Reliability modelling and cost benefit analysis of fruit juice manufacturing system

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Abstract. This paper is based on a manufacturing unit situated in Jammu (J&K) and a model is developed for its reliability analysis. The proposed model comprising of four units viz. Fruit cutter, Fruit Pulper, Sterilizer and Homogenizer. For the system to work, working of Sterilizer and Homogenizer is required, system fails only if Sterilizer or Homogenizer fails. A single repair facility is always available with the system to repair Fruit Cutter and Fruit Pulper on first come first serve basis. A concept of Emergency repair is used in which a team of experts is called on the failure Homogenizer or Sterilizer and the whole system comes under emergency repair in order to make the system ready as early as possible. All the failure time distributions are taken to be negative exponential and all the repair time distributions are assumed to be general. Various reliability characteristics of interest have been studied along with graphical behaviour.

1 Introduction

Reliability, now a days is growing very fast in the important fields like consumer and capital goods industries, space and defence industries etc. Reliability provides the theoretical and practical tools to ascertain the probability and capacity of parts, components and system to perform their required functions in specified environments for the desired time period without failure. It is very essential for an industry and technology to be competitive in today’s highly competitive markets of the world. Reliability theory helps the system managers in knowing the reliability of their production systems and to produce at optimum reliable level. In the present world the economy of all the developed as well as developing countries is recognized by their industrial power in view of this, in recent time modern techniques are used to increase profit and to overcome the maintenance problems on the basis of real configuration of the models with real assumptions. Very few authors have studied the industrial system with real existing situations including Arora and Kumar [1], Sharma and Panigrahi

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[9], Singh et al [10], Singh and Singh [12] and Yadavalli [14]. Dhillon and Nateson [2] have done analysis of a pulverize system with common cause failure, Nateson and Jardine [8] have analysed door power systems in fluctuating environment, Kochar [4] developed a systematic method for investment decisions on an additional equipment to form a standby or redundant system in a production system. By working towards industries Singh and Singh [5] have analysed a feeding system in sugar industry, Gupta et al.[3] have done stochastic modelling and analysis of milk powder making system in dairy plant and Singh and Nair [11] have studied a stone crushing system having one apron feeder, one grizzly, one primary Gyrator crusher. A few attempts have been made to study the practical models and real data with the concept of emergency repair, Singh [13] has done the reliability analysis of systems of Bhilai Steel Plant, India. Kumar et al [6] have done reliability analysis of real life yarn dyeing system while Kumar and Bharti [7] have studied Battery production system with the technique of emergency repair.

Keeping in view the tremendous work done by the various authors in real life existing situations we also have tried to analyze a real existing model of Fruit Juice Manufacturing System with the concept of emergency repair by personally visiting the juice manufacturing unit situated at S.I.D.C.O. Jammu, Jammu and Kashmir. The said production system consists of four units of varying nature viz. Fruit Cutter, Fruit Pulper, Sterilizer and Homogenizer.

The working of different units and subunits of the system is described as follows:

- Fruit Cutter: The fruits are washed in a trough using potable water and then they are peeled off manually. After this the peeled fruits are fed into Fruit Cutter machine. Here the fruits are cut into small pieces.
- Fruit Pulper: It pulps the fruits. It consist of brushes and sieve, the gap between the brushes and sieve can be adjusted to suit different types, sizes and qualities of fruit to be pulped.
- Sterilizer: Sterilizer is fruit processing machinery used for Sterilize the products like fruit pulp of mangoes, papayas, guavas, peaches, juice concentrates, etc. Continuous scraping action in this unit ensures uniform heating of products and prevents product fouling/charring.
- Homogenizer: Homogenizer is used for reducing the particle size of fluid under conditions of extreme pressure, shear, turbulence, acceleration and impact, to make the juice more stable and have a better texture.

The proposed model comprising of four units viz. Fruit cutter, Fruit Pulper, Sterilizer and Homogenizer. For the system to work, working of Sterilizer and Homogenizer is required, system fails only if Sterilizer or Homogenizer fails. A single repair facility is always available with the system to repair Fruit Cutter and Fruit Pulper on first come first serve basis. A concept of Emergency repair is used; a team of experts is called on the failure Homogenizer or Sterilizer i.e. third or fourth unit. When the system is under emergency repair then the repair of the whole system starts afresh, by the panel of experts. Failures and repairs are stochastically independent. All the failure time distributions are taken to be negative exponential. All the repair time distributions are taken as arbitrary. A repaired unit is as good as new and is immediately reconnected to the system. A unit fails only after producing certain number of items.

