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Availability Evaluation of the serial processes in a Paper Production Industry-A Numerical Approach

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Abstract

The purpose of this research is to compute availability of the process of a paper production industry consisting of four subsystems. Mathematical formulation of the problem is carried out using probability considerations and the governing differential equations are solved using Runge-Kutta method of order four. Availability of the serial process in the paper production industry have been computed for various choice of failure and repair rates of subsystems of this plant.

Keywords: Reliability, availability, Markov method and Runge-Kutta method.

1 Introduction

Availability is characteristic of an item, often designated by A (t) , expressed by the probability that the item will perform its required function under given conditions at a stated instant of time , and is not easy to calculate. For repairable systems, "availability" is a more meaningful measure than reliability to measure the effectiveness of maintained systems, because it includes reliability as well as maintainability. Although, reliability and availability have been considered initially important in the defence and

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aerospace industry, but nowadays availability has become a very important design parameter in many other fields including commerce, communication, computer systems, and industrial systems. In existing literature, a number of researchers have investigated the theoretical problems of availability modeling for different industrial systems. For instance, D. Kumar et al [8] discussed the pulping system in paper industry consisting of four subsystems in series and presented a maintenance planning. Furthermore, the authors discussed the reliability or availability of feeding system, washing system, bleaching systems and screening system in a paper industry in a series of articles [7, 9, 11 and 12]. Whereas, the reliability and availability of the crushing system and refining system in a sugar industry are respectively, obtained in [6, 10]. M. Dresner et al [3] examined the impact of resource availability, namely labour and flight equipment availability, on entry into the US airline industry. T.O. Oyebisi et al [13] discussed the level of availability of technological capabilities in the telecommunication industry in Nigeria. J. K. Cochran et al [2] presented an alternative – generic Markov models which produce exact results in the case of exponential failure and repair times, are at least as easy to use during model building, and reduce computational effort by orders of magnitude. They studied a case of a reactor regenerator system in a Fluid Catalytic Cracking Unit in a petroleum refinery is presented. D. A. Black et al [1] studied shocks to the coal and steel industries to measure the effect of long-term changes in demand for low-skilled workers on welfare expenditures. C. Palanichamy et al [14] highlighted the EC potential availability and suggested some practicable environmental friendly EC policies suitable for the Indian context to achieve the estimated potential, and finally it highlights the Government's role in the EC endeavour. P. Gupta et al [5] examined numerical analysis of reliability and availability of the serial processes in butter-oil processing plant. S. Garg et al [4] described the availability of crank-case manufacturing system in an automobile industry. The units discussed here fail either directly from normal working state or indirectly through partial failure state. In present paper, we compute availability of the process of a paper production industry consisting of four subsystems. Mathematical formulation of the problem is carried out using probability considerations and the governing differential equations are solved using Runge-Kutta method of order four. Availability of the serial process in the paper production industry has been computed for various choice of failure and repair rates of subsystems of this plant.

2 System, Assumptions and Notations

System and Subsystems: In present paper, we consider a paper production industry as a whole system and divide its functioning into four parts-cooking section, pulping section, fibre bonding section and drier section with the help of following four subsystems.

(i) **Digesters** (D): After washing i.e. cleaning, filtering or screening the raw material is fed into the digester where it is cooked up to at least 3 hours and all raw materials is converted in to a pulp.

(ii) **Paper Making Wire** (P): Now the pulp is stored in a tank with the help of a pump from where it is fed to the head box of paper machine which provides the width for the paper and helps in removing the water from the pulp.

(iii) **Refiners** (R): The individual cellulose fibers are still hollow and stiff and therefore there is a need to stick with one another in the paper web. This process is accomplished by beating the pulp in the refiners. In refiners the pulp is beated, vessels with a series of rotating, serrated metal disks. The pulp will be beaten for various times depending on its origin and the type of paper product that will be made from it. At the end of process, the fibers will be flattened and frayed, ready to bond together in a sheet of paper. Refiners are in series and failure of any one will cause failure of the system.

(iv) **Drying Cylinder** (S): It is used to suck the water from the pulp and then dried paper is finally rolled on a pope reel.

Assumptions : In present analysis we adopt the following assumptions.

(i) Failure and repair rates for the system are constant;

(ii) Service includes repair and/ or replacement;

(iii) Each subsystem has a separate repair facility and there is no waiting time for repair in the system;

(iv) A repair unit is as good as new;

(v) Repair and failure rates are independent of each other;

(vi) There are no simultaneous failures among the subsystems.

Notation: D, P, R and S, indicate that unites are in full operating state whereas a lower bar case letters indicate reduced states. Small letters d, p, r and s represent respectively the failed states of the subsystems D, P, R and S.

$\lambda_i, \quad i = 1,\ 2, \ldots 8$, denote the failure rates of the subsystem D, P, R, S, $\underline{\text{D}}$, $\underline{\text{P}}$, $\underline{\text{R}}$ and $\underline{\text{S}}$ respectively.

$\mu_i, \quad i = 1,\ 2,\ 3, \quad \ldots 8$, repair rates of the subsystems D, P, R, S, $\underline{\text{D}}$, $\underline{\text{P}}$, $\underline{\text{R}}$ and $\underline{\text{S}}$ respectively.

