System Modeling & Behavioural Analysis of Bread Manufacturing
Unit- Case Study

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Abstract: This paper demonstrates a methodology to study the transient behaviour of repairable bread manufacturing unit. The methodology for determining the availability of the system is based on Markov Modeling. The failure and repair rates of the different subcomponents of the system are taken as constant. Probability considerations at various stages of the system give differential equations, which are solved using Laplace Transform to obtain the state probabilities. Availability analysis of the various sub systems helped in identifying the contributing factors and determining their impact on the system availability.

Keywords: System Availability, Markov process, Steady State, Reliability

I. INTRODUCTION

The reliability of a system, equipment and a product is very important for its consistence performance over its expected life span. In fact, uninterrupted service and hazard free operation is an essential requirement of large complex systems like electric power generation and distribution plants or communication network systems such as railways, airways etc (Agnihotri and Satsangi, 1996). A sudden failure of even a single component, assembly or system results in health hazard, accident or interruption in continuity of service. (Gupta and Gupta, 2006) Reliability is the probability of a device/ machine performing its purpose adequately for the period intended under the given operating conditions. Reliability is expressed in percentage. It is the ratio of survivors at any given time to the total initial population. The measure of reliability for a repairable system is Mean Time between Failure (MTBF) and Mean Time to Failure (MTTF). Mathematically reliability of a component for a period can be represented as \( R(t) = e^{-\lambda t} \), where ‘\( \lambda \)’ is mean failure rate. With the ever increasing demand for automation in the various industrial segments, the high capital investment is required for the installation of production plants especially process plants such as chemical, sugar, food, thermal, paper and fertilizer etc. (Kumar et al., 1988) To compete with the global market and to achieve higher production goals, the industrial system should remain operative for maximum possible duration (failure free). The manufacturers are very much concerned about reliability of the systems. Every year, the manufacturers lose billions of rupees as a direct consequence of the unreliability of industrial plants in terms of cost of lost production, cost of repairing or replacing equipment and due to the loss of human life that cannot be measured in terms of money. (Jayabal and Chaudhary, 1992) The process industries comprise of large complex engineering system and sub systems arranged in series, parallel or in combination of both. In the recent past, engineers and researchers have derived more benefits in terms of higher productivity and lower maintenance costs with the help of reliability/ availability /maintainability (RAM) engineering in the process industries(Ashwani & Abhishek ,2014).

II. SYSTEM DESCRIPTION

A bread manufacturing system is composed of various sub systems such as sieving unit, mixing unit, divider, moulding unit, proofing unit, baking unit and packing unit as shown in Fig.1. The different sub systems and processes are discussed as follows:

Sieving:
Sieving is done in order:
1. To aerate the flour
2. To remove coarse particles and other impurities
3. To make flour more homogeneous.

Mixing:
In this sub system proper mixing of different ingredients such as flour, yeast, salt, sugar, fat and water are mixed for making dough.

Dividing:
The dough is divided into individual pieces of predetermined uniform weight and size. The weight of the dough to be taken depends on the final weight of the bread required. Generally, 12% extra dough weight is taken to compensate for the loss.
Moulding:
The moulder receives pieces of dough from the intermediate proofer and shapes them into cylinders ready to be placed in the pans.

Proofing:
Proving or proofing refers to the dough resting period during fermentation after moulding has been accomplished and moulded dough pieces are placed in bread pans or tins. During this resting period the fermentation of dough continues. The dough finally proofed or fermented in baking pan for desired dough height. It is generally carried out at 30-35°C and at 85% relative humidity. Proofing takes about 55-65 minutes. During proofing the dough increases remarkably in volume. The dough expands by a factor of 3-4 during proofing.

Baking:
After proofing the dough is subjected to heat in a baking oven. Baking temperature generally varies depending up on oven and product type but it is generally kept in the range of 220-250°C. The baking time of bread may range from 25 to 30 minutes depending up on size of bread loaf. After baking, bread is cooled prior to packaging to facilitate slicing and to prevent condensation of moisture in the wrapper.

