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Availability Analysis of Milling System in a Rice Milling Plant

P. C. Tewari, Parveen Kumar

Abstract**—**The paper describes the availability analysis of milling system of a rice milling plant using probabilistic approach. The subsystems under study are special purpose machines. The availability analysis of the system is carried out to determine the effect of failure and repair rates of each subsystem on overall performance (i.e. steady state availability) of system concerned. Further, on the basis of effect of repair rates on the system availability, maintenance repair priorities have been suggested. The problem is formulated using Markov Birth-Death process taking exponential distribution for probable failures and repair rates. The first order differential equations associated with transition diagram are developed by using mnemonic rule. These equations are solved using normalizing conditions and recursive method to drive out the steady state availability expression of the system. The findings of the paper are presented and discussed with the plant personnel to adopt a suitable maintenance policy to increase the productivity of the rice milling plant.

Keywords**—**Markov process, milling system, availability modeling, rice milling plant.

I. Introduction

AVAILABILITY is one of the important measures of system performance besides reliability under the specified conditions of use [16]. The industrial systems comprise of complex engineering subsystems arranged in series, parallel or hybrid configuration. The Rice Milling Plant is divided into many sections like Paddy Drying Section, Rice Milling, Rice Finishing and Rice Grading Section. The rice milling system is one of the important functionary sections of the rice milling plant. The system consists of five subsystems namely Husker (A), Hush Separator (B), De-stoner (C), Paddy cleaner (D) and Rotary Magnet (E). The process flow diagram of milling system of a rice milling plants is shown in Fig. 1. Initially, the raw material i.e. paddy of various varieties has been provided by the paddy drying section of the plant. Firstly, the paddy is pass through the rotary magnet to separate the foreign iron particles present in the paddy to save the husker. Thereafter, paddy is supplied to the bulk storage cum weighing system, which act as a buffer system. After that paddy is fed to the paddy cleaner to separate the unwanted particles; it works on the principle of specific gravity, then clean paddy is fed to the de-stoner to separate out the stone (hard particles) from the paddy. Now, paddy is ready for milling in husker, here husk is removed from the paddy due to milling action to give mixture of rice and husk. Thereafter, mixture of rice and husk is fed to the husk separator to separate the husk from the rice, the husk is collected in the open storage while rice and unmilled paddy is sent to next section of the plant for finishing and grading of the rice. The industrial systems are subjected to random failures due to inappropriate design, poor maintenance and wrong operations etc. The failed systems can be brought back into working order within minimum period of time after repair. The availability analysis is useful for long duration with high performance level of the systems in the industries to minimize the production cost and hence to increase productivity.

The available literature shows the many approaches have been used to analyze the system performance in terms of availability. These are Reliability Block Diagram (RBD), Monte Carlo simulation, Markov approach, failure mode and effect analysis, Fault tree analysis and petri nets. Dhillon and Singh [7] used the Markovian approach for the availability analysis using exponential distribution for failure and repair rates. Kumar et al. [19] used the Markov modeling for analysis and performance evaluation of fertilizer plant. Coit et al. [4] proposed a multiple objective formulation for maximizing the system availability. Gupta et al. [8] discussed the reliability parameters of butter making system of dairy plant taking exponentially distributer failure and repair rates of various subsystems. Kumar et al. [20] evaluated the simulated availability of CO_2 cooling system of a fertilizer plant using Markovian approach. Sachdeva et al. [23] presented a new multi criteria optimization approach for developing optimal maintenance schedules for Preventive Maintenance (PM) which considers availability, maintenance cost and life cycle costs as the criteria for optimization purpose using Petri Net (PN) technique and applied to the paper industry. Ying-Shen et al. [26] proposed a genetic algorithm based optimization model to optimize availability of a series-parallel system.

Azaron et al. [1] developed a new methodology for reliability evaluation and optimization of non-repairable dissimilar component cold standby redundant systems. Garg et al. [9] developed the mathematical model of a cattle feed plant using a birth-death Markov Process. The differential equations have been solved for the steady-state. The system performance has also been studied. Garg et al. [10] developed a reliability model of a block- board manufacturing system in the plywood industry using time dependent and steady state availability under idealized and faulty PM. Kajal et al. [15] developed a decision support system for a butter oil unit of a dairy plant. The mathematical model of the butter oil unit has been

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developed using probabilistic approach and the various differential equations have been derived on the basis of transition diagram (Fig. 2). These equations are further solved to find out the steady state availability of the unit, which is the measure of performance.

Kumar and Tewari [21] discussed the mathematical modeling and performance optimization of CO_2 cooling system of a fertilizer plant using genetic algorithm. Differential equations have been derived based on Markov birth-death process using probabilistic approach. These equations are then solved using normalizing conditions to determine the steady state availability of the CO_2 cooling system. Vora et al. [27] presented the stochastic analysis and performance evaluation of steam generator system of thermal power plant. Initially transition diagram representing the operational behavior has been drawn and problem addressed by using Markov approach. The availability of each system has been analyzed and condition based maintenance decisions has been proposed.

Garg and Sharma [11] presented a novel technique named as PSOBLT for determining the membership function of the reliability indices of complex repairable industrial system having lesser uncertainty. Major advantage of the proposed technique was that it had given compressed search space for each computed reliability index by utilizing available in formation and uncertain data. The PSOBLT technique had been applied through a case study of feeding unit in a paper plant.

Khanduja et al. [17] presented a performance model for stock preparation unit of a paper plant using Markov approach and further optimize the performance of the unit using Genetic Algorithm (GA) taking constant failure and repair rates. Khanduja et al. [18] described a performance enhancement model of crystallization unit of a sugar plant using Markov modeling and GA. Harish and Monika [13] suggested an approach for reliability analysis of industrial systems using PSO and Intuitionist Fuzzy Set (IFS) techniques applied to washing system of a paper industry. Modgil et al. [22] presented a performance model based on Markov process for shoe upper manufacturing unit and find out the time dependent system availability with long term availability of the system. Barabadi et al. [3] give an application of reliability models with covariates using spare parts requirements as reliability performance indicator and presented a case study of repairable system. Doostparast et al. [6] developed a reliability based periodic PM planning model for systems to minimize the total maintenance cost using simulated annealing approach. Feeding unit of a sugar industry is chosen here to develop a Decision Support System, so as to decide the maintenance priorities among its various subsystems.

Gowid et al. [12] suggested a reliability model based on time dependent Markov approach for LNG production plant. Shahrzad et al. [25] developed a model for availability assessment of multi-state weighted k-out-of-n systems. Zhang et al. [28] presented a simplified method for offshore oil production system which is a hybrid approach i.e. combination of continuous-time and discrete time.