$P_i(t)$, denote the probability that the system is in the ith state at time t.

In addition, we also assume that the system have following states

 represents the system is in full working capacity i.e. in good state.

 represents the system is in reduced state.

 represents the system is in failed state.

Using the above notations and assumptions, the transition diagram of the system is shown in Figure-1.

Transition Diagram

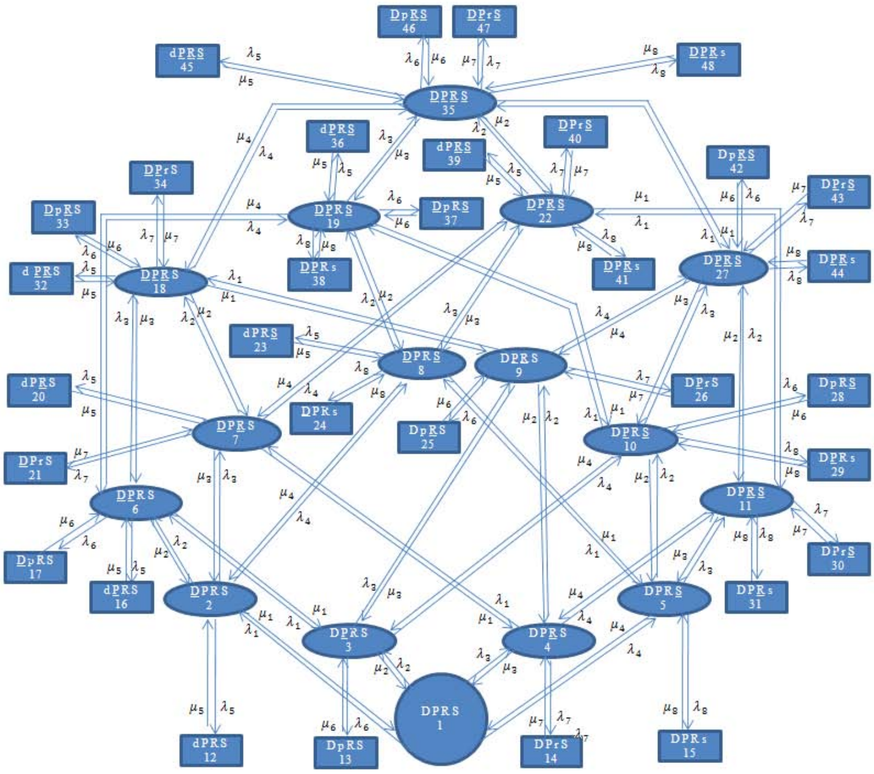


Figure-1

3 Mathematical Modeling

Probability considerations give the following differential equations associated with the transition diagram:

$$P_1^{/}\,(t) + \left(\sum_{i=1}^{4} \lambda_i\right) P_1\,(t) = \sum_{i=1}^{4} \mu_i\ P_{i+1}(t) \tag{1}$$

$$P_2^{/}\,(t) + \left(\left(\sum_{i=2}^{5} \lambda_i\right) +\ \mu_1\right)\ P_2\,(t) = \sum_{\substack{i=2,3,4,5;\,;\\ j=6,7,8,12\\ respecrively}} \mu_i\ P_j\,(t) + \lambda_1 P_1\,(t) \tag{2}$$

$$P_3^{/}(t) + \left(\left(\sum_{i=1,3,4,6}\lambda_i\right) + \mu_2\right) P_3(t) = \sum_{\substack{i=1,3,4,6;;\\ j=6,9,10,13\\ respecrively}} \mu_i\, P_j(t) + \lambda_2 P_1(t) \quad (3)$$

$$P_4^{/}(t) + \left(\left(\sum_{i=1,2,4,7}\lambda_i\right) + \mu_3\right) P_4(t) = \sum_{\substack{i=1,2,4,7;;\\ j=7,9,11,14\\ respecrively}} \mu_i\, P_j(t) + \lambda_3 P_1(t) \quad (4)$$

$$P_5^{/}(t) + \left(\left(\sum_{i=1,2,3,8}\lambda_i\right) + \mu_4\right) P_5(t) = \sum_{\substack{i=1,2,3,8;;\\ j=8,10,11,15\\ respecrively}} \mu_i\, P_j(t) + \lambda_4 P_1(t) \quad (5)$$

$$P_6^{/}(t) + \left(\left(\sum_{i=3}^{6}\lambda_i\right) + \left(\sum_{i=1}^{2}\mu_i\right)\right) P_6(t) = \sum_{\substack{i=3,4,5,6;;\\ j=18,19,16,17\\ respecrively}} \mu_i\, P_j(t) + \sum_{\substack{i=1,2;;\\ j=3,2\\ respectively}} \lambda_i P_j(t) \quad (6)$$

$$P_7^{/}(t) + \left(\left(\sum_{i=2,4,5,7}\lambda_i\right) + \left(\sum_{i=1,3}\mu_i\right)\right) P_7(t) = \sum_{\substack{i=2,4,5,7;;\\ j=18,22,20,21\\ respecrively}} \mu_i\, P_j(t) + \sum_{\substack{i=1,3;;\\ j=4,2\\ respectively}} \lambda_i P_j(t) \quad (7)$$