Notations:
- Sieving unit (S): One unit subjected to major failure only.
- Mixing unit (M): One unit subjected to major failure only.
- Divider (D): One unit subjected to major failure only.
- Moulding unit (m): One unit subjected to major failure only.
- Proofing unit (P): One unit subjected to major failure only.
- Baking unit (B): One unit subjected to major failure only.
- Packing unit (p): One unit subjected to major failure only.

\[ \lambda_j \] : Indicate failure rates of S, M, D, m, P, B, p (j=1, 2, 3, 4, 5, 6, 7).

\[ \mu_j \] : Indicate repair rates of S, M, D, m, P, B, p (j=1, 2, 3, 4, 5, 6, 7).

\( o \) : Indicate Component/Sub-system is operative.

\( q_r \) : Indicate component/Sub-system is in queue for repair.

\( r \) : Indicate component/Sub-system is under repair.

Assumptions
a) All the subsystems are initially operating.
b) All the sub-systems are initially in good state.
c) Each unit has two states viz., good and failed.
d) It is also assumed that there is only one repair facility and priority will be given to sub-system S, M, D, m, P, B, p for repair activity.
e) Each unit is as good as new after repair.
f) The failure rates and repair rates of all units are taken constant.
g) Failure and repair events are statistically independent.

The state transition diagram of a bread manufacturing plant is shown in Fig 2.

III. MATHEMATICAL MODELING OF THE SYSTEM

Probability consideration gives the following first order differential-difference equations associated with the state transition diagram of the system.

\[ \frac{d(P_S)}{dt} + (\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6)P_S(t) = \mu_1P_1(t) + \mu_2P_2(t) + \mu_3P_3(t) + \mu_4P_4(t) + \mu_5P_5(t) + \mu_6P_6(t) + \mu_7P_7(t) \]

\[ \frac{d(P_M)}{dt} + (\alpha_2)P_M(t) = \mu_2P_2(t) + \mu_3P_3(t) + \mu_4P_4(t) + \mu_5P_5(t) + \mu_6P_6(t) + \mu_7P_7(t) \]

Where \( \alpha_2 = \lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 \)

\[ \frac{d(P_D)}{dt} + \mu_kP_k(t) = \lambda_kP_k(t) \]

Where \( k = 1, 2, 3, 4, 5, 6, 7 \)
Taking Laplace transform of the above equations, which gives the following equations:

\[ sP_1(s) + a_1P_1(s) = \mu_1P_0(s) + \mu_2P_1(s) + \mu_1P_1(s) + \mu_2P_2(s) + \mu_3P_2(s) + P_1(s) \]  
\[ sP_2(s) + a_2P_2(s) = \mu_2P_1(s) + \mu_2P_2(s) + \mu_3P_3(s) + P_2(s) \]  
\[ sP_3(s) + a_3P_3(s) = \mu_3P_2(s) + \mu_3P_3(s) + \mu_5P_4(s) + \mu_3P_3(s) + \mu_5P_5(s) + \mu_5P_6(s) + P_3(s) \]  
\[ sP_4(s) + a_4P_4(s) = \mu_4P_3(s) + \mu_4P_4(s) + \mu_5P_5(s) + \mu_5P_6(s) + \mu_5P_7(s) + P_4(s) \]  
\[ sP_5(s) + a_5P_5(s) = \mu_5P_4(s) + \mu_5P_5(s) + \mu_5P_6(s) + \mu_5P_7(s) + P_5(s) \]  
\[ sP_6(s) + a_6P_6(s) = \mu_5P_5(s) + \mu_5P_6(s) + \mu_5P_7(s) + P_6(s) \]  
\[ sP_7(s) + a_7P_7(s) = \mu_7P_6(s) + \mu_7P_7(s) + P_7(s) \]  

