DEVELOPMENT OF DECISION SUPPORT SYSTEM FOR FEEDING UNIT OF A SUGAR INDUSTRY

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Abstract

This paper deals with the development of decision support system for Feeding unit of a sugar industry using Markov technique and probabilistic approach. The Feeding unit of a sugar industry has four main subsystems arranged in series. Considering exponential distribution for the probable failures and repairs, the mathematical formulation of the problem is done using probabilistic approach and differential equations are developed on the basis of Markov birth-death process. These equations are then solved using normalizing conditions so as to determine the steady-state availability of the Feeding unit of a sugar industry. Decision Support System is then developed to decide about the maintenance priorities among various subsystems of a Feeding unit of the sugar industry concerned.

Keywords: Feeding Unit, Steady State Availability, Markov Birth-Death Process, Decision Support System.

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1. Introduction

The sugar industry is becoming quite complex with large capital investment on process automation to enhance the reliability of the units. Invariably, the proper maintenance of such units and the frequency of maintenance activities are some of the issues that are gaining importance in industry. The production suffers due to failure of any intermediate unit even for small interval of time. The cause of failure may be due to poor design, unit complexity and poor maintenance, lack of experience and lack of communication and coordination. Thus, to run a process industry, highly experienced maintenance personnel are required. The failed subsystem can however be inducted back into service after repairs/replacements. The rate of failure of the subsystems in the particular unit depends upon the operating conditions and repair policies used. A probabilistic analysis of the unit under given operative conditions is helpful in forecasting the equipment behavior which further helps in design to achieve minimum failure in the unit i.e. to optimize the working of unit. A sugar industry is a complex manufacturing unit comprising of various units; Feeding, Crushing, Refining, Evaporation, Sulphonation and Crystallization etc. These units are connected in complex configuration. One of the most important functionaries of a sugar industry is Feeding unit. The performance optimization of each unit in relation to other is imperative to make the industry profitable for operation. Effectiveness of sugar industry is mainly influenced by the availability of the industry, and its capability to perform as expected. The present paper provides a Decision Support System to decide the maintenance priorities among various subsystems of a Feeding unit of a sugar industry concerned.

In a sugar industry, juice is produced and this juice is heated through some processes. The failure of Feeding unit will adversely affect the production. Here, the cane moves from storage to the cane carrier using cane unloader. The cane carrier is a moving belt which carries the cane to the cutter and leveler. A kicker is mounted on the cane carrier to remove the excess cane and to maintain a specified cane level. The cane cutter is having a set of knives used to cut the cane into small pieces. The leveler is used to increase cane compactness. It ensures minimum void among the cane pieces and hence maximum juice extraction while crushing. The compact cane pieces are fed to the crushing unit by a chain conveyor for juice extraction.

2. Literature Review

Murthy *et al.* [1] dealt with the case studies in reliability and maintenance. Rafael *et al.* [2] dealt with the multiple system governed by a quasi-birth-death process. Samrout *et al.* [3] dealt with the methods to minimize the preventive maintenance cost of series-parallel systems using ant colony optimization. According to Barabady *et al.* [4], the most important performance measures for repairable system designers and operators are system reliability and availability. Availability and reliability are good evaluations of a system's performance. Their values depend on the system structure as well as the component availability and reliability.

Sachdeva *et.al.* [5] described a new multi criteria optimization framework for deriving optimal cost and life cycle costs as the criteria for optimization using Petri Net. Khanduja *et al.* [6] also discussed the steady state behavior and maintenance planning of the bleaching system in a paper plant. Gupta *et al.* [7] dealt with performance modeling of power generation system of a thermal plant. Khanduja *et al.* [8] developed a performance model for stock preparation unit of a paper plant using Markov approach and optimize the performance using Genetic Algorithm. Wang *et. al.* [9] discussed the availability analysis of redundant Building, Cooling, Heating and Power (BCHP) system. A state space method combined to the probabilistic analysis of Markov model has been employed to analyze the reliability of BCHP system. Doostparast *et al.* [10] developed a reliability based periodic preventive maintenance planning model for systems to minimize the total maintenance cost using simulated annealing approach. Feeding unit of a sugar industry is hereby chosen to develop a Decision Support System, so as to decide the maintenance priorities among its various subsystems.