$$P_8^{/}(t) + \left(\left(\sum_{i=2,3,5,8}\lambda_i\right) + \left(\sum_{i=1,4}\mu_i\right)\right) P_8(t) = \sum_{\substack{i=2,3,5,8;;\\ j=19,22,23,24\\ respecrively}} \mu_i\, P_j(t) + \sum_{\substack{i=1,4;;\\ j=5,2\\ respectively}} \lambda_i P_j(t) \quad (8)$$

$$P_9^{/}(t) + \left(\left(\sum_{i=1,4,6,7}\lambda_i\right) + \left(\sum_{i=2,3}\mu_i\right)\right) P_9(t) = \sum_{\substack{i=1,4,6,7;;\\ j=18,27,25,26\\ respecrively}} \mu_i\, P_j(t) + \sum_{\substack{i=3,2;;\\ j=3,4\\ respectively}} \lambda_i P_j(t) \quad (9)$$

$$P_{10}^{/}(t)+\left(\left(\sum_{i=1,3,6,8}\lambda_i\right)+\left(\sum_{i=2,4}\mu_i\right)\right)P_{10}(t)=\sum_{\substack{i=1,3,6,8;;\\ j=19,27,28,29\\ respecrively}}\mu_i\,P_j(t)+\sum_{\substack{i=2,4;;\\ j=5,3\\ respectively}}\lambda_i P_j(t) \quad (10)$$

$$P_{11}^{/}(t)+\left(\left(\sum_{i=1,2,7,8}\lambda_i\right)+\left(\sum_{i=3,4}\mu_i\right)\right)P_{11}(t)=\sum_{\substack{i=1,2,7,8;;\\ j=22,27,30,31\\ respecrively}}\mu_i\,P_j(t)+\sum_{\substack{i=3,4;;\\ j=5,4\\ respectively}}\lambda_i P_j(t) \quad (11)$$

$$P_{18}^{/}(t)+\left(\left(\sum_{i=4}^{7}\lambda_i\right)+\left(\sum_{i=1}^{3}\mu_i\right)\right)P_{18}(t)=\sum_{\substack{i=4,5,6,7;;\\ j=35,32,33,34\\ respecriv??ly}}\mu_i\,P_j(t)+\sum_{\substack{i=1,2,3;;\\ j=9,7,6\\ respectively}}\lambda_i P_j(t) \quad (12)$$

$$P_{19}^{/}(t)+\left(\left(\sum_{i=3,5,6,8}\lambda_i\right)+\left(\sum_{i=1,2,4}\mu_i\right)\right)P_{19}(t)=\sum_{\substack{i=3,5,6,8;;\\ j=35,36,37,38\\ respecrively}}\mu_i\,P_j(t)+\sum_{\substack{i=1,2,4;;\\ j=10,8,6\\ respectively}}\lambda_i P_j(t) \quad (13)$$

$$P_{22}^{/}(t)+\left(\left(\sum_{i=2,5,7,8}\lambda_i\right)+\left(\sum_{i=1,3,4}\mu_i\right)\right)P_{22}(t)=\sum_{\substack{i=2,5,7,8;;\\ j=35,39,40,41\\ respecrively}}\mu_i\,P_j(t)+\sum_{\substack{i=1,3,4;;\\ j=11,8,7\\ respectively}}\lambda_i P_j(t) \quad (14)$$

$$P_{27}^{/}(t)+\left(\left(\sum_{i=1,6,7,8}\lambda_i\right)+\left(\sum_{i=2}^{4}\mu_i\right)\right)P_{27}(t)=\sum_{\substack{i=1,6,7,8;;\\ j=35,42,43,44\\ respecrively}}\mu_i\,P_j(t)+\sum_{\substack{i=2,3,4;;\\ j=11,10,9\\ respectively}}\lambda_i P_j(t) \quad (15)$$

$$P_{35}^{/}(t)+\left(\left(\sum_{i=5}^{8}\lambda_i\right)+\left(\sum_{i=1}^{4}\mu_i\right)\right)P_{35}(t)=\sum_{\substack{i=5,6,7,8;;\\ j=45,46,47,48\\ respecrively}}\mu_i\ P_j(t)+\sum_{\substack{i=1,2,3,4;;\\ j=27,22,19,18\\ respectively}}\lambda_i P_j(t) \quad (16)$$

$$P_i^{/}(t)+\mu_5 P_i(t)=\lambda_5 P_j(t), i=12,16,20,23,32,36,39,45; j=2,6,7,8,18,19,22,35\, respectively \quad (17)$$

$$P_i^{/}(t)+\mu_6 P_i(t)=\lambda_6 P_j(t), i=13,17,25,28,33,37,42,46; j=3,6,9,10,18,19,27,35,\ respectively \quad (18)$$

$$P_i^{/}(t)+\mu_7 P_i(t)=\lambda_7 P_j(t), i=14,21,26,30,34,40,43,47; j=4,7,9,11,18,22,27,35,\ respectively \quad (19)$$

$$P_i^{/}(t)+\mu_8 P_i(t)=\lambda_8 P_j(t), i=15,24,29,31,38,41,44,48; j=5,8,10,11,19,22,27,35,\ respectively \quad (20)$$

with initial conditions

$$P_i(0)=\begin{cases}1, & if\ i=1\\ 0, & otherwisw.\end{cases} \quad (21)$$

The equations from (1) to (20)with initial condition (21) have been solved numerically using Runge-Kutta method of order four and taking different failure and repair rates of various subsystems, the availability function of the system is computed by using

$$A(t)=\sum_{i=1}^{11}P_i(t)+\sum_{i=18}^{19}P_i(t)+P_{22}(t)+P_{27}(t)+P_{35}(t). \quad (22)$$

