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Research Article

Performance Modeling and Availability Simulation of a Malt Mill System of Brewery Industry

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Abstract

The major cause of production loss in brewery industry is the Machine failures which stopped the production operations. The Markov approach is used for studying the Performance modeling and Availability analysis of a Malt Mill system in brewery plant by using the concept of performance analysis. For carrying out analysis, transition diagrams (TD) for various subsystems in the brewery plant are drawn and Chapman-Kolmogorov differential equations associated with TD are derived. The probability of each state is calculated in terms of probability of full working state. The failure and repair time distributions are assumed to be exponential behavior. The performance analysis of the system in steady state conditions is analyzed using the data related to system's real operational behavior of a brewery system. The simulation model has been used for analyzing system availability for varying failure and the repair rates using the MATLAB tool. The dynamic behavior of the corresponding values of reliability is estimated for one year by using RungeKuttamethod of fourth order.

Keywords: *Availability, Failure rate, Markov, Performance Modeling, Transition Diagram (TD)*

1. Introduction

The probabilistic approach is the measure for the assessment of availability in the production optimization system in reliability studies. The process industry like brewery is consists of large complex engineering systems, subsystems arranged in series, parallel or a combination of both. For efficient and economical operation of a brewery plant, each system or subsystem should run failure free under the existing operative plant conditions.

Reliability estimations have been used successfully as a reliability engineering tool for eight decades. It is only one element of a well-structured reliability program and, to be effective, must be complemented by other elements. The history of reliability predictions have been used as a reliability engineering tool, and the current status of several issues relating to reliability prediction (William Denson, 1998). Most of the equipments used industrial applications, can be, and is often, repaired upon failure. So, the study of repairable systems is an important area within reliability engineering. The use of mathematical modeling for evaluating, improving, and optimizing the performance of repairable equipment is discussed in the literature (D.I. Cho and M. Parlar, 1991, R. Dekker, 1996; J. J. McCall, 1965; W. P. Pierskalla and J. A. Voelker, 1976). A key feature of these models is the assumption regarding the effect of repair on equipment aging. Perfect repair implies that the equipment is good as new after repair. Minimal repair implies that the equipment is bad as old after repair, i.e. the equipment has the same age as it did at the time of failure. Criticality-importance corresponds to the conditional probability of failure of a component, given that the system has failed (W. P. Pierskalla and J. A. Voelker, 1996; A. Hoyland and M. Rausand, 1994). A pumping system which performs differently according to the many different combinations of states of its subsystems are examples of multi-state systems with unordered multiple states and can be analyzed by the Multi state block diagrams and fault trees (S. Garribba et al, 1985). The deterministic processing times, multiple failure modes and finite buffer capacity can be used for performance evaluation of asynchronous production lines (R. Levantesi, 2003). The discrete flow of parts is approximated by a continuous flow of material. The performance and degradation of photo voltaic modules under outdoor operation is used for identifying research gaps for long term reliability of photovoltaic modules and improving the photovoltaic qualification standards for various geographical and climatic conditions (Vikrant Sharma and S.S. Chandel, 2013). A quantitative reliability and availability evaluation method has applied for subsea blowout preventer system by translating fault tree into dynamic Bayesian networks directly, taking account of imperfect repair (BaopingCai et al, 2013). A reliability-centered Dynamic Maintenance Threshold is used to improve the maintenance effectiveness to reduce equipment failures by maximizing system availability and is obtained by considering both the current system state

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and the lifetime distribution (Lin Li et al,2009).

Large engineering plants have certain unique features that necessitate a maintenance strategy that is a combination of both time and condition based maintenance. Such a strategy should also adopt a wholesome systemic approach so that the realization of the overall objectives of maintenance is optimized (Ajit Kumar Verma, 2010). Reliability analysis techniques have been accepted as standard tools for the planning and operation of automatic and complex process industries. A approach based on a particle swarm technique has been to optimize the design of the single-tuned passive filters for industrial plants in distribution networks (H. H. Zeineldin& A. F. Zobaa, 2011).