3. Description of Feeding Unit

Feeding unit comprises of four subsystems in series configuration with following description:

- Subsystem A_i is the 'cane unloader' and it comprises of three cane unloaders in parallel. If one of these gets failed, the unit goes in the reduced capacity state. Failure of all the three leads to the complete failure of the unit.
- Subsystem B_j is the 'cane carrier & kicker' and it consists of two cane carriers and kickers in series. If any one of these fails, the unit completely fails.

- Subsystem C_k is the 'cane cutter and leveler' and it comprises of two cane cutters and levelers in series. If any one of these fails, the failure of complete unit is the result.
- Subsystem D is the 'chain conveyor' and the failure of this chain conveyor causes complete failure of the 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) Standby components are of the same nature as that of the active components.
5) Component failure/repair follows the exponential distribution.
6) Service includes repair and/or replacement.
7) Unit may work at reduced capacity.

6) There are no simultaneous failures.

5. Notations

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

○ : Indicates that the unit is in workings state.

⬭ : Indicates that the unit is in reduced capacity state.

▭ : Indicates that the unit is in failed State.

A_i, B_j, C_k, D : Denotes that the subsystems are in full operating state.

a, b, c, d : Denotes that the subsystems A_i, B_j, C_k, D are in failed state.

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

$P_1(t)$, $P_2(t)$: Probabilities of the unit in reduced capacity (working) state.

$P_3(t)$-$P_{12}(t)$: Probabilities of the unit in failed state.

Φ_i, i=1-4 : Mean failure rates of A_i, B_j, C_k and D respectively.

λ_i, i=1-4 : Mean repair rates of A_i, B_j, C_k and D respectively.

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

Figure 1 shows the transition diagram associated with the Feeding unit.