Solving Equations (2), (3), (4), (5), (6), (7) & (8)

\[ P_1(s) = \frac{\lambda_2}{\lambda_2 + \mu_1} P_0(s) \]  
\[ P_2(s) = \frac{\lambda_2}{\lambda_2 + \mu_2} P_0(s) \]  
\[ P_3(s) = \frac{\lambda_3}{\lambda_3 + \mu_3} P_0(s) \]  
\[ P_4(s) = \frac{\lambda_4}{\lambda_4 + \mu_4} P_0(s) \]  
\[ P_5(s) = \frac{\lambda_5}{\lambda_5 + \mu_5} P_0(s) \]  
\[ P_6(s) = \frac{\lambda_6}{\lambda_6 + \mu_6} P_0(s) \]  

\[ P_7(s) = \frac{\lambda_7}{\lambda_7 + \mu_7} P_0(s) \]

Where \( K_1 = \frac{\lambda_1}{\lambda_1 + \mu_1} \)

Where \( K_2 = \frac{\lambda_2}{\lambda_2 + \mu_2} \)

Where \( K_3 = \frac{\lambda_3}{\lambda_3 + \mu_3} \)

Where \( K_4 = \frac{\lambda_4}{\lambda_4 + \mu_4} \)

Where \( K_5 = \frac{\lambda_5}{\lambda_5 + \mu_5} \)

Where \( K_6 = \frac{\lambda_6}{\lambda_6 + \mu_6} \)

Where \( K_7 = \frac{\lambda_7}{\lambda_7 + \mu_7} \)

Put the value of \( P_1(s), P_2(s), P_3(s), P_4(s), P_5(s), P_6(s) \) & \( P_7(s) \) in equation (1) and by using the normalizing condition,

\[ sP_1(s) + a_1P_1(s) = 1 + \mu_2P_1(s) + \mu_2P_2(s) + \mu_3P_2(s) + \mu_3P_3(s) + \mu_5P_5(s) + \mu_5P_6(s) + P_1(s) \]

\[ sP_2(s) + a_2P_2(s) = \mu_2P_1(s) + \mu_2P_2(s) + \mu_3P_3(s) + P_2(s) \]

\[ sP_3(s) + a_3P_3(s) = \mu_3P_2(s) + \mu_3P_3(s) + \mu_5P_4(s) + \mu_5P_5(s) + \mu_5P_6(s) + P_3(s) \]

\[ sP_4(s) + a_4P_4(s) = \mu_4P_3(s) + \mu_4P_4(s) + \mu_5P_5(s) + \mu_5P_6(s) + \mu_5P_7(s) + P_4(s) \]

\[ sP_5(s) + a_5P_5(s) = \mu_5P_4(s) + \mu_5P_5(s) + \mu_5P_6(s) + \mu_5P_7(s) + P_5(s) \]

\[ sP_6(s) + a_6P_6(s) = \mu_5P_5(s) + \mu_5P_6(s) + \mu_5P_7(s) + P_6(s) \]

\[ sP_7(s) + a_7P_7(s) = \mu_7P_6(s) + \mu_7P_7(s) + P_7(s) \]

Availability function for \( A(s) \) system is given as

\[ A(s) = P_0(s) \]

Inversion of \( A(s) \) gives the availability function \( A(t) \)

The steady state behaviour of the system can be analyzed by setting the state probabilities are:

\[ t \to \infty \quad \frac{d}{dt} \to 0 \]

We get

From equation (1)

\[ \alpha_1 P_0 = \mu_1 P_1 + \mu_3 P_3 + \mu_3 P_4 + \mu_4 P_4 + \mu_5 P_5 + \mu_5 P_6 + \mu_5 P_7 \]

Similarly from equations (2), (3), (4), (5), (6), (7) & (8) we get

\[ P_1 = \frac{\lambda_1}{\mu_1} P_0 \]

\[ P_2 = \frac{\lambda_2}{\mu_2} P_0 \]

\[ P_3 = \frac{\lambda_3}{\mu_3} P_0 \]

\[ P_4 = \frac{\lambda_4}{\mu_4} P_0 \]

\[ P_5 = \frac{\lambda_5}{\mu_5} P_0 \]

\[ P_6 = \frac{\lambda_6}{\mu_6} P_0 \]

\[ P_7 = \frac{\lambda_7}{\mu_7} P_0 \]

