Performance analysis of various sub systems of Nestle Cerelac plants using Markov chain method

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Abstract: In the performance analysis of production systems by using the traditional methods of engineering the knowledge of machine reliability factors is assumed to be precisely known. The current study entitled performance evaluation of food industry in India. To analyze and determine the availability of plant a case study has been undertaken from Moga Nestle food private limited industry in India. Various studies evaluating the performance of automated production systems with the help of modeling and simulation and analytical methods have always given priority to steady state performance as compared to transient performance. Production systems in which such kind of situations arises include systems with dysfunctional states and deadlocks, not stable queueing systems. This research work presents an approach for analyzing the performance of unreliable manufacturing systems that take care of uncertain machine factor estimates. The method that is being proposed is on the basis of Markov chain and probability density function discretization techniques for studying manufacture lines consist unreliable machines. To determine the performance of plant, important information has been collected from different systems and subsystems to find out long run availability of whole system.

Keywords: Maintenance policy, Maintenance, Reliability, Replacement, Optimization.

I. INTRODUCTION

Manufacturing flow line systems constitutes material, work areas, and storage areas. Material flows from work space to storage stretch and back again to work space. It visits every work and storage area specifically once in an exceedingly fastened sequence, there is a first work space through that material enters and a half work space through that it leaves the system. Manufacturing flow lines also are known as transfer lines. In this paper, we have a tendency to chiefly use the term „reliability, in General often outlined as the likelihood of a system or device playing its anticipated purpose adequately for the supposed amount of your time underneath the given operational conditions. Importance gained by reliability engineering in recent years is all due to the great results. Today the industries square measure of high concern with the security of their machines and additionally the uninterrupted operating of the system. So, the reliability engineering is associate degree important tool to cipher and improve the systems performance that is wide used currently these days. Recent studies by the researchers within the field of reliability/ availability/ maintainability planned many ways for industrial systems underneath maintenance. Reliability and availability analysis will profit the business in terms of upper productivity and lower maintenance value which is feasible to boost the provision of the plant with correct maintenance, planning, observance and control. In fact, uninterrupted operation is an important requirement of enormous complicated systems.

II. SYSTEM DESCRIPTION

In this system, the cerelac is prepared within the rinsed base powder where it is ready for next sub system. In this the tipping area wheat flour sugar, Rework are manually tipped as per the requirement of batch. For the processing of each batch, a weighed quantity of flour and sugar flow to the weighing scale. Any type of impurities or foreign material in held back in the sieve. The flour and sugar with the help of the air from blower now reach the mixer. Jet air filters are installed which prevent any wheat flour being carried away by the air used for its circulation. After passing through various stages of tipping area, different ingredients are then ended in fixed ratios as per recipe. Wheat flour, sugar, water, corn oil, enzyme are mixed here in papenmier.

After being mixed thoroughly, the mixture is now termed as the "soup" Further agitation of soup takes place in the soup vat to bring about homogeneity. The alpha amylase, which is a liquefying enzyme, causes the partial hydrolysis of starch. The amylase enzyme reduces the viscosity of the final product. The soup now flows from the soup vat after agitation for hydrolysis that is an important stage both by process and hygiene point of view. Hydrolysis takes place at a temperature of 70°C by direct steam injection into the soup. The pressure of steam at DSI-I is 1.5Kg/Cm2 .The soup now flows to the hydrolyzing vat Pasteurization of the soup now takes place as it passes after direct steam injection DSI-II. Here the soup is held at a temperature of 132°C for 6.1 sec. This step is CCP-1 in the process as it ensures both safety and quality for the product.

Raw Material

Tipping unit

Papenmier Unit

Hydrolysis Unit

Pasteurization Unit
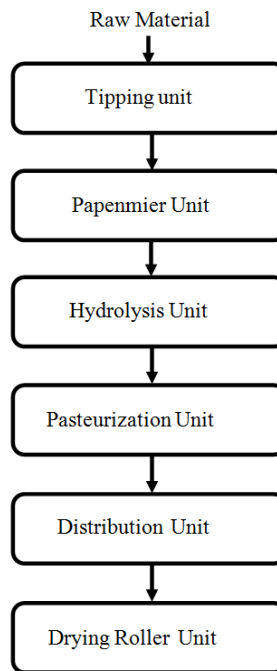
Distribution Unit

Drying Roller Unit

Fig. 3.2 Process flow diagram of base powder preparation sub-system

The distribution vat holds the soup that has passed through the two main critical control points of the process. From this distribution vat the soup is now fed to the four roller dryers with the help of their respective product pumps. Dryer Roller important function is to dry the soup by forming a thin layer on the dryer drums and hence remove the moisture. Steam is injected in the hollow drum through the Johnson joint .The surface of the roller dryers is very smoothing devoid of any edges or crevices. The outer surface of the drums is chrome plated. This is to impart the rollers greater strength to avoid wear and tear and also to enhance its surface qualities.

