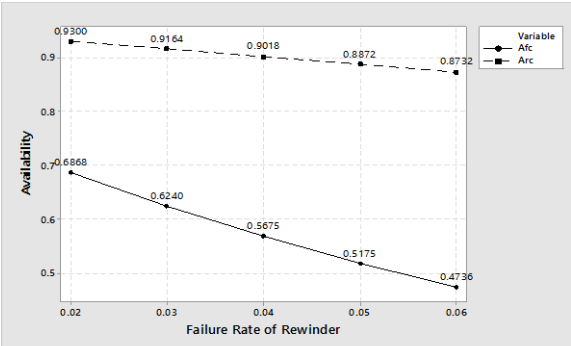

Fig. 2 Variation of A_{FC} and A_{RC} with increasing failure rate of Rewinder

(b) Effect of increasing failure rate of Cutter:-
Taking $\lambda_k = \lambda_{3\text{-}k} = 0.03$, $\lambda_3 = 0.001$, $\mu_j = \mu_{3\text{-}j} = 0.13$, $\mu_k = \mu_{3\text{-}k} = 0.2$, $\mu_3 = 0.25$ and varying the value of $\lambda_j = \lambda_{3\text{-}j}$ from 0.03 to 0.07, A_{FC} and A_{RC} has been evaluated and the variation shown in Fig. 4.

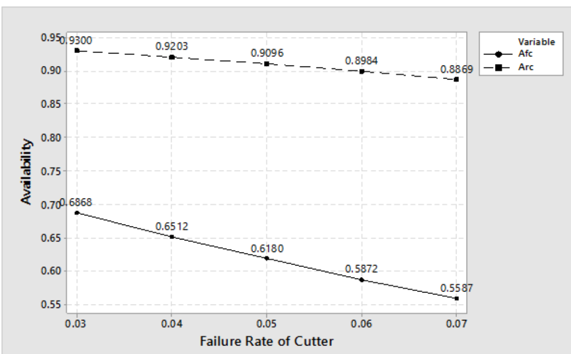

Fig 4 Variation of A_{FC} and A_{RC} with increasing failure rate of Cutter

(c) Effect of increasing failure rate of Packing:-
Taking $\lambda_j = \lambda_{3\text{-}j} = 0.02$, $\lambda_k = \lambda_{3\text{-}k} = 0.03$, $\mu_j = \mu_{3\text{-}j} = 0.13$, $\mu_k = \mu_{3\text{-}k} = 0.2$, $\mu_3 = 0.25$ and varying the value of λ_3 from 0.01 to 0.05, A_{FC} and A_{RC} has been evaluated and the variation shown in Fig. 5.

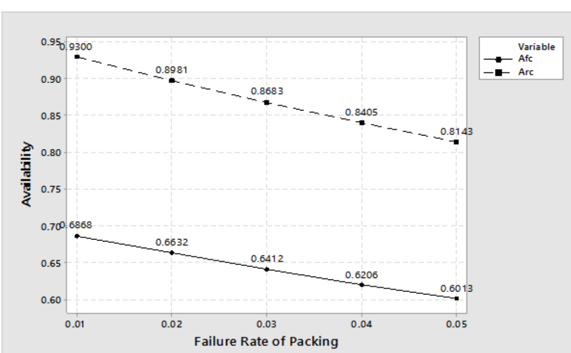

Fig 5 Variation of A_{FC} and A_{RC} with increasing failure rate of Packing

(d) Effect of increasing repair rate of Rewinder:-
Taking $\lambda_j = \lambda_{3\text{-}j} = 0.02$, $\lambda_k = \lambda_{3\text{-}k} = 0.03$, $\lambda_3 = 0.001$, $\mu_k = \mu_{3\text{-}k} = 0.2$, $\mu_3 = 0.25$ and varying the value of $\mu_j = \mu_{3\text{-}j}$ from 0.13 to 0.53, A_{FC} and A_{RC} has been evaluated and the variation shown in Fig.6.

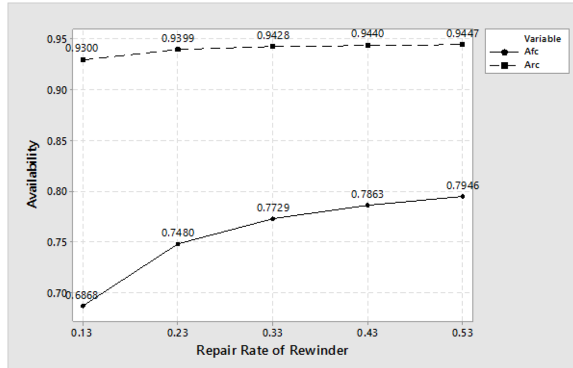

Fig 6 Variation of A_{FC} and A_{RC} with increasing repair rate of Rewinder

(e) Effect of increasing repair rate of Cutter:-
Taking $\lambda_j = \lambda_{3\text{-}j} = 0.02$, $\lambda_k = \lambda_{3\text{-}k} = 0.03$, $\lambda_3 = 0.001$, $\mu_j = \mu_{3\text{-}j} = 0.13$, $\mu_3 = 0.25$ and varying the value of $\mu_k = \mu_{3\text{-}k}$ from 0.2 to 0.6, A_{FC} and A_{RC} has been evaluated and the variation shown in Fig. 7.

