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PERFORMANCE ANALYSIS OF A PROCESS INDUSTRY TO PROVIDE DECISION SUPPORT SYSTEM

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Abstract: The present paper deals with development of Decision Support System by performance analysis of Milk Powder Manufacturing System of VITA plant, Ambala using Markov Birth-Death process. The system comprises of five subsystem viz. Preheating system, Agitator, Pasteurizer, Drum Drier and Scraping Machine, Pulverized Machine connected in series. After drawing transition diagram, differential equations are developed and solved recursively using probabilistic approach. Normalizing conditions is used to predict steady state availability for different combinations of failure and repair rates. The decision matrix is also developed to facilitate the maintenance decision to be made to critical points where repair priority should be given.

Key words: Markov Birth-death process, Availability, Reliability, Maintainability

I. INTRODUCTION

System availability is defined as combination of reliability and maintainability which is a measure of performance of the system under specified conditions. Complex plant consists of systems/subsystems connected in series, parallel or a combination of these. Availability and maintainability of systems/subsystems in operation must be maintained at highest in order to have higher productivity which is ultimate goal of every industry. To achieve high production goals, system should remain operative (failure free run) for maximum possible duration.

II. LITERATURE REVIEW

Various researchers gave number of theories in the field availability and reliability for complex manufacturing industries. Tewari et. al.[2002] discussed behavioural analysis of crushing system in a sugar plant. Blischke [2003], Yadav et al. [2003] and Dai et al. [2003] performed reliability and availability analysis for several complex systems. Ocon et al. [2004] and Murthy et al. [2004] proposed a reliability and analysis technique using different modeling methods. Edwards et al. [2004] discussed the importance of simulation, an effective tool in improving the maintenance schedule in an automotive engine production facility and for effecting changes to decision maker's strategy over time. Gupta et al. [2005] evaluated reliability parameters of a butter manufacturing unit in a dairy plant taking into consideration exponentially distributed failure rates of various components. Lapa et al. [2006] presented a methodology for preventive maintenance policy evaluation based upon a reliability model using Genetic Algorithm. Zio et al. [2007] presented a Monte Carlo simulation model for the evaluation of the availability of a multi state and multi output offshore installation. Khanduja et al. [2008] discussed development of decision support system for washing unit of a paper plant. Gupta et al. [2009] developed a Markov model for performance evaluation of coal handling unit of a thermal power plant. Garg et al. [2010] discussed about the availability and maintenance scheduling of a repairable block-board manufacturing system. Kajal [2012] discussed the performance optimization for milk processing unit of a dairy plant at National Dairy Research Institute (N. D. R. I.), Karnal using Genetic Algorithm (G.A.). Guan [2012] developed an efficient analytical Bayesian method for reliability and system response updating based on Laplace and inverse first-order reliability computations. Pardeep [2013] developed a decision Support System for soft drink (beverage) Manufacturing plant using Markov Birth-death process. Wang [2013] discussed new approach, nested extreme response surface (NERS)

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which efficiently tackle time dependency issue in time-variant reliability analysis.

III. SYSTEM DESCRIPTION

Milk Powder manufacturing system consists of the following components:

Preheating System (A): It is used to heat the roller. The steam is allowed to move onto the roller still drum's surface achieve a temperature high enough to dry the milk film. The flow is allowed over the entire drum length.

Agitator (B): It works on the centrifugal force principle. Chilled milk from chiller is taken to the agitator where fat is separated from the milk. The skimmed milk is stored in milk silos for preparing milk powder. It consists of three components in series- motor, bearing and high speed gearbox. Failure of any one component causes failure of this system.

Pasteurizer (C): It pasteurizes the milk coming from pumping system. Here the cream is heated around 80^0 to 82^0 for no holding time. The purpose is to destroy pathogenic organism, to destroy undesirable organism, to inactivate the enzymes present and to make possible removal of volatile flavors. It consists of a motor and bearing in series.

Drum drier and scraping machine (D): The drum revolves and a thin film of milk is adhered to it which is dried by the time of a complete revolution and then scrapped by a blade. This machine consists of gearbox, motor, two drums and bearings in series.