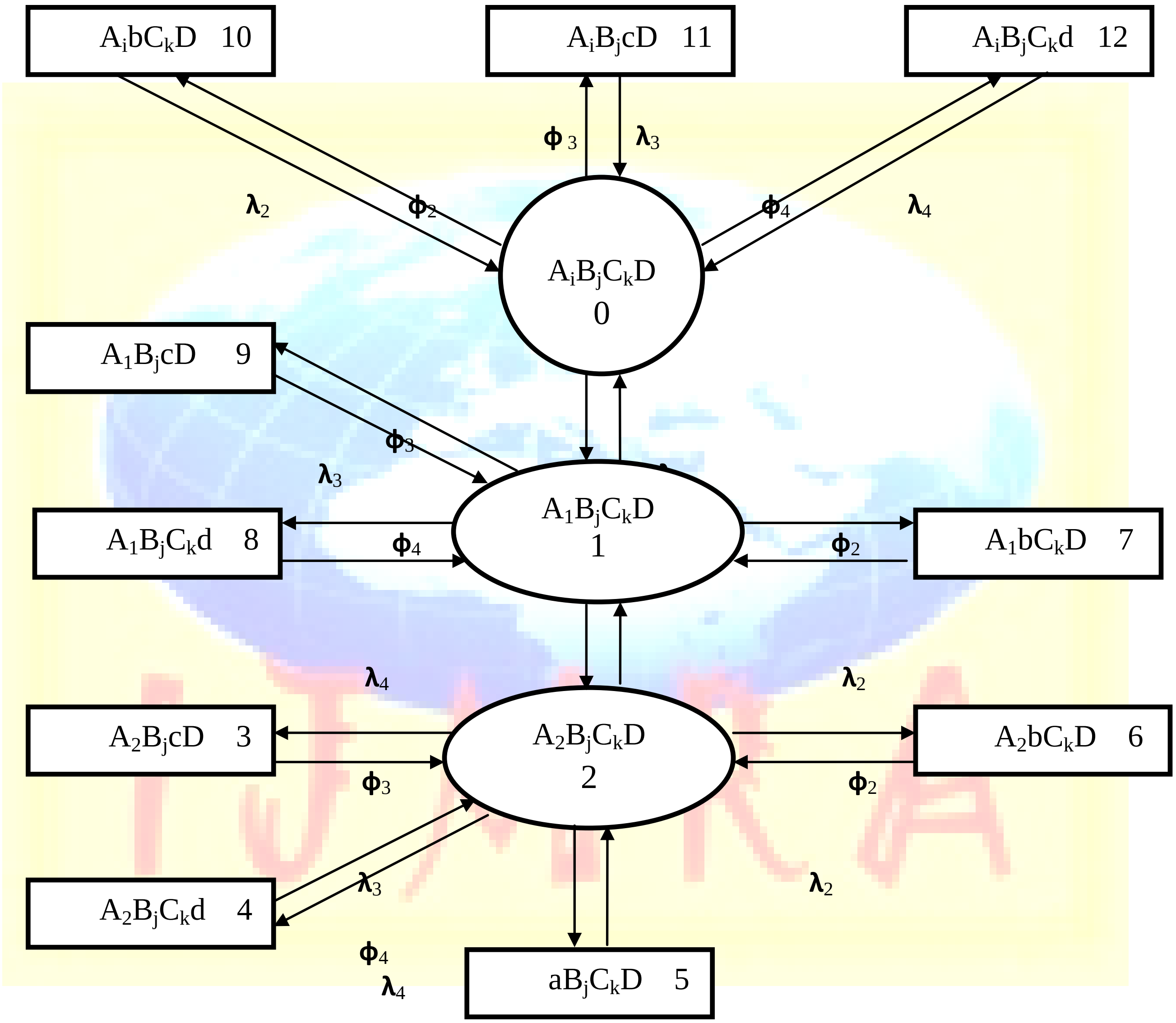

Figure 1: Transition Diagram of Feeding unit

6. Performance Evaluation

The performance evaluation of the Feeding unit has been carried out with the help of simple probabilistic approach based upon Markov birth-death process. The Chapman-Kolmogorov differential equations are developed based on the transition diagram as shown in figure 1, which are as follows:

$P_0(t)(d/dt+\Phi_1+\Phi_2+\Phi_3+\Phi_4) = P_1(t)\lambda_1 + P_{10}(t)\lambda_2 + P_{11}(t)\lambda_3 + P_{12}(t)\lambda_4$...1

$P_1(t)(d/dt + \Phi_1+\Phi_2+\Phi_3+ \Phi_4) = P_2(t)\lambda_1 + P_7(t)\lambda_2 + P_8(t)\lambda_4 + P_9(t)\lambda_3$..2

$P_2(t)(d/dt+\Phi_1+\Phi_2+\Phi_3 + \Phi_4) = P_5(t)\lambda_1 +P_6(t)\lambda_2 + P_3(t)\lambda_3+ P_4(t)\lambda_4$..3

$P_3(t)(d/dt+\lambda_3) = P_2(t)\Phi_3$..4

$P_4(t)(d/dt+\lambda_4) = P_2(t)\Phi_4$..5

$P_5(t)(d/dt + \lambda_1) = P_2(t)\Phi_1$..6

$P_6(t)(d/dt+\lambda_2) = P_2(t)\Phi_2$..7

$P_7(t)(d/dt+\lambda_2) = P_1(t)\Phi_2$..8

$P_8(t)(d/dt+\lambda_4) = P_1(t)\Phi_4$..9

$P_9(t)(d/dt+\lambda_3) = P_1(t)\Phi_3$..10

$P_{10}(t)(d/dt+\lambda_2) = P_0(t)\Phi_2$...11

$P11(t)(d/dt + \lambda 3) = P0(t)\Phi 3$...12

$P_{12}(t)(d/dt + \lambda_4)$ =

$P_0(t)\Phi_4$...13

In the process industry, long run availability of the unit is required and it is obtained by setting d/dt→ 0 and taking probabilities independent of t. The limiting probabilities from equations (1) – (13) are:

$P_0\Phi_1 = P_1\lambda_1$ $\qquad$ $P_7\lambda_2 = P_1\Phi_2$

$P_1\Phi_1 = P_2\lambda_1$ $\qquad$ $P_8\lambda_4 = P_1\Phi_4$

$P_3\lambda_3 = P_2\Phi_3$ $\qquad$ $P_9\lambda_3 = P_1\Phi_3$

$P_4\lambda_4 = P_2\Phi_4$ $\qquad$ $P_{10}\lambda_2 = P_0\Phi_2$

$P_5\lambda_1 = P_2\Phi_1$ $\qquad$ $P_{11}\lambda_3 = P_0\Phi_3$

$P_6\lambda_2 = P_2\Phi_2$ $\qquad$ $P_{12}\lambda_4 = P_0\Phi_4$

Solving these equations recursively, the values of all state probabilities, in terms of full working state probability (P0), are obtained are follows:

$P_1 = P_0K_1$ $\qquad$ $P_7 = P_0K_1K_2$

$P_2 = P_0(K_1)^2$ $\qquad$ $P_8 = P_0K_1K_4$

$P_3 = P_0(K_1)^2K_3$ $\qquad$ $P_9 = P_0K_1K_3$

$P_4 = P_0(K_1)^2K_4$ $\qquad$ $P_{10} = P_0K_2$

$P_5 = P_0(K_1)^3$ $\qquad$ $P_{11} = P_0K_3$

$P_6 = P_0(K_1)^2K_2$ $\qquad$ $P_{12} = P_0K_4$

Where, $K_i = \Phi_i / \lambda_i$ $\qquad$ i = 1, 2, 3, 4.