The evolutionary concept of PSO is clear-cut in nature, easy to implement in practice, and computationally efficient in comparison to other evolutionary algorithms. The performance of conventional PSO on the solution quality and convergence speed deteriorates when the function to be optimized is multimodal or with a large problem size. Optimization is one of the most frequently used techniques for evaluating optimum conditions of a scientific system under the greatest possible utilization of limited resources. In computer science, particle swarm optimization (PSO) is a computational method that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality (Shu-Kai S. Fan & Yi-Yin Chiu, 2007). PSO is originally attributed to Kennedy, Eberhart and Shi and was first intended for simulating social behavior, as a stylized representation of the movement of organisms in a bird flock or fish school (J. Kennedy et al, 1995). A complex repairable system is often important to assess system mean time to failure for a variety of component reliability characteristics and repair capabilities (J.M Kontoleon, 1978). The availability of a system can be improved by using the standby units of limited subsystems, where the chances of failure are high (Jai Singh et al, 1995). A system of n-independent reparable units can be described by a homogeneous-time discrete-state Markov Process (M.A El-Damcese, 1995). A fluid catalytic cracking unit of a refinery has required high levels of availability for cost effective operation (G. Thangamani, 1995). The behavioral analysis for shell gasification and carbon recovery process in a urea fertilizer plant, pumping system has analyzed by Markov model by considering various failure and repairs rates and the effect of each unit on the system availability are analyzed (Sunand Kumar, 1996; D. V. Raje et al, 1995). Non- homogeneous semi- Markov Process can be used as an approach to model reliability characteristics of components or small systems with complex test maintenance strategies (G.Becker et al, 2000). The effect of limited availability of the voting units on the entire voting system reliability and a method for determining indices that measure importance of voting units availability for the system is analyzed (Gregory Levitin, 1991).

The Steady state availability and mean time to system failure of repairable system with operating units, warm standby units and repairmen in which units balking and reneging can be improved (Kuo- Hsiung Wang and Jau-ChuanKe, 2003). (Lori E. Seward and Joel A. Nachlas, 2004) constructed a model of the operational reliability and availability of multitask systems and constitute an extension to model of repairable system behavior and application of renewal theory. (Francesco Martinelli, 2005) Consider a failure prone, single machine, single part type, limited inventory, manufacturing system subject to a non- homogeneous Markov Failure/ repair process with the failure rate depending on the production rate through a value function. The cost function is applied to determine the optimal number of warm and cold standby units required for the desired level of quality of services for a a multi-component repairable system with state dependent rate (Komal et al, 2009). The Genetic Algorithms based Lambda–Tau (GABLT) technique can be applied to estimate the RAM parameters of these systems by utilizing available information and uncertain data. As far as reliability is concerned, it has been established as a useful tool for risk analysis, production availability studies and design of systems. Availability has been considered as an important measure of performance for many industrial systems which are generally considered as repairable ones (Peter Bullemer et al, 2010). The process industry plants involve operations of complex human machine systems. An analytical aggregation method can be used for evaluating the throughput (or production rate) of tandem homogenous production lines (Ahmed-TidjaniBelmansour and Mustapha, 2010; Ling Wang et al, 2011). The Imperfect maintenance will decrease the expected values of cycle length and long-run availability (A. Kumar, and S. Lata, 2012). (K.S. Upadhya and N.K. Srinivasan, 2012) Developed a fuzzy Markov model to develop Kolmogorov's differential equations of condensate system and evaluated the reliability of the system. A Discrete Event Simulation technique using Monte-Carlo methods, applied to estimate the availability of military systems. The reliability and availability aspects of one of the significant constituent in a Railway Diesel Locomotive Engine and ABC analysis has been used for the maintenance of spare parts inventory (D. Bose et al, 2013).

After going through a comprehensive survey of the reported literature, most of the researchers reserved their work in the development and analysis of theoretical mathematical models and none of the author has tried to solve the mathematical model using more realistic conditions. The performance optimization and numerical analysis in the Brewery plant have also not been taken up by any researcher.

2. System Description

The Malt Mill system comprises of three subsystems arranged in series.

1. Subsystem B1: This subsystem consists of three units (Elevator, feed roller, and crushing roller) arranged in series. Each unit comprises of two working units (in parallel to increase the capacity of the respective units). Failure of one unit at a time only reduces the processing capacity. The complete failure is considered only when two units of particular equipment remain in fail state.

2. Subsystem B2: It consists of screw conveyor. It is single unit and has no replacement. Therefore, it causes severe effect on the system performance i.e complete failure of the system.
3. Subsystem B3: It consists of elevator. It is single unit. If it fails, the complete failure of system takes place.The flow process of Malt Mill system is shown in figure 1.

