Availability Optimization of ICE Cream Making Unit of Milk Plant Using Genetic Algorithm

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Abstract
The Paper discusses the availability analysis of the ice cream making unit in milk plant. Here we consider three states of various components, good, reduced and failed. The failure and repair rates of each subsystem are assumed to be constant and statistically independent. Mathematical formulation of the system is done with the help of markov birth-death process. The various differential equations have been derived from state transition diagram. After that steady state probabilities are determined by using various combinations of failure and repair rates. Based upon various performance level in terms of availability are obtained in decision matrices. The performance of each subsystem is analyzed and then maintenance strategies all subsystems. The model helps in evaluation of alternate maintenance strategies.

Keywords
Availability, Markov Birth Death Process, Ice Cream Unit,

I. Introduction

With the continuous improvement in technology, the industrial systems are getting more and more complex and thus to run these systems failure-free is very tedious task. A plant/industry cannot attain success if its systems are unreliable and unavailable. The availability analysis is desirable for long working duration with good performance level of the systems in the industries to reduce the cost and productivity. Thus, the reliability engineering is a vital tool to figure out the systems performance which is widely used now days. The industrial systems are subjected to failures due to various reasons such as improper design, poor maintenance and wrong operations etc. The failed systems can be brought back into working condition with in minimum possible time after repair. The performance of these systems is computed in term of availability using mathematical modeling. The mechanical systems have attracted the attention of several researchers in the area of reliability analysis from last four decades. Amir Azaron et al. [1] developed a new methodology for reliability evaluation and optimization of non repairable dissimilar component cold standby redundant systems Kumar et al. [2] derived the availability and MTTF expression of washing system of a paper industry using simple probability consideration. Coit et al. [3] proposed a multiple objective formulation for maximizing the system availability. Dai et al. [4] developed an optimization model for the grid service allocation using Genetic Algorithm. Garg et al. [5] 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 Preventive Maintenance. Juang et al. [6] proposed a Genetic Algorithm based optimization model to optimize the availability for a series parallel system. Castro et al. [7] proposed a maintenance optimization model of an engineering system assembled in a series configuration. Srinivas and Deb [8] discussed the various optimization techniques and their implementation in the Engineering problems.Zequn Wang et al. [9] presented a new approach Nested Extreme Response Surface(NERS) that can be use to solve the time variant reliability problems efficiently.

II. System Description

A. Cream Separator (A)

The subsystem performs on the principle of centrifugal force. Chilled milk from chiller is taken to the cream separator where fat is separated from the milk in the form of cream containing 40 to 50% fats.

B. Freezer cum Mixture (B)

it is used for mixing Fat, sugar, milkier and flavor with the help of mixing blade mounted in it. it chills up to temperature of 4^0C.

C. Packaging Machine(C)

It is used to pack the final mixture i.e. ice cream in cups. The filling capacity of machine is about 25 to 30 cups in a minute.

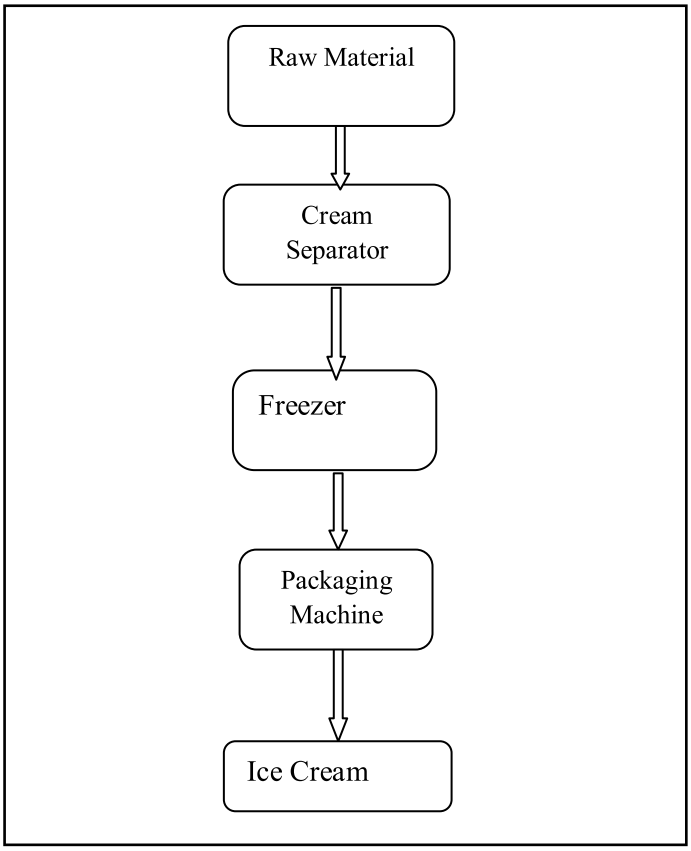

Fig. 1: Process Flow Diagram of Ice Cream Making Unit

III. Assumptions and Notations

A. Assumptions

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

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

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B. Notations

Subsystem-A : Cream Separator subjected to major failure only.
Subsystem-B : Freezer Cum Mixture subjected to major and minor failure.
Subsystem-C : Packaging Machine subjected to major and minor failure.
$\lambda_1, \lambda_2, \lambda_3$: Failure rates of A,B,C,
μ_1, μ_2, μ_3 : Repair rates of A, B,C,
$P_i(t)$: Probability at time 't' all units are good and the system is in i^{th} state.
' : Derivatives w.r.t. 't'