The probability of full working capacity (without standby units) i.e. P_0 is determined by using normalizing conditions i.e.

$$\sum_{i=0}^{12} \mathbf{Pi} = \mathbf{1}$$

$P_0 + P_1 + P_2 + P_3 + P_4 + P_5 + P_6 + P_7 + P_8 + P_9 + P_{10} + P_{11} + P_{12} = 1$

$P_0 [1+ K_1 + K_1^2 + K_1^2K_3 + K_1^2K_4 + K_1^3 + K_1^2K_2 + K_1K_2 + K_1K_4 + K_1K_3 + K_2 + K_3 + K_4] = 1$

$P_0 [1+ K_1 (1 + K_1 + K_1K_3 + K_1K_4 + K_1^{2+} K_1K_2 + K_2 + K_4 + K_3) + K_2 + K_3 + K_4] = 1$

$P_0 = 1 / [1+ K_1 (1 + K_1 + K_1K_3 + K_1K_4 + K_1^{2+} K_1K_2 + K_2 + K_4 + K_3) + K_2 + K_3 + K_4]$

$P_0 = 1 / N$

Where,

$N = [1 + K_1 (1 + K_1 + K_1K_3 + K_1K_4 + K_1^{2} + K_1K_2 + K_2 + K_4 + K_3) + K_2 + K_3 + K_4]$

Now, the steady state availability (AV) of the Feeding unit is given by summation of all the full working and reduced capacity states probabilities.

$AV = P_0 + P_1 + P_2$

$AV = P_0 + P_0K_1 + P_0K_1^2$

$AV = P_0 (1 + K_1 + K_1^2)$

$AV = (1 / N) (1 + K_1 + K_1^2)$

$$\mathbf{AV = (1 + K_1 + K_1^2) / [1 + K_1 (1+K_1+K_1K_3+K_1K_4+K_1^2+ K_1K_2+K_2+K_4+K_3) + K_2 + K_3 + K_4]}$$

7. Performance Analysis

Availability is in fact a measure of performance of the concerned unit. The failure and repair rates of various subsystems of Feeding unit are taken from the maintenance history sheets of a sugar plant. The availability matrices are developed to analyze the various performance levels for different combinations of failures and repair rates. Table 1, 2, 3, 4 represent the availability matrices for various subsystems of Feeding unit. Accordingly, maintenance decisions can be made for various subsystems keeping in view the repair criticality and we may select the best possible combinations (Φ, λ).

λ_1 / Φ_1	**0.05**	**0.10**	**0.15**	**0.20**	**0.25**	**Constant Values**
0.01	0.827505	0.831324	0.831755	0.831865	0.831904	$\Phi_2 = 0.01$,
0.02	0.804489	0.827505	0.830524	0.831324	0.831621	$\Phi_3 = 0.001$,
0.03	0.782077	0.818716	0.827505	0.829959	0.830894	$\Phi_4 = 0.01$,
0.04	0.768298	0.804489	0.822250	0.827505	0.829562	$\lambda_2 = 0.10$,
0.05	0.741324	0.785282	0.814570	0.823788	0.827505	$\lambda_3 = 0.50$,

