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Research Paper

MAINTENANCE STRATEGY FOR BEER MANUFACTURING PLANT

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The present paper aims to propose methodology to evaluate availability of beer manufacturing unit in a realistic environment and based upon the evaluation, propose a maintenance planning regarding maintenance of plant machinery. Paper discussed three stages of system: good working state, reduced state and failed state. Failure and repair rates are assumed to be constant. The mathematical modelling of system is carried out on basis of probabilistic approach using Markov Birth-death process. After drawing transition diagram for the system, differential equations are developed which are further solved recursively using normalising conditions in order to develop the performance model using steady state availability. After that availability matrix and plots of failure/repair rates of all subsystems are prepared to decide availability trends using different combinations of failure and repair rates. The critical subsystems are identified with the help of performance analysis in terms of various availability levels from availability matrix. The maintenance planning of identified critical subsystems are proposed in order to have maintenance scheduling. Finding of this paper might be helpful to plant management for futuristic maintenance decisions.

Keywords: Markov birth-death process, Availability, Reliability, Maintainability

INTRODUCTION

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

LITERATURE REVIEW

Many researchers gave number of theories in the field of availability and reliability for complex

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manufacturing industries. Tewari *et al.* (2002) carried out behavioural analysis of crushing system in a sugar plant. Blischke (2003), Yadav *et al.* (2003) and Dai *et al.* (2003) performed availability and reliability and analysis for several complex systems. Ocon *et al.* (2004) and Murthy *et al.* (2004) proposed a reliability analysis technique using different modelling methods. Edwards *et al.* (2004) discussed the significance 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 different 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 (NDRI), Karnal using Genetic Algorithm (GA). 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) which efficiently tackle time dependency issue in time-variant reliability analysis.

SYSTEM DESCRIPTION

Mashing Kettle

The malt is crushed in a malt mill to break apart the grain kernels, increase their surface area, and separate the smaller pieces from the husks. The resulting grist is mixed with heated water in a vat called a "mash tun" for a process known as "mashing".

Lauter Tun

After the mashing, the mash is pumped to a lauter tun where the resulting liquid is strained from the grains in a process known as lautering. The lauter tun generally contains a slotted "false bottom" or other form of manifold which acts as a strainer allowing for the separation of the liquid from the grain.

Cylindrical Conical Tank Fermenter

Fermenters are also called CCT's (Cylindrical Conical Tanks), primary fermentor or unitanks, as they are used both for fermenting and lagering. Fermenting is the process during which the yeast transforms the wort into beer. Lagerings takes place after fermenting and is the time given to the beer to stabilize and age after fermenting.

Diatomaceous Earth steel Beer Filter

Beer filters are used to filter yeast, proteins and other impurities out of the beer as it is being transferred to the distribution tanks or

CBT's (Clear Beer Tanks). For beer filtration you can opt for a food grade DE filter (Diatomaceous Earth steel beer filter or Kieselguhr filter) or a plate and frame filter, also called plate and frame press, with filter pads.

ASSUMPTIONS AND NOTATIONS

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

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.

Notations

The following symbols are associated with the system:

A, *B*, *C*, *D*: Subsystems in good operating state.

$\overline{C}$: *C* is working in reduced state

a, *b*, *c*, *d*, : Indicates the failed state of *A*, *B*, *C*, *D*,

a_i: Mean constant repair rate

«_i: Mean constant failure rate

$P_i(t)$: Probability that at time '*t*' all units are good and system is in i^{th} state

System working at full capacity

System working at reduced capacity

System in failed state

PERFORMANCE EVALUATION

The performance evaluation of the 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:

$$P_0'(t)+(a_1+a_2+a_3+a_4)P_0(t)$$

$$=\text{«}_1P_1(t)+\text{«}_2P_2(t)+\text{«}_3P_3(t)+\text{«}_4P_4(t) \quad ...(1)$$

$$P_1'(t)+\text{«}_1P_1(t)=a_1P_0(t) \quad ...(2)$$

$$P_2'(t)+\text{«}_2P_2(t)=a_2P_0(t) \quad ...(3)$$

$$P_4'(t)+\text{«}_4P_4(t)=a_4P_0(t) \quad ...(4)$$

$$P_3'(t)+(a_1+a_2+a_3+a_4)P_3(t)$$

$$=\text{«}_1P_5(t)+\text{«}_2P_6(t)+\text{«}_4P_8(t)+a_3P_0 \quad ...(5)$$

$$P_5'(t)+\text{«}_1P_5(t)=a_1P_3(t) \quad ...(6)$$

$$P_6'(t)+\text{«}_2P_6(t)=a_2P_3(t) \quad ...(7)$$

$$P_7'(t)+\text{«}_3P_7(t)=a_5P_3(t) \quad ...(8)$$

$$P_8'(t)+\text{«}_4P_8(t)=a_4P_3(t) \quad ...(9)$$

In the process industry, we require long run availability of the system, which is obtained by putting derivate equal to zero as $t\to\infty$ and taking probabilities independent of *t*.

