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AVAILABILITY ASSESSMENT AND DETERMINATION OF MAINTENANCE PRIORITIES FOR CRUSHING UNIT OF A SUGAR PLANT

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Abstract

This paper presents an assessment of operational reliability of crushing unit of a sugar plant. On the basis of the analyses, this paper presents the unit element that was found to be most critical and the unit element which is least critical. In process plants having increasing demand for its product, the effective operation is very important. This must be met by increasing its production. Prior to an increase in production, reliability evaluation and maintenance planning are unavoidable. Ultimate aim is to increase the performance of the machineries without compromising safety or environmental issues. Maintenance strategies of the plant affect the performance of machineries and hence affect production. Thus it is considered as the first step to improve reliability of components. Calculating availability of the plant will give a good measure of reliability of the components in the system. Reliability evaluation plays an important role in improving plant availability. This work discusses the reliability modeling and availability assessment of crushing unit of the sugar plant concerned. A model for improving the availability of the crushing unit of the plant has been proposed. By applying this model, an optimum maintenance priority level can be shaped.

1. INTRODUCTION

Reliability, Availability and Maintainability (RAM) analyses are at the basis of informed maintenance decision-making and thus are essential for the management of profitable and safe production plants and assets. In this work, we are interested in sugar plant, where the harsh operating environment and extreme operating conditions not only demand addressing peculiar technical issues in design and construction, but also greatly challenge maintenance engineering, as the harsh environment renders it difficult to perform labor actions, with consequent large downtimes and business interruptions and affects the degradation processes, and therefore the reliability of components and systems. For these reasons, it is fundamental that RAM analyses of sugar plant give due account to the influence of the environmental and operational parameters of the sugar plant concerned. Since failure cannot be prevented entirely, itis important to minimize both its probability of occurrence and the impact of failures when they do occur. Maintenance costs are a major part of the total operating costs of all manufacturing or production plants, and depending on the specific industry, maintenance costs can represent between 15% and 60% of the cost of the goods produced. In today's competitive environment, companies are under intense pressure to sell their products in the market. Process plants having high demand for its product may have to run for more times. Without planning a preventive maintenance schedule, failures can happen in the process units at any level. Downtime happens only when there is a replacement or repair for worn-out parts. The time for which the components work successfully between its replacements is defined as its life. Reliability, describes the ability of a system or component to function under specified conditions for a specified period of time. It is theoretically defined as the probability of failure, the frequency of failures, or in terms of availability. The use of less reliable components and the lack of perfect maintenance schedule are main concerns and will lead to plant failure eventually. Unexpected failures usually have adverse effects on the environment and may result in major accidents. The main challenge is to implement a maintenance strategy which maximizes availability and efficiency of the system/unit, decrease the rate of deterioration of the components, ensures safety and environmental friendly operation, and reduces the total cost of the operation. This can be achieved only by adopting a structured approach to the study of component failure and the execution of an optimum strategy for inspection and maintenance. This paper discusses the reliability modeling and availability assessment of crushing unit of the sugar plant concerned.

2. LITERATURE REVIEW

Vora et al. (2011) discussed the simulation model for stochastic analysis and performance evaluation of steam generation system of a thermal power plant. Shakuntla et al. (2011) dealt with reliability analysis of polytube industry using supplementary variable technique", Khanduja et al. (2011) discussed the steady state behavior and maintenance planning of a bleaching system in a paper plant. Brissaud et al. (2011) presented the reliability analysis for new technology-based transmitters. Garg et al. (2012) discussed the stochastic behavior analysis of complex repairable industrial systems utilizing uncertain data. Garg et al. (2013) predicted the uncertain behavior of press unit in a paper industry using artificial antcolony and fuzzy lambda–tau methodology. Doostparast et al. (2014) discussed areliability based approach to optimize preventive maintenance scheduling for coherent system. Cekyay et al. (2015) dealt with reliability, MTTF and Steady-state Availability Analysis of Systems with Exponential Lifetimes.Kumar et al. (2016) dealt with the maintenance priorities for a repairable system of a thermal power plant subject to availability constraint. They considered a repairable system consisting of flue gases and air system for deciding the maintenance priorities. Based upon various availability values, performance of each subsystem is analyzed. Consequently, maintenance priorities are decided for all the subsystems of a thermal power plant. Sabouhi et al. (2016) discussed the reliability modeling and availability analysis of combined cycle power plants.Kumar et al. (2016) dealt with maintenance strategy for a system of a thermal power plant. Kumar et al. (2017) discussed the time dependent availability analysis of rice finishing and grading system of a rice milling plant using markovian approach to identify the critical subsystem for deciding the maintenance priorities from maintenance view point.