Using regenerative point technique important reliability characteristics like transition probabilities, mean sojourn times, mean time to system failure (MTSF), point wise and steady-state availabilities of the system, expected up-time of the system, expected busy period of the repairman during \((0, t]\) and in the steady state, expected number of repairs during \((0, t]\) and in the steady state and net expected profit incurred by the system during \((0, t]\) and in steady are obtained.

The various states of the system can be described with the help of following notations:
\( \alpha_1 \) Failure rate of the first unit i.e. \( F_c \).
\( \alpha_2 \) Failure rate of the second unit i.e. \( F_p \).
\( \alpha_3 \) Failure rate of the third and fourth unit i.e. \( S \) or \( H \).

\( G(.) \) cdf of repair time of emergency repair.
\( G_1(.) \) cdf of repair time of first unit.
\( G_2(.) \) cdf of repair time of second unit.

\( \gamma \) Rate at which \( S \) and \( H \) shifts from ideal to operative mode.

\( F_{c_0} \) Fruit cutter machine is operative.
\( F_{c_r} \) Fruit cutter machine is under repair.
\( F_{c_w} \) Fruit cutter machine is waiting for repair.
\( F_{p_0} \) Fruit Pulper is operative.
\( F_{p_r} \) Fruit Pulper is under repair.
\( F_{p_w} \) Fruit Pulper is waiting for repair.
\( S_1 \) Sterilizer is under ideal condition.
\( S_0 \) Sterilizer is operative.
\( H_1 \) Homogenizer is under ideal condition.
\( H_0 \) Homogenizer is operative.

Emergency Repair System is put under emergency repair on the failure of \( H \) or \( S \).

With the help of the above symbols the possible states of the system are:

\[
S_0 = [F_{c_0}, F_{p_0}, S_1, H_1] \quad S_1 = [F_{c_0}, F_{p_0}, S_0, H_0] \\
S_2 = [F_{c_0}, F_{p_r}, S_0, H_0] \quad S_3 = [F_{c_r}, F_{p_0}, S_0, H_0] \\
S_4 = \{\text{Emergency Repair}\} \quad S_5 = [F_{c_w}, F_{p_r}, S_0, H_0] \quad S_6 = [F_{c_r}, F_{p_w}, S_0, H_0]
\]

The transition diagram along with all the transitions is shown in Fig.1.

### 2 Transition Probabilities and Mean Time To System Failure

Let \( T_0(\equiv 0), T_1, T_2, \ldots \) denotes the regenerative epochs and \( X_n \) denotes the state visited at epoch \( T_n \), i.e. just after the transition at \( T_n \) then \( \{X_n, T_n\} \) constitute a Markov-Renewal process with state space \( E \), set of regenerative states and

\( Q_{ij}(t) = P[X_{n+1} - T_n \leq t|X_n = i] \) is the semi Markov kernel over \( E \). Then the transition probability matrix of the embedded Markov chain is \( p = p_{ij} = [Q_{ij}(\infty)] \)

The various transitions probabilities can be obtained in the form of \( Q_{ij}(t) \) and by taking the limit as \( t \) tends to \( \infty \) in \( Q_{ij}(\infty) \)'s we obtain the following steady state transition probabilities:

\[
p_{01} = \lim_{t \to \infty} Q_{01}(t) = \gamma \int_0^\infty \exp[-(\gamma + \alpha_1 + \alpha_2)t]dt = \frac{\gamma}{\gamma + \alpha_1 + \alpha_2} \\
p_{02} = \frac{\alpha_2}{\gamma + \alpha_1 + \alpha_2} \quad p_{03} = \frac{\alpha_1}{\gamma + \alpha_1 + \alpha_2} \\
p_{12} = \frac{\alpha_2}{\alpha_1 + \alpha_2 + \alpha_3} \quad p_{13} = \frac{\alpha_1}{\alpha_1 + \alpha_2 + \alpha_3}
\]
From these steady state probabilities, it can easily be seen that \( \sum_{j} p_{ij} = 1 \), for all \( i \).