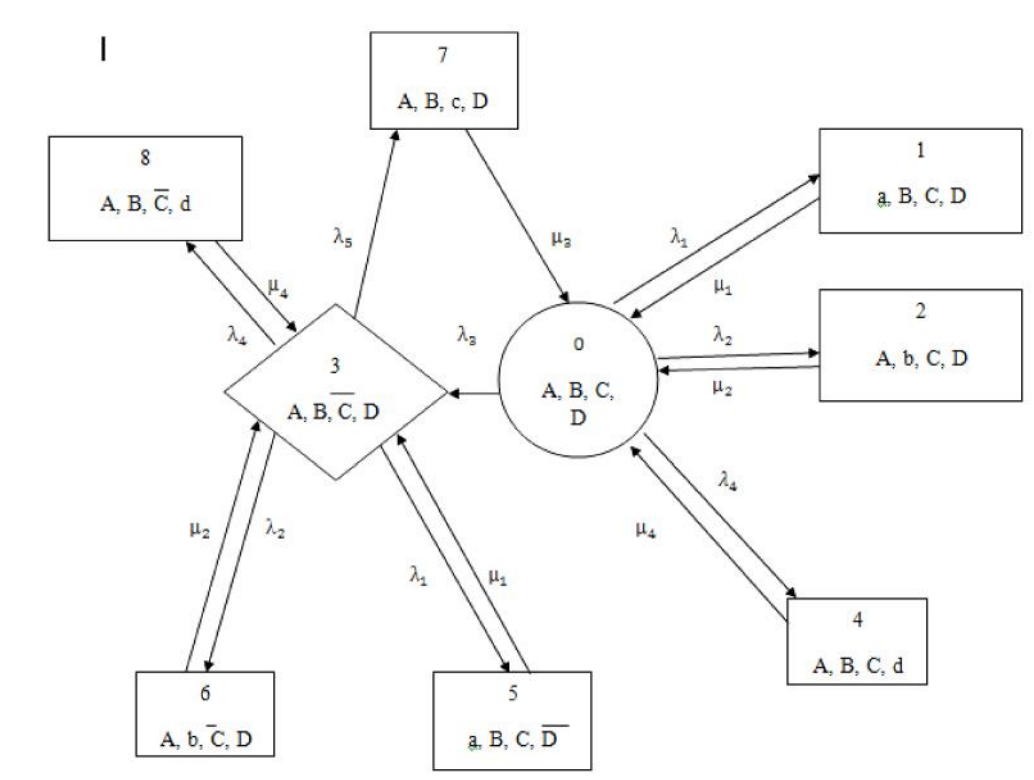
For steady state availability, transition rates are taken to be constant.

$$(a_1+a_2+a_3+a_4)P_0-1=\text{«}_1P_1+\text{«}_2P_2+\text{«}_3P_3+\text{«}_4P_4 \quad ...(10)$$

$$\text{«}_1P_1=a_1P_0 \quad ...(11)$$

$$\text{«}_2P_2=a_2P_0 \quad ...(12)$$

Figure 1: Transition Diagram



$$\mu_4 P_4 = \lambda_4 P_0 \qquad ...(13)$$

$$(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4) P_3 = \mu_1 P_5 + \mu_2 P_6 + \mu_4 P_8 + \lambda_3 P_0 \qquad ...(14)$$

$$\mu_1 P_5 = \lambda_1 P_3 \qquad ...(15)$$

$$\mu_2 P_6 = \lambda_2 P_3 \qquad ...(16)$$

$$\mu_4 P_8 = \lambda_4 P_3 \qquad ...(17)$$

$$\mu_3 P_7 = \lambda_5 P_3 \qquad ...(18)$$

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

$$P_1 = N_1 P_0 \qquad P_5 = N_1 Y_1 P_0$$

$$P_2 = N_2 P_0 \qquad P_6 = N_2 Y_1 P_0$$

$$P_3 = Y_1 P_0 \qquad P_7 = N_4 Y_1 P_0$$

$$P_4 = N_4 P_0 \qquad P_8 = \left(\frac{\lambda_5}{\mu_5}\right) Y_1 P_0$$

where $N_1 = \left(\frac{\lambda_1}{\mu_1}\right), N_2 = \left(\frac{\lambda_2}{\mu_2}\right), N_4 = \left(\frac{\lambda_4}{\mu_4}\right)$

$$Y_1 = (\lambda_3)/(T_2 - N_1\mu_1 - N_2\mu_2 - N_4\mu_4)$$

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

$$T_2 = \lambda_1 + \lambda_2 + \lambda_4 + \lambda_5$$

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

$$\sum_{i=0}^{8} P_i = 1$$

$$P_0 = \frac{1}{1 + N_1 + N_2 + N_4 + \left\{1 + N_1 + N_2 + N_4 + \left(\frac{\lambda_5}{\mu_3}\right)\right\} Y_1}$$

Now Steady state availability is summation of all working state probabilities:

$$A_b = P_0 + P_3$$

$$A_b = [1 + Y_1] P_0$$

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 system.

