Reliability and Availability Analysis of Uncaser System in A Brewary Plant

[1]Sunil Kadiyan, [2]Dr. R. K. Garg, Rajesh [3]Gautam
[1,3]Dept. of Mechanical Engg., Panipat Institute of Engg. and Tech., Samalkha, Panipat, Haryana, India
[2]Dept. of Civil Engg., Deen Bandhu Chhotu Ram University of Science & Technology, Murthal Sonepat, Haryana, India

Abstract

The paper discusses the availability and reliability analysis of an uncaser system in brewery plant by using the concept of performance analysis. Markov Birth Death process is used to find out all the probabilities (full working state, reduced state, failure state) of systems. After understanding the layout of the plant, draw transition diagram then differential equations and Steady state probabilities are determined. By taking data from the plant personal or from the log table available in the industry about the failure rate and repair rate of various systems and sub-systems the decision matrix are developed by using MATLAB programming. This gives availability for various combinations of failure rate and repair rate of all sub-systems. Graphs between availability and failure rate and availability and repair rate suggest the availability is decreases as the failure rate increases and availability is increases as the repair rate increase.

Keywords

Availability, Reliability, Steady state probabilities, Reliability Estimation.

I. Introduction

If we really want to understand the reliability of a system we must understand all the possible ways of failure of that system. Therefore if we wish to increase the availability of the system, we should know the all mode of failure of the system. The reliability of any system is very importance for the success of that system. In case of process industries the large number of systems and subsystems are there if anyone is failed all the process is affected. So the concept of reliability becomes very important in process industries.

The system with subsystems has been discussed in the literature. In this paper, we discuss a system consisting of seven subsystems (A, B, C, D, E, F, G) in series and the subsystem E also worked in reduced capacity. Where A=Sensor Assembly, B=Conveyer Belt, C= Belt Derive (Motor), D=Air Pressure Regulator, E= Plunger, F=Conveyer Belt 2, G= Visual Inspection Assembly.

According to Jai Singh et al. (19 April, 1994), The Availability of a system can be improved by using the standby units of limited subsystems, where the chances of failure is high.

According to Navneet Arora et al.(19 May 1995), the availability analysis of a steam generation system consisting of three subsystems A, B and D and a power generation system consisting of four subsystems E, F, G and H arranged in series, with three states i.e. good, reduced and failed. Taking constant failure and repair rates for each working unit, the mathematical formulation is done using the Birth-Death process. Expressions for steady state availability and the MTBF (mean time between failures) are derived. The graphs are given, depicting the effect of failure and repair rates on the system availability. The results are supplied to the plant personnel, to plan the policies for failure free running of the systems for a long duration.

According to Medardo Yanez et al. Repairable systems can be brought to one of possible states following a repair. These states are: 'as good as new', 'as bad as old', 'better than old but worse than new', 'better than new', and 'worse than old'.

According to Komal et al. (16 Dec., 2009) In recent years, reliability, availability and maintainability have expanded their influence in various industries and fields, thus serve as integral quality elements in the organization system and manufacturing process. As far as reliability is concerned, it has been established as a useful tool for risk analysis, production availability studies and design of systems [1–3]. Availability has been considered as an important measure of performance for many industrial systems which are generally considered as repairable ones

According to Peter Bullemer et al. (17May, 2010) Process industry plants involve operations of complex humane machine systems. The processes are large, complex, distributed, and dynamic. The sub-systems and equipment are often coupled, much is automated, data has varying levels of reliability, and a significant portion of the humane machine interaction is mediated by computer. This monitoring of the whole humane machine shows the all possible failure mode of process industries.

II. Markov Process

Markov process is named after the Russian mathematician ANDREY MARKOV. Markov analysis provides a method of analyzing the reliability and availability of sub-systems representing components with strong interdependencies. The availability of a single repairable system can be computed using familiar Markov Model. It is assumed that the failure rate and repair rates are constants. The repair starts as soon as the component fails. α is failure rate and β is repair rate.

If state 0 denotes that no failure has occurred and state 1 denotes that one failure has occurred. If the component has not failed at time t, then the probability that the component will fail in the time interval (t, t+dt) is equal to αdt. On the other hand, if the component is in state 1, then the probability that the component will enter into state 0 is equal to βdt.