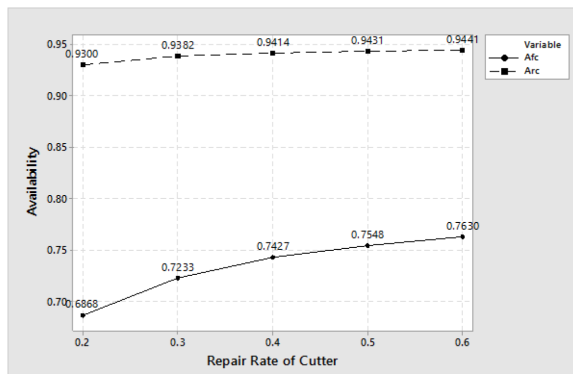

Fig 7 Variation of A_{FC} &A_{RC} with increasing repair rate of Cutter

(f) Effect of increasing repair rate of Cutter:-
Taking $\lambda_j = \lambda_{3\text{-}j} = 0.02$, $\lambda_k = \lambda_{3\text{-}k} = 0.03$, $\lambda_3 = 0.001$, $\mu_k = \mu_{3\text{-}k} = 0.2$, $\mu_j = \mu_{3\text{-}j} = 0.13$ and varying the value of μ_3 from 0.25 to 0.65, A_{FC} and A_{RC} has been evaluated and the variation shown in Fig. 8.

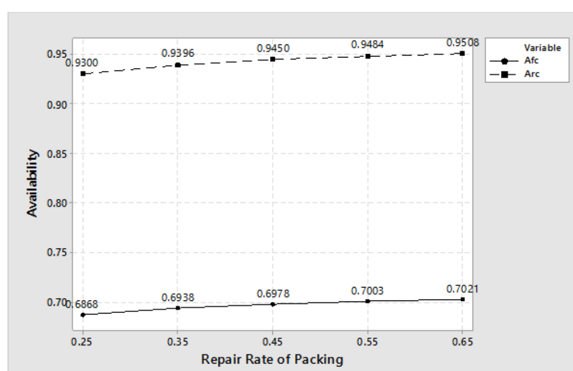

Fig 8 Variation of A_{FC} and A_{RC} with increasing repair rate of Packing

IV. DISCUSSION AND CONCLUSIONS

First order differential equations are used to solve the markov model for the finishing system of paper manufacturing unit. The analysis highlights the effect of increasing the failure rate and repair rate on the availability of the system. With increase in the failure rate both A_{FC} and A_{RC} decreases significantly (Fig.9). The maximum decrease of 11.57% in A_{FC} has been observed in packing subsystem with increase in failure rate from 0.01 to 0.05 repairs per hour whereas the minimum decrease in A_{FC} of 4.31% has been observed in case of cutter when the failure rate increases from 0.03 to 0.07 repair per hour. The minimum effect on A_{FC} and A_{RC} of increasing the failure rate has been found on cutter and rewinder respectively.

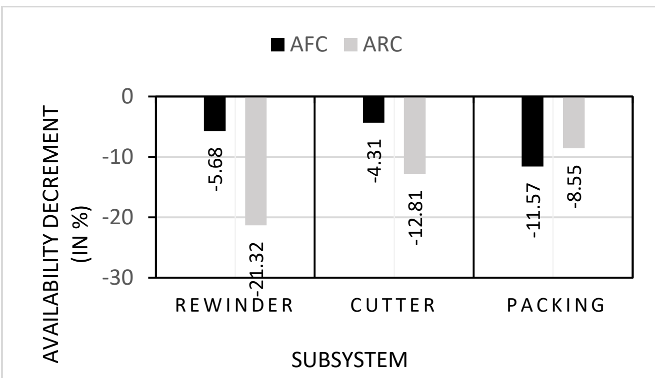

Fig.9. Availability decrement (in %) with increase in failure rate of subsystems

The improvement in availability has been observed with increase in repair rate. Repair rate significantly effect availability. Maximum increase of 10.78% in A_{RC} been observed in rewinder when the repair rate increases from 0.13 to 0.53 repairs per hour. A_{FC} is maximum improved by 2.08% in case of packing when repair rate increases from 0.25 to 0.65 repair per hour.(Fig.10)

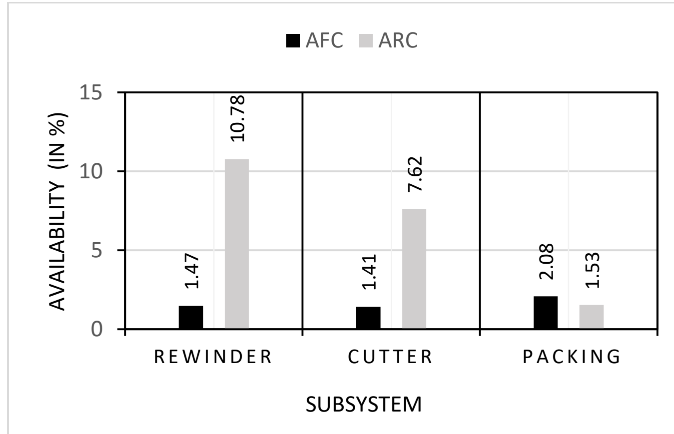

Fig. 10. Availability increment (in %) with increase in repair rate of subsystems

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