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Availability Analysis of Digestive Unit of A Paper Plant

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Abstract

The present paper availability analysis of Digestive Unit of a paper plant has been done using Markov Modeling. Here we consider three states of various subsystems i.e. good, reduced and failed. The failure and repair rates of each subsystem are assumed to be constant and statistically independent. Mathematical modeling of the system is done with the help of markov birth-death process. The various differential equations have been derived from state transition diagram. After that equation are solved using normalizing conditions and recursive method. The various steady state availability levels has been determined by using various combinations of failure and repair rates. Based upon various performance level in terms of availability are obtained. The effect of failure and repair rates of each subsystems on the performance of digestive system of a paper plant has been studied.

Keywords

Availability, Markov Approach, Digestive Unit, Paper Plant

I. Introduction

With the continuous improvement in technology, the industrial systems are getting more and more complex and thus to run these systems failure-free is very tedious task. A plant/industry cannot attain success if its systems are unreliable and unavailable. The availability analysis is desirable for long working duration with good performance level of the systems in the industries to reduce the cost and productivity. Thus, the reliability engineering is a vital tool to figure out the systems performance which is widely used now days. The industrial systems are subjected to failures due to various reasons such as improper design, poor maintenance and wrong operations etc. The failed systems can be brought back into working condition with in minimum possible time after repair. The performance of these systems is computed in term of availability using mathematical modeling. The mechanical systems have attracted the attention of several researchers in the area of reliability analysis from last four decades. Dyal and Singh [1] studied reliability analysis of a system in a fluctuating environment. Deepika Garg et.al.[2] developed the mathematical model of a cattle feed plant using a birth-death Markov Process. Jorn Vatn and Terje Aven [3] touched the various techniques for maintenance optimization in Norwegian railways. Kumar et.al. [4] discussed the availability of the crystallization system in the Sugar Industry under Common – Cause Failure. Kiureghian and Ditlevson [5] analyzed the availability, reliability and downtime of system with repairable components. Rajiv Khanduja et. al [6] reported the availability analysis of the bleaching system of a paper plant. Tewari et.al. [7] analyzed the performance evaluation and optimization for urea crystallization system in a fertilizer plant using Genetic Algorithm. Reattieri et al [8] estimate the reliability characteristics of a light commercial vehicle manufacturing system using failure process modeling.

II. System Description

The process flow diagram of Digestive system of paper plant is shown in fig. no.1. It consist four subsystems as described below:

Subsystem Z_1: It consists of one screw feeder. The function of screw feeder is to extract the wooden chips from storage silos and transfer it to the belt conveyor .when screw feeder fail, it causes the complete failure of the unit.

Subsystem Z_2: It consists of one belt conveyor to carry the chips. When belt conveyor fails, it causes the complete failure of the unit.

Subsystem Z_3: It consists of one shuttle conveyor to carry the chips from belt conveyor to digester.

Subsystem Z_4: It consists of three digesters in parallel to cook the wooden chips. If the one unit digester fails, the system is subjected to reduce capacity .when all the three digesters fail at a time, it causes the complete failure of the unit.

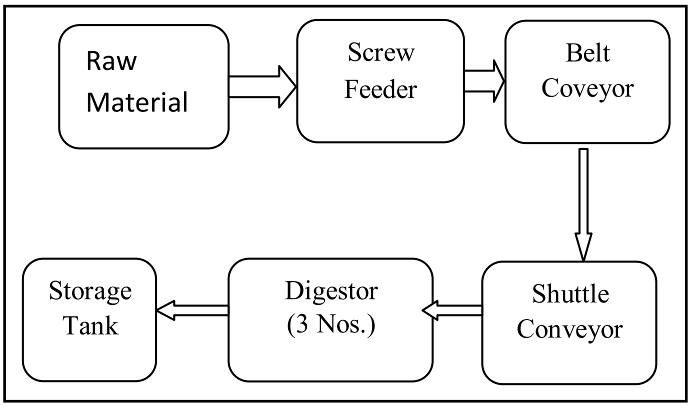

Fig. 1: Process Flow Diagram of Digestive Unit

III. Assumptions and Notations

Assumptions

Failure and repair rates for each subsystem are constant and statistically independent.

- There are no simultaneous failures.
- Performance wise a repaired unit is as good as new.
- Subsystem failure/repair follows exponential distribution.
- System may work in reduced capacity/efficiency.
- All the units are initially operating and are in working state.