III. NOTATIONS AND ASSUMPTIONS

Notations
Tipping Unit (T): One unit subjected to major failure only.
Papenmier Unit (P): One unit subjected to major failure only.
Hydrolysis Unit (H): One unit subjected to major failure only.
Pasteurization Unit (A): One unit subjected to major failure only.
Distribution Unit (D): One unit subjected to major failure only.
Dry Roller Unit (R): One unit subjected to major failure only.
λ_i: Failure rate of T,P,H,A,D& R units, (i = 1,2,3,4,5,6).
μ_i = Repair rate T,P,H,A,D& R units, (i = 1,2,3,4,5,6).
o: Represents the system/sub-system is operating.
r: Component/sub-system is under repair.
g: Component is working in good condition.
s: Laplace transform variable
λ_i (t): Represents derivative w. r. t't'

5.3 Assumptions
a)   All the sub-systems are initially operating and all the sub-systems are initially in good state.
b)   Each unit has two states, good and failed.
c)   It is also assumed that there is only one repair facility to handle corrective maintenance.
d)   Each unit is good as new after repair.
e)   The failure rates and repair rates of all units are taken constant.
f)   Failure and repair events are statistically independent.

IV. MATHEMATICAL ANALYSIS AND NUMERICAL RESULTS OF THE SYSTEM

Probability consideration gives the following first order differential-difference equations associated with the state transition diagram of sub-system as shown in fig 3.3.
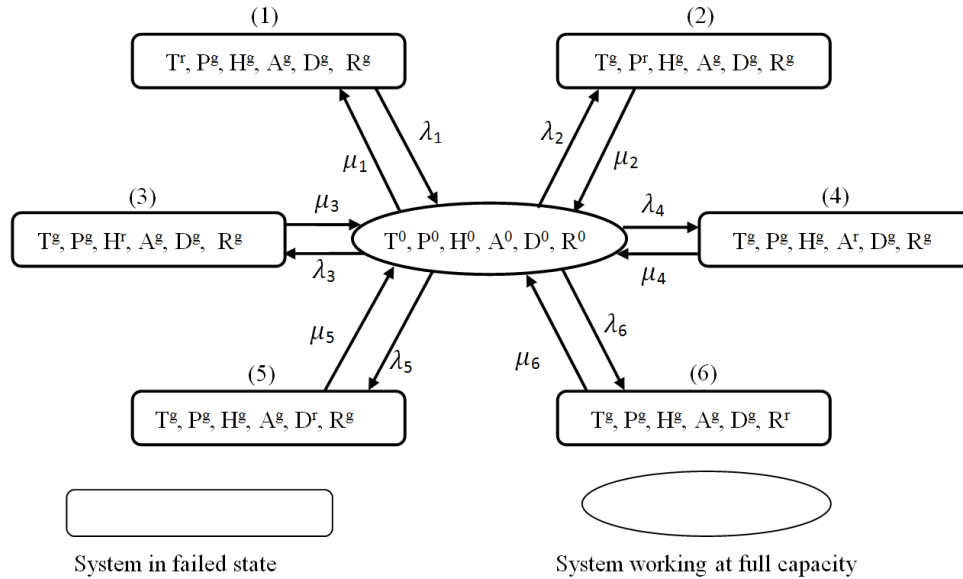

Fig. 2 Base Powder preparation sub-system state transition diagram

$P'_0(t) + (\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6)P_0(t) = \mu_1 P_1(t) + \mu_2 P_2(t) + \mu_3 P_3(t) + \mu_4 P_4(t) + \mu_5 P_5(t) + \mu_6 P_6(t)$

$P'_0(t) + \alpha_1 P_0(t) = \mu_1 P_1(t) + \mu_2 P_2(t) + \mu_3 P_3(t) + \mu_4 P_4(t) + \mu_5 P_5(t) + \mu_6 P_6(t)$ (1)

Where $\alpha_1 = \lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6$

$P'_1(t) + \mu_1 P_1(t) = \lambda_1 P_0(t)$ (2)