Hou et al. [14] discussed the availability analysis of systems using random set theory. They use random set theory for availability assessment of systems with rare failure events. Instead of using failure probabilities calculated directly from each component's observation, they propose to construct pseudo-system observations directly from components observations. Cekyay et al. [5] presented the reliability, MTTF and steady-state availability analysis of systems with exponential failure. They focused mainly on coherent systems and series connection of k-out-of-n stand by subsystems with exponentially distributed component lifetimes. Sabouhi et al. [24]) dealt with the reliability modeling and availability analysis of Combined Cycle Power Plants (CCPP). Reliability-based sensitivity indices are proposed to identify the plant critical components and hence to decide the efficient maintenance strategies.

Literature review shows that most of researchers confined there work to power plant, paper plant, chemical plant, sugar plant and fertilizer plant etc. But author did not find adequate work in the area of rice plant which is one of the important system of food processing industry. In the present work, availability analysis of milling system of a rice milling plant has been discussed. The paper focus on the system availability and find out value of system availability under various possible combination of failure and repair rates. The steady state availability has been calculated using software package MATLAB 2007a. Further, on the basis of availability analysis, suggestion have been made to decide the maintenance repair priorities of various subsystems of the system concerned.

II. System Description

The process flow diagram of milling system of a rice milling plant is shown in Fig. 1. It consists of five subsystems as described below:

[1] Rotary Magnet: Firstly, the paddy is passed through the Rotary Magnet to separate the foreign iron particles present in the paddy to save the Husker.

[2] Paddy Cleaner: This subsystem is used to clean the paddy and separate out the unwanted particles present in paddy. It works on the principle of specific gravity.

[3] De-Stoner: The clean paddy is feed to the de-stoner to separate out the stone (hard particles) from the paddy.

[4] Husker: This subsystem is the heart of the milling system, here husk is removed from the paddy due to rubbing action to give mixture of rice and husk.

[5] Husk Separator: It is used to separate out the rice and husk from the mixture coming out from the Husker. The husk separated from the rice is collected in the open storage, while rice and unmilled paddy is sent to the next system of the plant.

III. Assumptions and Notations

The following assumptions and notations are used to develop state transition diagram (Fig. 2) of the system concerned.

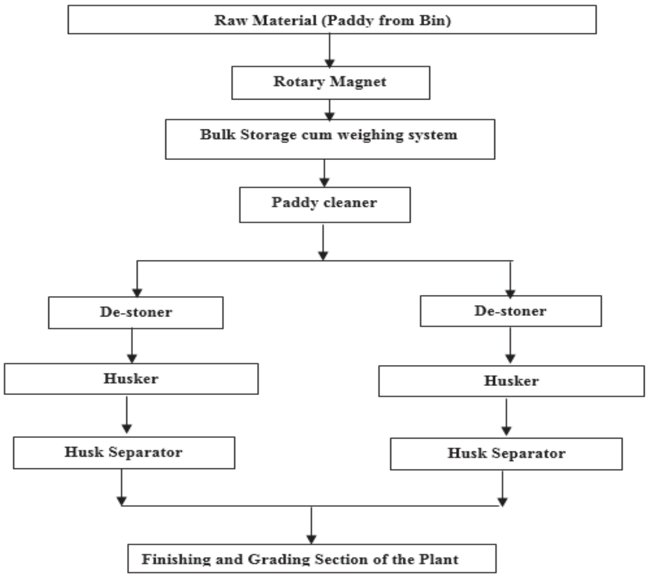


Fig. 1 Process flow diagram of milling system of a rice milling plant

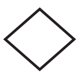
A. Assumptions

i. The failure and repair rates of all subsystems are constant, statistically independent to each other and there are no simultaneous failures of the subsystems [19].

ii. A repaired subsystem is as good as new one, performance wise and switchover devices used for standby systems are perfect [17].

iii. There are sufficient repair facilities. The failure and repair rates of each subsystem follows exponential distribution [2].

B. Notations

- Subsystem A consists of two Huskers subjected to major as well as minor failures.
- Subsystem B consists of two Husk Separators subjected to major as well as minor failures.
- Subsystem C consists of two De-Stoners subjected to major as well as minor failures.
- Subsystem D consists of one Paddy Cleaner subjected to major as well minor failures.
- Subsystem E consists of one number of Rotary Magnet subjected to minor failure and not considered for analysis.
- : System working in full capacity.
- : System working in reduced capacity.
- : System in the failed state.

– A^O, B^O, C^O, D^O: Subsystems in good operating state.

– A^F, B^F, C^F, D^F indicate the failed state of A, B, C, and D.

– A^R, B^R, C^R indicate that the subsystems A, B, and C are working in reduced capacity.

– λ_i: Mean failure rates from states A^O, B^O, C^O, D^O to A^R, B^R, C^R and A^R, B^R, C^R to A^F, B^F, C^F, D^F states.

– β_i: Mean repair rates from A^F, B^F, C^F, D^F to A^R, B^R, C^R and A^R, B^R, C^R to A^O, B^O, C^O and D^O states.

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

– ': Derivatives w.r.t. 't'

– Ass: Steady State Availability.

Based on the above assumptions and notations, state transition diagram has been developed as shown in Fig. 2.

IV. Availability Modeling

The availability modeling of the system based on the Markov Birth-Death process is carried out using various probabilities considerations. The differential equations associated with the state transition diagram shown in Fig. 2, are developed using mnemonic rules as discussed by [17]. The different probability consideration generates the following sets of differential equations for each state one by one out of 28 states of transition diagram as explained by [19]:

$$P_1'(t) + M_1P_1(t) = \beta_1P_2(t) + \beta_2P_3(t) + \beta_3P_4(t) + \beta_4P_9(t) \quad (1)$$

$$P_2'(t) + M_2P_2(t) = \beta_5P_{13}(t) + \beta_4P_{12}(t) + \beta_3P_5(t) + \beta_2P_7(t) + \alpha_1P_1(t) \quad (2)$$

$$P_3'(t) + M_3P_3(t) = \beta_1P_7(t) + \beta_3P_6(t) + \beta_6P_{11}(t) + \beta_4P_{10}(t) + \alpha_2P_1(t) \quad (3)$$

$$P_4'(t) + M_4P_4(t) = \beta_1P_5(t) + \beta_4P_{15}(t) + \beta_7P_{14}(t) + \beta_2P_6(t) + \alpha_3P_1(t) \quad (4)$$