Pulverized Machine (E): The scrapped milk is collected and fed into pulverized machine which converts it into the fine powder form. This fine powder is then packed and stored. This machine consists of gearbox, motor, two roller and bearing in series.

IV. ASSUMPTIONS AND NOTATIONS

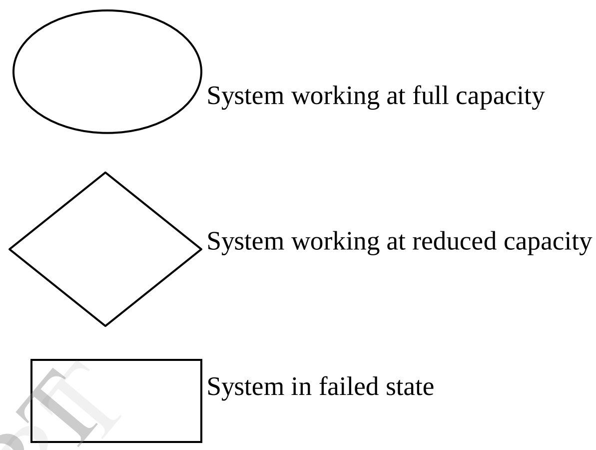
The following notations and assumptions are used for the purpose of mathematical modeling :

4.1 Assumptions

1. A repaired system is as good as new, performance wise, for a specified duration.
2. Failure and repair rates are constant over time and statistically independent.
3. There is no simultaneous failure i.e. not more than one failure occurs at a time.
4. Standby systems are of the same nature as that of active systems.
5. Sufficient repair facilities are provided.

4.2 Notations

The following symbols are associated with the system:
A,B,C,D,E : Subsystems in good operating state
D': D is working in reduced state
a,b,c,d,e : Indicates the failed state of A,B,C,D,E
λ_i : Mean constant repair rate
μ_i : Mean constant failure rate
$P_i(t)$: Probability that at time 't' all units are good and system is in i^{th} state



Performance Evaluation: The performance evaluation of the Milk Powder manufacturing system has been carried out with the help of probabilistic approach based upon Markov birth-death process. The differential equations are developed based on transition diagram as shown in figure 1, as follows:

$$P_0'(t) + (\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5)P_o(t) = \mu_1 P_1(t) + \mu_2 P_2(t) + \mu_3 P_3(t) + \mu_4 P_9(t) + \mu_5 P_5(t) \ldots . (1)$$

$$P_1'(t) + \mu_1 P_1(t) = \lambda_1 P_o(t) \ldots \ldots \ldots . (2)$$

$$P_2'(t) + \mu_2 P_2(t) = \lambda_2 P_o(t) \ldots \ldots \ldots . (3)$$

$$P_3'(t) + \mu_3 P_3(t) = \lambda_3 P_o(t) \ldots \ldots . . (4)$$

$$P_5'(t) + \mu_5 P_5(t) = \lambda_5 P_o(t) \ldots \ldots . (5)$$

$$P_4'(t) + (\lambda_1 + \lambda_2 + \lambda_3 + \lambda_5 + \lambda_6)P_4(t) = \mu_1 P_6(t) + \mu_2 P_7(t) + \mu_3 P_8(t) + \mu_5 P_{10}(t) + \lambda_4 P_o(t) \ldots \ldots \ldots . (6)$$

$$P_6'(t) + \mu_1 P_6(t) = \lambda_1 P_4(t) \ldots \ldots (7)$$

$$P_7'(t) + \mu_2 P_7(t) = \lambda_2 P_4(t) \ldots \ldots . (8)$$

$$P_8'(t) + \mu_3 P_8(t) = \lambda_3 P_4(t) \ldots \ldots (9)$$

$$P_9'(t) + \mu_4 P_9(t) = \lambda_6 P_4(t) \ldots \ldots (10)$$

$P'_{10}(t) + \mu_5 P_{10}(t) = \lambda_5 P_4(t) \ldots\ldots (11)$

In the process industry, we require long run availability of the system, which is obtained by putting $\frac{d}{dt} \rightarrow 0$ at $t \rightarrow \infty$ and taking probabilities independent of t.