Notations

Z_1, Z_2, Z_3, Z_4	: Represent working state
z_1, z_2, z_3, z_4	: Failed state
$\lambda_1, \lambda_2, \lambda_3, \lambda_4$,	: Failure rates of Z_1, Z_2, Z_3, Z_4
$\mu_1, \mu_2, \mu_3, \mu_4$,	: Repair rates of Z_1, Z_2, Z_3, Z_4.
$P_i(t)$	: Probability at time 't' and the system is in i^{th} state.
'	: Derivatives w.r.t. 't'

Based on above assumptions and notations, the State Transition Diagram of digestive system has been developed as shown in fig. 2.

III. Performance Modeling

The differential equations associated with the transition diagram shown in fig. no. 2, are developed on the basis of Markov birth-death process. Various probability considerations generate the following sets of differential equations:

$$P_0'(t)+(\lambda_1+\lambda_2+\lambda_3+\lambda_4)P_0(t)=\mu_1P_3(t)+\mu_2P_4(t)+\mu_3P_5(t)+\mu_4P_1(t) \quad (1)$$

$$P_1'(t)+(\lambda_1+ \lambda_2+ \lambda_3+ \lambda_4)P_1(t)+\mu_4P_1(t)= \mu_1P_6(t)+\mu_2P_7(t)+ \mu_3P_8(t)+ \mu_4P_2(t)+ \lambda_4 P_0(t) \quad (2)$$

$P_2'(t)+ (\lambda_1+ \lambda_2+ \lambda_3+ \lambda_4+\mu_4)P_2(t)= \mu_1P_9(t)+\mu_2P_{10}(t)+ \mu_3P_{11}(t)+ \mu_4P_{12}(t)+ \lambda_4 P_1(t)$ (3)
$P'_j(t)+\mu_iP_j(t)=\lambda_iP_k(t)$ (4)
Where,
(for i=1,2,3, j=3,4,5 when k=0)
(for i=1,2,3, j=6,7,8 when k=1)
(for i=1,2,3,4 j=9,10,11,12 when k=2)
Initial conditions at time t = 0 are Pi(t)=1 for i=0, Pi(t)=0 for $i\neq0$ (5)
Steady State analysis i.e. when $t\rightarrow\infty$ and $d/dt\rightarrow 0$ applying on set of first order differential (1) to (5) we get:
$(\lambda_1+ \lambda_2+ \lambda_3+ \lambda_4)P_0= \mu_1P_3+ \mu_2P_4+ \mu_3P_5+ \mu_4P_1$
$(\lambda_1+ \lambda_2+ \lambda_3+ \lambda_4+ \mu_4)P_1= \mu_1P_6+ \mu_2P_7+ \mu_3P_8+ \mu_4P_2+ \lambda_4P_0$
$(\lambda_1+ \lambda_2+ \lambda_3+ \lambda_4+ \mu_4)P_2= \mu_1P_9+ \mu_2P_{10}+ \mu_3P_{11}+ \mu_4P_{12}+ \lambda_4P_1$
$P'_j+\mu_iP_j=\lambda_iP_k$
Where,
(for i=1,2,3, j=3,4,5 when k=0)
(for i=1,2,3, j=6,7,8 when k=1)
(for i=1,2,3,4 j=9,10,11,12 when k=2)
Solving these equations and using normalizing condition, we get:

$$\sum_{i=1}^{12} P_i = 1$$

$$P_1 = \left[1 + P_2 + P_3 + \cdots \ldots \ldots + P_{12}\right]^{-1}$$

The Steady State Availability of the system A_{ss} is given by
$A_{ss} = P_0 + P_1 + P_2$

V. Performance Analysis

The effect of failure and repair rates of various subsystems comprising the system are examined and their impact on system availability is shown in the following tables:

A. Effect of Failure and Repair Rates of Screw Feeder on Availability of the System:

Table 1: Effect of Failure and Repair Rates of Screw Feeder on Availability of the System:

λ_1/μ_1	0.003	0.005	0.009	0.012
0.25	0.9656	0.9582	0.9437	0.9332
0.35	0.9688	0.9635	0.9530	0.9452
0.45	0.9706	0.9664	0.9582	0.9521
0.55	0.9717	0.9683	0.9615	0.9565

B. Effect of Failure and Repair Rates of Belt Conveyor on Availability of the System:

Table 2: Effect of Failure and Repair Rates of Belt Conveyor on Availability of the System:

λ_2/μ_2	0.003	0.005	0.009	0.012
0.25	0.9656	0.9582	0.9437	0.9332
0.35	0.9688	0.9635	0.9530	0.9452
0.45	0.9706	0.9664	0.9582	0.9521
0.55	0.9717	0.9683	0.9615	0.9565

C. Effect of Failure and Repair Rates of Shuttle Conveyor on Availability of the System:

Table 3: Effect of Failure and Repair Rates of Shuttle Conveyor on Availability of the System:

λ_3/μ_3	0.003	0.005	0.009	0.012
0.25	0.9656	0.9584	0.9444	0.9341
0.35	0.9687	0.9635	0.9533	0.9459
0.45	0.9704	0.9664	0.9584	0.9525
0.55	0.9715	0.9682	0.9617	0.9568

D. Effect of Failure and Repair Rate of Digester on Availability of the System:

Table 4: Effect of Failure and Repair Rate of Digester on Availability of the System:

λ_4/μ_4	.002	.005	.009	0.012
0.06	0.9656	0.9655	0.9654	0.9653
0.1	0.9660	0.9657	0.9656	0.9655
0.15	0.9663	0.9660	0.9658	0.9657
0.2	0.9765	0.9662	0.9660	0.9658

VI. Results and Discussion

From table no. 1 to 4, it has been revealed that the increase in failure and repair rates of various subsystems affects the availability of the system and need to be control.
Table 1 shows the effect of failure and repair rate of screw feeder on the long run availability of digestive unit, as the failure rate (λ_1) increases from 0.003 to 0.012 the system availability decreases significantly by 3.3%. Similarly as the repair rate (μ_1) increases from 0.25 to 0.55, the availability of the system increases 0.63%.
Table 2 reveals the effect of failure and repair rate of belt conveyor on the availability of the system, as the failure rate (λ_2) increases from 0.003 to 0.012 the system's availability reduces by 3.3%. Similarly as the repair rate (μ_2) increases from 0. 25 to .45, the unit availability increases by 0.6%.
Table 3 shows the effect of failure and repair rates of the shuttle conveyor on the availability of system, as the failure rate (λ_3) increases from 0.003 to 0.012 the availability decreases by 3.2%. Similarly as the repair rate (μ_3) increases from 0.25 to 0.45 the availability increases by 0.6%.
Table 4 shows the effect of failure and repair rates of the Digester on the availability of the system, as the failure rate (λ_5) increases from 0.002 to 0.012 the availability decreases by 0.03%. Similarly as the repair rate (μ_5) increases from 0.06 to 0.2 the availability increases by 1.1%.

VII. Conclusion

The performance analysis of Digestive unit of paper plant has been done with the help of mathematical modeling using probabilistic approach. The results are shown in Tables 1 to 4 is derived to assists the maintenance decisions
The results clearly indicate that Digester is the most critical component of the system. Other subsystem almost has same effect on the availability of the system.

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References

[1] Dayal,B., Singh, J.,"Reliability analysis of a system in a fluctuating environment", Micro electron Reliability, Vol. 32, pp. 601-3, 1992.

[2] Garg Deepika, Singh, Jai, Kumar, Kuldeep,"Performance Analysis of a Cattle Feed Plant", The Icfai University Journal of Science & Technology, Vol. 5, No. 2, pp. 83-94, 2009.

[3] Jorn Vatn, Treje Aven,"An approach to maintenance optimization where safety issues are important", Reliability Engineering and System Safety, Vol. 95, No. 1, pp. 58-63, 2010.

[4] Kumar, D., Singh, J., Pandey P.C.,"Availability of the Crystallization System in the Sugar Industry under Common – Cause Failure", IEEE Transactions on Reliability, Vol. 41, No. 1, pp. 85-91, 1992.

[5] Kiureghian A.D., Ditlevson O.D.,"Availability, Reliability & downtime of system with repairable components", Reliability Engineering and System Safety, Vol. 92, Issue 2, pp. 66-72, 2007.

[6] Rajiv Khanduja, Tewari, P.C., Dinesh Kumar,"Availability Analysis of Bleaching System of Paper Plant. Journal of Industrial Engineering", Udyog Pragati, N.I.T.I.E. Mumbai (India), Vol. 32 No.1, pp. 24-29, 2008.

