Availability Analysis of a System in a Process Industry by using Markov Death Birth Rule

Sunil kadiyan[1], Seeone Sharma[2], Rajesh Gautam[3], Naveen[4], Sandeep Olhan[5]

[1]*Assistant Professor, Mechanical Engg. Deptt. in Panipat Institute of Engg. and Technology, Samalkha,Panipat Haryana India.,* ***sunkadiyan@gmail.com., Mob. +91972895088***

[2]*Assistant Professor, Mechanical Engg. Deptt. in Panipat Institute of Engg. and Technology, Samalkha,Panipat Haryana India.*
[3]*Assistant Professor, Mechanical Engg. Deptt. MSIT, Jagdishpur, Sonepat, India,*
[4]*Assistant Professor, Mechanical Engg. Deptt. in Panipat Institute of Engg. and Technology, Samalkha,Panipat Haryana India.,*
[5]*Assistant Professor, Mechanical Engg. Deptt. in Panipat Institute of Engg. and Technology, Samalkha,Panipat Haryana India.*

Abstract

In this paper we find out availability of the Bottle Washer System by using Markov Death Birth rule, 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. Markov Birth Death process is used to find out all the probabilities (Full working, Reduced capacity, and Failed State) of the systems and the subsystems. The decision matrixes are developed by using MATLAB programming. This gives availability for various combinations of failure rate and repair rate.

Keyword list: *Performance, Availability, Reliability, Maintenance, Mean Time to Failure, Mean Time between Failures, Steady state probabilities.*

--- *** ---

1. INTRODUCTION:

The Bottle Washer system consist of eight sub systems A, B, C, D, E, F,G,H in series. Where A=Infeed Conveyer belt, B=Finger, C= Pockets, D=High Pressure Pump, E= Caustic Tank 1, F= Caustic Tank 2,G= Caustic Tank 3,H= Conveyer belt

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 Per Hokstad et.al. (1998), provides guidance on the process of establishing input data to safety and reliability engineering analyses when no or little field data exist, and expert judgment is required. According to Attila Csenki (1999), Current Issues and Challenges in the Reliability and Maintenance of Complex Systems According to D.V. Raje et.al. (2000), The paper aims at assessing the availability of a critical pumping system of the Crude Distillation Unit of a refinery with recourse to the Markovian model. 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.

2. 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

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

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

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

The above equations can be rewritten as:

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

$\{P_1(t+dt)- P_1(t)\}/dt = P_0(t), \alpha- P_1(t)- \beta$ (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, P0 (0) = 1 and P_1 (t) = 0

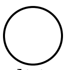
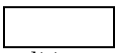
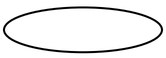
3. Assumptions:

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. In subsystem A, standby unit is always available when online unit fails.

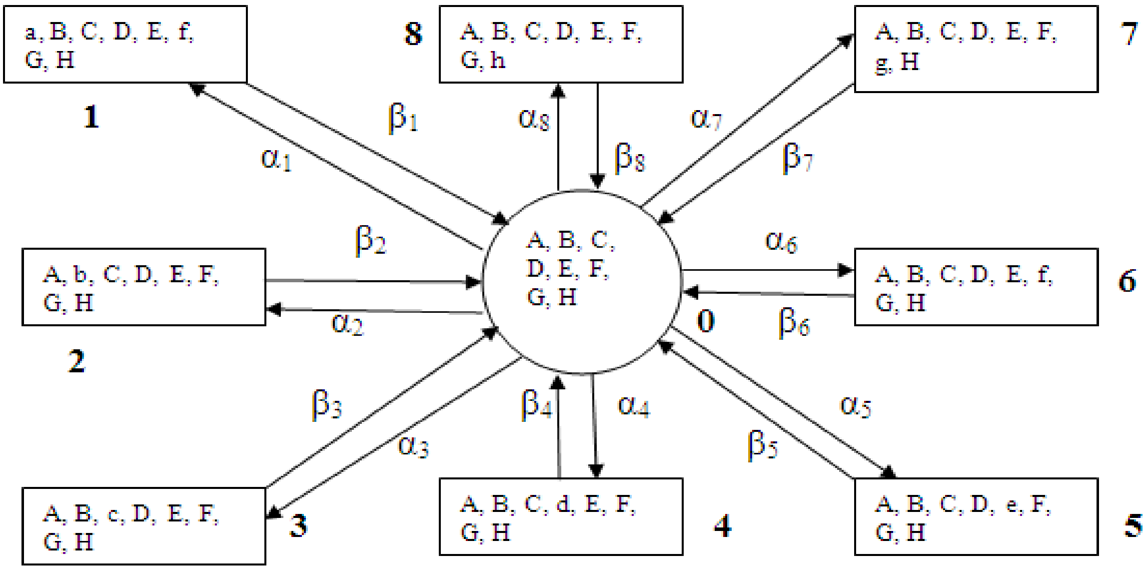
4. Approaches used for Availability estimation are:

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

5. Notations:

1.  Indicate the system in operating condition.
2.  Indicates the system in fail condition.
3.  Indicates the system in reduced capacity state (If any).
4. A, B, C, D, E, F, G, H indicates the subsystems are working at full capacity.
5. a, b, c, d, e, f, g, h indicates that all subsystems are in failed state.
6. α_1 Failure Rate of subsystem A
7. α_2 Failure Rate of subsystem B
8. α_3 Failure Rate of subsystem C
9. α_4 Failure Rate of subsystem D
10. α_5 Failure Rate of subsystem E
11. α_6 Failure Rate of subsystem F
12. α_7 Failure Rate of subsystem G
13. α_8 Failure Rate of subsystem H
14. $ß_1$ Repair Rate of subsystem A
15. $ß_2$ Repair Rate of subsystem B
16. $ß_3$ Repair Rate of subsystem C
17. $ß_4$ Repair Rate of subsystem D
18. $ß_5$ Repair Rate of subsystem E
19. $ß_6$ Repair Rate of subsystem F
20. $ß_7$ Repair Rate of subsystem G
21. $ß_8$ Repair Rate of subsystem H
22. d/dt indicates derivative w.r.t.'t'.
23. P_0 (t) denotes the probability that at time t all units are working.
24. $P_1(t)$ denotes the probability that at time t the system is in reduced capacity state due to failure of subsystem A.
25. $P_2(t)$ denotes the probability that at time t the system is in failed state due to failure of subsystem B.
26. $P_3(t)$ denotes the probability that at time t the system is in failed state due to failure of subsystem C.
27. $P_4(t)$ denotes the probability that at time t the system is in failed state due to failure of subsystem D.
28. $P_5(t)$ denotes the probability that at time t the system is in failed state due to failure of subsystem E.
29. $P_6(t)$ denotes the probability that at time t the system is in failed state due to failure of subsystem F.
30. $P_7(t)$ denotes the probability that at time t the system is in failed state due to failure of subsystem G.
31. $P_8(t)$ denotes the probability that at time t the system is in failed state due to failure of subsystem H.

6. Transition Diagram:



7. PERFORMANCE MODELING of BOTTLE WASHER SYSTEM:

$(d/dt + \alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 + \alpha_5 + \alpha_6 + \alpha_7 + \alpha_8)P_0(t) = \beta_1P_1(t) + \beta_2P_2(t) + \beta_3P_3(t) + \beta_4P_4(t) + \beta_5P_5(t) + \beta_6P_6(t) + \beta_7P_7(t) + \beta_8P_8(t)$… (1)

$(d/dt + \beta_1)P_1(t) = \alpha_1P_0(t)$ … (2)

$(d/dt + \beta_2)P_2(t) = \alpha_2P_0(t)$ … (3)

$(d/dt + \beta_3)P_3(t) = \alpha_3P_0(t)$ … (4)

$(d/dt + \beta_4)P_4(t) = \alpha_4P_0(t)$ … (5)

$(d/dt + \beta_5)P_5(t) = \alpha_5P_0(t)$ … (6)

$(d/dt + \beta_6)P_6(t) = \alpha_6P_0(t)$ … (7)

$(d/dt + \beta_7)P_7(t) = \alpha_7P_0(t)$ … (8)

$(d/dt + \beta_8)P_8(t) = \alpha_8P_0(t)$ … (9)

With initial conditions at time t =0

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

$= 0$ for $i \neq 0$

7.1 Steady State Availability of Bottle Washer System:

By putting $d/dt = 0$ at $t \to \infty$ in equations (1 to 9), the steady state probabilities are given as:-