3. DESCRIPTION OF CRUSHING UNIT

The Crushing Unit of a sugar plant comprises of three main subsystems with following description:

I. Subsystem B_1: It consists of four set of crushers in series. The function of crushers is to extract the juice by squeezing the pulp like mass of cane under high pressure. The failure of anyone set of crusher causes complete failure of the unit.

II. Subsystem B_2: It comprises of three inter-carriers in series. The failures of any one inter carrier causes complete failure of the unit.

III. Subsystem B_3: It consists of four set of pumps (each set has two pumps, one working and other in cold standby). Failure in any one pump, start automatically the respective standby pump and failed pump is sent for repair. Complete failure of the system will occur only when any two pumps of the system remained in failed state at a time.

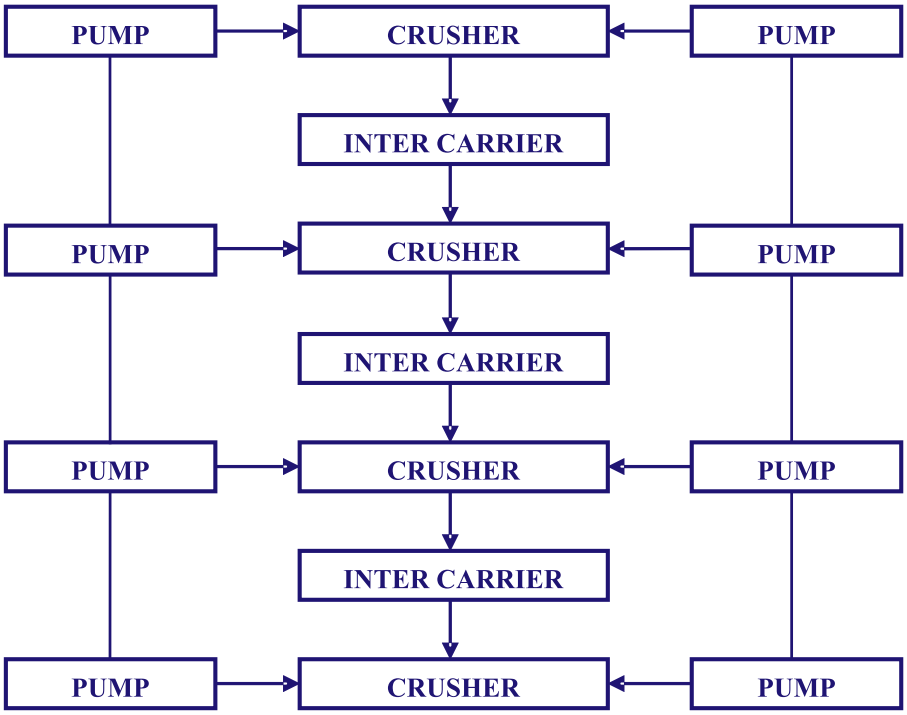

Figure 1: Schematic Flow Diagram of Crushing Unit

4. ASSUMPTIONS

The assumptions used for developing the probabilistic model are:

1) Failure/Repair rates are constant over time and statistically independent.
2) A repaired component is as good as new, performance wise, for a specified duration.
3) Repair facilities are provided sufficiently, means, waiting time to start the repairs is zero.
4) Component failure/repair follows the exponential distribution.
5) Service includes repair and/or replacement.
6) Unit may work at reduced capacity.

5. NOTATIONS The following notations are addressed for the purpose of mathematical analysis of the unit:

○ :Indicates that the unit is in working state.

▭ :Indicates that the unit is in failed State.

B_1, B_2, B_3: Denotes that the subsystems are in full operating state.

b_1, b_2, b_3 : Denotes that the subsystems B_1, B_2, B_3 are in failed state.

$P_0(t)$, $P_3(t)$: Probabilities of the unit in working with full capacity at time t.

$P_1(t)$, $P_2(t)$, $P_4(t)$, $P_5(t)$, $P_6(t)$: Probabilities of the unit in failed state.

$\Phi_{i,}$ i = 6-8: Mean failure rates of B_1, B_2 and B_3 respectively.