Using normalizing condition

\[ \sum_{i=0}^{7} P_i = 1 \]

we get

\[ P_0 + P_1 + P_2 + P_3 + P_4 + P_5 + P_6 + P_7 = 1 \]

\[ P_0 = \left[ 1 + \sum_{i=0}^{7} \frac{\lambda_i}{\mu_i} \right]^{-1} \]

(A)
Steady state availability of the system is given as
\[ A(\infty) = P_0 \]

Where \( P_0 \) is given by equation (A)
\[ A(\infty) = 0.8710 \] taking the values as mention in Table No.1

<table>
<thead>
<tr>
<th>( \lambda_1 )</th>
<th>( \lambda_2 )</th>
<th>( \lambda_3 )</th>
<th>( \lambda_4 )</th>
<th>( \lambda_5 )</th>
<th>( \lambda_6 )</th>
<th>( \lambda_7 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.003</td>
<td>0.002</td>
<td>0.001</td>
<td>0.001</td>
<td>0.01</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>( \mu_1 )</td>
<td>( \mu_2 )</td>
<td>( \mu_3 )</td>
<td>( \mu_4 )</td>
<td>( \mu_5 )</td>
<td>( \mu_6 )</td>
<td>( \mu_7 )</td>
</tr>
<tr>
<td>0.33</td>
<td>0.50</td>
<td>0.50</td>
<td>0.33</td>
<td>0.25</td>
<td>0.20</td>
<td>0.50</td>
</tr>
</tbody>
</table>

**IV. AVAILABILITY ANALYSIS**

The effect of various parameters on availability is studied. If the failure and repair rates are varied, the availability is affected. This effect is shown in following tables obtained for availability analysis of bread making system.

(a) Effect of failure rate of Sieving unit on availability \( A(\infty) \) :
\[ \lambda_1 = 0.002, \lambda_3 = 0.001, \lambda_4 = 0.001, \lambda_5 = 0.01, \lambda_6 = 0.02, \mu_1 = 0.33, \mu_2 = 0.50, \mu_3 = 0.50, \mu_4 = 0.33, \mu_5 = 0.25, \mu_6 = 0.20, \mu_7 = 0.50 \]

**TABLE II Steady State availability versus failure rate of sieving unit**

<table>
<thead>
<tr>
<th>( \lambda_1 )</th>
<th>A(\infty)</th>
<th>0.003</th>
<th>0.004</th>
<th>0.005</th>
<th>0.006</th>
<th>0.007</th>
</tr>
</thead>
<tbody>
<tr>
<td>A(\infty)</td>
<td>0.8710</td>
<td>0.8687</td>
<td>0.8664</td>
<td>0.8641</td>
<td>0.8619</td>
<td></td>
</tr>
</tbody>
</table>

(b) Effect of failure rate of Mixing unit on availability A(\infty) :
\[ \lambda_1 = 0.003, \lambda_3 = 0.001, \lambda_4 = 0.001, \lambda_5 = 0.01, \lambda_6 = 0.02, \mu_1 = 0.33, \mu_2 = 0.50, \mu_3 = 0.50, \mu_4 = 0.33, \mu_5 = 0.25, \mu_6 = 0.20, \mu_7 = 0.50 \]

**TABLE III Steady State availability versus failure rate of mixing unit**

<table>
<thead>
<tr>
<th>( \lambda_1 )</th>
<th>A(\infty)</th>
<th>0.002</th>
<th>0.003</th>
<th>0.004</th>
<th>0.005</th>
<th>0.006</th>
</tr>
</thead>
<tbody>
<tr>
<td>A(\infty)</td>
<td>0.8710</td>
<td>0.8695</td>
<td>0.8680</td>
<td>0.8665</td>
<td>0.8650</td>
<td></td>
</tr>
</tbody>
</table>

(c) Effect of failure rate of Divider on availability A(\infty) :
\[ \lambda_1 = 0.003, \lambda_3 = 0.002, \lambda_4 = 0.001, \lambda_5 = 0.01, \lambda_6 = 0.02, \mu_1 = 0.33, \mu_2 = 0.50, \mu_3 = 0.50, \mu_4 = 0.33, \mu_5 = 0.25, \mu_6 = 0.20, \mu_7 = 0.50 \]