$P_1 = \alpha_1/\beta_1 P_0$ … (10)

$P_2 = \alpha_2/\beta_2 P_0$ … (11)

$P_3 = \alpha_3/\beta_3 P_0$ … (12)

$P_4 = \alpha_4/\beta_4 P_0$ … (13)

$P_5 = \alpha_5/\beta_5 P_0$ … (14)

$P_6 = \alpha_6/\beta_6 P_0$ … (15)

$P_7 = \alpha_7/\beta_7 P_0$ … (16)

$P_8 = \alpha_8/\beta_8 P_0$ … (17)

$P_0 = \beta_1P_1 + \beta_2P_2 + \beta_3P_3 + \beta_4P_4 + \beta_5P_5 + \beta_6P_6 + \beta_7P_7 + \beta_8P_8 / (\alpha 1 + \alpha_2 + \alpha_3 + \alpha_4 + \alpha_5 + \alpha_6 + \alpha_7 + \alpha_8)$ ……. (18)

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.

$$\sum_{i=0}^{9} Pi = 1$$

$P_0 + P_1 + P_2 + P_3 + P_4 + P_5 + P_6 + P_7\ P_8 = 1$

$P_0\ (1+A) = 1$

Where $A = (\alpha_1/\beta_1 + \alpha_2/\beta_2 + \alpha_3/\beta_3 + \alpha_4/\beta_4 + \alpha_5/\beta_5 + \alpha_6/\beta_6 + \alpha_7/\beta_7 + \alpha_8/\beta_8)$

$P_0 = 1/(1+A)$

Availability = Sum of probability of working state/ reduced state

$A_0 = P_0$

$A_0 = 1/(1+A)$

8.0 DECISION MATRIX for BOTTLE WASHER MACHINE

(Infeed Conveyer Belt= α_1, β_1):

β_1 \ α_1	0.00011	0.00012	0.00013	0.00014	0.00015	Constant Values
0.03	0.9587	0.9584	0.9581	0.9578	0.9575	α_2=0.00015 , β_2=0.028 α_3=0.00013, β_3=0.018 α_4=0.00017, β_4=0.02 α_5=0.00015, β_5=0.033 α_6=0.00014, β_6=0.028 α_7=0.00012, β_7=0.025 α_8= 0.00013, β_8=0.033
0.04	0.9596	0.9594	0.9591	0.9589	0.9587	
0.05	0.9601	0.9599	0.9597	0.9595	0.9594	
0.06	0.9604	0.9603	0.9601	0.9600	0.9598	
0.07	0.9607	0.9605	0.9604	0.9603	0.9601	

8.1 Decision Matrix for Bottle Washer Machine
(Finger=α_2, β_2):

β_2 \ α_2	0.00013	0.00014	0.00015	0.00016	0.00017	Constant Values
0.01	0.9527	0.9518	0.9509	0.9500	0.9491	α_1=0.00013 , β_1=0.05 α_3=0.00013, β_3=0.018 α_4=0.00017, β_4=0.02 α_5=0.00015, β_5=0.033 α_6=0.00014, β_6=0.028 α_7=0.00012, β_7=0.025 α_8= 0.00013, β_8=0.033
0.02	0.9587	0.9582	0.9578	0.9573	0.9568	
0.03	0.9607	0.9604	0.9601	0.9597	0.9594	
0.04	0.9617	0.9614	0.9612	0.9610	0.9607	
0.05	0.9623	0.9621	0.9619	0.9617	0.9615	

8.2 Decision Matrix for Bottle Washer Machine
(Pockets=α_3, β_3):

β_3 \ α_3	0.00011	0.00012	0.00013	0.00014	0.00015	Constant Values
0.016	0.9600	0.9595	0.9589	0.9583	0.9577	α_1=0.00013 , β_1=0.05 α_2 =0.00015, β_2=0.028 α_4=0.00017, β_4=0.02 α_5=0.00015, β_5=0.033 α_6=0.00014, β_6=0.028 α_7=0.00012, β_7=0.025 α_8= 0.00013, β_8=0.033
0.017	0.9604	0.9599	0.9593	0.9588	0.9583	
0.018	0.9608	0.9602	0.9597	0.9592	0.9587	
0.019	0.9610	0.9606	0.9601	0.9596	0.9591	
0.020	0.9613	0.9609	0.9604	0.9599	0.9595	