$\mu_{i,}$ i = 6-8 : Mean repair rates of B_1, B_2 and B_3 respectively.

d/dt : Represents derivative w.r.t time (t).

Figure 2 shows the transition diagram associated with the Crushing unit.

The unit consists of 7 states as:

State 0 and 3 – Full Capacity States

State 1, 2, 4, 5, 6 shows that the unit is in failed state due to complete failure of one or the other subsystem of the unit.

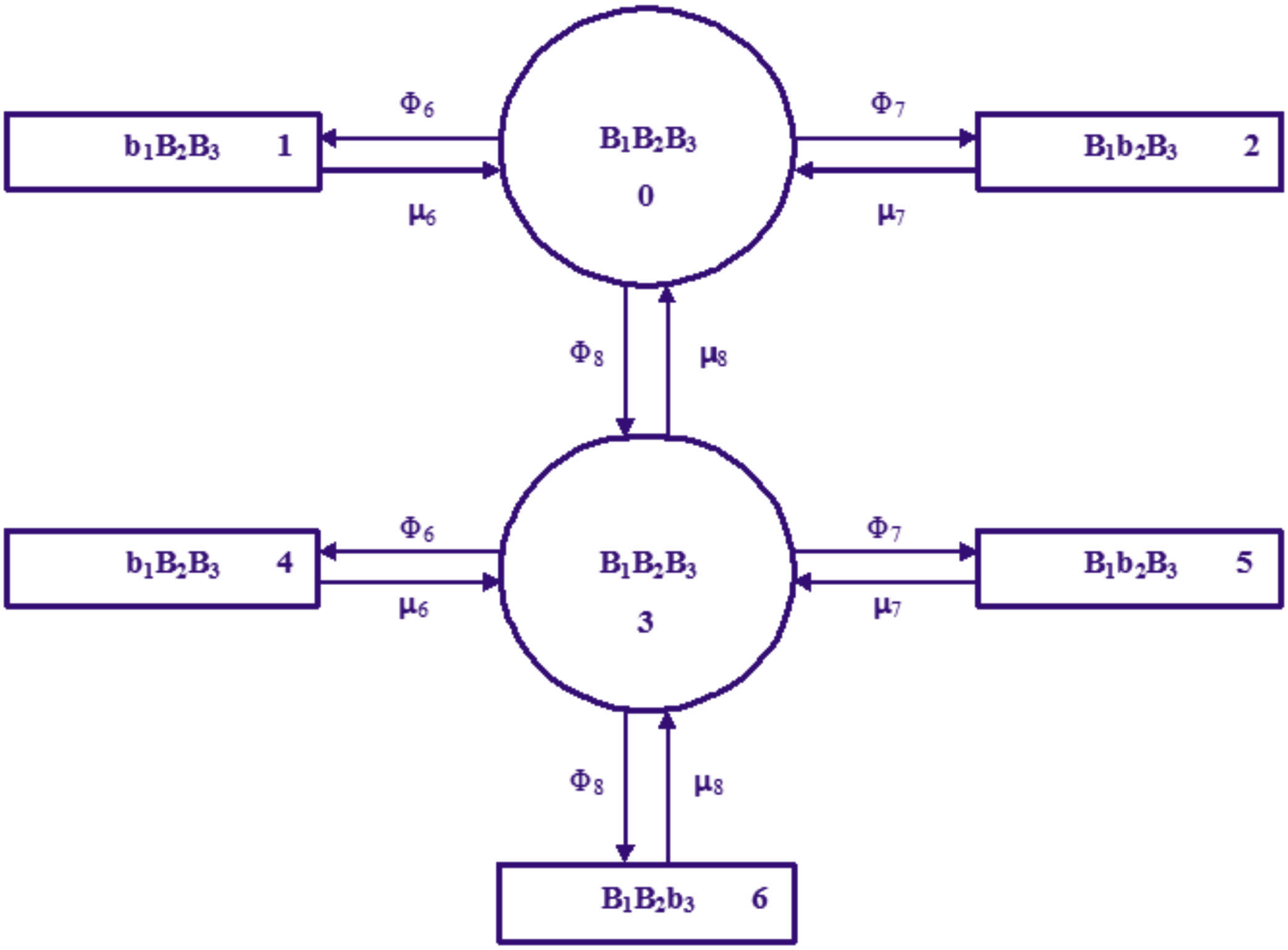

Figure 2: Transition Diagram of Crushing Unit

6. PERFORMANCE MODELING

The performance modeling is carried out using simple probabilistic considerations and differential equations associated with the transition diagram (figure 3) are developed on the basis of Markov birth-death process. These equations are further solved for determining the steady state availability of the crushing unit. Various probability considerations give the following differential equations associated with the crushing unit:

$$P'_0(t) + \Phi_6 P_0(t) + \Phi_7 P_0(t) + \Phi_8 P_0(t) = \mu_6 P_1(t) + \mu_7 P_2(t) + \mu_8 P_3(t) \quad (1)$$

$$P'_1(t) + \mu_6 P_1(t) = \Phi_6 P_0(t) \quad (2)$$

$$P'_2(t) + \mu_7 P_2(t) = \Phi_7 P_0(t)(3) \quad (3)$$

$$P'_3(t) + \Phi_6 P_3(t) + \Phi_7 P_3(t) + \Phi_8 P_3(t) + \mu_8 P_3(t) = \mu_6 P_4(t) + \mu_7 P_5(t) + \mu_8 P_6(t) + \Phi_8 P_0(t) \quad (4)$$

$$P'_4(t) + \mu_6 P_4(t) = \Phi_6 P_3(t) \quad (5)$$

$$P'_5(t) + \mu_7 P_5(t) = \Phi_7 P_3(t) \quad (6)$$

$$P'_6(t) + \mu_8 P_6(t) = \Phi_8 P_3(t) \quad (7)$$

With initial conditions at time t = 0

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

$P_i(t) = 0$ for $i \neq 0$

Solution of Equations

Steady State Behavior

Since the Sugar Plant is a process industry, its every system should be available for long period. Therefore, steady state behavior of the Crushing Unit can be analyzed by setting P' = 0 as t. The limiting probabilities from equations (1) to (7) are:

$$[\Phi_6 + \Phi_7 + \Phi_8]P_0 = \mu_6 P_1 + \mu_7 P_2 + \mu_8 P_3 \qquad (8)$$

$$\mu_6 P_1 = \Phi_6 P_0 \qquad (9)$$

$$\mu_7 P_2 = \Phi_7 P_0 \qquad (10)$$

$$\mu_8 P_6 = \Phi_8 P_3 \qquad (11)$$

Solving these equations (8 to 11) recursively,

$$P_1 = G_6 P_0 \qquad P_4 = G_6 G_8 P_0$$

$$P_2 = G_7 P_0 \qquad P_5 = G_7 G_8 P_0$$

$$P_3 = G_8 P_0 \qquad P_6 = G_8 G_8 P_0$$

$$G_i = \Phi_i / \mu_i \, i = 1,2,3,4,5$$

Use of Normalizing condition i.e. sum of all the state probabilities is equal to one $[\sum_{i=0}^{6} P_i = 1]$, gives the solution as follows:

$$P_0 + P_1 + P_2 + P_3 + P_4 + P_5 + P_6 = 1$$

$$P_0 + G_6 P_0 + G_7 P_0 + G_8 P_0 + G_6 G_8 P_0 + G_7 G_8 P_0 + G_8 G_8 P_0 = 1$$

$$P_0 [1 + G_6 + G_7 + G_8 + G_6 G_8 + G_7 G_8 + G_8 G_8] = 1$$

$$P_0 = 1/[1 + G_6 + G_7 + G_8 + G_6 G_8 + G_7 G_8 + G_8 G_8]$$

Now, the Steady State Availability (AV) of the Crushing Unit is given by summation of full working state probabilities.

$$AV = P_0 + P_3$$

$$AV = P_0 + G_8 P_0$$

$$AV = P_0 [1 + G_8]$$

$$AV = [1 + G_8] / [1 + G_6 + G_7 + G_8 + G_6 G_8 + G_7 G_8 + G_8 G_8]$$

$$\textbf{Availability} = [1 + G_8] / [1 + G_6 + G_7 + G_8 + G_6 G_8 + G_7 G_8 + G_8 G_8] \qquad (12)$$

7. PERFORMANCE ANALYSIS

Availability is in fact a measure of performance of the concerned unit. The failure and repair rates of various subsystems of Crushing unit are taken from the maintenance history sheets of the sugar plant concerned. The decision matrices are developed to analyze the various performance levels for different combinations of failures and repair rates. Tables 1, 2, 3, 4, 5 represent the decision matrices for various subsystems of Crushing unit. Accordingly, maintenance decisions can be made for various subsystems. Keeping in view the repair criticality, the best possible combination (Φ, μ) may be selected.