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

III. Performance Modeling of the System

The differential equations associated with the transition diagram shown in fig. 2, are developed on the basis of Markov birth-death process. Various probability considerations generate the following sets of differential equations:

$$P_0'(t)+(\lambda_1+\lambda_2+\lambda_3)P_0(t) = \mu_2 P_1(t)+\mu_1 P_4(t)+\mu_3 P_2(t) \quad (1)$$

$$P_1'(t)+(\lambda_1+\lambda_3+\lambda_4+\mu_2)P_1(t)=\mu_3 P_3(t)+\mu_1 P_5(t)+\mu_4 P_6(t)+\lambda_2 P_0(t) \quad (2)$$

$$P_2'(t)+(\lambda_1+\lambda_2+\lambda_5+\mu_3)P_2(t)=\mu_1 P_7(t)+\mu_5 P_8(t)+\mu_2 P_3(t)+\lambda_3 P_0(t) \quad (3)$$

$$P_3'(t)+(\lambda_1+\lambda_4+\lambda_5+\mu_2+\mu_3)P_3(t)=\mu_1 P_9(t)+\mu_4 P_{10}(t)+\mu_5 P_{11}(t)+\lambda_3 P_1(t)+\lambda_2 P_2(t)$$

$$P'_j(t)+\mu_i P_j(t)=\lambda_i P_k(t) \quad (4)$$

Where,
(for i=1 j=4 when k=0)
(for i=1,2,3, j=5,6,7 when k=1)
(for i=1,4 ,5 j=9,10,11 when k=2)

Initial conditions at time t = 0 are $P_i(t)=1$ for i=0, $P_i(t)=0$ for $i\neq0$ (5)

Steady State analysis i.e. when $t\rightarrow\infty$ and $d/dt\rightarrow 0$ applying on set of first order differential (1) to (5) we get:

$$P'_j+\mu i P_j=\lambda_i P_k$$

Where,

(for i=1 j=4 when k=0)
(for i=1,2,3, j=5,6,7 when k=1)
(for i=1,4 ,5 j=9,10,11 when k=2)

Solving these equations and using normalizing condition, we get:

The Steady State Availability of the system Ass is given by

V. Performance Analysis

The effects of failure rate and repair rate of various subsystems/ machines comprising the system are examined and their impact on system availability is shown in the following tables:

A. Effect of Failure and Repair Rate of Cream Separator on Availability of the System

Table 1: Effect of Failure and Repair Rate of Cream Separator on Availability of the System:

λ_l/μ_1	0.0002	0.0004	0.0007	0.0009
0.002	0.8646	0.8327	0.7890	0.7623
0.004	0.8815	0.8646	0.8404	0.8251
0.007	0.8890	0.8790	0.8646	0.8552
0.009	0.8912	0.8834	0.8720	0.8646

B. Effect of Failure and Repair Rate of Freezer Cum Mixture on Availability of the System:

Table 2: Effect of Failure and Repair Rate of Freezer cum mixture on Availability of the System:

λ_3/μ_3	0.0005	0.0007	0.0009	0.001
0.004	0.8646	0.8518	0.8393	0.8332
0.007	0.8788	0.8712	0.8637	0.8600
0.009	0.8831	0.8771	0.8712	0.8682
0.01	0.8846	0.8792	0.8738	0.8712

C. Effect of Failure and Repair Rate of Packaging Machine on Availability of the System:

Table 3: Effect of Failure and Repair Rate of Packaging Machine on Availability of the System:

λ_3/μ_3	0.0009	0.002	0.005	0.009
0.002	0.8646	0.8061	0.6806	0.5636
0.004	0.8910	0.8589	0.7821	0.6987
0.007	0.9029	0.8837	0.8355	0.7788
0.01	.9077	0.8941	0.8589	0.8162

VI. Results and Discussion

From table no. 1 to 3, it has been revealed that the increase in failure and repair rates of various subsystems affects the availability of the system and need to be control.