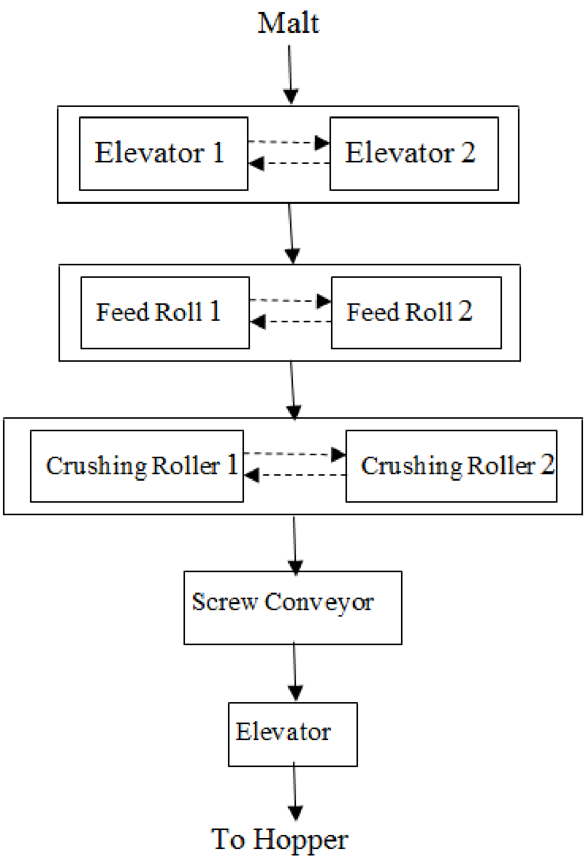

Figure: 1 Flow process of Malt Mill system

3. Performance Modeling

The calculation of the Availability of a system with elements exhibiting dependent failures and involving repair or standby operation is, in general, complicated and several approaches have been suggested to carry out the computations. A technique that has much appeal and works well when failure hazards and repair hazards are constant requires the use of Markov models. It is beneficial to represent a Markov process pictorially, and this pictorial representation is called a Markov Graph. A stochastic process in a physical system is known as Markov process if the occurrence of any future state of the system is independent of any past state and depends only on the present state. In Markov process, we deal with two random variables either one of which can be discrete or continuous. Generally, one of the random variable refers to the state of a physical system and the other random variable refers to time. A discrete state, continuous time process is called a Markov chain.

In order to find reliability/availability of a system, one has to form a system of linear differential equations using mnemonic rule. The idea for formulating the Chapman-Kolmogorov differential equations for a simple system whose transition diagram is given by figure 2 is as follows:

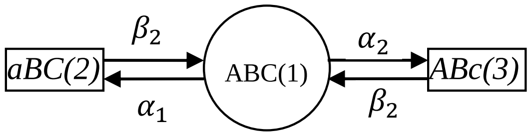

Figure 2: Transition Diagram for a System

Let us define,
$P_1(t)$= Probability that the system is in good state at time *t*.
$P_2(t)$= Probability that the system fails due to failure of sub-system *A* at time *t*.
$P_3(t)$= Probability that the system fails due to failure of sub-system *C* at time *t*.

Here, reliability/Availability of a system will be sum of probabilities of good states. As such,

$$R(t) = P_1(t)$$

$$P_1(t+\Delta t) = (1 - \alpha_1 \Delta t - \alpha_2 \Delta t) P_1(t) + \beta_1 \Delta t P_2(t) + \beta_2 \Delta t P_3(t)$$

or,

$$P_1(t+\Delta t) - P_1(t) = (-\alpha_1 \Delta t - \alpha_2 \Delta t) P_1(t) + \beta_1 \Delta t P_2(t) + \beta_2 \Delta t P_3(t)$$

Dividing both sides by Δt, we get

$$\frac{P_1(t+\Delta t) - P_1(t)}{\Delta t} = -(\alpha_1 + \alpha_2) P_1(t) + \beta_1 P_2(t) + \beta_2 P_3(t)$$

$$\frac{dP_1(t)}{dt} = -(\alpha_1 + \alpha_2) P_1(t) + \beta_1 \boldsymbol{P_2(t)} + \boldsymbol{\beta_2 P_3(t)} \qquad (1)$$