$$P_5'(t) + M_5P_5(t) = \beta_2P_8(t) + \beta_4P_{18}(t) + \beta_7P_{17}(t) + \beta_5P_{16}(t) + \alpha_3P_2(t) + \alpha_1P_4(t) \quad (5)$$

$$P_6'(t) + M_6P_6(t) = \beta_1P_8(t) + \beta_6P_{19}(t) + \beta_7P_{20}(t) + \beta_4P_{21}(t) + \alpha_3P_3(t) + \alpha_2P_4(t) \quad (6)$$

$$P_7'(t) + M_7P_7(t) = \beta_3P_8(t) + \beta_4P_{24}(t) + \beta_6P_{23}(t) + \beta_5P_{22}(t) + \alpha_2P_2(t) + \alpha_1P_3(t) \quad (7)$$

$$P_8'(t) + M_8P_8(t) = \beta_5P_{25}(t) + \beta_6P_{26}(t) + \beta_7P_{27}(t) + \beta_4P_{28}(t) + \alpha_1P_6(t) + \alpha_2P_5(t) + \alpha_3P_7(t) \quad (8)$$

$$P_9'(t) + \beta_4P_9(t) = \alpha_4P_1(t) \quad (9)$$

$$P_{10}'(t) + \beta_4P_{10}(t) = \alpha_4P_3(t) \quad (10)$$

$$P_{11}'(t) + \beta_6P_{11}(t) = \alpha_6P_3(t) \quad (11)$$

$$P_{12}'(t) + \beta_4P_{12}(t) = \alpha_4P_2(t) \quad (12)$$

$$P_{13}'(t) + \beta_5P_{13}(t) = \alpha_5P_2(t) \quad (13)$$

$$P_{14}'(t) + \beta_7P_{14}(t) = \alpha_7P_4(t) \quad (14)$$

$$P_{15}'(t) + \beta_4P_{15}(t) = \alpha_4P_4(t) \quad (15)$$

$$P_{16}'(t) + \beta_5P_{16}(t) = \alpha_5P_5(t) \quad (16)$$

$$P_{17}'(t) + \beta_7P_{17}(t) = \alpha_7P_5(t) \quad (17)$$

$$P_{18}'(t) + \beta_4P_{18}(t) = \alpha_4P_5(t) \quad (18)$$

$$P_{19}'(t) + \beta_6P_{19}(t) = \alpha_6P_6(t) \quad (19)$$

$$P_{20}'(t) + \beta_7 P_{20}(t) = \alpha_7 P_6(t) \quad (20)$$

$$P_{21}'(t) + \beta_4 P_{21}(t) = \alpha_4 P_6(t) \quad (21)$$

$$P_{22}'(t) + \beta_5 P_{22}(t) = \alpha_5 P_7(t) \quad (22)$$

$$P_{23}'(t) + \beta_6 P_{23}(t) = \alpha_6 P_7(t) \quad (23)$$

$$P_{24}'(t) + \beta_4 P_{24}(t) = \alpha_4 P_7(t) \quad (24)$$

$$P_{25}'(t) + \beta_5 P_{25}(t) = \alpha_5 P_8(t) \quad (25)$$

$$P_{26}'(t) + \beta_6 P_{26}(t) = \alpha_6 P_8(t) \quad (26)$$

$$P_{27}'(t) + \beta_7 P_{27}(t) = \alpha_7 P_8(t) \quad (27)$$

$$P_{28}'(t) + \beta_4 P_{28}(t) = \alpha_4 P_8(t) \quad (28)$$

where,

$$M_1 = (\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4)$$

$$M_2 = (\alpha_5 + \alpha_4 + \alpha_3 + \alpha_2 + \beta_1)$$

$$M_3 = (\alpha_1 + \alpha_3 + \alpha_4 + \alpha_6 + \beta_2)$$

$$M_4 = (\alpha_1 + \alpha_7 + \alpha_4 + \alpha_2 + \beta_3)$$

$$M_5 = (\alpha_2 + \alpha_4 + \alpha_7 + \alpha_5 + \beta_3 + \beta_1)$$

$$M_6 = (\alpha_1 + \alpha_6 + \alpha_7 + \alpha_4 + \beta_3 + \beta_2)$$

$$M_7 = (\alpha_3 + \alpha_4 + \alpha_6 + \alpha_5 + \beta_2 + \beta_1)$$

$$M_8 = (\alpha_5 + \alpha_6 + \alpha_7 + \alpha_4 + \beta_2 + \beta_1 + \beta_3)$$

With initial condition at time t = 0,

$$P_i(t) = 1 \text{ for } i=1$$
$$P_i(t) = 0 \text{ for } i \neq 1 \quad (29)$$

V. Steady State Availability of the System

Khanduja et al. [17] suggested that in process plant, the management is interested to get the steady state availability of the system. The steady state availability of the system has been found out by applying steady state conditions i.e. $t\rightarrow\infty$ and $d/dt\rightarrow 0$, on the set of differential equations (1) to (8), the equations are derived as:

$$M_1P_1 = \beta_1P_2 + \beta_2P_3 + \beta_3P_4 + \beta_4P_9 \quad (30)$$

$$M_2P_2 = \beta_5P_{13} + \beta_4P_{12} + \beta_3P_5 + \beta_2P_7 + \alpha_1P_1 \quad (31)$$

$$M_3P_3 = \beta_1P_7 + \beta_3P_6 + \beta_6P_{11} + \beta_4P_{10} + \alpha_2P_1 \quad (32)$$

$$M_4P_4 = \beta_1P_5 + \beta_4P_{15} + \beta_7P_{14} + \beta_2P_6 + \alpha_3P_1 \quad (33)$$

$$M_5P_5 = \beta_2P_8 + \beta_4P_{18} + \beta_7P_{17} + \beta_5P_{16} + \alpha_3P_2 + \alpha_1P_4 \quad (34)$$

$$M_6P_6 = \beta_1P_8 + \beta_6P_{19} + \beta_7P_{20} + \beta_4P_{21} + \alpha_3P_3 + \alpha_2P_4 \quad (35)$$

$$M_7P_7 = \beta_3P_8 + \beta_4P_{24} + \beta_6P_{23} + \beta_5P_{22} + \alpha_3P_2 + \alpha_1P_3 \quad (36)$$

$$M_8P_8 = \beta_5P_{25} + \beta_6P_{26} + \beta_7P_{27} + \beta_4P_{28} + \alpha_2P_5 + \alpha_1P_6 + \alpha_3P_7 \quad (37)$$