The probability that the component will be in state 0 at time t+dt is

$$P_0(t+dt) = P_0(t)(1-\alpha dt)+P_1(t)\,\beta dt \quad (1)$$

Similarly, the probability that the component will be in state 1 at time t+dt is

$$P_1(t+dt) = P_1(t)(1-\beta dt)+P_0(t)\,\alpha dt \quad (2)$$

The above equations can be rewritten as:

$$\{P_0(t+dt)- P_0(t)\}/dt = -P_0(t),\ \alpha+P_1(t)\ \beta \quad (3)$$

$$\{P_1(t+dt)- P_1(t)\}/dt = P_0(t),\ \alpha- P_1(t)- \beta \quad (4)$$

The resultant differential equations are:

$$dP_0(t)/dt = P_0'(t) = P_0(t)\ \alpha- P_0(t)\ \beta$$

$$dP_1(t)/dt = P_1'(t) = P_0(t)\ \alpha- P_1(t)\ \beta$$

At time t=0, $P_0(0) = 1$ and $P_1(t) = 0$

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III. Approaches used for reliability estimation are:

1. Monte-Carlo Simulation Technique
2. The Markov process approach
3. Failure Modes and Effects Analysis (FMEA)
4. Reliability Block Diagrams (RBD)
5. Functional Logic Diagrams
6. The structure function approach
7. Fault tree analysis
8. Event tree analysis

A. Assumptions

1. At any given time the system is either in operating state or in the failed state.
2. Failure rate and repair rate are constant.
3. A repaired sub system is as good as new.
4. Standby sub systems are of the same nature and capacity as the active sub system.
5. Repair facilities are always available.

B. Notations

1. ◯ Indicate the system in operating condition.

2. ▭ Indicates the system in fail condition.

3. ⬭ Indicates the system in reduced capacity state.

4. A, B, C, D, E, F, G indicate the subsystems are working at full capacity.

5. $\overline{\overline{E}}$ Indicates that the subsystem is working at reduced capacity.

6. a,b,c,d,e,f,g indicates that all subsystems are in failed state.

7. α_1 Failure Rate of subsystem A

8. α_2 Failure Rate of subsystem B

9. α_3 Failure Rate of subsystem C

10. α_4 Failure Rate of subsystem D

11. α_5 Failure Rate of subsystem E

12. α_6 Failure Rate of subsystem F

13. α_7 Failure Rate of subsystem G

14. β_1 Repair Rate of subsystem A

15. β_2 Repair Rate of subsystem B

16. β_3 Repair Rate of subsystem C

17. β_4 Repair Rate of subsystem D

18. β_5 Repair Rate of subsystem E

19. β_6 Repair Rate of subsystem F

20. β_7 Repair Rate of subsystem G

21. d/dt indicates derivative w.r.t.'t'.

22. P_0 (t) denotes the probability that at time t all units are working

23. P_1(t) denotes the probability that at time t the system is in reduced capacity state due to failure of subsystem E.

24. P_2(t) denotes the probability that at time t the system is in failed state due to failure of subsystem E.

25. P_3(t) denotes the probability that at time t the system is in failed state due to failure of subsystem A.

26. P_4(t) denotes the probability that at time t the system is in failed state due to failure of subsystem B.

27. P_5(t) denotes the probability that at time t the system is in failed state due to failure of subsystem C.

28. P_6(t) denotes the probability that at time t the system is in failed state due to failure of subsystem D.

29. P_7(t) denotes the probability that at time t the system is in failed state due to failure of subsystem F.

30. P_8(t) denotes the probability that at time t the system is in failed state due to failure of subsystem G.

31. P_9(t) denotes the probability that at time t the system is in failed state due to failure of subsystem A. and subsystem E working within reduced capacity.

32. P_{10}(t) denotes the probability that at time t the system is in failed state due to failure of subsystem B. and subsystem E working within reduced capacity.

33. P_{11}(t) denotes the probability that at time t the system is in failed state due to failure of subsystem C. and subsystem E working within reduced capacity.

34. P_{12}(t) denotes the probability that at time t the system is in failed state due to failure of subsystem D. and subsystem E working within reduced capacity.

35. P_{13}(t) denotes the probability that at time t the system is in failed state due to failure of subsystem F. and subsystem E working within reduced capacity.

36. P_{14}(t) denotes the probability that at time t the system is in failed state due to failure of subsystem G. and subsystem E working within reduced capacity.