It is observed that if the failure and repair rates are altered, the availability of the system is affected which is shown in the tables as given below.

EFFECT OF FAILURE RATE (λ_1) OF DIGESTER ON THE SYSTEM:

Taking λ_1= 0.05, λ_2= 0.01, λ_3= 0.05, λ_4= 0.033, λ_5= 0.016, λ_6= 0.02, λ_7= 0.01, λ_8=0.05; μ_1= 0.1, μ_2 = 0.1, μ_3= 0.08, μ_4 = 0.033, μ_5= 0.01, μ_6= 0.02, μ_7= 0.01, μ_8= 0.04 and $\lambda_1$at the levels 0.05, 0.1, 0.15, 0.2, 0.25, we have the following table.

$\lambda_1 \rightarrow$ Time(in year)$\downarrow$	0.05	0.1	0.15	0.2	0.25
20	0.999984	0.999980	0.999976	0.999972	0.999969
40	0.999938	0.999922	0.999906	0.999891	0.999875
60	0.999860	0.999825	0.999791	0.999756	0.999722
80	0.999753	0.999692	0.999631	0.999571	0.999511
100	0.999617	0.999521	0.999427	0.999335	0.999244

Table-1

The table shows that the availability of the system decreases by approximately 0.00003873 with the increase of the failure rate of the digester subsystem 0.05 to 0.25 and availability decreases by approximately 0.0001368 with increase in the time 20 years to 100 years.

EFFECT OF REPAIR RATE (μ_1) OF DIGESTER ON THE SYSTEM :

Taking λ_1= 0.6, λ_2= 0.01, λ_3= 0.05, λ_4= 0.033, λ_5= 0.02, λ_6= 0.02, λ_7= 0.05, λ_8=0.2; μ_1= 0.05, μ_2 = 0.01, μ_3= 0.05, μ_4 = 0.033, μ_5= 0.01, μ_6= 0.01, μ_7= 0.04, μ_8= 0. 08 and $\mu_1$at the levels 0.05, 0.2, 0.35, 0.5, 0.65, we have the following table.

$\mu_1 \rightarrow$ Time(in year)$\downarrow$	0.05	0.2	0.35	0.5	0.65
20	0.999895	0.999896	0.999896	0.999896	0.999896
40	0.999588	0.999590	0.999593	0.999595	0.999597
60	0.999089	0.999096	0.999103	0.999110	0.999117
80	0.998407	0.998424	0.998440	0.998455	0.998471
100	0.997552	0.997583	0.997613	0.997642	0.997670

Table-2

The above table shows the availability of the system increases approximately by 0.00001 when repair rates increases from 0.05 to 0.65 and decreases approximately by 0.005696 when time increases from 20 years to 100 years.

EFFECT OF FAILURE RATE (λ_2) OF PAPER MAKING WIRE ON THE SYSTEM:

Taking λ_1= 0.05, λ_2= 0.1, λ_3= 0.05, λ_4= 0.033, λ_5= 0.02, λ_6= 0.02, λ_7= 0.05, λ_8=0.01; μ_1= 0.1, μ_2 = 0.1, μ_3= 0.08, μ_4 = 0.03, μ_5= 0.02, μ_6= 0.02, μ_7= 0.01, μ_8= 0.005 and λ_2 at the levels 0.1, 0.2, 0.3, 0.4, 0.5, we have the following table.

$\lambda_2\rightarrow$ Time(in year)$\downarrow$	0.1	0.2	0.3	0.4	0.5
20	0.999971	0.999961	0.999951	0.999942	0.999932
40	0.999885	0.999846	0.999808	0.999770	0.999733
60	0.999743	0.999657	0.999575	0.999490	0.999408
80	0.999546	0.999395	0.999248	0.999105	0.998965
100	0.999295	0.999063	0.998838	0.998620	0.998410

Table-3

The above table shows that the availability of the system decreases approximately by 0.0001003 asλ_2 increases from 0.1 to 0.5and decreases by 0.000277 as the time increases from 20 years to 100 years.

EFFECT OF REPAIR RATE OF PAPER MAKING WIRE (μ_2) ON THE SYSTEM:

Taking λ_1= 0.1, λ_2= 0.1, λ_3= 0.5, λ_4= 0.1, λ_5= 0.2, λ_6= 0.1, λ_7= 0.2, λ_8=0.1; μ_1= 0.1, μ_2 = 0.2, μ_3= 0.3, μ_4 = 0.05, μ_5= 0.1, μ_6= 0.1, μ_7= 0.2, μ_8= 0.2 and $\mu_2$at the levels 0.2, 0.4, 0.6, 0.8, 1, we have the following table.