$P'_2(t) + \mu_2 P_2(t) = \lambda_2 P_0(t)$ (3)

$P'_3(t) + \mu_3 P_3(t) = \lambda_3 P_0(t)$ (4)

$P'_4(t) + \mu_4 P_4(t) = \lambda_4 P_0(t)$ (5)

$P_5^{'}(t) + \mu_5 P_5(t) = \lambda_5 P_0(t)$ (6)

$P_6^{'}(t) + \mu_6 P_6(t) = \lambda_6 P_0(t)$ (7)

With initial condition at time t = 0

$P_i(t) = 1$ For i = 0

$P_i(t) = 0$ For i ≠ 0

1) Solution of equations

Solving above equations after taking Laplace transformation of equations (2)-(5), the following Laplace transformations of state probabilities as obtained:

$P_i(s) = K_i P_0(s)$ For i = 1 to 6   (8)

Where

$$K_1 = \frac{\lambda_1}{s + \mu_1}, \qquad K_2 = \frac{\lambda_2}{s + \mu_2}$$

$$K_3 = \frac{\lambda_3}{s + \mu_3}, \qquad K_4 = \frac{\lambda_4}{s + \mu_4}$$

$$K_5 = \frac{\lambda_5}{s + \mu_5}, \qquad K_6 = \frac{\lambda_6}{s + \mu_6}$$

Taking Laplace transformation of equation (1) using initial condition and relation with (8), we get

$sP_0(s) + \alpha_1 P_0(s) = 1 + \mu_1 K_1 P_0(s) + \mu_2 K_2 P_0(s) + \mu_3 K_3 P_0(s) + \mu_4 K_4 P_0(s) + \mu_5 K_5 P_0(s) + \mu_6 K_6 P_0(s)$

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$(s + \alpha_1)P_0(s) = 1 + P_0(s)(\mu_1 K_1 + \mu_2 K_2 + \mu_3 K_3 + \mu_4 K_4 + \mu_5 K_5 + \mu_6 K_6)$

$P_0(s) = \{(s + \alpha_1) - (\mu_1 K_1 + \mu_2 K_2 + \mu_3 K_3 + \mu_4 K_4 + \mu_5 K_5 + \mu_6 K_6)\}^{-1}$ (9)

Laplace transformation of availability function A(t) is obtained as

$A(s) = P_0(s)$ (10)

Where $P_0(s)$ is given by equation (9)7

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

2) Steady state behavior of sub-system

Now applying steady state condition on first order differential-difference equation setting

$t \to \infty, d / dt = 0$

The limiting probabilities from equation (1) to (7) are:

$\alpha_1 P_0 = \mu_1 P_1 + \mu_2 P_2 + \mu_3 P_3 + \mu_4 P_4 + \mu_5 P_5 + \mu_6 P_6$ (11)

$\mu_1 P_1 = \lambda_1 P_0$ (12)

$\mu_2 P_2 = \lambda_2 P_0$ (13)

$\mu_3 P_3 = \lambda_3 P_0$ (14)

$\mu_4 P_4 = \lambda_4 P_0$ (15)

$\mu_5 P_5 = \lambda_5 P_0$ (16)

$\mu_6 P_6 = \lambda_6 P_0$ (17)

Solving these equations recursively, we get

$P_i = L_i P_0$ Where i = 1 to 6   (18)

Where

$L_i = \lambda_i / \mu_i$

Using normalizing equation, when sum of all the probabilities is equal to one than

$$\sum_{i=0}^{6} P_i = 1 , gives$$

$P_0 + P_1 + P_2 + P_3 + P_4 + P_5 + P_6 = 1$

$$P_0 = [1 + \sum_{i=1}^{6} \frac{\lambda_i}{\mu_i}]^{-1} \qquad (19)$$

The overall steady state availability of Base Powder preparation sub-system when running at full capacity is given by:

AFC $= P_0$

Where P_0 is given by equation (19)

$$AFC = [1 + \sum_{i=1}^{6} \frac{\lambda_i}{\mu_i}]^{-1}$$

(Taking $\lambda_1 = 0.002$ $\lambda_2 = 0.006, \lambda_3 = 0.001$, $\lambda_4 = 0.003, \lambda_5 = 0.01$, $\lambda_6 = 0.0008$ & $\mu_1 = 0.2$, $\mu_2 = 0.25$, $\mu_3 = 0.33$, $\mu_4 = 0.2, \mu_5 = 0.125, \mu_6 = 0.08$

AFC $= \mathbf{0.8756}$

V. PERFORMANCE ANALYSIS

The effects of failure rate, repair rate and maintenance rate of various components and sub components comprising the sub-system are examined and their impact on availability are described in following tables.