C. Transition Diagram

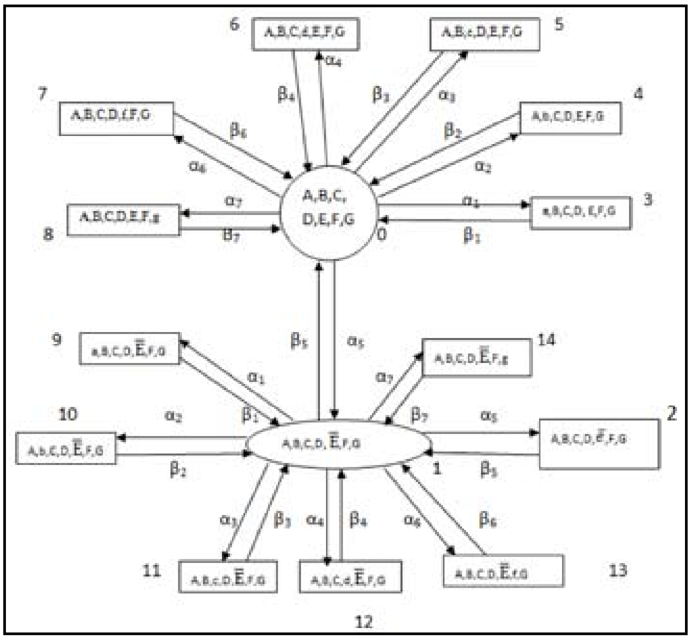

Fig. 1:

D. Performance modeling of Uncaser System

$(d/dt+\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_7)P_0(t)=\beta_1P_3(t)+\beta_2P_4(t)+\beta_3P_5(t)+\beta_4P_6(t)+\beta_5P_1(t)+\beta_6P_7(t)+\beta_7P_8(t)$ (1)

$(d/dt+\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_7+\beta_5)P_1(t)=\beta_1P_9(t)+\beta_2P_{10}(t)+\beta_3P_{11}(t)+\beta_4P_{12}(t)+\alpha_5P_0(t)+\beta_6P_{13}(t)+\beta_7P_{14}(t)+\beta_5P_2(t)$ (2)

$(d/dt+\beta_5)P_2(t)=\alpha_5P_1(t)$ (3)

$(d/dt+\beta_1)P_3(t)=\alpha_1P_0(t)$ (4)

$(d/dt+\beta_2)P_4(t)=\alpha_2P_0(t)$ (5)

$(d/dt+\beta_3)P_5(t)=\alpha_3P_0(t)$ (6)

$(d/dt+\beta_4)P_6(t)=\alpha_4P_0(t)$ (7)

$(d/dt+\beta_6)P_7(t)=\alpha_6P_0(t)$ (8)

$(d/dt+\beta_7)P_8(t)=\alpha_7P_0(t)$ (9)

$(d/dt+\beta_1)P_9(t)=\alpha_1P_1(t)$ (10)

$(d/dt+\beta_2)P_{10}(t)=\alpha_2P_1(t)$ (11)

$(d/dt+\beta_3)P_{11}(t)=\alpha_3P_1(t)$ (12)

$(d/dt+\beta_4)P_{12}(t)=\alpha_4P_1(t)$ (13)

$(d/dt+\beta_6)P_{13}(t)=\alpha_6P_1(t)$ (14)

$(d/dt + \beta_7)P_{14}(t) = \alpha_7 P_1(t)$ (15)

With initial conditions at time t =0

$P_i(t) = 1$ for i=0

$=0$ for $i \neq 0$

Steady state availability of Uncaser System:

By putting d/dt =0 at $t \to \infty$ in equations (1 to 15), the steady state probabilities are given as:-

$P_2 = \alpha_5/\beta_5 P_1$ (16)

$P_3 = \alpha_1/\beta_1 P_0$ (17)

$P_4 = \alpha_2/\beta_2 P_0$ (18)

$P_5 = \alpha_3/\beta_3 P_0$ (19)

$P_6 = \alpha_4/\beta_4 P_0$ (20)

$P_7 = \alpha_6/\beta_6 P_0$ (21)

$P_8 = \alpha_7/\beta_7 P_0$ (22)

$P_9 = \alpha_1/\beta_1 P_1$ (23)

$P_{10} = \alpha_2/\beta_2 P_1$ (24)

$P_{11} = \alpha_3/\beta_3 P_1$ (25)

$P_{12} = \alpha_4/\beta_4 P_1$ (26)