Table 1: Decision Matrices for 'Cane Unloader' subsystem of Feeding unit

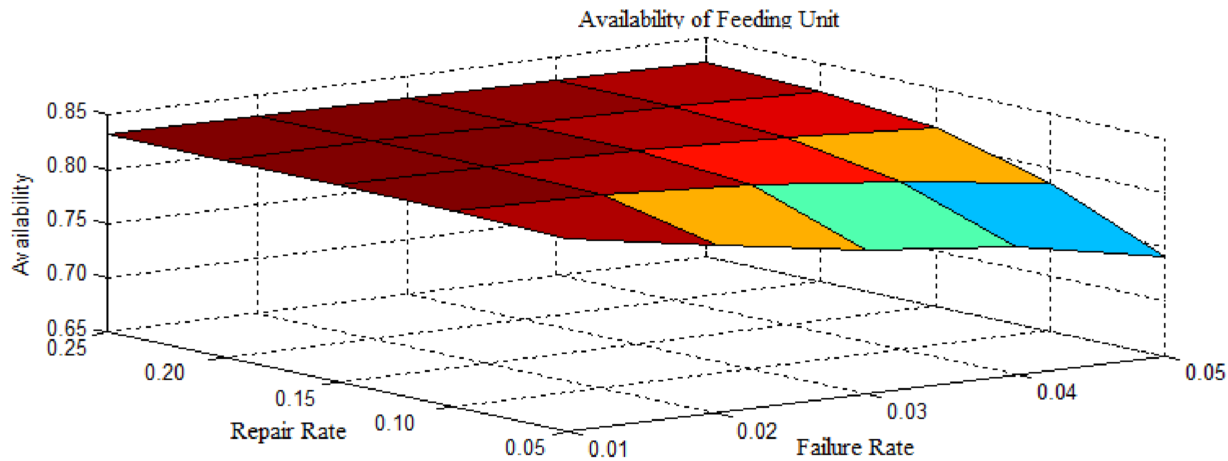

Figure 2: Effect of failure and repair rates of 'Cane Unloader' subsystem on unit availability

Table 2: Decision Matrices for 'Cane Carrier' subsystem of Feeding unit

λ_2	**0.25**	**0.30**	**0.35**	**0.40**	**0.45**	**Constant Values**
0.05	0.764262	0.784241	0.799163	0.810733	0.810966	$\Phi_1 = 0.06$,
0.06	0.741591	0764262	0.781323	0.794627	0.805292	$\Phi_3 = 0.001$,
0.07	0.720227	0.745276	0.764262	0.779149	0.791135	$\Phi_4 = 0.01$,
0.08	0.700059	0.727210	0.747930	0.764262	0.777466	$\lambda_1= 0.3$,
0.09	0.680989	0.710000	0.732282	0.749933	0.764262	$\lambda_3 = 0.50$,

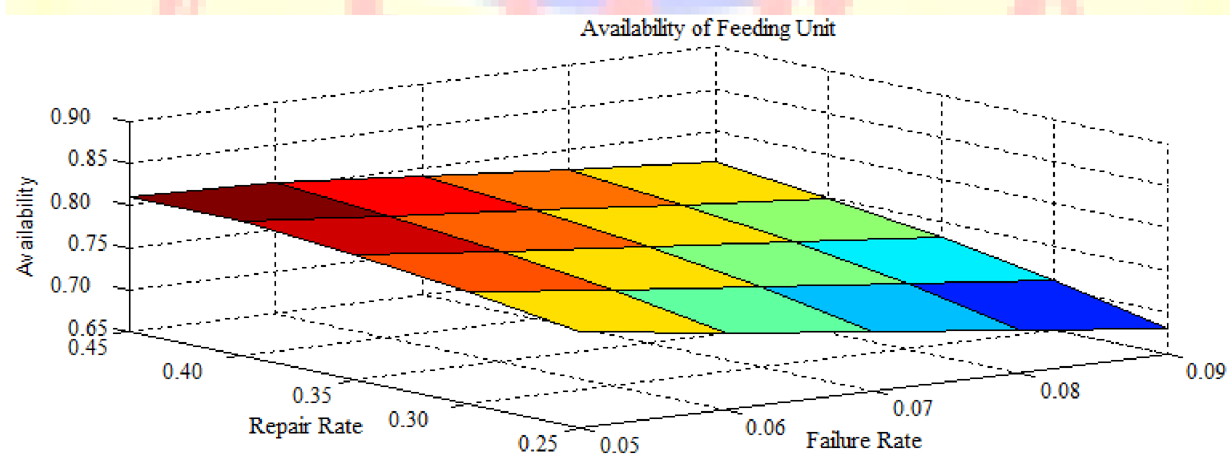

Figure 3: Effect of failure and repair rates of 'Cane Carrier' subsystem on unit availability

