International Journal of Scientific & Engineering Research, Volume 3, Issue 10, October 2012
ISSN 2229-5518

Availability Analysis of Filler System in a Process Industry (Brewary Plant)

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Abstract: The most of the systems in the industries are complex and repairable. If we wish to achieve the optimum performance of the system then we need to understand the Reliability, Availability and maintenance (RAM) parameters. In this paper we discuss the availability of Filler system in brewery plant by using the concept of mathematical modeling. Markov Birth Death process is used to find out all the probabilities of the systems and the subsystems. These probabilities are full working, reduced and failure state. After understanding the layout of the packaging department, draw transition diagram for various subsystems then differential equations and Steady state probabilities are determined. By taking data 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: Reliability, Availability, Mean Time to Failure, Mean Time between Failures, Steady state probabilities, Performance.

1. Introduction

The filler system consist of six sub systems A, B, C, D, E, F in series and the subsystem A also worked in reduced capacity. Where A=Conveyer belt speed, B=Sensor Assembly, C= Star Wheel, D=Rotary Filler, E= Rotary Cork Assembly, F=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 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.

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.

The Most appropriate 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.

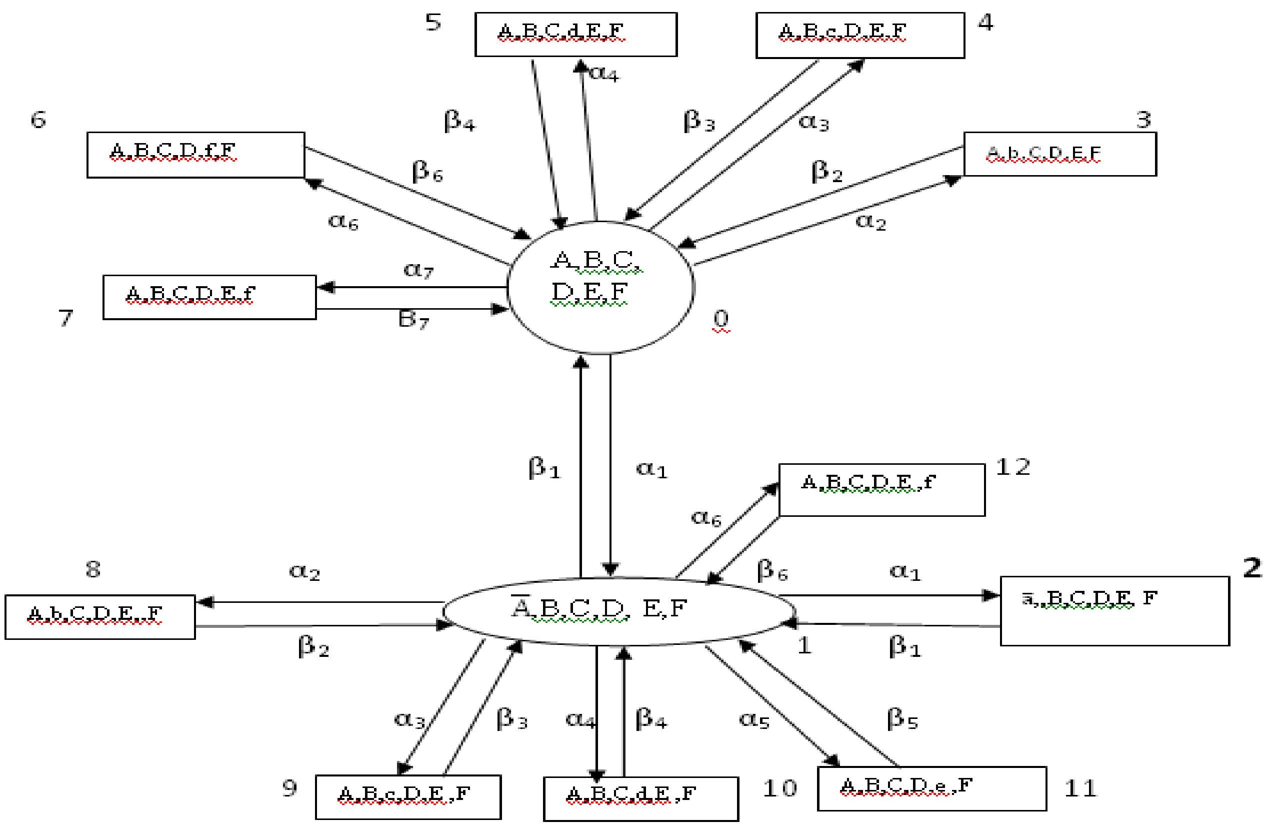
Notations

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 indicate the subsystems are working at full capacity.
5. $\bar{A}$ indicates that the subsystem is working at reduced capacity.
6. a,b,c,d,e,f indicates that all subsystems are in failed state.
7. $\alpha 1$ Failure Rate of subsystem A
8. $\alpha 2$ Failure Rate of subsystem B
9. $\alpha 3$ Failure Rate of subsystem C
10. $\alpha 4$ Failure Rate of subsystem D
11. $\alpha 5$ Failure Rate of subsystem E
12. $\alpha 6$ Failure Rate of subsystem F
13. ß1 Repair Rate of subsystem A
14. ß2 Repair Rate of subsystem B
15. ß3 Repair Rate of subsystem C

ISSN 2229-5518

16. β_4 Repair Rate of subsystem D
17. β_5 Repair Rate of subsystem E
18. β_6 Repair Rate of subsystem F