$P_{13} = \alpha_6/\beta_6 P_1$ (27)

$P_{14} = \alpha_7/\beta_7 P_1$ (28)

$P_0 = \beta_1P_3 + \beta_2P_4 + \beta_3P_5 + \beta_4P_6 + \beta_5P_1 + \beta_6P_7 + \beta_7P_8 / (\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 + \alpha_5 + \alpha_6 + \alpha_7)$ (29)

$P_1 = \beta_1P_9 + \beta_2P_{10} + \beta_3P_{11} + \beta_4P_{12} + \alpha_5P_0 + \beta_6P_{13} + \beta_7P_{14} + \beta_5P_2 / (\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 + \alpha_5 + \alpha_6 + \alpha_7 + \beta_5)$ (30)

Put the values of P_3, P_4, P_5, P_6, P_1, P^7, P_8, in equation no. 29 and find the value of P_0.

$P_0 = \beta_1P_3 + \beta_2P_4 + \beta_3P_5 + \beta_4P_6 + \beta_5P_1 + \beta_6P_7 + \beta_7P_8 / (\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 + \alpha_5 + \alpha_6 + \alpha_7)$

$P_0 = \{(\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 + \alpha_6 + \alpha_7) P_0 + \beta_5P_1\}/A$

$(A-C) P_0 = \beta_5P_1$

$P_0 = \beta_5P_1/(A-C)$

$P_0 = EP_1$ (31)

Put the values of P_9, P_{10}, P_{11}, P_{12}, P_{13}, P_{14}, P_2, P_0, in equation no. 30 and find the value of P_1.

$P_1 = \beta_1P_9 + \beta_2P_{10} + \beta_3P_{11} + \beta_4P_{12} + \alpha_5P_0 + \beta_6P_{13} + \beta_7P_{14} + \beta_5P_2 / (\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 + \alpha_5 + \alpha_6 + \alpha_7 + \beta_5)$

$P_1 = \{(\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 + \alpha_5 + \alpha_6 + \alpha_7) P_1 + \alpha_5P_0\}/B$

$(B-A) P_1 = \alpha_5 P_0$

$P_1 = \alpha_5 P_0/(B-A)$

$P_1 = FP_0$ (32)

The probability of full working/reduced state determined by using normalizing conditions i.e. sun of the probabilities of all working states and failed states is equal to 1.

$$\sum_{i=0}^{15} P_i = 1$$

$P_0 + P_1 + P_2 + P_3 + P_4 + P_5 + P_6 + P_7 + P_8 + P_9 + P_{10} + P_{11} + P_{12} + P_{13} + P_{14} = 1$

$P_0 (1+FG+H) = 1$

$P_0 = 1/(1+FG+H)$

$P_1 = F/(1+FG+H)$

Where $A = (\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 + \alpha_5 + \alpha_6 + \alpha_7)$

$B = (\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 + \alpha_5 + \alpha_6 + \alpha_7 + \beta_5)$

$C = (\alpha1 + \alpha2 + \alpha3 + \alpha4 + \alpha6 + \alpha7)$

$E = \beta_5/(A-C)$

$F = \alpha_5/(B-A)$

$G = (1 + \alpha_1/\beta_1 + \alpha_2/\beta_2 + \alpha_3/\beta_3 + \alpha_4/\beta_4 + \alpha_5/\beta_5 + \alpha_6/\beta_6 + \alpha_7/\beta_7)$

$H = (\alpha_1/\beta_1 + \alpha_2/\beta_2 + \alpha_3/\beta_3 + \alpha_4/\beta_4 + \alpha_6/\beta_6 + \alpha_8/\beta_8)$

Availability = Sum of probability of working state/ reduced state

$A_0 = P_0 + P_1$

$A_0 = 1/(1+FG+H) + F/(1+FG+H)$

$A_0 = P_0 (1+F)$

E. Decision Matrix for Uncaser Machine (Sensor and stopper assembly= α_1, β_1):

β_1 \ α_1	0.00011	0.00012	0.00013	0.00014	0.00015	Constant Values
.03	0.9782	0.9779	0.9775	0.9772	0.9769	α_2=0.00012, β_2=0.04 α_3=0.00023, β_3=0.03 α_4=0.00019 , β_4=0.02 α_5=0.00012, β_5=0.02 α_6=0.00001, β_6=0.05 α_7=0.00011, β_7=0.10
.04	0.9791	0.9788	0.9786	0.9783	0.9781	
.05	0.9796	0.9794	0.9792	0.9790	0.9788	
.06	0.9799	0.9798	0.9796	0.9795	0.9793	
.07	0.9802	0.9801	0.9799	0.9798	0.9796	