**TABLE IV Steady State availability versus failure rate of divider unit**

<table>
<thead>
<tr>
<th>( \lambda_1 )</th>
<th>A(\infty)</th>
<th>0.001</th>
<th>0.002</th>
<th>0.003</th>
<th>0.004</th>
<th>0.005</th>
</tr>
</thead>
<tbody>
<tr>
<td>A(\infty)</td>
<td>0.8710</td>
<td>0.8695</td>
<td>0.8680</td>
<td>0.8665</td>
<td>0.8650</td>
<td></td>
</tr>
</tbody>
</table>

(d) Effect of failure rate of Moulding unit on availability A(\infty) :
\[ \lambda_1 = 0.003, \lambda_2 = 0.002, \lambda_3 = 0.001, \lambda_4 = 0.01, \lambda_5 = 0.02, \mu_1 = 0.33, \mu_2 = 0.50, \mu_3 = 0.50, \mu_4 = 0.33, \mu_5 = 0.25, \mu_6 = 0.20, \mu_7 = 0.50 \]

**TABLE V Steady State availability versus failure rate of moulding unit**

<table>
<thead>
<tr>
<th>( \lambda_1 )</th>
<th>A(\infty)</th>
<th>0.001</th>
<th>0.002</th>
<th>0.003</th>
<th>0.004</th>
<th>0.005</th>
</tr>
</thead>
<tbody>
<tr>
<td>A(\infty)</td>
<td>0.8710</td>
<td>0.8696</td>
<td>0.8664</td>
<td>0.8641</td>
<td>0.8619</td>
<td></td>
</tr>
</tbody>
</table>

(e) Effect of failure rate of Proofing unit on availability A(\infty) :
\[ \lambda_1 = 0.003, \lambda_2 = 0.002, \lambda_3 = 0.001, \lambda_4 = 0.01, \lambda_5 = 0.02, \mu_1 = 0.33, \mu_2 = 0.50, \mu_3 = 0.50, \mu_4 = 0.33, \mu_5 = 0.25, \mu_6 = 0.20, \mu_7 = 0.50 \]

**TABLE VI Steady State availability versus failure rate of proofing unit**

<table>
<thead>
<tr>
<th>( \lambda_1 )</th>
<th>A(\infty)</th>
<th>0.01</th>
<th>0.02</th>
<th>0.03</th>
<th>0.04</th>
<th>0.05</th>
</tr>
</thead>
<tbody>
<tr>
<td>A(\infty)</td>
<td>0.8710</td>
<td>0.8417</td>
<td>0.8143</td>
<td>0.7886</td>
<td>0.7645</td>
<td></td>
</tr>
</tbody>
</table>

(f) Effect of failure rate of Baking unit on availability A(\infty) :
\[ \lambda_1 = 0.003, \lambda_2 = 0.002, \lambda_3 = 0.001, \lambda_4 = 0.01, \lambda_5 = 0.02, \mu_1 = 0.33, \mu_2 = 0.50, \mu_3 = 0.50, \mu_4 = 0.33, \mu_5 = 0.25, \mu_6 = 0.20, \mu_7 = 0.50 \]

**TABLE VII Steady State availability versus failure rate of baking unit**

<table>
<thead>
<tr>
<th>( \lambda_1 )</th>
<th>A(\infty)</th>
<th>0.01</th>
<th>0.02</th>
<th>0.03</th>
<th>0.04</th>
<th>0.05</th>
</tr>
</thead>
<tbody>
<tr>
<td>A(\infty)</td>
<td>0.8710</td>
<td>0.8346</td>
<td>0.8012</td>
<td>0.7703</td>
<td>0.7418</td>
<td></td>
</tr>
</tbody>
</table>

(g) Effect of failure rate of Packing unit on availability A(\infty) :
\[ \lambda_1 = 0.003, \lambda_2 = 0.002, \lambda_3 = 0.001, \lambda_4 = 0.01, \lambda_5 = 0.01, \mu_1 = 0.33, \mu_2 = 0.50, \mu_3 = 0.50, \mu_4 = 0.33, \mu_5 = 0.25, \mu_6 = 0.20, \mu_7 = 0.50 \]