8.3 Decision Matrix for Bottle Washer Machine
(High Pressure Pump=α_4, β_4):

β_4 \ α_4	0.00021	0.00022	0.00023	0.00024	0.00025	Constant Values
0.01	0.8633	0.8625	0.8618	0.8610	0.8603	α_1=0.00013 , β_1=0.05 α_2 =0.00015, β_2=0.028 α_3=0.00013, β_3=0.018 α_5=0.00015, β_5=0.033 α_6=0.00014, β_6=0.028 α_7=0.00012, β_7=0.025 α_8= 0.00013, β_8=0.033
0.02	0.8712	0.8708	0.8704	0.8700	0.8697	
0.03	0.8738	0.8736	0.8733	0.8731	0.8728	
0.04	0.8752	0.8750	0.8748	0.8746	0.8744	
0.05	0.8760	0.8758	0.8757	0.8755	0.8754	

8.4 Decision Matrix for Bottle Washer Machine
(Caustic Tank 1=α_5, β_5):

β_5 \ α_5	0.00013	0.00014	0.00015	0.00016	0.00017	Constant Values
0.01	0.9520	0.9511	0.9502	0.9493	0.9484	α_1=0.00013, β_1=0.05
0.02	0.9579	0.9575	0.9570	0.9566	0.9561	α_2=0.00015, β_2=0.028
0.03	0.9599	0.9596	0.9593	0.9590	0.9587	α_3=0.00013, β_3=0.018
0.04	0.9609	0.9607	0.9605	0.9602	0.9600	α_4=0.00017, β_4=0.02
0.05	0.9615	0.9613	0.9612	0.9610	0.9608	α_6=0.00014, β_6=0.028 α_7=0.00012, β_7=0.025 α_8= 0.00013, β_8=0.033

8.5 Decision Matrix for Bottle Washer Machine (Caustic Tank 2=α_6, β_6):

β_6 \ α_6	0.00012	0.00013	0.00014	0.00015	0.00016	Constant Values
0.01	0.9533	0.9524	0.9515	0.9506	0.9497	α_1=0.00013, β_1=0.05
0.02	0.9588	0.9583	0.9579	0.9574	0.9570	α_2=0.00015, β_2=0.028
0.03	0.9606	0.9603	0.9600	0.9597	0.9594	α_3=0.00013, β_3=0.018
0.04	0.9616	0.9613	0.9611	0.9609	0.9606	α_4=0.00017, β_4=0.02
0.05	0.9621	0.9619	0.9618	0.9616	0.9614	α_5=0.00015, β_5=0.033 α_7=0.00012, β_7=0.025 α_8= 0.00013, β_8=0.033

8.6 Decision Matrix for Bottle Washer Machine (Caustic Tank 3=α_7 β_7):

β_7 \ α_7	0.00010	0.00011	0.00012	0.00013	0.00014	Constant Values
0.01	0.9550	0.9540	0.9531	0.9522	0.9513	α_1=0.00013, β_1=0.05
0.02	0.9595	0.9591	0.9586	0.9582	0.9577	α_2=0.00015, β_2=0.028
0.03	0.9611	0.9608	0.9605	0.9602	0.9598	α_3=0.00013, β_3=0.018
0.04	0.9618	0.9616	0.9614	0.9612	0.9609	α_4=0.00017, β_4=0.02
0.05	0.9623	0.9621	0.9619	0.9618	0.9616	α_5=0.00015, β_5=0.033 α_6=0.00014, β_6=0.028 α_8= 0.00013, β_8=0.033