$\mu_2\rightarrow$ Time(in year)$\downarrow$	0.2	0.4	0.6	0.8	1
20	0.999323	0.999323	0.999323	0.999324	0.999324
40	0.997379	0.997382	0.997385	0.997387	0.997389
60	0.994295	0.994304	0.994312	0.994319	0.994327
80	0.990186	0.990205	0.990224	0.990241	0.990258
100	0.985161	0.985197	0.985231	0.985263	0.985295

Table-4

The above table shows the availability of the system increases approximately by 0.0000129 when the repair rates increases from 0.2 to 1.0 and decreases approximately by 0.0035 when the time increases from 20 years to 100 years.

EFFECT OF FAILURE RATE OF REFINER (λ_3) ON THE SYSTEM:

Taking λ_1= 0.05, λ_2= 0.1, λ_3= 0.05, λ_4= 0.03, λ_5= 0.01, λ_6= 0.02, λ_7= 0.03, λ_8=0.01; μ_1= 0.05, μ_2 = 0.05, μ_3= 0.03, μ_4 = 0.02, μ_5= 0.01, μ_6= 0.02, μ_7= 0.03, μ_8= 0.005 and λ_3 at the levels 0.05, 0.1, 0.15, 0.2, 0.25, we have the following table.

$\lambda_3\rightarrow$ Time(in year)$\downarrow$	0.05	0.1	0.15	0.2	0.25
20	0.999979	0.999971	0.999964	0.999956	0.999949
40	0.999915	0.999885	0.999856	0.999827	0.999798
60	0.999809	0.999744	0.999678	0.999614	0.999550
80	0.999663	0.999547	0.999432	0.999319	0.999207
100	0.999476	0.999296	0.999119	0.998945	0.998777

Table-5

The above table shows that the availability of the system decreases approximately by 0.0000767 asλ_3 increases from 0.05 to 0.25 and decreases by 0.000189 as the time increases from 20 years to 100 years.

EFFECT OF REPAIR RATE OF REFINER (μ_3) ON THE SYSTEM:

Taking λ_1= 0.1, λ_2= 0.5, λ_3= 0.3, λ_4= 0.1, λ_5= 0.2, λ_6= 0.1, λ_7= 0.2, λ_8=0.1; μ_1= 0.1, μ_2 = 0.5, μ_3= 0.1, μ_4 = 0.1, μ_5= 0.1, μ_6= 0.1, μ_7= 0.1, μ_8= 0.1 and $\mu_3$at the levels 0.1, 0.3, 0.5, 0.7, 0.9, we have the following table.

μ_3→ Time(in year)↓	0.1	0.3	0.5	0.7	0.9
20	0.999319	0.999321	0.999323	0.999325	0.999327
40	0.997351	0.997366	0.997380	0.997395	0.997409
60	0.994203	0.994252	0.994298	0.994344	0.994388
80	0.989978	0.990088	0.990193	0.990295	0.990393
100	0.984772	0.984978	0.985174	0.985361	0.985540

Table-6

The above table shows the availability of the system increases approximately by 0.000072 when the repair rates increases from 0.1to 0.9 and decreases approximately by 0.00354 when the time increases from 20 years to 100 years.

EFFECT OF FAILURE RATE OF DRYING CYLINDER (λ_4) ON THE SYSTEM:

Taking λ_1= 0.05, λ_2= 0.04, λ_3= 0.05, λ_5= 0.02, λ_6= 0.02, λ_7= 0.03, λ_8=0.05; μ_1= 0.01, μ_2 = 0.03, μ_3= 0.04, μ_4 = 0.03, μ_5= 0.02, μ_6= 0.02, μ_7= 0.04, μ_8= 0. 04 and λ_4 at the levels 0.02, 0.04, 0.06, 0.08, 0.1, we have the following table.

λ_4→ Time(in year)↓	0.02	0.04	0.06	0.08	0.1
20	0.999979	0.999974	0.999969	0.999964	0.999959
40	0.999915	0.999895	0.999875	0.999856	0.999836
60	0.999809	0.999765	0.999721	0.999677	0.999633
80	0.999662	0.999584	0.999506	0.999429	0.999352
100	0.999474	0.999353	0.999233	0.999113	0.998994

Table-7

The above table shows that the availability of the system decreases approximately by 0.0000534 asλ_4 increases from 0.02 to 0.1 and decreases by 0.000184 as the time increases from 20 years to 100 years.

EFFECT OF REPAIR RATE OF DRYING CYLINDER (μ_4) ON THE SYSTEM:

Taking λ_1= 0.1, λ_2= 0.1, λ_3= 0.3, λ_4= 0.1, λ_5= 0.2, λ_6= 0.09, λ_7= 0.1, λ_8=0.1; μ_1= 0.1, μ_2 = 0.05, μ_3= 0.2, μ_5= 0.04, μ_6= 0.06, μ_7= 0.1, μ_8= 0.03 and $\mu_4$at the levels 0.1, 0.3, 0.5, 0.7, 0.9, we have the following table.