Table 1: Decision Matrix for 'Crusher' subsystem of Crushing Unit

μ_6 / Φ_6	0.05	0.10	0.15	0.20	0.5	Constant Parameters
0.005	0.8627	0.9016	0.9154	0.9224	0.9267	Φ_7=0.005, μ_3=0.10
0.010	0.7942	0.8627	0.8883	0.9016	0.9098	Φ_8=0.01, μ_8=0.10
0.015	0.7358	0.8271	0.8627	0.8818	0.8936	
0.020	0.6854	0.7942	0.8386	0.8627	0.8779	
0.025	0.6414	0.7639	0.8158	0.8445	0.8627	

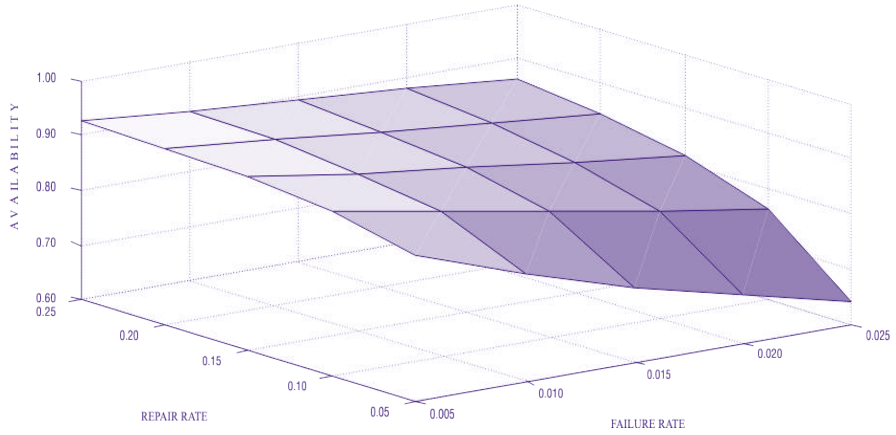

Figure 3: Effect of failure and repair rates of 'Crusher' subsystem on Unit availability

μ_7 / Φ_7	0.10	0.15	0.20	0.25	0.30	Constant Parameters
0.005	0.9154	0.9296	0.9368	0.9412	0.9442	Φ_6=0.005, μ_6=0.15
0.010	0.8753	0.9016	0.9154	0.9239	0.9296	Φ_8=0.01, μ_8=0.1
0.015	0.8386	0.8753	0.8949	0.9071	0.9154	
0.020	0.8049	0.8505	0.8753	0.8909	0.9016	
0.025	0.7737	0.8271	0.8566	0.8753	0.8883	

Table 2: Decision Matrix for 'Inter Carrier' subsystem of Crushing Unit

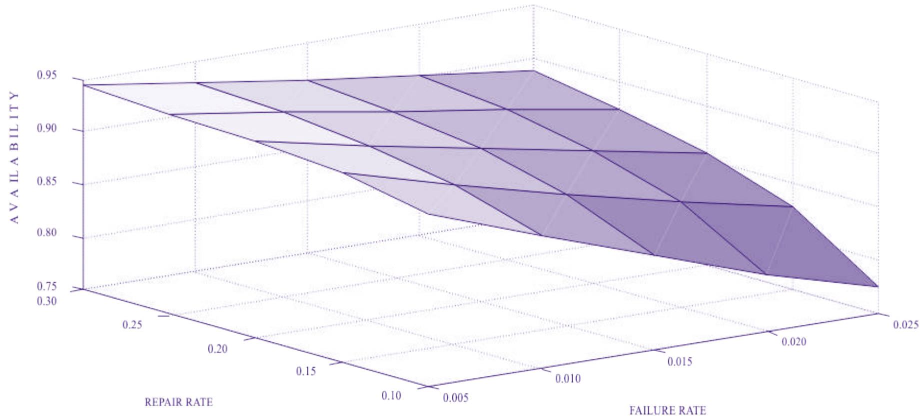

Figure 4: Effect of failure and repair rates of 'Inter Carrier' subsystem on unit availability

μ_8 / Φ_8	0.10	0.15	0.20	0.25	0.30	Constant Parameters
0.01	0.9154	0.9195	0.9211	0.9218	0.9222	Φ_6=0.005, μ_6=0.15
0.02	0.8955	0.9099	0.9154	0.9181	0.9195	Φ_7=0.005, μ_7=0.10
0.03	0.8676	0.8955	0.9067	0.9123	0.9154	
0.04	0.8350	0.8776	0.8955	0.9046	0.9099	
0.05	0.8000	0.8571	0.8824	0.8955	0.9032	