### 2.1 Mean sojourn time

The mean sojourn time in state \( S_i \) denoted by \( \mu_i \) is defined as the expected time taken by the system in state \( S_i \) before transiting to any other state. To obtain mean sojourn time \( \mu_i \) in state \( S_i \), we observe that as long as the system is in state \( S_i \), there is no transition from \( S_i \) to any other state. If \( T_i \) denotes the sojourn time in state \( S_i \) then mean sojourn time in state \( S_i \) is
\[ \mu_i = E[T_i] = \int_0^\infty P[T_i \leq t] dt, \]  

thus

\[ \mu_0 = E[T_0] = \int_0^\infty P[T_0 \leq t] dt = \int_0^\infty \exp[-(\gamma + \alpha_1 + \alpha_2)t] dt = \frac{1}{\gamma + \alpha_1 + \alpha_2} \]

\[ \mu_1 = \frac{1}{\alpha_1 + \alpha_2 + \alpha_3} \]

\[ \mu_2 = \frac{1}{\alpha_1 + \alpha_3} [1 - g_2^*(\alpha_1 + \alpha_3)] \]

\[ \mu_3 = \frac{1}{\alpha_2 + \alpha_3} [1 - g_1^*(\alpha_2 + \alpha_3)] \]

\[ \mu_4 = \int_0^\infty \tilde{G}(t) dt \]

\[ \mu_5 = \frac{1 - g_2^*(\alpha_3)}{\alpha_3} \]

\[ \mu_6 = \frac{1 - g_1^*(\alpha_3)}{\alpha_3} \]

Let the random variable \( T_i \) denotes the time to system failure when \( E_0 = E_i \in E \) and \( \phi_i(t) \) is the c.d.f. of the time to system failure for the first time when the system starts operation from state \( E_i \). To obtain the expressions of \( \phi_i(t) \) for different values of \( \alpha_i \), the arguments of regenerative point processes has been used. Taking the Laplace transform and solving the resultant set of equations for \( \tilde{\phi}_0(s) \),

\[ \tilde{\phi}_0(s) = \frac{N_1(s)}{D_1(s)} \]

where

\[ N_1(s) = \tilde{Q}_{14}(s)[\tilde{Q}_{01}(s)\{1 - \tilde{Q}_{23}^{(5)}(s)\tilde{Q}_{22}^{(6)}(s)\} + \tilde{Q}_{02}(s)\{\tilde{Q}_{21}(s) + \tilde{Q}_{23}^{(5)}(s)\tilde{Q}_{31}(s)\} + \tilde{Q}_{03}(s)\{\tilde{Q}_{21}(s) + \tilde{Q}_{32}^{(5)}(s)\tilde{Q}_{32}(s)\}] + \tilde{Q}_{02}(s)\{1 - \tilde{Q}_{12}(s)\tilde{Q}_{31}(s)\} + \tilde{Q}_{03}(s)\{\tilde{Q}_{32}^{(6)}(s) + \tilde{Q}_{31}(s)\tilde{Q}_{12}(s)\} + \tilde{Q}_{03}(s)\{1 - \tilde{Q}_{12}(s)\tilde{Q}_{21}(s)\} \]

and

\[ D_1(s) = [1 - \tilde{Q}_{23}^{(5)}(s)\tilde{Q}_{32}^{(6)}(s)] - \tilde{Q}_{12}(s)\{\tilde{Q}_{21}(s) + \tilde{Q}_{23}^{(5)}(s)\tilde{Q}_{31}(s)\} - \tilde{Q}_{13}(s)\{\tilde{Q}_{31}(s) + \tilde{Q}_{32}^{(6)}(s)\tilde{Q}_{21}(s)\} \]