**TABLE VIII Steady State availability versus failure rate of packing unit**

<table>
<thead>
<tr>
<th>( \lambda_1 )</th>
<th>A(\infty)</th>
<th>0.02</th>
<th>0.04</th>
<th>0.06</th>
<th>0.08</th>
<th>0.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>A(\infty)</td>
<td>0.8710</td>
<td>0.8417</td>
<td>0.8143</td>
<td>0.7886</td>
<td>0.7645</td>
<td></td>
</tr>
</tbody>
</table>

(h) Effect of repair rate of Sieving unit on availability A(\infty) :
\[ \lambda_1 = 0.003, \lambda_2 = 0.002, \lambda_3 = 0.001, \lambda_4 = 0.01, \lambda_5 = 0.01, \lambda_6 = 0.02, \mu_1 = 0.33, \mu_2 = 0.50, \mu_3 = 0.50, \mu_4 = 0.33, \mu_5 = 0.25, \mu_6 = 0.20, \mu_7 = 0.50 \]

**TABLE IX Steady State availability versus repair rate of sieving unit**

<table>
<thead>
<tr>
<th>( \mu_1 )</th>
<th>0.33</th>
<th>0.44</th>
<th>0.55</th>
<th>0.66</th>
<th>0.77</th>
</tr>
</thead>
<tbody>
<tr>
<td>A(\infty)</td>
<td>0.8710</td>
<td>0.8727</td>
<td>0.8738</td>
<td>0.8745</td>
<td>0.8749</td>
</tr>
</tbody>
</table>
(i) Effect of repair rate of Mixing unit on availability $A(z)$:
\[
\lambda_1 = 0.003, \lambda_2 = 0.004, \lambda_3 = 0.001, \lambda_4 = 0.001, \lambda_5 = 0.01, \\
\lambda_6 = 0.01, \lambda_7 = 0.02, \mu_1 = 0.33, \mu_2 = 0.50, \mu_3 = 0.33, \mu_4 = 0.25, \\
\mu_5 = 0.20, \mu_6 = 0.50
\]

**TABLE X Steady State availability versus repair rate of mixing unit**

<table>
<thead>
<tr>
<th>$\mu_2$</th>
<th>0.50</th>
<th>0.55</th>
<th>0.60</th>
<th>0.65</th>
<th>0.70</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A(z)$</td>
<td>0.8710</td>
<td>0.8713</td>
<td>0.8715</td>
<td>0.8717</td>
<td>0.8719</td>
</tr>
</tbody>
</table>

(j) Effect of repair rate of Divider unit on availability $A(z)$:
\[
\lambda_1 = 0.003, \lambda_2 = 0.004, \lambda_3 = 0.001, \lambda_4 = 0.001, \lambda_5 = 0.01, \\
\lambda_6 = 0.01, \lambda_7 = 0.02, \mu_1 = 0.33, \mu_2 = 0.50, \mu_3 = 0.33, \mu_4 = 0.25, \\
\mu_5 = 0.20, \mu_6 = 0.50
\]

**TABLE XI Steady State availability versus repair rate of divider unit**

<table>
<thead>
<tr>
<th>$\mu_3$</th>
<th>0.50</th>
<th>0.55</th>
<th>0.60</th>
<th>0.65</th>
<th>0.70</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A(z)$</td>
<td>0.8710</td>
<td>0.8711</td>
<td>0.8712</td>
<td>0.8713</td>
<td>0.8714</td>
</tr>
</tbody>
</table>

(k) Effect of repair rate of Moulding unit on availability $A(z)$:
\[
\lambda_1 = 0.003, \lambda_2 = 0.004, \lambda_3 = 0.001, \lambda_4 = 0.001, \lambda_5 = 0.01, \\
\lambda_6 = 0.01, \lambda_7 = 0.02, \mu_1 = 0.33, \mu_2 = 0.50, \mu_3 = 0.33, \mu_4 = 0.25, \\
\mu_5 = 0.20, \mu_6 = 0.50
\]