Similarly, we can obtain

$$\boldsymbol{\frac{dP_2(t)}{dt} = \alpha_1 P_1(t) - \beta_1 P_2(t)} \qquad (2)$$

$$\boldsymbol{\frac{dP_3(t)}{dt} = \alpha_2 P_1(t) - \beta_2 P_3(t)} \qquad (3)$$

The eqns. (1) to (3) are Chapman-Kolmogorov differential equations which can be solved recursively or by Runge-Kutta fourth order method when the initial conditions are as follows:

$$\boldsymbol{P_1(0) = 1, P_2(0) = 0, P_3(0) = 0} \qquad (4)$$

4. Development of Availability Model

Availability models for Malt Mill system has been developed on the basis of simple probabilistic considerations. First, difference-differential equations

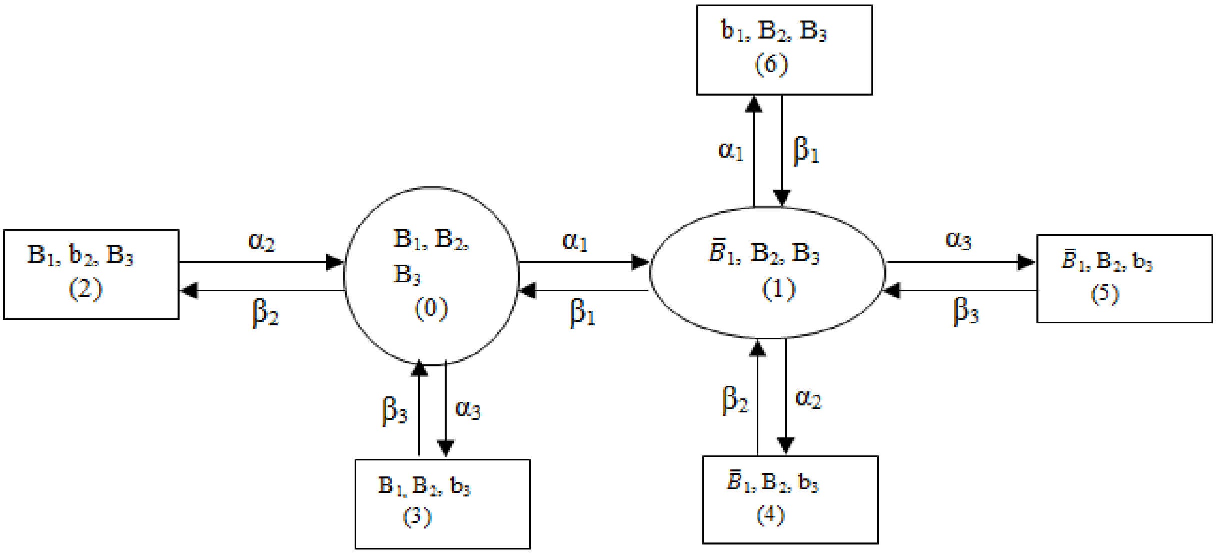

Figure 3 Transition Diagram of Malt Mill System in brewery industry

have been formulated and then these equations are solved recursively for steady state conditions. The obtained steady state probabilities are further solved using normalizing conditions i.e.

$$\sum_{i=0}^{n} P_i = 1 \quad (5)$$

Where n is the total number of states shown in transition diagram.

5. Runge- Kutta Method

The eqns. (1) to (3) can be written as follows:

$$\frac{dP_1}{dt} = f_1[t, P_1(t), P_2(t), P_3(t)] \quad (6)$$

$$\frac{dP_2}{dt} = f_2[t, P_1(t), P_2(t), P_3(t)] \quad (7)$$

$$\frac{dP_3}{dt} = f_3[t, P_1(t), P_2(t), P_3(t)] \quad (8)$$

with initial conditions $P_1(0) = 1, P_2(0) = 0, P_3(0) = 0$
The variables $(K_j, L_j, M_j,\ j = 1,2,3,4)$ can be calculated with the development of Runge- Kutta method, which is illustrated as below:

$$K_1 = hf_1[t_j, P_1(t_j), P_2(t_j), P_3(t_j)]$$
$$L_1 = hf_2[t_j, P_1(t_j), P_2(t_j), P_3(t_j)]$$
$$M_1 = hf_3[t_j, P_1(t_j), P_2(t_j), P_3(t_j)]$$
$$K_2 = hf_1[t_j + \frac{h}{2}, P_1(t_j) + \frac{K_1}{2}, P_2(t_j) + \frac{L_1}{2}, P_3(t_j) + \frac{M_1}{2}]$$
$$L_2 = hf_2[t_j + \frac{h}{2}, P_1(t_j) + \frac{K_1}{2}, P_2(t_j) + \frac{L_1}{2}, P_3(t_j) + \frac{M_1}{2}]$$
$$M_2 = hf_3[t_j + \frac{h}{2}, P_1(t_j) + \frac{K_1}{2}, P_2(t_j) + \frac{L_1}{2}, P_3(t_j) + \frac{M_1}{2}]$$
$$K_3 = hf_1[t_j + \frac{h}{2}, P_1(t_j) + \frac{K_2}{2}, P_2(t_j) + \frac{L_2}{2}, P_3(t_j) + \frac{M_2}{2}]$$
$$L_3 = hf_2[t_j + \frac{h}{2}, P_1(t_j) + \frac{K_2}{2}, P_2(t_j) + \frac{L_2}{2}, P_3(t_j) + \frac{M_2}{2}]$$
$$M_3 = hf_3[t_j + \frac{h}{2}, P_1(t_j) + \frac{K_2}{2}, P_2(t_j) + \frac{L_2}{2}, P_3(t_j) + \frac{M_2}{2}]$$
$$K_4 = hf_1[t_j + h, P_1(t_j) + K_3, P_2(t_j) + L_3, P_3(t_j) + M_3]$$
$$L_4 = hf_2[t_j + h, P_1(t_j) + K_3, P_2(t_j) + L_3, P_3(t_j) + M_3]$$
$$M_4 = hf_3[t_j + h, P_1(t_j) + K_3, P_2(t_j) + L_3, P_3(t_j) + M_3]$$

h represents the step size. We can obtain,

$$P_1(t_j + h), P_2(t_j + h) and P_3(t_j + h)$$

as given below:

$$P_1(t_j + h) = P_1(0) + \frac{K_1 + 2K_2 + 2K_3 + K_4}{6}$$
$$P_2(t_j + h) = P_2(0) + \frac{L_1 + 2L_2 + 2L_3 + L_4}{6}$$
$$P_3(t_j + h) = P_3(0) + \frac{M_1 + 2M_2 + 2M_3 + M_4}{6}$$

Therefore, we can find

$$R(t_j + h) = P_1(t_j + h) \text{at time } (t_j + h) \quad (9)$$

The process can be repeated to obtain $R(t_j + 2h)$ etc. with the help of Runge-Kutta method of fourth order.

6. Assumptions

The following assumptions are made to carry out the performance modeling and analysis of the system under consideration.

- At any given time the system is either in operating state or in the failed state.
- Failure rate and repair rate are constant.
- A repaired sub system is as good as new.
- Standby sub systems are of the same nature and capacity as the active sub system.
- Repair facilities are always available.

Table 1 Notations used in Performance Modeling and Analysis of Malt Mill System

Transition diagram	Figure 3
Full capacity (without standby)	$\boldsymbol{B_1, B_2, B_3}$
Full capacity (with standby)	--------
Failed state	b_1,b_2,b_3
Reduced capacity	B_1
Failure rates	$\boldsymbol{\alpha_i}$, i = 1 to 3 From $\boldsymbol{B_1, B_2, B_3}$, to $\boldsymbol{b_1, b_2, b_3}$,
Repair rates	$\boldsymbol{\beta_i}$, i = 1 to 3 from $\boldsymbol{b_1, b_2, b_3}$ to $\boldsymbol{B_1, B_2, B_3}$
Probability of full capacity working (without standby unit)	$\boldsymbol{P_0}$
Probability of full capacity working (with standby unit)	--------
Probability of reduced capacity working	$\boldsymbol{P_1}$
Probability of failed state	$\boldsymbol{P_2}$ to $\boldsymbol{P_6}$