On taking \( s \to 0 \) and using the relations \( \tilde{Q}_{ij}(s) \to p_{ij} \), it can easily be proved that \( \tilde{\phi}_0(0) = 1 \). Therefore, mean time to system failure when the initial state is \( S_0 \), is expressed in the form

\[ E(T) = -\frac{d\tilde{\phi}_0(s)}{ds} |_{s=0} = \frac{D_1'(0) - N_1'(0)}{D_1(0)} = \frac{A_1}{B_1} \]

where
Availability Analysis

Define \( A_t(t) \) as the probability that the system is in up-state at epoch \( t \) when it initially started from regenerative state \( S_0 \). To obtain recurrence relations among different point wise availabilities we use the simple probabilistic arguments. Taking the Laplace transform and solving the resultant set of equations for \( A_t^*(s) \), we have

\[
A_0^*(s) = \frac{N_2(s)}{D_2^*(s)}, \text{ where}
\]

\[
N_2(s) = [Z_1'(q_{02}^*(s)(g_{02}^*(q_{02}^*(s)) + q_{03}^*(s))) - Z_0'(q_{12}^*(s)(q_{12}^*(q_{12}^*(s)) + q_{02}^*(s))) + Z_3'(q_{02}^*(q_{02}^*(s)) + q_{03}^*(s)))] [q_{14}(q_{34}^*(s) + q_{34}^*(s)) + q_{12}^*(s)] +
\]

\[
Z_1'(q_{02}^*(s)(g_{02}^*(s) + q_{03}^*(s))) - Z_0'(q_{12}^*(q_{12}^*(s)) + q_{02}^*(s))) + Z_4' (q_{12}^*(q_{12}^*(s)) + q_{02}^*(s))] [q_{12}^*(s) + q_{14}(q_{24}^*(s) + q_{24}^*(s)) ] +
\]

\[
(1-q_{14}q_{41}) [Z_0'(1-(q_{23}^*(s) + q_{24}^*(s))) + Z_1'(q_{02}^*(q_{02}^*(s)) + q_{03}^*(s)) + Z_3'(q_{03}^*(s) + q_{02}^*(q_{02}^*(s)) + q_{12}^*(s)) ] + (1-q_{23}^*(s) + q_{24}^*(s))
\]

\[
D_2(S) = (1-q_{14}q_{41})(1-q_{23}^*(s) + q_{24}^*(s)) - q_{41}^*(q_{13}^*(s) + q_{12}^*(s)) + (q_{34}^*(s) + q_{34}^*(s)) - q_{41}^*(q_{24}^*(s) + q_{24}^*(s)) + q_{12}^*(s)
\]

The steady state Availability will be given by

\[
A_0 = \lim_{s \to 0} A_0(t) = \lim_{s \to 0} A_0^*(s) = \frac{N_2(0)}{D_2(0)}, \text{ since } D_2(0) = 0,
\]

where

\[
N_2(0) = (\alpha_1 + \alpha_3)[\alpha_2 g_2^*(\alpha_3) + \alpha_1 - \alpha_2 g_2^*(\alpha_1 + \alpha_3)][(\alpha_2 + \alpha_3) \{ \alpha_1 + \alpha_3 \{ 1 - g_1^*(\alpha_3) + g_1^*(\alpha_2 + \alpha_3) \}
\]

\[
\{ \alpha_1 + \alpha_2 \{ 1 - g_1^*(\alpha_2 + \alpha_3) \} \} + (\alpha_1 + \alpha_3)(\alpha_2 + \alpha_3) \{ 1 - g_1^*(\alpha_3) + g_1^*(\alpha_2 + \alpha_3) \}
\]

\[
\{ g_1^*(\alpha_3) + g_1^*(\alpha_2 + \alpha_3) \} \{ \alpha_1 + \alpha_2 + \gamma \} + (\alpha_2 + \alpha_3)(\alpha_1 g_1^*(\alpha_3) - g_1^*(\alpha_2 + \alpha_3) + \alpha_2)
\]

\[
(\alpha_1 + \alpha_3) \{ 1 - g_1^*(\alpha_3) + g_1^*(\alpha_2 + \alpha_3) \} + (\alpha_1 + \alpha_2 + \alpha_3) \{ 1 - g_1^*(\alpha_2 + \alpha_3) \} \} (\alpha_1 + \alpha_3)
\]
Thus in the long run, the fraction of time for which system is under repair is given by
\[
D_2(0) = (\alpha_1 + \alpha_2 + \gamma)(\alpha_1 + \alpha_3)(\alpha_2 + \alpha_3)[1 - \alpha_3 \int_0^\infty \tilde{G}(t)dt][1 - \{g_2^*(\alpha_2) + g_2^*(\alpha_1 + \alpha_3)\}
\]
and
\[
D_2(0) = (\alpha_1 + \alpha_2 + \gamma)(\alpha_1 + \alpha_3)(\alpha_2 + \alpha_3)[1 - \alpha_3 \int_0^\infty \tilde{G}(t)dt][1 - \{g_2^*(\alpha_2) + g_2^*(\alpha_1 + \alpha_3)\}
\]