(A) Effect of failure rate of Tipping unit on availability (AFC):

Taking, $\lambda_2 = 0.006, \lambda_3 = 0.001$, $\lambda_4 = 0.003, \lambda_5 = 0.01$, $\lambda_6 = 0.0008$ & $\mu_1 = 0.2$, $\mu_2 = 0.25$, $\mu_3 = 0.33$, $\mu_4 = 0.2, \mu_5 = 0.125, \mu_6 = 0.08$

Table 1 Steady state availability versus failure rate of Tipping unit

λ_1	0.002	0.004	0.006	0.008
AFC	0.8756	0.8680	0.8606	0.8532

(B) Effect of failure rate of Papenmier unit on availability (AFC):

Taking, $\lambda_1 = 0.002$, $\lambda_3 = 0.001$, $\lambda_4 = 0.003$, $\lambda_5 = 0.01$, $\lambda_6 = 0.0008$ & $\mu_1 = 0.2$, $\mu_2 = 0.25$, $\mu_3 = 0.33$, $\mu_4 = 0.2$, $\mu_5 = 0.125$, $\mu_6 = 0.08$

Table 2 Steady state availability versus failure rate of Papenmier unit

λ_2	0.006	0.012	0.018	0.024
AFC	0.8756	0.8576	0.8403	0.8237

(C) Effect of failure rate of Hydrolysis unit availability (AFC):

Taking, $\lambda_1 = 0.002$, $\lambda_2 = 0.006$, $\lambda_4 = 0.003$, $\lambda_5 = 0.01$, $\lambda_6 = 0.0008$ & $\mu_1 = 0.2$, $\mu_2 = 0.25$, $\mu_3 = 0.33$, $\mu_4 = 0.2$, $\mu_5 = 0.125$, $\mu_6 = 0.08$

Table 3 Steady state availability versus failure rate of Hydrolysis unit

λ_3	0.001	0.002	0.003	0.004
AFC	0.8756	0.8733	0.8710	0.8687

(D) Effect of failure rate of Pasteurization unit on availability (AFC):

Taking, $\lambda_1 = 0.002$, $\lambda_2 = 0.006$, $\lambda_3 = 0.001$, $\lambda_5 = 0.01$, $\lambda_6 = 0.0008$ & $\mu_1 = 0.2$, $\mu_2 = 0.25$, $\mu_3 = 0.33$, $\mu_4 = 0.2$, $\mu_5 = 0.125$, $\mu_6 = 0.08$

Table 4 Steady state availability versus failure rate of Pasteurizing unit

λ_4	0.003	0.006	0.009	0.012
AFC	0.8756	0.8643	0.8532	0.8424

(E) Effect of failure rate of Distribution unit on availability (AFC):

Taking, $\lambda_1 = 0.002$, $\lambda_2 = 0.006$, $\lambda_3 = 0.001$, $\lambda_4 = 0.003$, $\lambda_6 = 0.0008$ & $\mu_1 = 0.2$, $\mu_2 = 0.25$, $\mu_3 = 0.33$, $\mu_4 = 0.2$, $\mu_5 = 0.125$, $\mu_6 = 0.08$

Table 5 Steady state availability versus failure rate of Distribution unit

λ_5	0.01	0.02	0.03	0.04
AFC	0.8756	0.8183	0.7680	0.7236

(F) Effect of failure rate of drying roller unit on availability (AFC):

Taking, $\lambda_1 = 0.002$, $\lambda_2 = 0.006$, $\lambda_3 = 0.001$, $\lambda_4 = 0.003$, $\lambda_5 = 0.01$ & $\mu_1 = 0.2$, $\mu_2 = 0.25$, $\mu_3 = 0.33$, $\mu_4 = 0.2$, $\mu_5 = 0.125$, $\mu_6 = 0.08$

Table 6 Steady state availability versus failure rate of drying roller

λ_6	0.0008	0.0016	0.0024	0.0032
AFC	0.8756	0.08680	0.8606	0.8532

(G) Effect of repair rate of Tipping unit on availability (AFC):

Taking, $\lambda^1 = 0.002$, $\lambda^2 = 0.006$, $\lambda^3 = 0.001$, $\lambda^4 = 0.003$, $\lambda_5 = 0.01$, $\lambda_6 = 0.0008$ & $\mu^2 = 0.25$, $\mu^3 = 0.33$, $\mu^4 = 0.2$, $\mu_5 = 0.125$, $\mu_6 = 0.08$