$$\beta_4P_9 = \alpha_4P_1 \quad (38)$$

$$\beta_4P_{10} = \alpha_4P_3 \quad (39)$$

$$\beta_6P_{11} = \alpha_6P_3 \quad (40)$$

$$\beta_4P_{12} = \alpha_4P_2 \quad (41)$$

$$\beta_5P_{13} = \alpha_5P_2 \quad (42)$$

$$\beta_7P_{14} = \alpha_7P_4 \quad (43)$$

$$\beta_4P_{15} = \alpha_4P_4 \quad (44)$$

$$\beta_5P_{16} = \alpha_5P_5 \quad (45)$$

$$\beta_7P_{17} = \alpha_7P_5 \quad (46)$$

$$\beta_4P_{18} = \alpha_4P_5 \quad (47)$$

$$\beta_6P_{19} = \alpha_6P_6 \quad (48)$$

$$\beta_4P_{21} = \alpha_4P_6 \quad (49)$$

$$\beta_5P_{22} = \alpha_5P_7 \quad (50)$$

$$\beta_6P_{23} = \alpha_6P_7 \quad (51)$$

$$\beta_5P_{25} = \alpha_5P_8 \quad (52)$$

$$\beta_6P_{26} = \alpha_6P_8 \quad (53)$$

$$\beta_7P_{27} = \alpha_7P_8 \quad (54)$$

$$\beta_4P_{28} = \alpha_4P_8 \quad (55)$$

On solving the above equations, we get:

$$P_2 = L_9P_1 \quad (56)$$

$$P_3 = L_{11}P_1 \quad (57)$$

$$P_4 = L_3P_1 \quad (58)$$

$$P_5 = L_{12}P_1 \quad (59)$$

$$P_6 = L_{13}P_1 \quad (60)$$

$$P_7 = L_{14}P_1 \quad (61)$$

$$P_8 = L_{15}P_1 \quad (62)$$

$$P_9 = \frac{\alpha_4}{\beta_4}P_1 \quad (63)$$

$$P_{10} = \frac{\alpha_4}{\beta_4}P_3 = \frac{\alpha_4}{\beta_4}L_{11}P_1 \quad (64)$$

$$P_{11} = \frac{\alpha_6}{\beta_6} P_3 = \frac{\alpha_6}{\beta_6} L_{11} P_1 \quad (65)$$

$$P_{12} = \frac{\alpha_4}{\beta_4} P_2 = \frac{\alpha_4}{\beta_4} L_9 P_1 \quad (66)$$

$$P_{13} = \frac{\alpha_5}{\beta_5} P_2 = \frac{\alpha_5}{\beta_5} L_9 P_1 \quad (67)$$

$$P_{14} = \frac{\alpha_7}{\beta_7} P_3 = \frac{\alpha_7}{\beta_7} L_{10} P_1 \quad (68)$$

$$P_{15} = \frac{\alpha_4}{\beta_4} P_4 = \frac{\alpha_4}{\beta_4} L_{10} P_1 \quad (69)$$

$$P_{16} = \frac{\alpha_5}{\beta_5} P_5 = \frac{\alpha_5}{\beta_5} L_{12} P_1 \quad (70)$$

$$P_{17} = \frac{\alpha_7}{\beta_7} P_5 = \frac{\alpha_7}{\beta_7} L_{12} P_1 \quad (71)$$

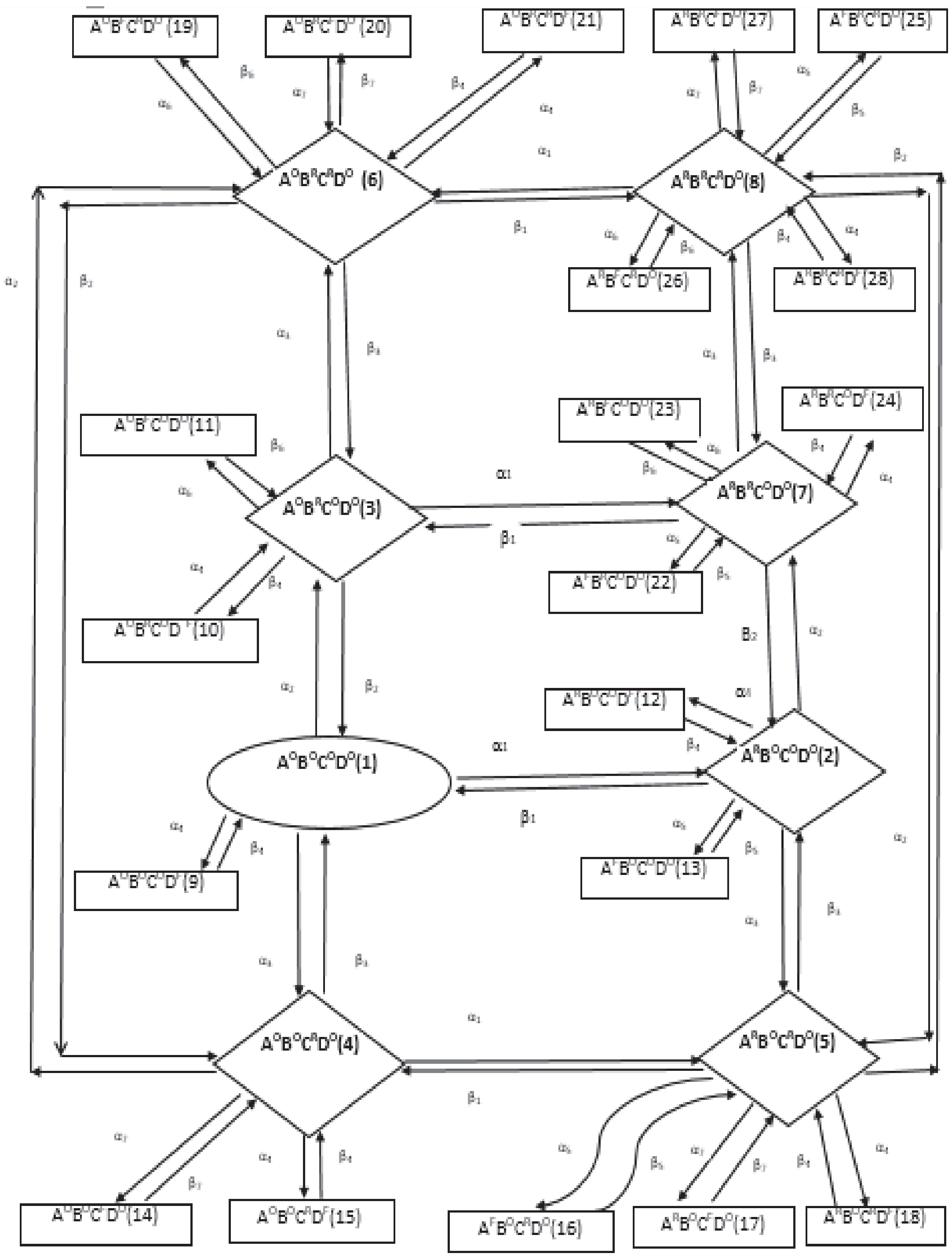


Fig. 2 State transition diagram of milling system of a rice plant

$$P_{18} = \frac{\alpha_4}{\beta_4} P_5 = \frac{\alpha_4}{\beta_4} L_{12} P_1 \quad (72)$$