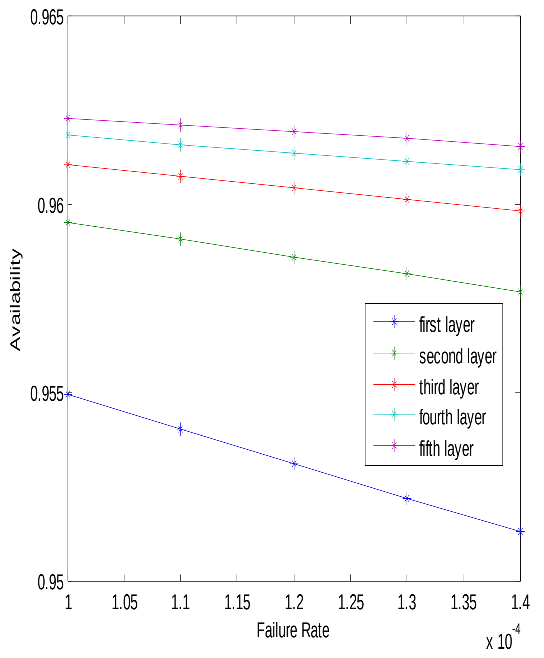
8.7 Decision Matrix for Bottle Washer Machine (Conveyer Belt 4=α_8 β_8):

β_8 \ α_8	0.00011	0.00012	0.00013	0.00014	0.00015	Constant Values
0.01	0.9533	0.9524	0.9515	0.9506	0.9497	α_1=0.00013, β_1=0.05
0.02	0.9588	0.9583	0.9579	0.9574	0.9570	α_2=0.00015, β_2=0.028
0.03	0.9606	0.9603	0.9600	0.9597	0.9594	α_3=0.00013, β_3=0.018
0.04	0.9616	0.9613	0.9611	0.9609	0.9606	α_4=0.00017, β_4=0.02
0.05	0.9621	0.9619	0.9618	0.9616	0.9614	α_5=0.00015, β_5=0.033 α_6=0.00014, β_6=0.028 α_7=0.00012, β_7=0.025

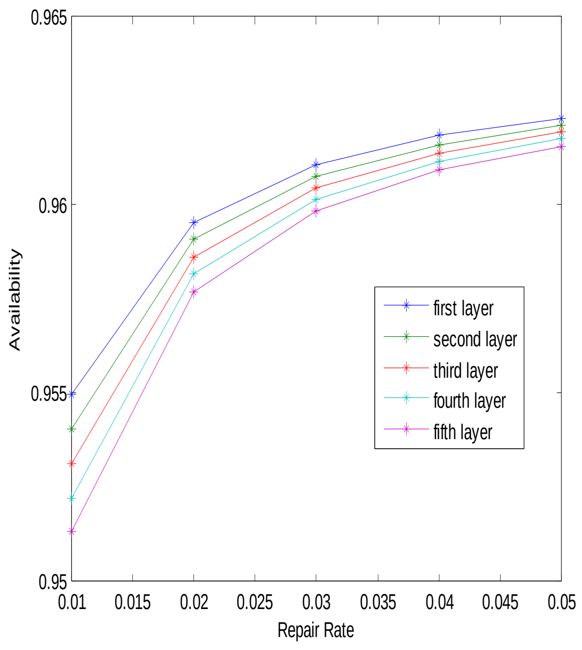
9. ANALYSIS THROUGH GRAPH:

As we seen in the tables the Availability changes as failure rate and repair rate changes. The most significant changes appear in "**Caustic Tank 3**" the changes can be seen in the graphs below:

ISSN: 2250-3676
Volume-3, Issue-2, 67-74



Graph A: - Between Failure Rate and Availability for Caustic Tank 3



Graph B: - Between Repair Rate and Availability for Caustic Tank 3.

10. CONCLUSIONS:

The most critical sub-system of Bottle Washer System is "**Caustic Tank 3**", the table and graphs show the variation of availability with the change in failure rate and repair rate. As the value of failure rate increases from 0.00010 to 0.00014 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%.

REFERENCES:

1) Jai Singh et.al. "Availability for a system composed of four subsystems in series having standby in one subsystem". Microelectron. Reliability, Vol. 35, No. 2, pp. 285-288, 1994.
2) Per Hokstad et.al. "Reliability engineering analyses when no or little field data exist, and expert judgment is required" *Reliabiliaility Engineering and System Safety*, Vol. 61, pp. 65-76, 1998
3) E. Zio et.al."Maintenance and repair activities for the safe and efficient operation of any industrial plant" *Reliability Engineering and System Safety*, Vol. 68, pp. 69–83, 2000.
4) Jesu´s Carretero et.al. "RCM methodology adapted to large infrastructure networks and a RCM toolkit to perform the RCM analysis" *Reliability Engineering and System Safety*, Vol. 82, pp. 257–273, 2003.
5) Dongwoon Kim et.al. "A systematic safety-cost decision making method based on an automatic accident scenario generation and multi objective optimization" *Journal of Loss Prevention in the Process Industries*, Vol. 19, pp. 705–713, 2006.
6) M.C. Eti "The applications of failure mode effect analysis, failure mode effect and criticality analysis, feedback information, upportive systems and risk analysis, in order to reduce the frequency of failures and

maintenance costs" *Applied Energy*, Vol. 84, pp. 202–221, 2007.