Performance Modeling of Malt Mill

The following differential equations equation with the transition diagram of Malt Mill system is formed:

$$\left(\frac{d}{dt}+\alpha_1+\alpha_2+\alpha_3\right)P_0(t)=\beta_1P_1(t)+\beta_2P_2(t)+\beta_3P_3(t) \quad (10)$$

$$\left(\frac{d}{dt}+\alpha_1+\alpha_2+\alpha_3+\beta_1\right)P_1(t)=\beta_1P_6(t)+\beta_2P_4(t)+\beta_3P_5(t)+\alpha_1P_0(t) \quad (11)$$

$$\left(\frac{d}{dt}+\beta_2\right)P_2(t)=\alpha_2P_0(t) \quad (12)$$

$$\left(\frac{d}{dt}+\beta_3\right)P_3(t)=\alpha_3P_0(t) \quad (13)$$

$$\left(\frac{d}{dt}+\beta_2\right)P_4(t)=\alpha_2P_1(t) \quad (14)$$

$$\left(\frac{d}{dt}+\beta_3\right)P_5(t)=\alpha_3P_1(t) \quad (15)$$

$$\left(\frac{d}{dt}+\beta_1\right)P_6(t)=\alpha_1P_1(t) \quad (16)$$

7. Steady State Availability of Malt Mill

A constant failure rate is indicative of externally induced failures and it is also typical of complex systems subjected to repair and overhaul, where different parts exhibit different patterns of failure with time and parts have different ages since repair or replacement. When a plant operates initially, the various constraints come into play to affect the plant operation i.e. the initial conditions. After some time, as the infant period is over, the system becomes independent of its initial conditions. This state is known as steady state condition of a system. If $\boldsymbol{P_i(t)}$ designates the probability that an equipment is in succession at time ‘t’, then for smooth and continuous operation of a system without failure, time (t) will approach to infinity. Therefore, system probability $\boldsymbol{P_i(t)}$ becomes independent of time‘t’ and known as steady state condition.

Thus, as $t\rightarrow\infty$, $d/dt=0$

i.e. $\lim_{t\to\infty}P_i'(t)=0$

The steady state availability $\boldsymbol{A_v}$ of a system can be obtained by summing up all full working and reduced capacity states:

$$A_v=\sum_{k=0}^{m}P_k$$

Where, k represents the working as well as reduced capacity states.

By putting $d/dt=0$ as $t\rightarrow\infty$ in equation 10-16, the steady state probabilities are given as:

$$(\alpha_1+\alpha_2+\alpha_3)P_0=\beta_1P_1+\beta_2P_2+\beta_3P_3 \quad (17)$$

$$(\alpha_1+\alpha_2+\alpha_3+\beta_1)P_1=\beta_1P_6+\beta_2P_4+\beta_3P_5+\alpha_1P_0 \quad (18)$$

$$(\beta_2)P_2=\alpha_2P_0 \quad (19)$$

$$(\beta_3)P_3=\alpha_3P_0 \quad (20)$$

$$(\beta_2)P_4=\alpha_2P_1 \quad (21)$$

$$(\beta_3)P_5=\alpha_3P_1 \quad (22)$$

$$(\beta_1)P_6=\alpha_1P_1 \quad (23)$$

On solving the equations 17 to 23 recursively, we get:

$$P_1=\frac{\alpha_1}{\beta_1}P_0 \quad (24)$$

The probability of full working capacity P_0 is determined using normalizing condition:

$P_0+P_1+P_2+\ldots\ldots\ldots.+P_6=1$

$$P_0=\frac{1}{N}$$

Where

$$N=\left[1+\left(\frac{\alpha_1}{\beta_1}\left(1+\frac{\alpha_1}{\beta_1}\right)+\frac{\alpha_2}{\beta_2}+\frac{\alpha_3}{\beta_3}+\frac{\alpha_1\alpha_2}{\beta_1\beta_2}+\frac{\alpha_1\alpha_2}{\beta_1\beta_2}\right)\right] \quad (25)$$

Availability= P_0+P_1

$$Availibility=\left(1+\frac{\alpha_1}{\beta_1}\right)\frac{1}{N} \quad (26)$$

9. Results and Discussion

The availability expression as given by equation 26 includes failure events (α_i) and repair priorities (β_i). The different combinations of failure and repair rates can be used to compute the maximum value of system availability. Tables 1-3 represent the decision matrices for various subsystems of the Malt Mill system.