$$P_{19} = \frac{\alpha_6}{\beta_6} P_6 = \frac{\alpha_6}{\beta_6} L_{13} P_1 \quad (73)$$

$$P_{20} = \frac{\alpha_7}{\beta_7} P_6 = \frac{\alpha_7}{\beta_7} L_{13} P_1 \quad (74)$$

$$P_{21} = \frac{\alpha_4}{\beta_4} P_6 = \frac{\alpha_4}{\beta_4} L_{13} P_1 \quad (75)$$

$$P_{22} = \frac{\alpha_5}{\beta_5} P_7 = \frac{\alpha_5}{\beta_5} L_{14} P_1 \quad (76)$$

$$P_{23} = \frac{\alpha_6}{\beta_6} P_7 = \frac{\alpha_6}{\beta_6} L_{14} P_1 \quad (77)$$

$$P_{24} = \frac{\alpha_4}{\beta_4} P_7 = \frac{\alpha_4}{\beta_4} L_{14} P_1 \quad (78)$$

$$P_{25} = \frac{\alpha_5}{\beta_5} P_8 = \frac{\alpha_5}{\beta_5} L_{15} P_1 \quad (79)$$

$$P_{26} = \frac{\alpha_6}{\beta_6} P_8 = \frac{\alpha_6}{\beta_6} L_{15} P_1 \quad (80)$$

$$P_{27} = \frac{\alpha_7}{\beta_7} P_8 = \frac{\alpha_7}{\beta_7} L_{15} P_1 \quad (81)$$

$$P_{28} = \frac{\alpha_4}{\beta_4} P_8 = \frac{\alpha_4}{\beta_4} L_{15} P_1 \quad (82)$$

where

$$M_1 = (\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4)$$

$$M_2 = (\alpha_5 + \alpha_4 + \alpha_3 + \alpha_2 + \beta_1)$$

$$M_3 = (\alpha_1 + \alpha_3 + \alpha_4 + \alpha_6 + \beta_2)$$

$$M_4 = (\alpha_1 + \alpha_7 + \alpha_4 + \alpha_2 + \beta_3)$$

$$M_5 = (\alpha_2 + \alpha_7 + \alpha_4 + \alpha_5 + \beta_3 + \beta_1)$$

$$M_6 = (\alpha_1 + \alpha_6 + \alpha_7 + \alpha_4 + \beta_3 + \beta_2)$$

$$M_7 = (\alpha_3 + \alpha_6 + \alpha_5 + \alpha_4 + \beta_1 + \beta_2)$$

$$M_8 = (\alpha_6 + \alpha_7 + \alpha_4 + \alpha_5 + \beta_3 + \beta_1 + \beta_2)$$

$$L_1 = \frac{1}{T_4}[\frac{\beta_2\alpha_3}{A_5} + \frac{\alpha_1\alpha_3\beta_1\beta_2}{T_5}(\frac{1}{A_4} + \frac{1}{A_5})(\frac{1}{A_5} + \frac{1}{A_5})]$$

$$L_2 = \frac{1}{T_4}[\frac{\beta_1\alpha_3}{A_4} + \frac{\alpha_2\alpha_3\beta_1\beta_2}{T_5}(\frac{1}{A_4} + \frac{1}{A_6})(\frac{1}{A_4} + \frac{1}{A_5})]$$

$$L_3 = \frac{1}{T_3}[\frac{\beta_1\alpha_2}{A_6} + \frac{\alpha_2\alpha_3\beta_1\beta_3}{T_5}(\frac{1}{A_6} + \frac{1}{A_5})(\frac{1}{A_4} + \frac{1}{A_6})]$$

$$L_4 = \frac{1}{T_3}[\frac{\beta_3\alpha_3}{A_5} + \frac{\alpha_1\alpha_2\beta_1\beta_3}{T_5}(\frac{1}{A_6} + \frac{1}{A_5})(\frac{1}{A_5} + \frac{1}{A_4})]$$

$$L_5 = \frac{L_2 + L_1L_3}{1 - L_1L_4}$$

$$L_6 = \frac{1}{1 - L_1L_4}[\frac{\alpha_3}{T_4} + \frac{L_1\alpha_2}{T_3}]$$

$$L_7 = \frac{1}{T_2}[\frac{\beta_2\alpha_1}{A_6} + \frac{\alpha_1\alpha_3\beta_2\beta_3}{T_5}(\frac{1}{A_4} + \frac{1}{A_6})(\frac{1}{A_5} + \frac{1}{A_5})]$$

$$L_8 = \frac{1}{T_2}[\frac{\beta_3\alpha_1}{A_4} + \frac{\alpha_1\alpha_2\beta_2\beta_3}{T_5}(\frac{1}{A_4} + \frac{1}{A_5})(\frac{1}{A_4} + \frac{1}{A_6})]$$

$$L_9 = \frac{1}{T_1}[\frac{L_4(L_7 + L_1L_8)}{1 - L_1L_4}(\frac{\alpha_3}{T_4} + \frac{L_1\alpha_2}{T_3}) + \frac{L_7\alpha_2}{T_3} + \frac{L_1L_8\alpha_2}{T_3} + \frac{L_8\alpha_3}{T_4} + \frac{\alpha_1}{T_2}]$$

$$L_{10} = (L_5L_9 + L_6)$$

$$L_{11} = \left(L_3L_9 + L_4L_{10} + \frac{\alpha_2}{T_3}\right)$$

$$L_{12} = \frac{1}{A_4}[L_9\{\alpha_3 + \frac{\beta_2\alpha_1\alpha_3}{T_5}(\frac{1}{A_4} + \frac{1}{A_6})\} + L_{10}\{\alpha_1 + \frac{\alpha_1\alpha_2\beta_2}{T_5}(\frac{1}{A_5} + \frac{1}{A_4})\} + L_{11}\frac{\alpha_1\alpha_3\beta_2}{T_5}(\frac{1}{A_5} + \frac{1}{A_6})]$$