19. d/dt indicates derivative w.r.t.'t'.
20. P0 (t) denotes the probability that at time t all units are working.
21. P1(t) denotes the probability that at time t the system is in reduced capacity state due to failure of subsystem A.
22. P2(t) denotes the probability that at time t the system is in failed state due to failure of subsystem A.
23. P3(t) denotes the probability that at time t the system is in failed state due to failure of subsystem B.
24. P4(t) denotes the probability that at time t the system is in failed state due to failure of subsystem C.
25. P5(t) denotes the probability that at time t the system is in failed state due to failure of subsystem D.
26. P6(t) denotes the probability that at time t the system is in failed state due to failure of subsystem E.
27. P7(t) denotes the probability that at time t the system is in failed state due to failure of subsystem F.
28. P8(t) denotes the probability that at time t the system is in failed state due to failure of subsystem B. and subsystem A working within reduced capacity.
29. P9(t) denotes the probability that at time t the system is in failed state due to failure of subsystem C. and subsystem A working within reduced capacity.
30. P10(t) denotes the probability that at time t the system is in failed state due to failure of subsystem D. and subsystem A working within reduced capacity.
31. P11(t) denotes the probability that at time t the system is in failed state due to failure of subsystem E. and subsystem A working within reduced capacity.
32. P12(t) denotes the probability that at time t the system is in failed state due to failure of subsystem F. and subsystem A working within reduced capacity.

Transition Diagram:



Performance modeling of Filler System:

$(d/dt + \alpha 1 + \alpha 2 + \alpha 3 + \alpha 4 + \alpha 5 + \alpha 6)P0(t) = \beta 1P1(t) + \beta 2P3(t) + \beta 3P4(t) + \beta 4P5(t) + \beta 5P6(t) + \beta 6P7(t)$ …(1)

$(d/dt + \alpha 1 + \alpha 2 + \alpha 3 + \alpha 4 + \alpha 5 + \alpha 6 + \beta 1)P1(t) = \beta 1P2(t) + \beta 2P8(t) + \beta 3P9(t) + \beta 4P10(t) + \beta 5P11(t) + \beta 6P12(t) + \alpha 1P0(t)$ … (2)

$(d/dt + \beta 2)P3(t) = \alpha 2P0(t)$ … (3)

$(d/dt + \beta 1)P2(t) = \alpha 1P1(t)$ … (4)

$(d/dt + \beta 3)P4(t) = \alpha 3P0(t)$ … (5)

$(d/dt + \beta 4)P5(t) = \alpha 4P0(t)$ … (6)

$(d/dt + \beta 5)P6(t) = \alpha 5P0(t)$ … (7)