$\mu_4\rightarrow$ Time(in year)$\downarrow$	0.1	0.3	0.5	0.7	0.9
20	0.999661	0.999661	0.999662	0.999662	0.999662
40	0.998667	0.998670	0.998672	0.998675	0.998677
60	0.997053	0.997062	0.997070	0.997078	0.997086
80	0.994853	0.994873	0.994892	0.994910	0.994927
100	0.992100	0.992138	0.992173	0.992207	0.992239

Table-8

The table shows that the availability of the system increases approximately 0.0000129 with the increase of the repair rate of the drying cylinder subsystem from 0.1 to 0.9 and availability decreases by approximately 0.00187 with increase in time from 20 years to 100 years.

EFFECT OF FAILURE RATE OF DIGESTER IN REDUCED STATE (λ_5) ON THE SYSTEM:

Taking λ_1= 0.1, λ_2= 0.04, λ_3= 0.03, λ_4= 0.04, λ_5= 0.02, λ_6= 0.02, λ_7= 0.1, λ_8=0.04; μ_1= 0.05, μ_2 = 0.05, μ_3= 0.05, μ_4 = 0.03, μ_5= 0.01, μ_6= 0.02, μ_7= 0.08, μ_8= 0.02 and λ_5 at the levels 0.02, 0.04, 0.06, 0.08, 0.1, we have the following table.

$\lambda_5\rightarrow$ Time(in year)$\downarrow$	0.02	0.04	0.06	0.08	0.1
20	0.999963	0.999953	0.999943	0.999934	0.999924
40	0.999854	0.999814	0.999775	0.999736	0.999697
60	0.999673	0.999585	0.999498	0.999410	0.999323
80	0.999423	0.999268	0.999114	0.998960	0.998807
100	0.999105	0.998864	0.998625	0.998387	0.998151

Table-9

It decreases by approximately .000106 with the increase of failure rate from .02 to .08 and the availability decreases by approximately .000328 with the increase in time from 20 years to 100 years.

EFFECT OF REPAIR RATE OF DIGESTER IN REDUCED STATE (μ_5) **ON THE SYSTEM:**

Taking λ_1= 0.1, λ_2= 0.1, λ_3= 0.5, λ_4= 0.1, λ_5= 0.1, λ_6= 0.2, λ_7= 0.09, λ_8=0.2; μ_1= 0.05, μ_2 = 0.2, μ_3= 0.2, μ_4 = 0.3, μ_5= 0.2, μ_6= 0.1, μ_7= 0.06, μ_8= 0.1 and $\mu_5$at the levels 0.05, 0.1, 0.15, 0.2, 0.25, we have the following table.

$\mu_5\rightarrow$ Time(in year)$\downarrow$	0.05	0.1	0.15	0.2	0.25
20	0.999536	0.999536	0.999536	0.999536	0.999536
40	0.998188	0.998189	0.998189	0.998190	0.998190
60	0.996019	0.996021	0.996023	0.996025	0.996027
80	0.993089	0.993094	0.993099	0.993104	0.993109
100	0.989457	0.989467	0.989476	0.989486	0.989495

Table-10

The table shows that by increasing the repair rate from .05 to .25 the system availability is affected by the value 0.000021 and if the time is increased by 20 years to 100 years, the availability is decreased by 0.002515 .

EFFECT OF FAILURE RATE OF PAPER MAKING WIRE IN REDUCED STATE (λ_6) ON THE SYSTEM:

Taking λ_1= 0.04, λ_2= 0.1, λ_3= 0.04, λ_4= 0.03, λ_5= 0.02, λ_6= 0.02, λ_7= 0.04, λ_8=0.1; μ_1= 0.05, μ_2 = 0.05, μ_3= 0.03, μ_4 = 0.05, μ_5= 0.02, μ_6= 0.01, μ_7= 0.04, μ_8= 0.1 and λ_6 at the levels 0.02, 0.07, 0.12, 0.17, 0.22, we have the following table.

λ_6→ Time(in year)↓	0.02	0.07	0.12	0.17	0.22
20	0.999963	0.999938	0.999914	0.999889	0.999865
40	0.999854	0.999756	0.999658	0.999561	0.999464
60	0.999673	0.999454	0.999237	0.999022	0.998809
80	0.999423	0.999036	0.998655	0.998272	0.997906
100	0.999105	0.998505	0.997916	0.997336	0.996766

Table-11

It can be noticed that the availability of the system decreases by approximately 0.00044 with failure rate varied from 0.02to0.22 and decreases by approximately 0.000497 with increase in time from 20 years to 100 years.

EFFECT OF REPAIR RATE OF PAPER MAKING WIRE IN REDUCED STATE (μ_6) ON THE SYSTEM:

Taking λ_1= 0.5, λ_2= 0.3, λ_3= 0.1, λ_4= 0.1, λ_5= 0.1, λ_6= 0.5, λ_7= 0.2, λ_8=0.3; μ_1= 0.4, μ_2 = 0.1, μ_3= 0.09, μ_4 = 0.05, μ_5= 0.08, μ_6= 0.1, μ_7= 0.2, μ_8= 0.09 and $\mu_6$at the levels 0.1, 0.3, 0.5, 0.7, 0.9, we have the following table.