For steady state availability, transition rates are taken to be constant.

$(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5)P_o - 1 = \mu_1 P_1 + \mu_2 P_2 + \mu_3 P_3 + \mu_4 P_4 + \mu_5 P_5 \ldots\ldots\ldots (12)$

$\mu_1 P_1 = \lambda_1 P_o \ldots\ldots (13)$

$\mu_2 P_2 = \lambda_2 P_o \ldots\ldots (14)$

$\mu_3 P_3 = \lambda_3 P_o \ldots\ldots\ldots (15)$

$\mu_5 P_5 = \lambda_5 P_o \ldots\ldots (16)$

$(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_5 + \lambda_6)P_4 = \mu_1 P_6 + \mu_2 P_7 + \mu_3 P_8 + \mu_5 P_{10} + \lambda_4 P_o \ldots\ldots (17)$

$\mu_1 P_6 = \lambda_1 P_4 \ldots\ldots\ldots (18)$

$\mu_2 P_7 = \lambda_2 P_4 \ldots\ldots\ldots\ldots (19)$

$\mu_3 P_8 = \lambda_3 P_4 \ldots\ldots\ldots (20)$

$\mu_4 P_9 = \lambda_6 P_4 \ldots\ldots\ldots (21)$

$\mu_5 P_{10} = \lambda_5 P_4 \ldots\ldots\ldots (22)$

Solving the above equations, we get the values of all state probabilities in terms of full working state probability i.e. P_o:-

$P_1 = N_1 P_o \ldots\ldots (23)$

$P_2 = N_2 P_o \ldots\ldots (24)$

$P_3 = N_3 P_o \ldots\ldots (25)$

$P_4 = Y_1 P_0 \ldots\ldots\ldots (26)$

$P_5 = N_5 P_o \ldots\ldots\ldots (27)$

$P_6 = N_1 Y_1 P_0 \ldots\ldots (28)$

$P_7 = N_2 Y_1 P_0 \ldots\ldots (29)$

$P_8 = N_3 Y_1 P_0 \ldots\ldots (30)$

$P_9 = \frac{\lambda_6}{\mu_4} Y_1 P_0 \ldots\ldots (31)$

$P_{10} = N_5 Y_1 P_0 \ldots\ldots (32)$

Where,

$N_1 = \frac{\lambda_1}{\mu_1}, \quad N_2 = \frac{\lambda_2}{\mu_2}, \quad N_3 = \frac{\lambda_3}{\mu_3}, \quad N_5 = \frac{\lambda_5}{\mu_5},$

$Y_1 = \frac{\lambda_4}{T_2 - \mu_1 N_1 - \mu_2 N_2 - \mu_3 N_3 - \mu_5 N_5}$

$T_1 = \lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5$

$T_2 = \lambda_1 + \lambda_2 + \lambda_3 + \lambda_5 + \lambda_6$

Using Normalizing conditions, i.e. Sum of all probabilities is equal to one

$$\sum_{i=0}^{10} P_i = 1$$

$$P_0 = \frac{1}{\left[1+N_1+N_2+N_3+N_5\left(1+N_1+N_2+N_3+\frac{\lambda_6}{\mu_4}+N_5\right)Y_1\right]}$$

Now Steady state availability is summation of all working state prob.

$A_v = P_0 + P_4 = [P_0 + Y_1 P_0]$

$A_v = [1 + Y_1]P_0$

Where P_0 = Probability of initial working state (0) with full capacity

Availability index which is derived from the above equation can be used for maintenance planning and scheduling of Milk Powder Manufacturing system.

Availability Analysis: The failure and repair rates of various subsystems of Milk Powder Manufacturing System are taken from the maintenance history sheet of plant. The performance analysis deals with quantitative analysis of all factors viz. states of nature and courses of action which also influence the maintenance decisions associated with system. The availability matrixes are generated to calculate the various availability levels for different combinations of failure and repair rates. The models are developed under the real decision making environment i.e. decision making under risk (probabilistic model) for the purpose of performance evaluation. Such models are used to implement the proper decision regarding maintenance of Milk Powder Manufacturing System of VITA plant.