$(d/dt + \beta 6)P7(t) = \alpha 6P0(t)$ … (8)

$(d/dt + \beta 2)P8(t) = \alpha 2P1(t)$ … (9)

$(d/dt + \beta 3)P9(t) = \alpha 3P1(t)$ … (10)

$(d/dt + \beta 4)P10(t) = \alpha 4P1(t)$ … (11)

$(d/dt + \beta 5)P11(t) = \alpha 5P1(t)$… (12)

$(d/dt + \beta 6)P12(t) = \alpha 6 P1(t)$… (13)

With initial conditions at time t =0

Pi (t) =1 for i=0

=0 for i≠0

Steady state availability of Filler Machine:

By putting d/dt =0 at t→∞ in equations (1 to 13), the steady state probabilities are given as:-

$P3 = \alpha 2/\ \beta 2\ P0$ … (14)

$P2 = \alpha 1/\ \beta 1\ P0$ … (15)

$P4 = \alpha 3/\ \beta 3\ P0$ … (16)

$P5 = \alpha 4/\ \beta 4\ P0$ … (17)

$P6 = \alpha 5/\ \beta 5\ P0$ … (18)

$P7 = \alpha 6/\ \beta 6\ P0$ … (19)

$P8 = \alpha 2/\ \beta 2\ P1$ … (20)

$P9 = \alpha 3/\ \beta 3\ P1$ … (21)

$P10 = \alpha 4/\ \beta 4\ P1$ … (22)

$P11 = \alpha 5/\ \beta 5\ P1$ … (23)

$P12 = \alpha 6/\ \beta 6\ P1$ … (24)

$P0 = \beta 1P1+ \beta 2P3+ \beta 3P4+ \beta 4P5+ \beta 5P6+ \beta 6P7/(\alpha 1+ \alpha 2+ \alpha 3+ \alpha 4+\alpha 5+ \alpha 6)$ … (25)

$P1=\beta 1P2+\beta 2P8+\beta 3P9+\beta 4P10+\beta 5P11+\beta 6P12+\alpha 1P0/(\alpha 1+\alpha 2+\alpha 3+\alpha 4+\alpha 5+\alpha 6+\beta 1)$ …(26)

Put the values of P1, P2, P4, P5, P6, P7, in equation no. 25 and find the value of P0

$P0 = \beta 1P1+ \beta 2P2+ \beta 3P4+ \beta 4P5+ \beta 5P6+ \beta 6P7/ (\alpha 1+ \alpha 2+ \alpha 3+ \alpha 4+\alpha 5+ \alpha 6)$

$(A-C)\ P0 = \beta 1P1$

$P0= \beta 1P1/ (A-C)$

$F= \alpha 1 / (B-A)$

$G= (1+\alpha 1/\beta 1+ \alpha 2/ \beta 2+ \alpha 3 /\beta 3+ \alpha 4 /\beta 4+\alpha 5 /\beta 5+ \alpha 6 /\beta 6)$

$H= (\alpha 2/ \beta 2+ \alpha 3 /\beta 3+ \alpha 4 /\beta 4+ \alpha 6 /\beta 6+ \alpha 5 /\beta 5$

Availability = Sum of probability of working state/ reduced state

$P0=EP1$ … (27)

Put the values of P2, P8, P9, P10, P11, P12, P0, in equation no. 26 and find the value of P1

$P1 = \beta 1P2+ \beta 2P8+ \beta 3P9+ \beta 4P10+\beta 5P11+ \beta 6P12+ \alpha 1P0 / (\alpha 1+ \alpha 2+ \alpha 3+ \alpha 4+ \alpha 5+ \alpha 6+ \beta 1)$

$P1 = \{(\alpha 1+ \alpha 2+ \alpha 3+ \alpha 4+ \alpha 5+ \alpha 6)\ P1 + \alpha 1P0\}/B$

$(B-A)\ P1= \alpha 1\ P0$

$P1= \alpha 1\ P0/ (B-A)$

$P1=FP0$ … (28)