Table 3: Decision Matrix for 'Pump' subsystem of Crushing Unit

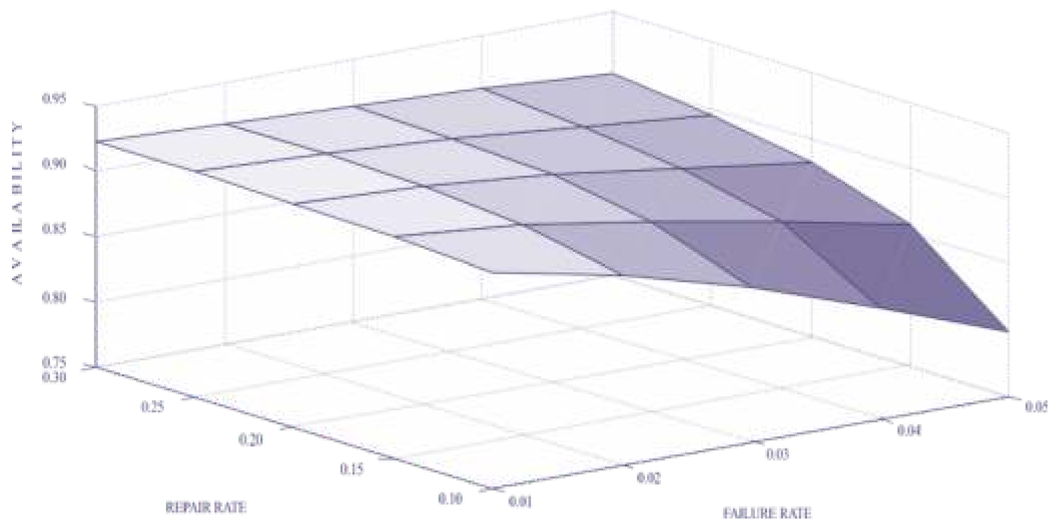

Figure 5: Effect of failure and repair rates of 'Cane Cutter' subsystem on unit availability

8. RESULTS AND DISCUSSION

Decision matrix for crusher and figure 3, reveal the variation of unit availability with change in failure rate and repair rate of crusher subsystem. As failure rate of crusher (Φ_6) increases from 0.005 (once in 200 hrs) to 0.025 (once in 40 hrs), availability of the unit decreases drastically by 22%. Also, as the repair rate (μ_6) increases from 0.05 (once in 20 hrs) to 0.25 (once in 4 hrs), availability of the unit increases by 0.6%. Decision matrix for inter carrier and figure 4, show the variation of unit availability with change in failure rate and repair rate of inter carrier subsystem. As failure rate of inter carrier (Φ_7) increases from 0.005 (once in 200 hrs) to 0.025 (once in 40 hrs), availability of the unit decreases extensively by 14%. Also, as the repair rate (μ_7) increases from 0.10 (once in 10 hrs) to 0.30 (once in 4 hrs), availability of the unit increases simply by 4%.

Decision matrix for pump and figure 5, reflect the variation of unit availability with change in failure rate and repair rate of pump subsystem. As failure rate of pump (Φ_8) increases from 0.01 (once in 100 hrs) to 0.05 (once in 20 hrs), availability of the unit decreases by 12%. Similarly, as the repair rate (μ_8) increases from 0.10 (once in 10 hrs) to 0.30 (once in 3 hrs), availability of the unit increases hardly by 1%.

Table 4: Maintenance Priorities of Various Subsystems of Crushing Unit

Sr. No.	Subsystem	Repair Priority Level
1.	Crusher	I
2.	Inter Carrier	II
3.	Pump	III

9. CONCLUSION

A case study is conducted to illustrate the performance of crushing unit of the concerned sugar plant. The performance model has been developed for evaluating the performance of Crushing unit of sugar industry under study. It would help in deciding maintenance priorities among various subsystems of Crushing unit. It grantsvarious availability levels for different combinations of failure and repair rates of different subsystems of Crushing unit.Such results are found extremely beneficial to the plant management for the evaluation of performance and analysis of availability of crushing unit and thus to decide maintenance precedenceamong various subsystems of the unit concerned in a sugar plant.

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