$$L_{13} = \frac{1}{A_5}[L_{11}\{\alpha_3 + \frac{\beta_1\alpha_1\alpha_3}{T_5}(\frac{1}{A_4} + \frac{1}{A_6})\} + L_{10}\{\alpha_2 + \frac{\alpha_1\alpha_2\beta_1}{T_5}(\frac{1}{A_5} + \frac{1}{A_4})\} + L_9\frac{\alpha_2\alpha_3\beta_1}{T_5}(\frac{1}{A_4} + \frac{1}{A_6})]$$

$$L_{14} = \frac{1}{A_6}[L_9\{\alpha_2 + \frac{\beta_3\alpha_2\alpha_3}{T_5}(\frac{1}{A_4} + \frac{1}{A_6})\} + L_{11}\{\alpha_1 + \frac{\alpha_1\alpha_3\beta_3}{T_5}(\frac{1}{A_5} + \frac{1}{A_6})\} + L_{10}\frac{\alpha_1\alpha_2\beta_3}{T_5}(\frac{1}{A_5} + \frac{1}{A_4})]$$

$$L_{15} = \frac{1}{T_5}[L_{11}\{\alpha_1\alpha_3(\frac{1}{A_5} + \frac{1}{A_6}) + \alpha_2\alpha_3(\frac{1}{A_4} + \frac{1}{A_6})L_9\} + L_{10}\{\alpha_1\alpha_2(\frac{1}{A_5} + \frac{1}{A_4})]$$

$$(\beta_1 + \beta_2 + \beta_3) = A_7$$

$$(\beta_1 + \beta_2 + \alpha_3) = A_6$$

$$(\beta_3 + \beta_2 + \alpha_1) = A_5$$

$$(\beta_1 + \beta_3 + \alpha_2) = A_4$$

$$(\alpha_1 + \beta_3 + \alpha_2) = A_3$$

$$(\alpha_1 + \beta_2 + \alpha_3) = A_2$$

$$(\alpha_3 + \beta_1 + \alpha_2) = A_1$$

$$T_5 = A_7 - \frac{\beta_1\alpha_1}{A_5} - \frac{\beta_2\alpha_2}{A_4} - \frac{\beta_3\alpha_3}{A_6}$$

$$T_4 = A_3 - \frac{\beta_1\alpha_1}{A_4} - \frac{\beta_2\alpha_2}{A_5} - \frac{\beta_2\beta_1\alpha_1\alpha_2}{T_5}(\frac{1}{A_5} + \frac{1}{A_4})(\frac{1}{A_5} + \frac{1}{A_4})$$

$$T_3 = A_2 - \frac{\beta_1\alpha_1}{A_6} - \frac{\beta_3\alpha_3}{A_5} - \frac{\beta_3\beta_1\alpha_1\alpha_3}{T_5}(\frac{1}{A_5} + \frac{1}{A_6})(\frac{1}{A_5} + \frac{1}{A_6})$$

$$T_2 = A_1 - \frac{\beta_3\alpha_3}{A_4} - \frac{\beta_2\alpha_2}{A_6} - \frac{\beta_2\beta_3\alpha_2\alpha_3}{T_5}(\frac{1}{A_4} + \frac{1}{A_6})(\frac{1}{A_4} + \frac{1}{A_6})$$

$$T_1 = 1 - L_3L_7 - L_2L_8 - L_8L_1L_3 - \frac{L_4(L_7 + L_1L_8)(L_2 + L_1L_3)}{1 - L_1L_4}$$

Under Normalizing Condition (i.e. sum of all the probabilities is equal to one)

$$\sum_{i=1}^{28} P_i = 1$$

$$P_1 = \begin{bmatrix} 1 + L_9 + L_{11} + L_{10} + L_{12} + L_{13} + L_{14} + L_{15} + \frac{\alpha_4}{\beta_4} + \frac{\alpha_4}{\beta_4}L_{11} + \frac{\alpha_6}{\beta_6}L_{11} + \frac{\alpha_4}{\beta_4}L_9 \\ + \frac{\alpha_5}{\beta_5}L_9 + \frac{\alpha_7}{\beta_7}L_{10} + \frac{\alpha_4}{\beta_4}L_{10} + \frac{\alpha_5}{\beta_5}L_{12} + \frac{\alpha_7}{\beta_7}L_{12} + \frac{\alpha_4}{\beta_4}L_{12} + \frac{\alpha_6}{\beta_6}L_{13} + \frac{\alpha_7}{\beta_7}L_{13} \\ + \frac{\alpha_4}{\beta_4}L_{13} + \frac{\alpha_5}{\beta_5}L_{14} + \frac{\alpha_6}{\beta_6}L_{14} + \frac{\alpha_4}{\beta_4}L_{14} + \frac{\alpha_5}{\beta_5}L_{15} + \frac{\alpha_6}{\beta_6}L_{15} + \frac{\alpha_7}{\beta_7}L_{15} + \frac{\alpha_4}{\beta_4}L_{15} \end{bmatrix}^{-1} \quad (83)$$

The steady state availability of the milling system A_{ss} is given by

$$A_{ss} = P_1 + P_2 + P_3 + P_4 + P_5 + P_6 + P_7 + P_8$$

$$Ass = [1 + L_9 + L_{11} + L_{10} + L_{12} + L_{13} + L_{14} + L_{15}]P_1 \quad (84)$$

VI. Availability Analysis

The availability analysis is carried out by taking appropriate range of failure and repair rates of all subsystems from maintenance record of milling system and detailed discussion with the maintenance personnel of the plant. The effect of various subsystems on availability of the system with various combinations of failure and repair parameters has been shown in Tables I-VII and Figs. 3-9. It also reveals the effect of failure and repair parameters of all subsystems on milling system performance.

TABLE I
Steady State Availability versus Failure and Repair Rates of Husker

β_1 / α_1	0.020	0.040	0.060	0.080	Other Constant Parameters
0.0001	0.9201	0.9399	0.9468	0.9503	α_2=0.001, α_3=0.002,
0.0002	0.8856	0.9204	0.9333	0.9400	α_4=0.003, α_5=0.025,
0.0003	0.8563	0.9025	0.9205	0.9301	α_6=0.005, α_7=0.004, β_2=0.020, β_3=0.020,
0.0004	0.8310	0.8861	0.9085	0.9260	β_4=0.20, β_5=0.025, β_6=0.020, β_7=0.025

TABLE II
Steady State Availability versus Failure and Repair Rates of Husk Separator

β_2 / α_2	0.020	0.050	0.080	0.11	Other Constant Parameters
0.001	0.9201	0.9248	0.9261	0.9269	α_1=0.001, α_3=0.002,
0.002	0.9133	0.9216	0.9239	0.9251	α_4=0.003, α_5=0.025,
0.003	0.9071	0.9185	0.9219	0.9235	α_6=0.005, α_7=0.004, β_1=0.020, β_3=0.020,
0.004	0.9015	0.9156	0.9199	0.9220	β_4=0.20, β_5=0.025, β_6=0.020, β_7=0.025.