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

$$\sum_{i=0}^{13} Pi = 1$$

P0+ P1+ P2+ P3+ P4+ P5+ P6+ P7 P8+ P9+ P10+ P11+ P12=1

P0 (1+FG+H) =1

P0=1/ (1+FG+H)

P1=F/ (1+FG+H)

Where $A= (\alpha 1+ \alpha 2+ \alpha 3+ \alpha 4+\alpha 5+ \alpha 6)$

$B = (\alpha 1+ \alpha 2+ \alpha 3+ \alpha 4+ \alpha 5+ \alpha 6+\beta 1)$

$C= (\alpha 2+ \alpha 3+ \alpha 4+ \alpha 5+ \alpha 6)$

$E= \beta 1/ (A-C)$

A0 = P0 + P1

A0=1/ (1+FG+H) + F/ (1+FG+H)

A0= P0 (1+F)

Decision Matrix for Filler System (Conveyer belt speed):

β_1 \ α_1	0.00017	0.00018	0.00019	0.00020	0.00021	Constant Values
0.01	0.9749	0.9749	0.9749	0.9748	0.9748	α_2=0.00013 , β_2=0.05
0.02	0.9751	0.9751	0.9751	0.9751	0.9751	α_3=0.00023, β_3=0.02
0.03	0.9752	0.9752	0.9752	0.9752	0.9752	α_4=0.00025, β_4=0.04
0.04	0.9752	0.9752	0.9752	0.9752	0.9752	α_5=0.00019, β_5=0.06
0.05	0.9752	0.9752	0.9752	0.9752	0.9752	α_6=0.00011, β_6=0.05

Decision Matrix for Filler System (Sensors Assembly):

β_2 \ α_2	0.00011	0.00012	0.00013	0.00014	0.00015	Constant Values
0.03	0.9741	0.9738	0.9735	0.9732	0.9728	α_1=0.00019 , β_1=0.02
0.04	0.9750	0.9747	0.9745	0.9743	0.9740	α_3=0.00023, β_3=0.02
0.05	0.9755	0.9753	0.9751	0.9749	0.9747	α_4=0.00025, β_4=0.04
0.05	0.9758	0.9757	0.9755	0.9754	0.9752	α_5=0.00019, β_5=0.06
0.07	0.9761	0.9760	0.9758	0.9757	0.9756	α_6=0.00011, β_6=0.05

Decision Matrix for Filler System (Star Infeed Wheel):

β_3 \ α_3	0.00021	0.00022	0.00023	0.00024	0.00025	Constant Values
0.01	0.8170	0.8104	0.8038	0.7974	0.7911	α_1=0.00019 , β_1=0.02
0.02	0.8936	0.8897	0.8857	0.8818	0.8779	α_2=0.00013 , β_2=0.05
0.03	0.9225	0.9197	0.9169	0.9141	0.9113	α_4=0.00025, β_4=0.04
0.04	0.9376	0.9354	0.9333	0.9311	0.9289	α_5=0.00019, β_5=0.06
0.05	0.9470	0.9452	0.9434	0.9416	0.9398	α_6=0.00011, β_6=0.05

Decision Matrix for Filler System (Rotary Filler):

β_4 \ α_4	0.00023	0.00024	0.00025	0.00026	0.00027	Constant Values
0.02	0.9667	0.9663	0.9658	0.9653	0.9649	α_1=0.00019 , β_1=0.02
0.03	0.9703	0.9700	0.9697	0.9694	0.9691	α_2=0.00013 , β_2=0.05
0.04	0.9721	0.9719	0.9717	0.9714	0.9712	α_3 =0.00023, β_3=0.02
0.05	0.9732	0.9730	0.9728	0.9727	0.9725	α_5=0.00019, β_5=0.06
0.06	0.9739	0.9738	0.9736	0.9735	0.9733	α_6=0.00011, β_6=0.05

Decision Matrix for Filler System (Rotary Cork Attachment):