V. RESULTS AND DISCUSSION

Table 1 to 5 show the effect of failure and repair rates of Pre-Heater, Agitator, Pasteurizer, Drum Drier and Scraping Machine, Pulverized Machine on the steady state availability of Milk powder manufacturing system.

Table 1 reveals that as failure rates of preheating system increases from 0.0005 (once in 2000 hours) to 0.00079 (once in 1266 hr), the availability decreases by 2.17%. Similarly as repair rates of Preheating system increases from 0.009 (once in 111 hr) to 0.025 (once in 40 hr), availability increases by 2.54%.
Table 2 depicts that as failure rate of Agitator increases from 0.008 (once in 125 hours) to 0.02 (once in 50 hr), the availability decreases by 6.88%. Similarly as repair rates of Agitator increases from 0.11 (once in 9 hr) to 0.35 (once in 3 hr), availability increases by 3.6 %.

Table 3 shows that as failure rates of Pasteurizer increases from 0.005 (once in 200 hours) to 0.014 (once in 72 hr), the availability decreases by 7.08 %. Similarly as repair rates of Pasteurizer increases from 0.08 (once in 13 hr) to 0.78 (once in 2 hr), availability increases by 4.07 %.

Table 4 depicts that as failure rate of Drum Drier and Scraping Machine increases from 0.0008 (once in 125 hours) to 0.02 (once in 50 hr), the availability decreases by 0.49 % . Similarly as repair rates of Drum Drier and Scraping Machine increases from 0.05 (once in 20 hr) to 0.10 (once in 10 hr), availability increases by 0.11 %.

Table 5 depicts that as failure rate of Pulverized Machine increases from 0.00009 (once in 11112 hours) to 0.0005 (once in 2000 hr), the availability decreases by 3.39 %. Similarly as repair rates of Pulverized Machine increases from 0.008 (once in 125 hr) to 0.040 (once in 25 hr), availability increases by 0.63 %.

VI. CONCLUSION

The developed availability model is used for performance evaluation of various subsystems of Milk powder manufacturing system. The availability matrix depicts the system performance for different combinations of failure and repair rate of various subsystems.

On the basis of repair rates, the maintenance priorities should be given as per following order:

1. Pasteurizer
2. Agitator
3. Pre-heater
4. Pulverized Machine
5. Drum Drier and Scraping Machine

These results might be highly beneficial to the plant management for performance evaluation and availability improvement of Milk powder manufacturing system.

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Figure 1 Transition Diagram of Milk Powder Manufacturing System