Table 3: Decision Matrices for 'Cane Cutter' subsystem of Feeding unit

λ_3	0.15	0.20	0.25	0.30	0.35	Constant Values
0.01	0.745473	0.775892	0.782277	0.796592	0.812701	$\Phi_1 = 0.06$,
0.02	0.726388	0.765432	0.777332	0.785473	0.791393	$\Phi_2 = 0.01$,
0.03	0.711009	0.737218	0.753891	0.765432	0.773894	$\Phi_4 = 0.01$,
0.04	0.678832	0.711009	0.731822	0.746388	0.757153	$\lambda_1 = 0.3$,
0.05	0.643441	0.686600	0.711009	0.728269	0.741120	$\lambda_2 = 0.10$,

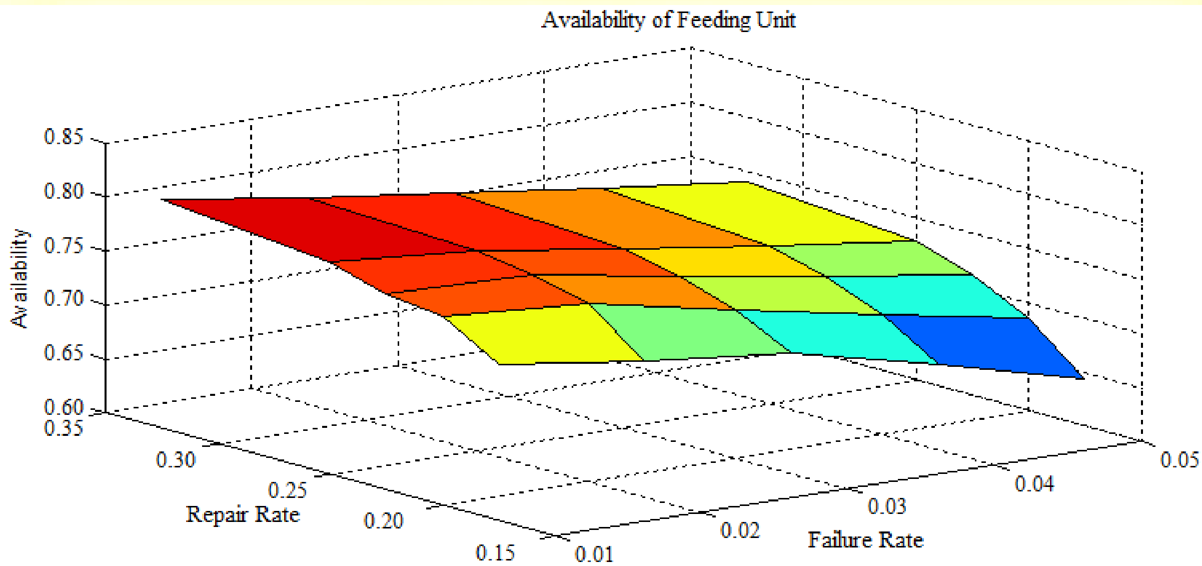

Figure 4: Effect of failure and repair rates of 'Cane Cutter' subsystem on unit availability

Table 4: Decision Matrices for 'Conveyor' subsystem of Feeding unit

λ_4	0.10	0.15	0.20	0.25	0.30	Constant Values
0.005	0.863221	0.875822	0.882261	0.886170	0.888795	$\Phi_1 = 0.06$,
0.010	0.827505	0.850978	0.863221	0.870738	0.875822	$\Phi_2 = 0.01$,
0.015	0.794627	0.827505	0.844986	0.855833	0.863221	$\Phi_3 = 0.001$,
0.020	0.764262	0.805292	0.827505	0.841431	0.850978	$\lambda_1 = 0.30$,
0.025	0.736132	0.784241	0.810733	0.827505	0.839078	$\lambda_2 = 0.10$,