TABLE III
Steady State Availability versus Failure and Repair Rates of De-Stoner

β_3 / α_3	0.020	0.060	0.10	0.14	Other Constant Parameters
0.002	0.9201	0.9275	0.9291	0.9298	α_1=0.001 α_2=0.001,
0.004	0.9094	0.9228	0.9261	0.9276	α_4=0.003, α_5=0.025,
0.006	0.8997	0.9179	0.9228	0.9251	α_6=0.005, α_7=0.004, β_1=0.020, β_2=0.020,
0.008	0.8908	0.9127	0.9192	0.9223	β_4=0.20, β_5=0.025, β_6=0.020, β_7=0.025.

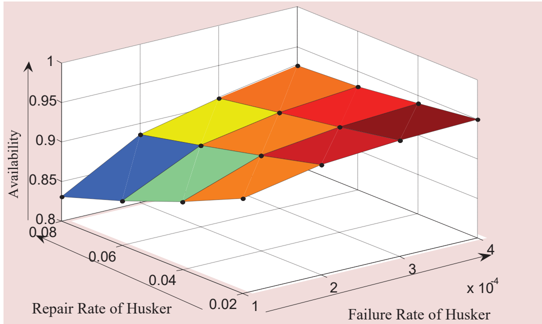


Fig. 3 Effect of failure and repair rates of husker on system availability

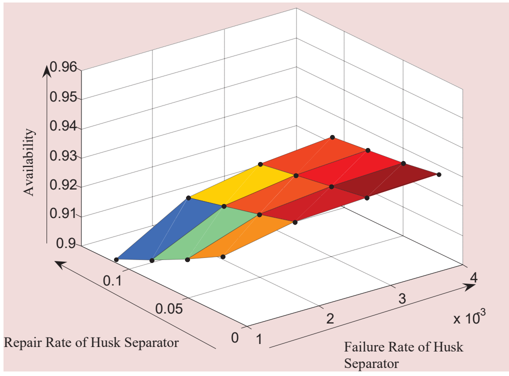


Fig. 4 Effect of Failure and Repair Rates of Husk Separator on System Availability

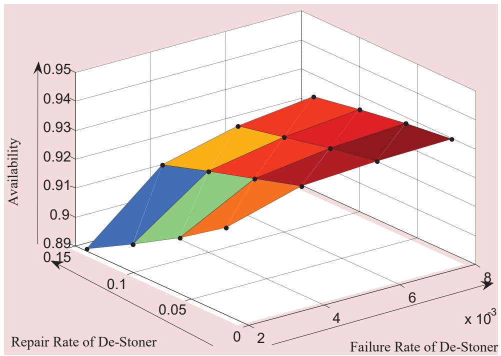


Fig. 5 Effect of Failure and Repair Rates of De-Stoner on System Availability

TABLE IV
Steady State Availability versus Failure and Repair Rates of Paddy Cleaner

β_4 / α_4	0.20	0.30	0.40	0.50	Other Constant Parameters
0.003	0.9201	0.9244	0.9265	0.9278	α_1=0.001, α_2=0.001,
0.005	0.9117	0.9187	0.9222	0.9244	α_3=0.002, α_5=0.025,
0.007	0.9035	0.9131	0.9180	0.9209	α_6=0.005, α_7=0.004, β_1=0.020, β_2=0.020,
0.009	0.8954	0.9076	0.9138	0.9189	β_3=0.020, β_5=0.025, β_6=0.020, β_7=0.025.

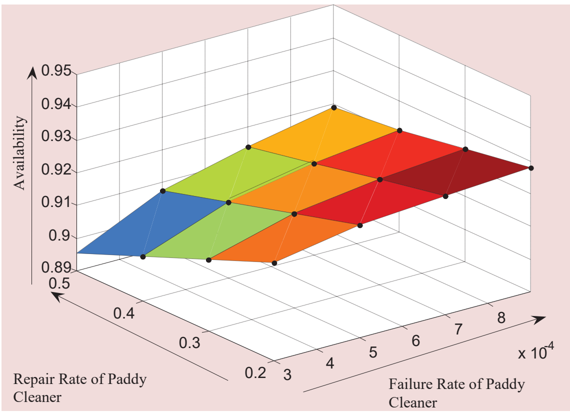


Fig. 6 Effect of Failure and Repair Rates of Paddy Cleaner on System Availability

TABLE V
STEADY STATE AVAILABILITY VERSUS FAILURE AND REPAIR RATES OF HUSKER WORKING IN REDUCED CAPACITY

α_5 \ β_5	0.025	0.050	0.075	0.10	Other Constant Parameters
0.025	0.9201	0.9403	0.9472	0.9507	α_1=0.001 α_2=0.001,
0.030	0.9123	0.9362	0.9444	0.9486	α_3=0.002, α_4=0.003,
0.035	0.9046	0.9321	0.9417	0.9465	α_6=0.005, α_7=0.004, β_1=0.020, β_2=0.020,
0.040	0.8970	0.9281	0.9389	0.9444	β_3=0.020, β_4=0.20, β_6=0.020, β_7=0.025.

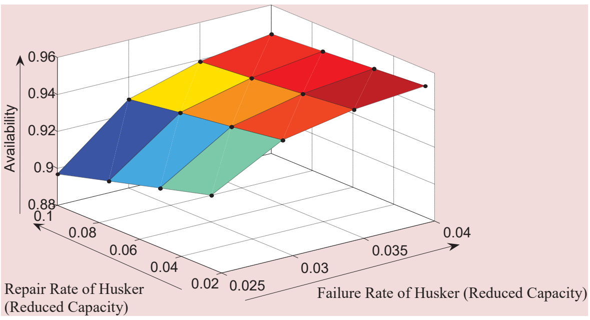


Fig. 7 Effect of Failure and Repair Rates of Husker on System Availability Working in Reduced Capacity

TABLE VI
STEADY STATE AVAILABILITY VERSUS FAILURE AND REPAIR RATES OF HUSK SEPARATOR WORKING IN REDUCED CAPACITY

α_6 \ β_6	0.020	0.040	0.060	0.080	Other Constant Parameters
0.005	0.9201	0.9248	0.9264	0.9272	α_1=0.001 α_2=0.001,
0.006	0.9182	0.9239	0.9258	0.9268	α_3=0.002, α_4=0.003,
0.007	0.9163	0.9229	0.9252	0.9263	α_5=0.025, α_7=0.004, β_1=0.020, β_2=0.020,
0.008	0.9145	0.9220	0.9245	0.9258	β_3=0.020, β_4=0.20, β_5=0.025, β_7=0.025.