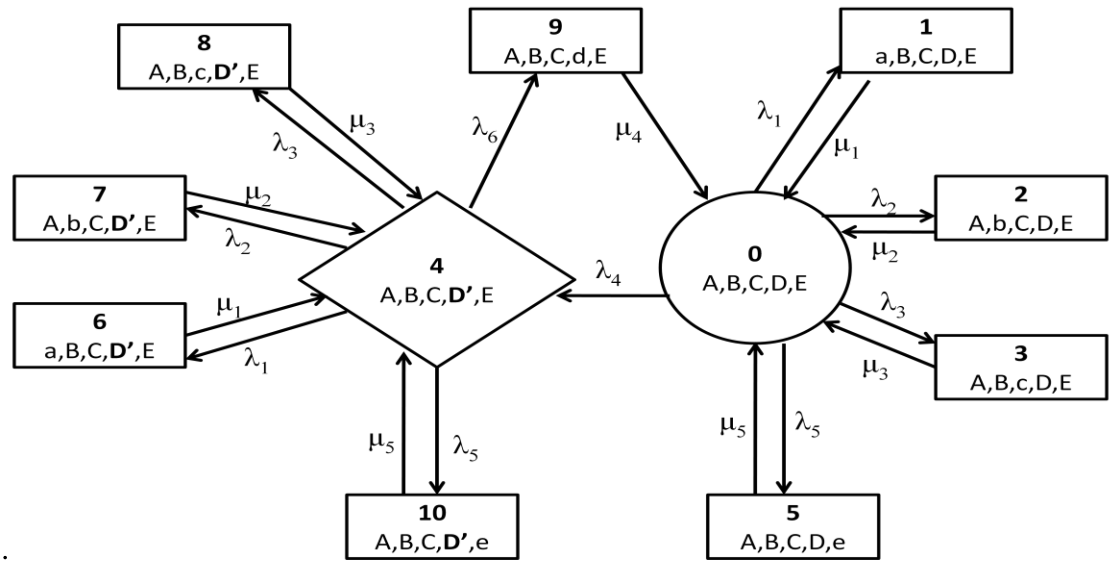

Table 1: Availability Matrix for Pre-heater

μ_1 \ λ_1	0.0005	0.00057	0.00065	0.00071	0.00079	
0.009	0.8314	0.8261	0.8201	0.8156	0.8097	λ_2=0.008, λ_3=0.005
0.010	0.8353	0.8304	0.8250	0.8209	0.8155	λ_4=0.0008, λ_5=0.00009
0.015	0.8471	0.8437	0.8401	0.8372	0.8334	λ_6=0.0008
0.018	0.8511	0.8483	0.8451	0.8427	0.8396	μ_2=0.11, μ_3=0.08
0.025	0.8568	0.8547	0.8524	0.8506	0.8483	μ_4=0.0008, μ_5=0.008

Table 2 Availability Matrix for Agitator

μ_2 \ λ_2	0.008	0.01	0.012	0.016	0.02	
0.11	0.8314	0.8191	0.8072	0.7843	0.7626	λ_1=0.0005, λ_3=0.005
0.18	0.8515	0.8436	0.8358	0.8207	0.8061	λ_4=0.0008, λ_5=0.00009
0.25	0.8606	0.8548	0.8491	0.8378	0.8268	λ_6=0.0008
0.30	0.8645	0.8597	0.8549	0.8454	0.8321	μ_1=0.009, μ_3=0.08

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0.35	0.8674	0.8632	0.8591	0.8508	0.8427	μ_4=0.0008, μ_5=0.008

Table 3 Availability Matrix for Pasteurizer

μ_3 \ λ_3	0.005	0.007	0.009	0.011	0.014	
0.08	0.8314	0.8146	0.7984	0.7828	0.7606	λ_1=0.0005, λ_2=0.008 λ_4=0.0008, λ_5=0.00009 λ_6=0.0008 μ_1=0.009, μ_2=0.11 μ_4=0.0008, μ_5=0.008
0.15	0.8521	0.8426	0.8333	0.8242	0.8109	
0.32	0.8651	0.8606	0.8561	0.8516	0.8449	
0.65	0.8711	0.8689	0.8667	0.8644	0.8611	
0.78	0.8721	0.8703	0.8684	0.8665	0.8638	

Table 4 Availability Matrix for Drum Drier and Scraping Machine

μ_4 \ λ_4	0.0008	0.0050	0.01	0.015	0.02	
0.05	0.8314	0.8291	0.8274	0.8263	0.8265	λ_1=0.0005, λ_2=0.008 λ_3=0.005, λ_5=0.00009 λ_6=0.0008 μ_1=0.009, μ_2=0.11 μ_3=0.008, μ_5=0.008
0.06	0.8315	0.8304	0.8290	0.8281	0.8274	
0.07	0.8316	0.8308	0.8295	0.8287	0.8282	
0.08	0.8325	0.8310	0.8299	0.8292	0.8287	
0.1	0.8325	0.8314	0.8305	0.8299	0.8295	

Table 5 Availability Matrix for Pulverized Machine

μ_5 \ λ_5	0.00009	0.0002	0.0003	0.0004	0.0005	
0.008	0.8314	0.8220	0.8137	0.8055	0.7975	λ_1=0.0005, λ_2=0.008 λ_3=0.005, λ_4=0.0008 λ_6=0.0008 μ_1=0.009, μ_2=0.11 μ_3=0.008, μ_4=0.05
0.016	0.8353	0.8306	0.8263	0.8220	0.8178	
0.024	0.8366	0.8335	0.8306	0.8277	0.8249	
0.032	0.8373	0.8349	0.8327	0.8306	0.8284	
0.040	0.8377	0.8358	0.8340	0.8323	0.8306	