Table 2 Decision Matrix of Elevator, feed roller, and crushing roller subsystem of Malt Mill system

β1 / α1	0.45	0.55	0.65	0.75	0.85	Constant values
0.0065	0.96	0.9601	0.9601	0.9601	0.9601	α2=0.0082, β2=0.45, α3=0.0070, β3=0.30,
0.0085	0.9599	0.96	0.9601	0.9601	0.9601	
0.0105	0.9597	0.9599	0.96	0.9601	0.9601	
0.0125	0.9595	0.9599	0.96	0.96	0.9601	
0.0145	0.9593	0.9598	0.9599	0.96	0.96	

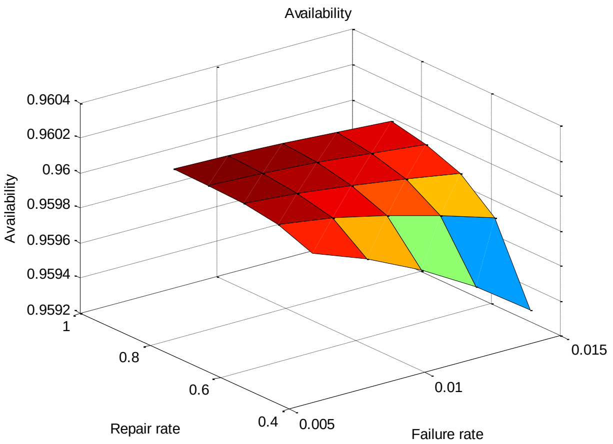

Figure 4 Effect of failure and repair rates of Elevator, feed roller, and crushing roller subsystem on availability Malt Mill system

Table 2 and figure 4 shows the effect of failure and repair rates of Elevator, feed roller, and crushing roller subsystem on availability Malt Mill system. As the failure rate of Elevator, feed roller, and crushing roller is increase from 0.0065(once in 153.84 hrs) to 0.0145(once in 68.98 hrs), the subsystem availability decrease by 0.07 percentage and as repair rate increases from 0.45(once in 2.22 hr) to 0.85(once in 1.17 hr), and the system availability increases 0.01 percentage.

Table 3 and figure 5 shows the effect of failure and repair rates of screw conveyor subsystem on availability Malt Mill system. As the failure rate of screw conveyor is increase from 0.0082(once in 121.95 hrs) to 0.0162(once in 61.72 hrs), the subsystem availability decrease by 1.64 percentage and as repair rate increases from 0.45(once in 2.22 hr) to 0.85(once in 1.172 hr), the system availability increases 0.81 percentage.

Figure 5 Effect of failure and repair rates of Screw conveyor subsystem on availability Malt Mill system

Table 4 and figure 6 shows the effect of failure and repair rates of elevator subsystem on availability Malt Mill system. As the failure rate of Elevator is increase from 0.007(once in 142.8 hrs) to 0.015(once in 66.66 hrs), the subsystem availability decrease by 2.36 percentage and as repair rate increases from 0.3(once in 3.33 hr) to 0.7(once in 1.42 hr), the system availability increases 1.22 percentage.

Table 3 Decision Matrix of screw conveyor subsystem of Malt Mill system

β2 / α2	0.45	0.55	0.65	0.75	0.85	Constant values
0.0082	0.9600	0.9631	0.9652	0.9668	0.9681	α_1=0.065, β_1=0.45, α_3=0.0070, β_3=0.30,
0.0102	0.9558	0.9597	0.9624	0.9643	0.9658	
0.0122	0.9517	0.9563	0.9595	0.9618	0.9636	
0.0142	0.9477	0.9529	0.9566	0.9593	0.9614	
0.0162	0.9436	0.9496	0.9538	0.9568	0.9592	

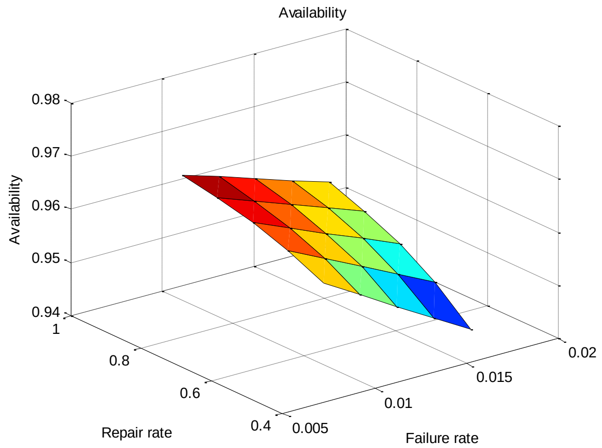

Figure 5 Effect of failure and repair rates of Screw conveyor subsystem on availability Malt Mill system