Table 1 revealed the Effect of Failure and Repair Rates of cream separator on Availability. As the failure rate is increase(λ1) from 0.0002(once in 15000 hours) to 0.0009 (once in 10000 hours) the system availability decreases by 11.83% as repair rate(μ1) increases from0.0020(once in 1500hours) to 0.009(once in 1000 hours) the availability increases 3%.

Table 2 Shows Effect of Failure and Repair Rates of freezer & mixture on Availability. As the failure rate is increase (λ4) from 0.0005(once in 1450 hours) to 0.001 (once in 9000 hours) the system availability decreases by 3.7% as repair rate(μ4) increases from 0.004(once in 1400 hours) to 0.01(once in 900 hours) the availability increases 2%.

Table 3 Shows Effect of Failure and Repair Rates of packing machine on Availability. As the failure rate is increase($\lambda 5$) from 0.0009(once in 15000 hours) to 0.009(once in 9000 hours) the system availability decreases by 38% as repair rate($\mu 5$) increases from .002(once in 1000 hours) to 0.01(once in 800 hours) the availability increases 5%.

VI. Conclusion

The performance analysis of ice cream unit of milk plant has been done with the help of mathematical modeling using probabilistic approach. The results are shown in tables 1 to 3 is derived to assists the maintenance decisions where repair priority should be given to subsystem of ice cream line.

Table 4 clearly specifies that the Freezer Cum Mixture is the most critical subsystem as far as maintenance aspect is concerned and given top priority. On the basis of above analysis, the maintenance priorities should be given as per following order:

Table 4: Machine Repair Priority Table

S/ No.	Sub-System	Decrease	Increase	Repair Priority
1	Cream Separator	11.83%	3%	3
2	Mixture & freezer	3.7%	2%	2
3	Packaging m/c	38%	5%	1

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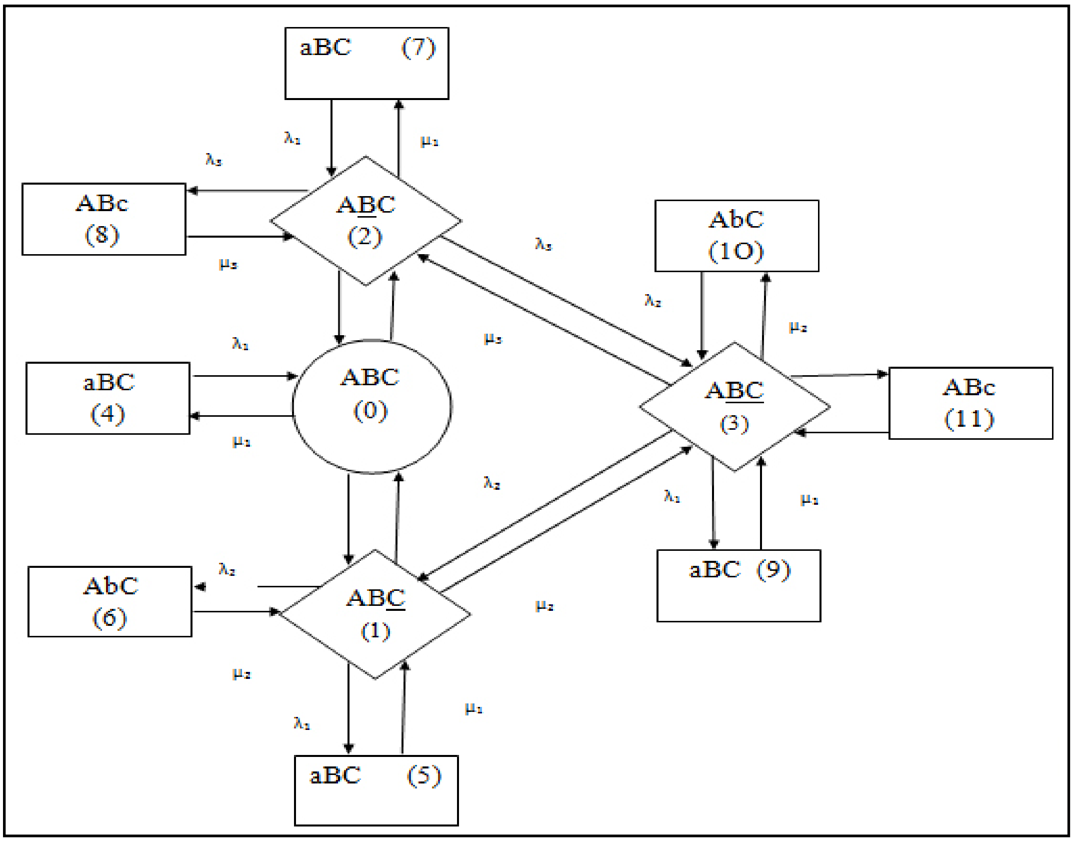

Fig. 2: State Transition Diagram of Ice Cream Unit