[7] Tewari, P.C., Kumar, S., Sunand Kumar, Meenu,"Performance Evaluation and Optimization for Urea Crystallization system in a Fertilizer Plant using Genetic Algorithm Technique", International Journal of Applied Engineering Research, Vol. 04, No. 6, pp.1093-1105, 2009.

[8] Regattieri, A., Manzini, R., Battini, D.,"Estimating reliability characteristics in the presence of censored data: A case study in a light vehicle manufacturing system", Reliability Engineering and System Safety , No. 95, pp. 1093-1102, 2010.

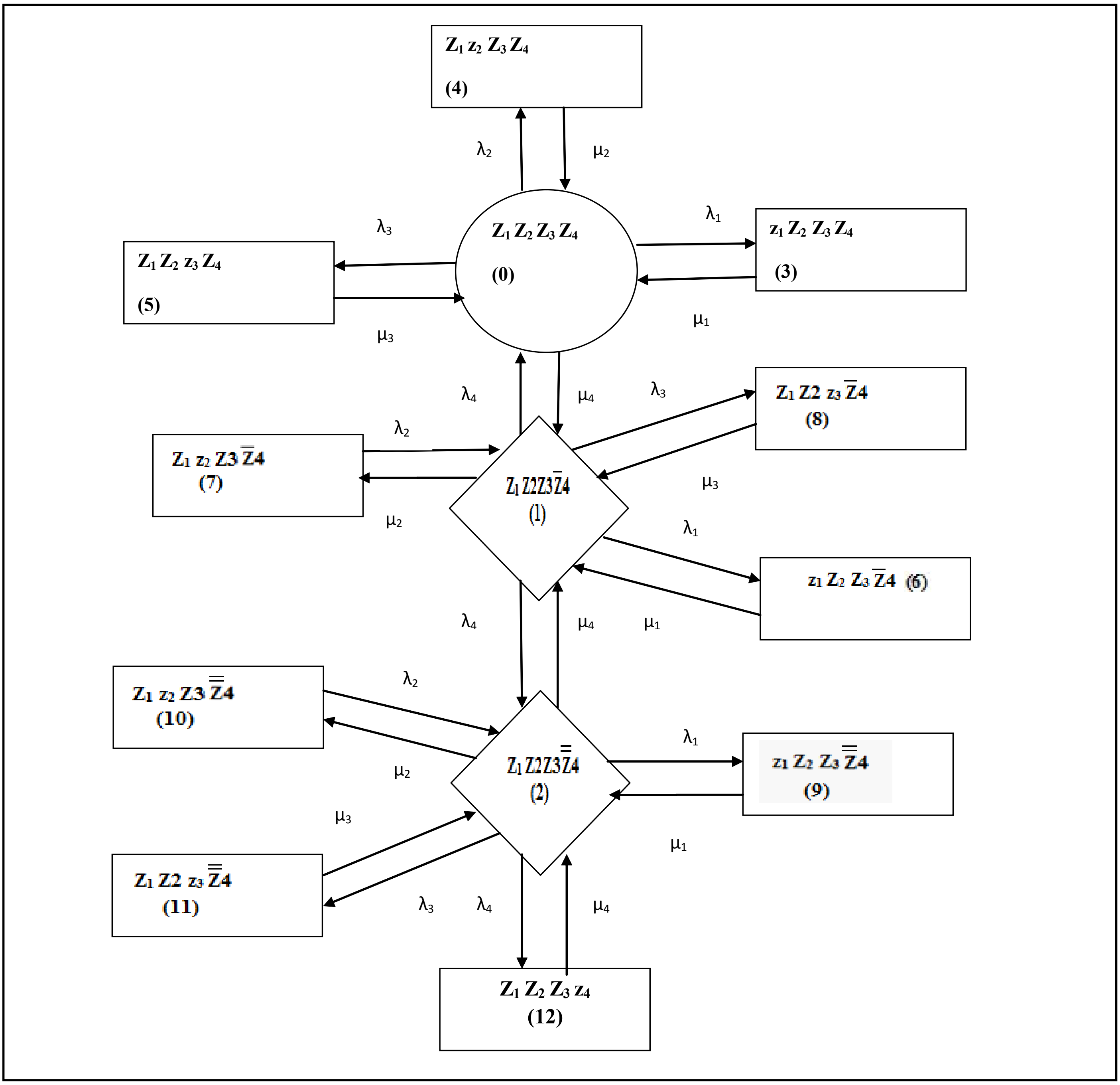

Fig. 2: State Transition Diagram of Digestive unit of a Paper Plant