Table 7 Steady state availability versus repair rate of Tipping unit

μ_1	0.2	0.4	0.6	0.8
AFC	0.8756	0.8795	0.8808	0.8814

(H) Effect of repair rate of Papenmier unit on availability (AFC):

Taking, $\lambda_1 = 0.002$, $\lambda_2 = 0.006$, $\lambda_3 = 0.001$, $\lambda_4 = 0.003$, $\lambda_5 = 0.01$, $\lambda_6 = 0.0008$ & $\mu_1 = 0.2$, $\mu_3 = 0.33$, $\mu_4 = 0.2$, $\mu_5 = 0.125$, $\mu_6 = 0.08$

Table 8 Steady state availability versus repair rate of Papenmier unit

μ_2	0.25	0.50	0.75	1
AFC	0.8756	0.8849	0.8881	0.8897

(I) Effect of repair rate of Hydrolysis unit on availability (AFC):

Taking, $\lambda_1 = 0.002$, $\lambda_2 = 0.006$, $\lambda_3 = 0.001$, $\lambda_4 = 0.003$, $\lambda_5 = 0.01$, $\lambda_6 = 0.0008$ & $\mu_1 = 0.2$, $\mu_2 = 0.25$, $\mu_4 = 0.2$, $\mu_5 = 0.125$, $\mu_6 = 0.08$

Table 9 Steady state availability versus repair rate of Hydrolysis unit

μ_3	0.33	0.66	0.99	1.32
AFC	0.8756	0.8768	0.8772	0.8774

(J) Effect of repair rate of Pasteurization unit on availability (AFC):

Taking, $\lambda_1 = 0.002$, $\lambda_2 = 0.006$, $\lambda_3 = 0.001$, $\lambda_4 = 0.003$, $\lambda_5 = 0.01$, $\lambda_6 = 0.0008$ & $\mu_1 = 0.2$, $\mu_2 = 0.25$, $\mu_3 = 0.33$, $\mu_5 = 0.125$, $\mu_6 = 0.08$

Table 10 Steady state availability versus repair rate of Pasteurization unit

μ_4	0.2	0.4	0.6	0.8
AFC	0.8756	0.8814	0.8834	0.8843

(K) Effect of repair rate of Distribution unit on availability (AFC):

Taking, $\lambda_1 = 0.002$, $\lambda_2 = 0.006$, $\lambda_3 = 0.001$, $\lambda_4 = 0.003$, $\lambda_5 = 0.01$, $\lambda_6 = 0.0008$ & $\mu_1 = 0.2$, $\mu_2 = 0.25$, $\mu_3 = 0.33$, $\mu_4 = 0.2$, $\mu_6 = 0.08$

Table 11 Steady state availability versus repair rate of Distribution unit

μ_5	0.125	0.250	0.375	0.500
AFC	0.8756	0.9187	0.9301	0.9315

(L) Effect of repair rate of drying roller unit on availability (AFC): Taking, $\lambda_1 = 0.002$, $\lambda_2 = 0.006$, $\lambda_3 = 0.001$, $\lambda_4 = 0.003$, $\lambda_5 = 0.01$, $\lambda_6 = 0.0008$ & $\mu_1 = 0.2$, $\mu_2 = 0.25$, $\mu_3 = 0.33$, $\mu_4 = 0.2$, $\mu_5 = 0.125$,

Table 12 Steady state availability versus repair rate of Drying roller

μ_6	0.08	0.16	0.24	0.32

AFC	0.8756	0.8901	0.8914	0.8920

VI. RESULTS AND DISCUSSION

The analysis of base powder preparation sub-system yields that with the increase in failure rates of tipping unit, papenmier unit, hydrolysis unit, pasteurization unit, distribution unit and dry roller the availability of the system reduces. This effects is shown in table 3.1 to 3.6. On the other hand increased repair rate of the constituent components increase the availability of the system .The effect of increasing repair rates is table 3.7 to 3.12. The improvement in availabilities of the system are 0.58% 1.41% 0.18% 0.87% 5.59% and 1.64% on increasing the repair rates of the tipping unit, papenmier unit, hydrolysis unit, pasteurization unit, distribution unit and dry roller from 0.2 to 0.8, 0.25 to 1, 0.33 to 1.32, 0.2 to 0.8, 0.125 to 0.500, 0.08 to 0.32 repair per hour respectively.

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