F. Decision Matrix for Uncaser Machine (Conveyor Belt 1=α_2, β_2):

β_2 \ α_2	0.00010	0.00011	0.000012	0.00013	0.00014	Constant Values
0.02	0.9773	0.9768	0.9763	0.9759	0.9754	α_1=0.00013 , β_1=0.05 α_3=0.00023, β_3=0.03 α_4=0.00019 , β_4=0.02 α_5=0.00012, β_5=0.02 α_6=0.00001, β_6=0.05 α_7=0.00011, β_7=0.1
0.03	0.9789	0.9786	0.9782	0.9779	0.9776	
0.04	0.9797	0.9794	0.9792	0.9790	0.9787	
0.05	0.9802	0.9800	0.9798	0.9796	0.9794	
0.06	0.9805	0.9803	0.9802	0.9800	0.9798	

G. Decision Matrix for Uncaser Machine (Belt Drive and Motor= α_3, β_3):

β_3 \ α_3	0.00021	0.00022	0.00023	0.00024	0.00025	Constant Values
0.01	0.9658	0.9649	0.9640	0.9630	0.9621	α_1=0.00013 , β_1=0.05 α_2=0.00012, β_2=0.04 α_4=0.00019 , β_4=0.02 α_5=0.00012, β_5=0.02 α_6=0.00001, β_6=0.05 α_7=0.00011, β_7=0.1
0.02	0.9757	0.9752	0.9748	0.9743	0.9738	
0.03	0.9791	0.9787	0.9784	0.9781	0.9778	
0.04	0.9807	0.9805	0.9803	0.9800	0.9798	
0.05	0.9817	0.9816	0.9814	0.9812	0.9810	

H. Decision Matrix for Uncaser Machine (Air Pressure Regulator= α_4, β_4):

β_4 \ α_4	0.00017	0.00018	0.00019	0.00020	0.00021	Constant Values
0.01	0.9696	0.9687	0.9678	0.9668	0.9659	α_1=0.00013 , β_1=0.05 α_2=0.00012, β_2=0.04 α_3=0.00023, β_3=0.03 α_5=0.00012, β_5=0.02 α_6=0.00001, β_6=0.05 α_7=0.00011, β_7=0.1
0.02	0.9777	0.9772	0.9767	0.9763	0.9758	
0.03	0.9804	0.9801	0.9798	0.9794	0.9791	
0.04	0.9818	0.9815	0.9813	0.9810	0.9808	
0.05	0.9826	0.9824	0.9822	0.9820	0.9818	

I. Decision Matrix for Uncaser Machine (Plunger and Gripper= α_5, β_5):

β_5 \ α_5	0.00009	0.00010	0.00011	0.00012	0.00013	Constant Values
0.02	0.9791	0.9790	0.9790	0.9790	0.9790	α_1=0.00013 , β_1=0.05 α_2=0.00012, β_2=0.04 α_3=0.00023, β_3=0.03 α_4=0.00019 , β_4=0.02 α_6=0.00001, β_6=0.05 α_7=0.00011, β_7=0.1
0.03	0.9791	0.9791	0.9791	0.9791	0.9791	
0.04	0.9791	0.9791	0.9791	0.9791	0.9791	
0.05	0.9791	0.9791	0.9791	0.9791	0.9791	
0.06	0.9791	0.9791	0.9791	0.9791	0.9791	

J. Decision Matrix for Uncaser Machine (Conveyer Belt 2 = α_6, β_6):

β_6 \ α_6	0.00010	0.00011	0.00012	0.00013	0.00014	Constant Values
0.03	0.9756	0.9749	0.9743	0.9737	0.9730	α_1=0.00013 , β_1=0.05 α_2=0.00012, β_2=0.04 α_3=0.00023, β_3=0.03 α_4=0.00019 , β_4=0.02 α_5=0.00012, β_5=0.02 α_7=0.00011, β_7=0.10
0.04	0.9772	0.9767	0.9762	0.9757	0.9752	
0.05	0.9781	0.9777	0.9773	0.9770	0.9766	
0.06	0.9787	0.9784	0.9781	0.9778	0.9775	
0.07	0.9792	0.9789	0.9787	0.9784	0.9781	