**TABLE XII Steady State availability versus repair rate of moulding unit**

<table>
<thead>
<tr>
<th>$\mu_4$</th>
<th>0.33</th>
<th>0.36</th>
<th>0.39</th>
<th>0.42</th>
<th>0.45</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A(z)$</td>
<td>0.8710</td>
<td>0.8712</td>
<td>0.8713</td>
<td>0.8715</td>
<td>0.8716</td>
</tr>
</tbody>
</table>

(l) Effect of repair rate of Proofing unit and storage on availability $A(z)$:
\[
\lambda_1 = 0.003, \lambda_2 = 0.004, \lambda_3 = 0.001, \lambda_4 = 0.001, \lambda_5 = 0.01, \\
\lambda_6 = 0.01, \lambda_7 = 0.02, \mu_1 = 0.33, \mu_2 = 0.50, \mu_3 = 0.33, \mu_4 = 0.25, \\
\mu_5 = 0.20, \mu_6 = 0.50
\]

**TABLE XIII Steady State availability versus repair rate of proofing unit**

<table>
<thead>
<tr>
<th>$\mu_5$</th>
<th>0.25</th>
<th>0.30</th>
<th>0.35</th>
<th>0.40</th>
<th>0.45</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A(z)$</td>
<td>0.8710</td>
<td>0.8761</td>
<td>0.8797</td>
<td>0.8825</td>
<td>0.8847</td>
</tr>
</tbody>
</table>

(m) Effect of repair rate of Baking unit on availability $A(z)$:
\[
\lambda_1 = 0.003, \lambda_2 = 0.004, \lambda_3 = 0.001, \lambda_4 = 0.001, \lambda_5 = 0.01, \\
\lambda_6 = 0.01, \lambda_7 = 0.02, \mu_1 = 0.33, \mu_2 = 0.50, \mu_3 = 0.33, \mu_4 = 0.25, \\
\mu_5 = 0.20, \mu_6 = 0.50
\]

**TABLE XIV Steady State availability versus repair rate of baking unit**

<table>
<thead>
<tr>
<th>$\mu_6$</th>
<th>0.20</th>
<th>0.30</th>
<th>0.40</th>
<th>0.50</th>
<th>0.60</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A(z)$</td>
<td>0.8710</td>
<td>0.8838</td>
<td>0.8904</td>
<td>0.8944</td>
<td>0.8970</td>
</tr>
</tbody>
</table>

(n) Effect of repair rate of Packing unit on availability $A(z)$:
\[
\lambda_1 = 0.003, \lambda_2 = 0.004, \lambda_3 = 0.001, \lambda_4 = 0.001, \lambda_5 = 0.01, \\
\lambda_6 = 0.01, \lambda_7 = 0.02, \mu_1 = 0.33, \mu_2 = 0.50, \mu_3 = 0.33, \mu_4 = 0.25, \\
\mu_5 = 0.20, \mu_6 = 0.50
\]

**TABLE XV Steady State availability versus repair rate of packing unit**

<table>
<thead>
<tr>
<th>$\mu_7$</th>
<th>0.50</th>
<th>0.55</th>
<th>0.60</th>
<th>0.65</th>
<th>0.70</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A(z)$</td>
<td>0.8710</td>
<td>0.8738</td>
<td>0.8761</td>
<td>0.8780</td>
<td>0.8797</td>
</tr>
</tbody>
</table>

V. DISCUSSION AND CONCLUSION

Availability analysis revealed that increase in the failure rate of different sub systems such as Sieving unit, Mixing unit, Divider, Moulding unit, Proofing unit and packing unit, reduces the availability of the system. Table II to VIII shows the effect of failure rate of different sub systems on the long run availability of the bread manufacturing system. On the other hand the repair rates of the constituent component increase the availability of the system. These effects are shown in tables IX to XV. Thus it can be concluded that the system availability can be improved by increasing the repair rates which in turn can be achieved by incorporating preventive maintenance of different sub systems.

REFERENCES


extraction system; Proceeding of ORSI International Conference held at Tirupati.