μ_6→ Time(in year)↓	0.1	0.3	0.5	0.7	0.9
20	0.998788	0.998793	0.998798	0.998803	0.998807
40	0.995304	0.995340	0.995376	0.995411	0.995446
60	0.989765	0.989883	0.989997	0.990108	0.990216
80	0.982380	0.982647	0.982903	0.983150	0.983387
100	0.973347	0.973844	0.974318	0.974770	0.975200

Table-12

By studying the table we observe that the availability of the system is affected by 0.0001736 when repair rate is increased by 0.1 to 0.9 and also decreased by 0.00613 as the time is increased by 20 years to 100 years.

EFFECT OF FAILURE RATE OF REFINERS IN REDUCED STATE (λ_7) ON THE SYSTEM:

Taking λ_1= 0.03, λ_2= 0.05, λ_3= 0.01, λ_4= 0.04, λ_5= 0.01, λ_6= 0.02, λ_7= 0.03, λ_8=0.05; μ_1= 0.01, μ_2 = 0.02, μ_3= 0.005, μ_4 = 0.02, μ_5= 0.01, μ_6= 0.01, μ_7= 0.03, μ_8= 0.01 and $\lambda_7$at the levels 0.03, 0.09, 0.15, 0.21, 0.27, we have the following table.

$\lambda_7\rightarrow$ Time(in year)$\downarrow$	0.03	0.09	0.15	0.21	0.27
20	0.999982	0.999979	0.999976	0.999973	0.999970
40	0.999929	0.999917	0.999905	0.999893	0.999882
60	0.999840	0.999813	0.999787	0.999761	0.999735
80	0.999716	0.999669	0.999623	0.999577	0.999533
100	0.999558	0.999485	0.999413	0.999343	0.999275

Table-13

Above table reveals that the availability of system decreases by approximately 0.0000315 with the increase of failure rate from 0.03 to 0.27 the availability of the system decreases also by approximately 0.000141 with increase in time from 20 years to 100 years.

EFFECT OF REPAIR RATE OF REFINERS IN REDUCED STATE (μ_7) ON THE SYSTEM:

Taking λ_1= 0.2, λ_2= 0.1, λ_3= 0.2, λ_4= 0.1, λ_5= 0.05, λ_6= 0.3, λ_7= 0.5, λ_8=0.09; μ_1= 0.09, μ_2 = 0.05, μ_3= 0.1, μ_4 = 0.1, μ_5= 0.02, μ_6= 0.1, μ_7= 0.02, μ_8= 0. 05 and $\mu_7$at the levels 0.02, 0.08, 0.14, 0.20, 0.26, we have the following table.

$\mu_7\rightarrow$ Time(in year)$\downarrow$	0.02	0.08	0.14	0.20	0.26
20	0.999272	0.999273	0.999274	0.999275	0.999276
40	0.997158	0.997165	0.997173	0.997180	0.997188
60	0.993757	0.993781	0.993805	0.993829	0.993853
80	0.989165	0.989220	0.989275	0.989329	0.989383
100	0.983475	0.983579	0.983683	0.983784	0.983885

Table-14

From this table it can be noticed that availability of the system increases by approximately 0.000038 with increase of the repair rate from 0.02 to 0.26 . But it decreases by 0.003899 with the increase in time from 20 years to 100 years.

EFFECT OF FAILURE RATE OF DRYING CYLINDER IN REDUCED STATE (λ_8) ON THE SYSTEM:

Taking λ_1= 0.09, λ_2= 0.1, λ_3= 0.2, λ_4= 0.04, λ_5= 0.05, λ_6= 0.08, λ_7= 0.09, λ_8=0.01; μ_1= 0.05, μ_2 = 0.-08, μ_3= 0.2, μ_4 = 0.02, μ_5= 0.03, μ_6= 0.05, μ_7= 0.07, μ_8= 0.01 and $\lambda_8$at the levels 0.01, 0.05, 0.09, 0.13, 0.17, we have the following table.

$\lambda_8\rightarrow$ Time (in year) $\downarrow$	0.01	0.05	0.09	0.13	0.17
20	0.999848	0.999840	0.999832	0.999824	0.999816
40	0.999400	0.999368	0.999337	0.999305	0.999274
60	0.998670	0.998599	0.998528	0.998458	0.998389
80	0.997670	0.997544	0.997420	0.997297	0.997175
100	0.996412	0.996217	0.996024	0.995834	0.995647

Table-15

It can be noticed that the availability of the system decreases by approximately 0.000085 with failure rate varied from 0.01 to 0.17 and decreases by approximately 0.0095 with increase in time from 20 years to 100 years.