AVAILABILITY ANALYSIS

The failure and repair rates of various subsystems of plant are taken from the maintenance history sheet of plant. The performance analysis deals with quantitative analysis of factors viz. states of nature and courses of action which also persuade the maintenance decisions related with system. The availability matrixes are developed to calculate the availability levels using various combinations of failure and repair rates. The models are generated under the real decision making environment, i.e., decision making under risk (probabilistic model) for the purpose of performance evaluation.

RESULTS AND DISCUSSION

Tables 1 to 4 show the effect of failure and repair rates of Mashing Kettle, Lauter Tun, Cylindrical Conical Tank Fermenter, Diatomaceous Earth steel beer filter on the steady state availability of beer manufacturing unit.

Table 1 reveals that as failure rates of Mashing Kettle system increases from 0.00007 to 0.00035, the availability decreases by 2.31%. Similarly as repair rates of Mashing Kettle system increases from 0.009 to 0.013, the availability increases by 0.87%.

Table 2 depicts that as failure rates of Lautering Tun system increases from 0.008 to 0.012, the availability decreases by 2.68%. Similarly as repair rates of Lautering Tun system increases from 0.11 to 0.15, the availability increases by 2.13%.

Table 3 shows that as failure rates of Cylindrical Conical Tank Fermenter system increases from 0.005 to 0.009, the availability decreases by 1.93%. Similarly as repair rates of Cylindrical Conical Tank Fermenter system increases from 0.08 to 0.12, the availability increases by 2.39%.

Table 1: Availability Matrix for Mashing Kettle

a$_1$ / «$_1$	**0.00007**	**0.00014**	**0.00021**	**0.00028**	**0.00035**	
0.009	0.8722	0.8663	0.8605	0.8548	0.8491	a$_2$ = 0.008
0.010	0.8728	0.8675	0.8622	0.8570	0.8519	«$_2$ = 0.11
0.011	0.8732	0.8684	0.8636	0.8589	0.8543	a$_3$ = 0.005
0.012	0.8736	0.8692	0.8648	0.8605	0.8562	«$_3$ = 0.08
0.013	0.8740	0.8699	0.8658	0.8618	0.8578	a$_4$ = 0.0008 «$_4$ = 0.05 a$_5$ = 0.008

Table 2: Availability Matrix for Lauter Tun

«$_2$ \ a$_2$	**0.008**	**0.009**	**0.010**	**0.011**	**0.012**	
0.11	0.8722	0.8653	0.8586	0.8519	0.8454	a$_1$ = 0.00007
0.12	0.8768	0.8704	0.8642	0.8580	0.8519	«$_1$ = 0.009
0.13	0.8808	0.8748	0.8690	0.8632	0.8575	a$_3$ = 0.005
0.14	0.8842	0.8786	0.8732	0.8677	0.8624	«$_3$ = 0.08
0.15	0.8872	0.8820	0.8768	0.8717	0.8667	a$_4$ = 0.0008
						«$_4$ = 0.05
						a$_5$ = 0.008

Table 3: Availability Matrix for Cylindrical Conical Tank Fermenter

«$_3$ \ a$_3$	**0.005**	**0.006**	**0.007**	**0.008**	**0.009**	
0.08	0.8536	0.8490	0.8445	0.8401	0.8343	a$_1$ = 0.00007
0.09	0.8582	0.8541	0.8501	0.8461	0.8421	«$_1$ = 0.009
0.10	0.8631	0.8594	0.8557	0.8521	0.8485	a$_2$ = 0.008
0.11	0.8672	0.8638	0.8604	0.8571	0.8538	«$_2$ = 0.11
0.12	0.8706	0.8675	0.8644	0.8613	0.8582	a$_4$ = 0.0008
						«$_4$ = 0.05
						a$_5$ = 0.008

Table 4: Availability Matrix for Diatomaceous Earth Steel Beer Filter

«$_4$ \ a$_4$	**0.0008**	**0.0012**	**0.0016**	**0.0020**	**0.0024**	
0.05	0.8722	0.8661	0.8602	0.8543	0.8485	a$_1$ = 0.00007
0.06	0.8742	0.8691	0.8641	0.8592	0.8543	«$_1$ = 0.009
0.07	0.8757	0.8713	0.8670	0.8627	0.8585	a$_2$ = 0.008
0.08	0.8768	0.8729	0.8691	0.8654	0.8616	«$_2$ = 0.11
0.09	0.8776	0.8742	0.8708	0.8675	0.8641	a$_3$ = 0.005
						«$_3$ = 0.08
						a$_5$ = 0.008

Table 4 shows that as failure rates of Diatomaceous Earth Filter system increases from 0.0008 to 0.0024, the availability decreases by 2.31%. Similarly as repair rates of Cylindrical Conical Tank Fermenter system increases from 0.05 to 0.09, the availability increases by 1.56%.

CONCLUSION

The availability model developed in this research is used for performance evaluation of various subsystems of beer 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. Cylindrical conical tank fermenter
2. Lautering tun
3. Diatomaceous Earth Filter
4. Mashing tun

These results may be highly beneficial to the plant management for performance evaluation and availability enhancement of plant.

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