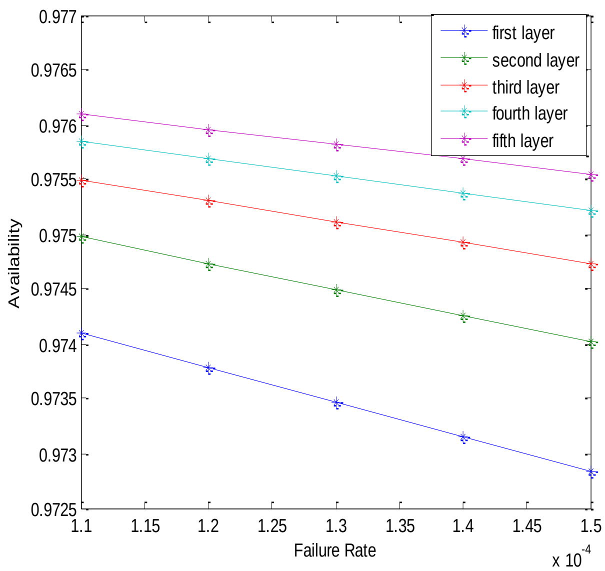
β_5 \ α_5	0.00017	0.00018	0.00019	0.00020	0.00021	Constant Values
0.04	0.9736	0.9733	0.9731	0.9728	0.9726	α_1=0.00019, β_1=0.02
0.05	0.9744	0.9742	0.9740	0.9738	0.9736	α_2=0.00013, β_2=0.05
0.06	0.9749	0.9747	0.9746	0.9744	0.9743	α_3=0.00023, β_3=0.02
0.07	0.9753	0.9751	0.9750	0.9749	0.9747	α_4=0.00025, β_4=0.04
0.08	0.9756	0.9754	0.9753	0.9752	0.9751	α_6=0.00011, β_6=0.05

Decision Matrix for Filler System (Conveyer Belt):

β_6 \ α_6	0.00009	0.00010	0.00011	0.00012	0.00013	Constant Values
0.03	0.9744	0.9740	0.9737	0.9734	0.9731	α_1=0.00019, β_1=0.02
0.04	0.9751	0.9748	0.9746	0.9744	0.9741	α_2=0.00013, β_2=0.05
0.05	0.9755	0.9753	0.9751	0.9749	0.9747	α_3=0.00023, β_3=0.02
0.06	0.9758	0.9756	0.9755	0.9753	0.9751	α_4=0.00025, β_4=0.04
0.07	0.9760	0.9759	0.9757	0.9756	0.9754	α_5=0.00019, β_5=0.06

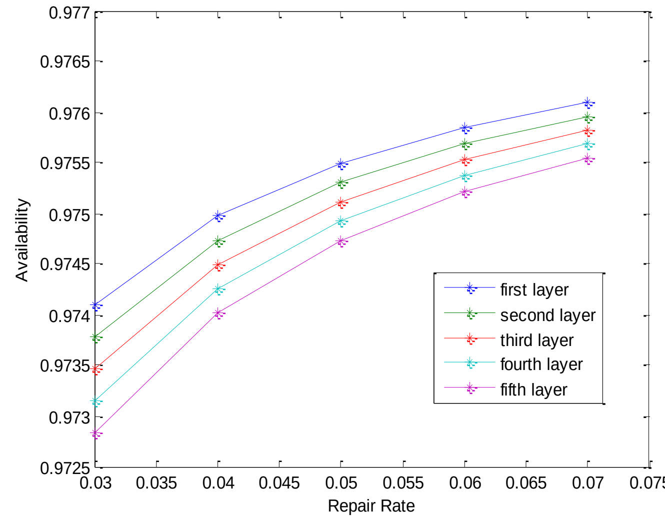
Analysis through Graph:
As we seen in the table the Availability changes as failure rate and repair rate changes. The most significant changes appears in Sensor Assambly the changes can be seen in the graphs below:

Graph A



Graph A: Failure Rate and Availability for Sensor Assambly

Graph B



Graph B: Repair Rate and Availability for Sensor Assambly

Conclusions:

The most critical sub-system of Filler system is "Sensor Assambly", 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 0.00011 to 0.00015 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 0.2 to0.5%.

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