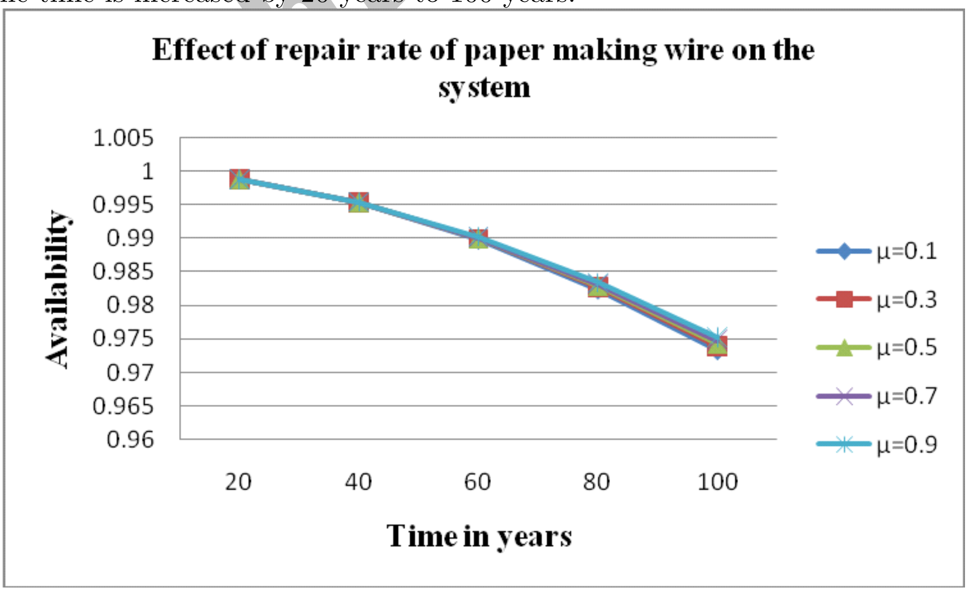
EFFECT OF REPAIR RATE OF DRYING CYLINDER IN REDUCED STATE (μ_8) ON THE SYSTEM:

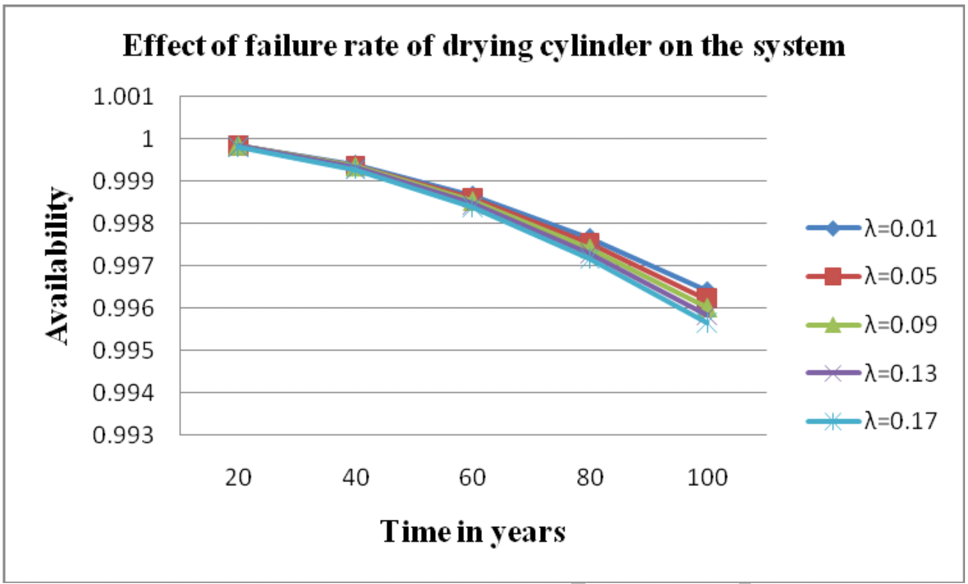
Taking λ_1= 0.1, λ_2= 0.2, λ_3= 0.09, λ_4= 0.1, λ_5= 0.3, λ_6= 0.05, λ_7= 0.2, λ_8=0.5; μ_1= 0.05, μ_2 = 0.1, μ_3= 0.08, μ_4 = 0.1, μ_5= 0.1, μ_6= 0.02, μ_7= 0.09, μ_8= 0. 08 and $\mu_8$at the levels 0.08, 0.16, 0.24, 0.32, 0.40, we have the following table.

$\mu_8\rightarrow$ Time(in year)$\downarrow$	0.08	0.16	0.24	0.32	0.40
20	0.999471	0.999472	0.999472	0.999473	0.999474
40	0.997929	0.997934	0.997939	0.997944	0.997948
60	0.995438	0.995454	0.995470	0.995486	0.995501
80	0.992061	0.992098	0.992135	0.992170	0.992206
100	0.987860	0.987930	0.987998	0.988065	0.988131

Table-16

By studying the table we observe that the availability of the system is affected by 0.00002505 when repair rate is increased by 0.08 to 0.40 and also decreased by 0.0028 as the time is increased by 20 years to 100 years.





4 Conclusions

Analysis of long run availability before the failure of paper production system can helping increases the production and quality of paper. Detailed study of tables 1 to 16 reveal that subsystem drying cylinder has maximum effect on the long run availability of the complete system. Hence it is suggested that management should take utmost care of this subsystem to increase overall performance of the paper production plant and also should take extra care of the repair of paper making wire.

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