Table 4 Decision Matrix of screw Elevator subsystem of Malt Mill system

β3 / α3	0.3	0.4	0.5	0.6	0.7	Constant values
0.007	0.9600	0.9653	0.9685	0.9707	0.9722	α_1=0.065, β_1=0.45, α_2=0.0082, β_2=0.45
0.009	0.9540	0.9607	0.9648	0.9676	0.9696	
0.011	0.9480	0.9562	0.9612	0.9645	0.9670	
0.013	0.9421	0.9517	0.9576	0.9615	0.9643	
0.015	0.9364	0.9473	0.9540	0.9585	0.9617	

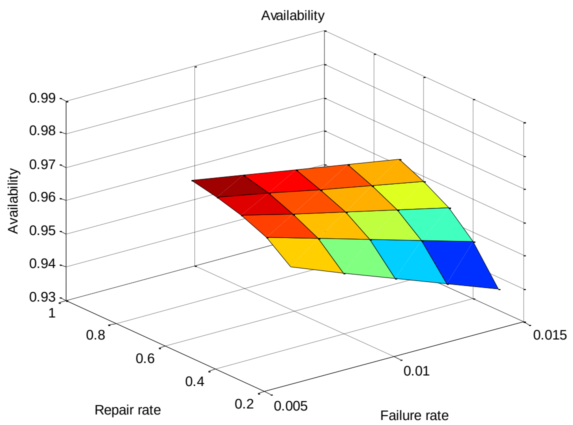

Figure 6 Effect of failure and repair rates of Elevator subsystem on availability Malt Mill system

Transition Behavior of Malt Mill System

The system of differential equations (10) to (16) with initial conditions has been solved numerically using Runge-Kutta fourth order method. Taking data for failure and repair rates of different subsystems from maintenance history sheets, the computations have been performed up to 360 days as shown in table 5. Figure 7 shows the variation in availability with time, which reveals that the availability attains steady state after some time.

Table 5 Variation in Availability with Time for Malt Mill System

Time	Availability	
0	1.0000	α_1=0.065, β_1=0.45, α_2=0.0082, β_2=0.45, α_3=0.007, β_3=0.30
30	0.9501	
60	0.9501	
90	0.9501	
120	0.9501	
150	0.9501	
180	0.9501	
210	0.9501	
240	0.9501	
270	0.9501	
300	0.9501	
330	0.9501	
360	0.9501	

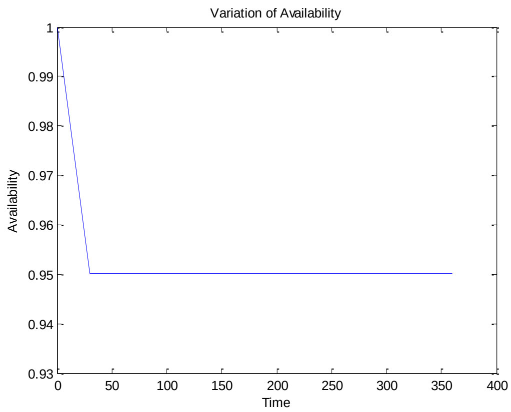

Figure 7 Variations in Availability with Time for Malt Mill System

Conclusions

Availability analysis of Malt Mill system in brewery has been studied extensively. The performance analysis of Malt Mill system of brewery plant had been carried out utilizing the Markov modeling. The decision support system has developed which showed the effects of failure and repair rates on the system performance in terms of steady state availability. The criticality of various subsystems has been found to develop the DSS which can be helpful for deciding the maintenance policy. This availability model is effectively used for analysis of availability and evaluation of performance of various subsystems of Malt Mill system of Brewery plant. The model developed shows the relationships between availability and various repair and failure rates for each subsystem of brewery plant. From the results we can conclude that the Elevator subsystem is critical one. It can be concluded from table 2-4, that as the failure rate increases, the availability shows decreasing trend and as repair rate increases, the availability shows increasing trend. The variation in availability with time reveals that the availability attains steady state behavior after some time.

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