K. Decision Matrix for Uncaser Machine (Visual Inspection Assembly = α_7, β_7):

β_7 \ α_7	0.00009	0.00010	0.00011	0.00012	0.00013	Constant Values
0.08	0.9798	0.9795	0.9793	0.9791	0.9788	α_1=0.00013 , β_1=0.05 α_2=0.00012, β_2=0.04 α_3=0.00023, β_3=0.03 α_4=0.00019 , β_4=0.02 α_5=0.00012, β_5=0.02 α_6=0.00001, β_6=0.05
0.09	0.9800	0.9798	0.9796	0.9794	0.9792	
0.10	0.9802	0.9800	0.9798	0.9796	0.9794	
0.11	0.9804	0.9802	0.9800	0.9798	0.9797	
0.12	0.9805	0.9803	0.9802	0.9800	0.9799	

IV. Analysis Through Graph

As we seen in the tables the Availability changes as failure rate and repair rate changes. The most significant changes appears in Air Pressure Regulator, the changes can be seen in the graphs below:

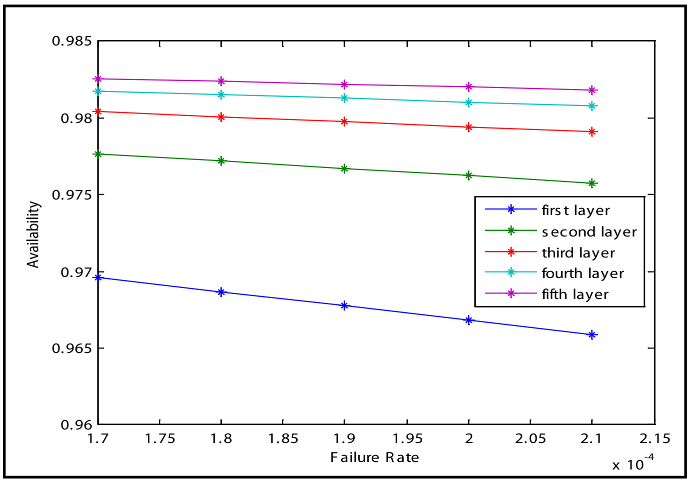

Fig. 2: Repair Rate and Availability for air Pressure Regulator

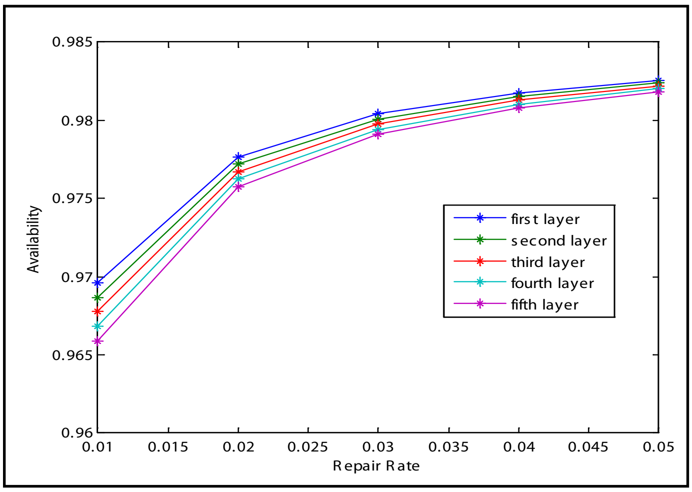

Fig. 3: Failure Rate and Availability for air Pressure Regulator

V. Conclusions

The most critical sub-system of Uncaser system is "Air Pressure Regulator", the table and graphs shows the variation of availability with the change in failure rate and repair rate. As the value of failure rate increases from 0.00017 to 0.00021 the value of availability decreases but as we increase the value of repair rate from 0.01 to 0.05 the value of availability is increases nearly by 1.5%.

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Sunil Kadiyan received his B.Tech degree in Mechanical Engineering from N.C. College of Engg. Israna Panipat, Kurukshetra University, in 2008, the M.Tech degree in Computer Aided Design (CAD) Mechanical Engg. from DCRUST, Murthal University, Sonepat, Haryana in 2011. He is Assistant Professor, with Department of Mechanical Engg. in Panipat Institute of Engineering & Techanology, Samalkha Near Panipat (Haryana). He has more than 2 years teaching experience in Mechanical engineering.