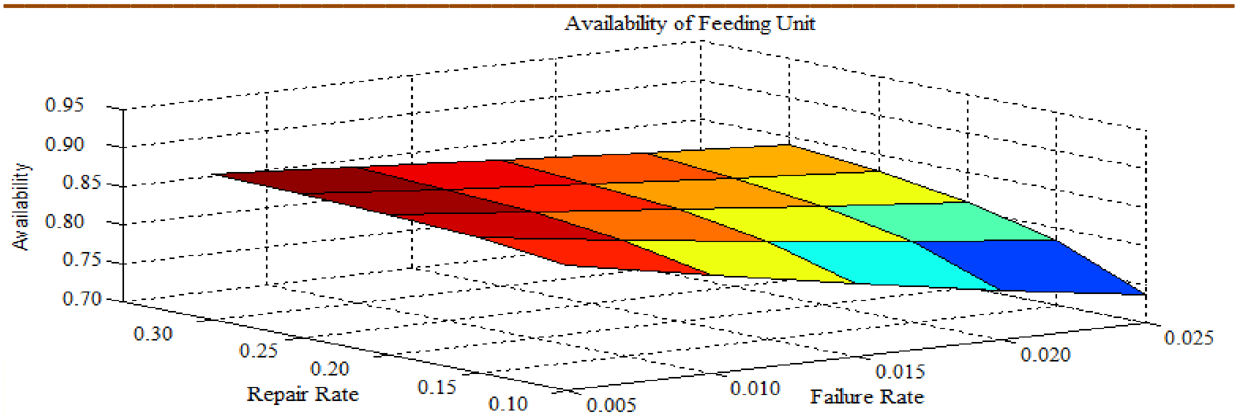

Figure 5: Effect of failure and repair rates of 'Conveyor' subsystem on unit availability

8. Results and Discussion

Decision matrices for cane unloader and figure 2, reveal the variation of unit availability with change in failure rate and repair rate of cane unloader subsystem. As failure rate of cane unloader (Φ_1) increases from 0.01 (once in 100 hrs) to 0.05 (once in 20 hrs), availability of the unit decreases significantly by 8%. Also, as the repair rate (λ_1) increases from 0.05 (once in 20 hrs) to 0.25 (once in 4 hrs), availability of the unit increases merely by 1%.

Decision matrices for cane carrier and figure 3, show the variation of unit availability with change in failure rate and repair rate of cane carrier subsystem. As failure rate of cane carrier (Φ_2) increases from 0.05 (once in 20 hrs) to 0.09 (once in 11 hrs), availability of the unit decreases extensively by 8%. Also, as the repair rate (λ_2) increases from 0.25 (once in 4 hrs) to 0.45 (once in 2 hrs), availability of the unit increases considerably by 5%.

Decision matrices for cane cutter and figure 4, reflect the variation of unit availability with change in failure rate and repair rate of cane cutter subsystem. As failure rate of cane cutter (Φ_3) increases from 0.01 (once in 100 hrs) to 0.05 (once in 20 hrs), availability of the unit decreases drastically by 10%. Similarly, as the repair rate (λ_3) increases from 0.15 (once in 6 hrs) to 0.35 (once in 3 hrs), availability of the unit increases appreciably by 7%.

Decision matrices for conveyor and figure 5, reveal the variation of unit availability with change in failure rate and repair rate of conveyor subsystem. As failure rate of conveyor (Φ_4) increases from 0.005 (once in 200 hrs) to 0.025 (once in 40 hrs), availability of the unit decreases hugely by 13%. Similarly, as the repair rate (λ_4) increases from 0.10 (once in 10 hrs) to 0.30 (once in 3 hrs), availability of the unit increases noticeably by 3%.

9. Development of Decision Support System

The performance analysis of Feeding unit of a sugar industry has been done with the help of mathematical modeling using probabilistic approach. The results are shown in the decision matrices for respective subsystems. These decision matrices will assist the maintenance department to decide the maintenance priorities. It is clear from the study of above four decision matrices that 'cane cutter' is the most critical subsystem. As the repair rate of cane cutter subsystem is increasing, the availability of the Feeding unit is increases appreciably by 7%. So this subsystem will be kept on top priority while taking the maintenance decisions. On the basis of above performance analysis of various subsystems of the Feeding unit, the maintenance priorities can be given as per the following order:

Table 5: Decision Support System for Feeding unit

Sr. No.	Subsystem	Repair Priority Level
1.	Cane Cutter	I
2.	Cane Carrier	II
3.	Conveyor	III
4.	Cane Unloader	IV

10. Conclusion

A Decision Support System has been developed for the Feeding unit of a sugar industry. It would help in deciding the maintenance priorities among various subsystems of Feeding unit. A real case study has been presented to illustrate the proposed methodology to aid such a decision-making process. The performance model has been developed for evaluating the performance of Feeding unit of sugar industry under study. It provides various availability levels for different combinations of failure and repair rates of various subsystems of Feeding unit. Even though this paper is focused on sugar industry, the proposed methodology can be applied in future to other process industries as well.

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