TABLE VII
STEADY STATE AVAILABILITY VERSUS FAILURE AND REPAIR RATES OF DE-STONER WORKING INREDUCED CAPACITY

α_7 \ β_7	0.025	0.050	0.075	0.10	Other Constant Parameters
0.004	0.9201	0.9260	0.9280	0.9290	α_1=0.001 α_2=0.001,
0.005	0.9172	0.9245	0.9270	0.9283	α_3=0.002, α_4=0.003,
0.006	0.9142	0.9231	0.9260	0.9275	α_5=0.025, α_6=0.005, β_1=0.020, β_2=0.020,
0.007	0.9113	0.9216	0.9250	0.9268	β_3=0.020, β_4=0.20, β_5=0.025, β_6=0.020,

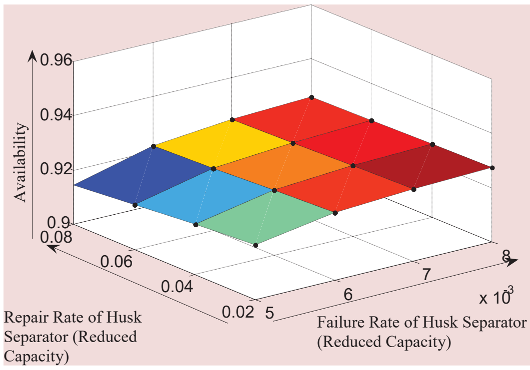


Fig. 8 Effect of Failure and Repair Rates of Husk Separator on System Availability Working in Reduced Capacity

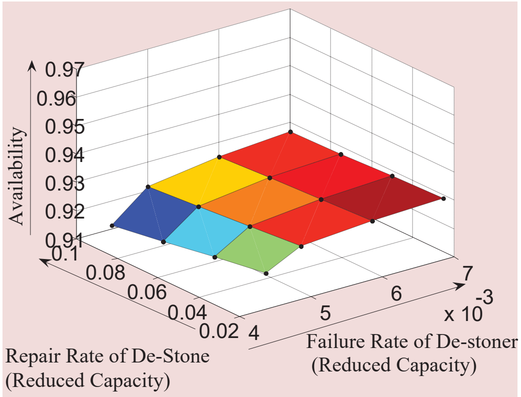


Fig. 9 Effect of Failure and Repair Rates of De-Stoner on System Availability Working in Reduced Capacity

VII. RESULTS AND DISCUSSION

From analysis part, it is found that increase in the failure and repair rates of Husker, Husk Separator, De-Stoner and Paddy Cleaner affects the availability of the system and needs to be controlled. Table I and Fig. 3 show the effect of failure and repair rate of Husker on the long run availability of milling system, as the failure rate (α_1) increases from 0.0001 to 0.0004 the system availability reduces considerably by 9.7%. Similarly, as the repair rate (β_1) increases from 0.020 to 0.080, the system availability significantly improves by 3.3%.

Table II and Fig. 4 reveal the effect of failure and repair rates of Husk Separator on the availability of milling system, as the failure rate (α_2) increases from 0.001 to 0.004 the system availability reduces by 2.0%. Similarly, as the repair rate (β_2) increases from 0.020 to 0.11 the system availability hardly increases by 0.8%.

Table III and Fig. 5 depict the effect of failure and repair rates of the De-Stoner on the availability of milling system, as the failure rate (α_3) of DeStoner increases from 0.002 to 0.008 the system availability decreases by 3.2%. Similarly, as the repair rate (β_3) increases from 0.020 to 0.14 the system availability increases by 1.1%.

Table IV and Fig. 6 highlight the effect of failure and repair rates of the Paddy Cleaner on the availability system, as the failure rate (α_4) of Paddy Cleaner increases from 0.001 to 0.004 the system availability decreases by 2.7%. Similarly, as the repair rate (β_4) increases from 0.020 to 0.50 the system availability increases by 0.8% only.

Table V and Fig. 7 explain the effect of failure and repair rates of the Husker working in reduced state on the availability of the system, as the failure rate (α_5) of Husker increases from 0.025 to 0.040 the availability decreases by 2.5%. Similarly, as the repair rate (β_5) increases from 0.025 to 0.10 the system availability increases by 3.3%.

Table VI and Fig. 8 reveal the effect of failure and repair rates of the Husk Separator working in reduced state on the availability of system, as the failure rate (α_6) of Husk Separator increases from 0.005 to 0.008 the availability decreases by 0.6%. Similarly, as the repair rate (β_6) increases from 0.020 to 0.080 the system availability increases by 0.8%.

Table VII and Fig. 9 depict the effect of failure and repair rates of the De-Stoner working in reduced state on the availability of the system, as the failure rate (α_7) of De-Stoner increases from 0.004 to 0.007 the availability decreases by 1.0%. Similarly, as the repair rate (β_7) increases from 0.025 to 0.10 the system availability improves by 1.7%.

VIII. Conclusions and Future Work

In this paper, we mainly focus on the availability analysis and maintenance repair priorities of the system using Markov approach with exponential subsystem failure and repair rates. The results are shown in Tables I-VII. They are derived to assist the maintenance decisions where repair priorities should be given to subsystems of rice milling section. It is clearly shown from Table VIII that the Husker is the most critical subsystem as far as repair aspect is concerned and hence given top priority. The De-Stoner should be given second priority as the effect of its failure and repair rates on the system availability is much higher than that of Paddy Cleaner and Husk Separator. Therefore, on the basis of above analysis, the repair priorities have been suggested as shown in Table VIII.

TABLE VIII
Repair Priorities for Milling System of a Rice Milling Plant

Subsystem	Failure Rates	Decrease in Availability	Repair Rates	Increase in Availability	Suggested Repair Priority
Husker	0.0001 to 0.0004	9.7%	0.020 to 0.080	3.3%	I
De-Stoner	0.002 to 0.008	3.2%	0.020 to0.14	1.0%	II
Paddy Cleaner	0.003 to 0.009	2.7%	0.2 to 0.5	0.8%	III
Husk Separator	0.001 to 0.004	2.0%	0.020 to 0.11	0.7%	IV

One of the main limitations of our model is the exponentially distributed failure and repair rates, which are assumed to carried out the performance analysis of system under study. We admit that if numbers of subsystems are more, computing the performance may take much more time. Finding less computational methods to address the problem might also be suitable for future work.

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