7) Javier Faulin et.al. "Predict reliability/availability levels in time-dependent systems" 29 *Reliability Engineering and System Safety*, Vol. 93, pp. 1761–1771, 2008.
8) Luca Marmob,et.al "Designing maintenance program and through the calculation of the risk due to plant failure" *Journal of Loss Prevention in the Process Industries*, Vol. 22, pp. 557–565, 2009.
9) Savita Garg et.al."The availability of crank-case manufacturing system in an automobile industry" Applied Mathematical Modelling, Vol. 34, pp. 1672–1683, 2010.
10) Komal et.al. "RAM analysis of repairable industrial systems utilizing uncertain data" *Applied Soft Computing*, Vol. 10, pp. 1208–1221, 2010.
11) Ling Wang et.al. "Imperfect maintenance will decrease the expected values of cycle length and long-run availability" Applied Mathematical Modelling, Vol. 35, pp. 2855–2863, 2011.
12) Li Yuan et.al. "Reliability analysis of a warm standby repairable system" Applied Mathematical Modelling ,2011.

ACKNOWLEDGEMENT

I would like to express my deep appreciation to My Father Mr. Balwan Singh Kadiyan and my family members (Kamla Devi, Rakesh Kadyan, Neelam Devi, Aruna, Ashmit, Utkarsh) and my friend Raju for being a great source of inspiration, I owe my gratitude to My Supervisors during my M.Tech., Dr. R. K. Garg, and Mr Ajay Kumar Professor and Assistant Professor in Mechanical Engineering Department, Deen Bandhu Chhotu Ram University of Science and Technology Murthal, for teaching me rigors of Availability Analysis and for always willing to share his time, even in late hours, with me from his valuable schedule whenever I knocked on his door. Without their kind heart and guidance, I would have never been able to complete this work.

BIOGRAPHIES

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.

Rajesh Gautam received his B.Tech degree in Mechanical Engineering from N.C. College of Engg. Israna Panipat ,Kurukshetra University, in 2006, the M.Tech degree in Computer Aided Design (CAD) Mechanical Engg. From DCR University Murthal, Sonepat, Haryana in 2010, and Pursuing Ph.D. degree in 'Effect of JIT Elements in Indian Organizations' (Mechanical Engg.) from Manav Bharti University Solan, Himachal Pradesh India. He is Assistant Professor, with Department of Mechanical Engg. in Mahaveer Swami Institut of Technology Jagdishpur, Sonepat Haryana.

He has attended 6 short term courses/workshops in Mechancal Engineering. He has more than 5 years teaching experience in Mechanical engineering

Sandeep Olhan received his B.Tech degree in Mechanical Engineering from N.C. College of Engg. Israna Panipat, Kurukshetra University, in 2009, the M.Tech degree in Mechanical Engg.with Gold Medal from N.C. College of Engg. Israna Panipat, Kurukshetra University, in 2011.

ISSN: 2250-3676
Volume-3, Issue-2, 67-74

He is Assistant Professor, with Department of Mechanical Engg. in Panipat Institute of Engineering & Techanology, Samalkha Near Panipat (Haryana). He has more than 1 years teaching experience in Mechanical engineering.

Seeone Sharma received his B.Tech degree in Mechanical Engineering from P.I.E.T. College of Engg. Samalkha, Panipat, Kurukshetra University, in 2010, the M.Tech (Pursuing) degree in Mechanical Engg from P.I.E.T. College of Engg. Samalkha Panipat, Kurukshetra University.

He is Assistant Professor, with Department of Mechanical Engg. in Panipat Institute of Engineering & Techanology, Samalkha Near Panipat (Haryana). He has more than 1 years teaching experience in Mechanical engineering.