4 Busy Period Analysis

We define \(B_i(t)\) as the probability that the regular repairman is busy in the repair of the failed unit when the system initially starts from state \(S_i \in E\). Using probabilistic arguments, taking the Laplace transform and solving the resultant set of equations for \(B_0^*(s)\), we have
\[
B_0^*(s) = \frac{N_3(s)}{D_3(s)},
\]
where
\[
N_3(s) = [Z_2^s(g_{14}^s q_{34}^s + q_{34}^s) + q_{31}^s] - Z_4^s\{q_{14}^s (q_{24}^s + q_{24}^s) + q_{21}^s\} + Z_4^s\{q_{31}^s (q_{24}^s + q_{24}^s) - q_{21}^s\}
\]
and \(D_3\) is same as \(D_3\) as obtained in availability analysis.

Thus in the long run, the fraction of time for which system is under repair is given by
\[
B_0 = \lim_{t \to 0} B_0(t) = \lim_{s \to 0} B_0^*(s) = \frac{N_3(0)}{D_3(0)},
\]
where
\[
N_3(0) = [\alpha_2 + \alpha_1 g_1^s(\alpha_3) - \alpha_1 g_1^s(\alpha_2 + \alpha_3)]^{(\alpha_1 + \alpha_2)\{\alpha_1 + \alpha_2\}(\alpha_1 + \alpha_3)} g_2^s(\alpha_1 + \alpha_3) \int_0^\infty \tilde{G}(t)dt +
\]
and
\[
\int_0^\infty \tilde{G}(t)dt \{\alpha_2 + \alpha_3\}(\alpha_1 + \alpha_3)\{1 - g_2^s(\alpha_1 + \alpha_3)\}\int_0^\infty \tilde{G}(t)dt + (\alpha_1 + \alpha_3)\{\alpha_1 + \alpha_3\} g_2^s(\alpha_3) +
\]
and
\[
\int_0^\infty \tilde{G}(t)dt \{\alpha_2 + \alpha_3\}(\alpha_1 + \alpha_3)\{1 - g_2^s(\alpha_1 + \alpha_3)\}\int_0^\infty \tilde{G}(t)dt + (\alpha_1 + \alpha_3)\{\alpha_1 + \alpha_3\} g_2^s(\alpha_3) +
\]
and
\[
\int_0^\infty \tilde{G}(t)dt \{\alpha_2 + \alpha_3\}(\alpha_1 + \alpha_3)\{1 - g_2^s(\alpha_1 + \alpha_3)\}\int_0^\infty \tilde{G}(t)dt + (\alpha_1 + \alpha_3)\{\alpha_1 + \alpha_3\} g_2^s(\alpha_3) +
\]
and
\[
\int_0^\infty \tilde{G}(t)dt \{\alpha_2 + \alpha_3\}(\alpha_1 + \alpha_3)\{1 - g_2^s(\alpha_1 + \alpha_3)\}\int_0^\infty \tilde{G}(t)dt + (\alpha_1 + \alpha_3)\{\alpha_1 + \alpha_3\} g_2^s(\alpha_3) +
\]
and
\[(\alpha_1 + \alpha_2)\gamma(\alpha_2 g_2^*(\alpha_3) - \alpha_2 g_2^*(\alpha_1 + \alpha_3) + \alpha_1)[1 - g_2^*(\alpha_1 + \alpha_3) + (\alpha_1 + \alpha_3)\int_0^\infty \tilde{G}(t)dt]
\]
\[\{1 - g_1^*(\alpha_3)\} + [\alpha_3 \gamma \int_0^\infty \tilde{G}(t)dt][1 - \{g_2^*(\alpha_3) - g_2^*(\alpha_1 + \alpha_3)\}\{g_1^*(\alpha_3) - g_1^*(\alpha_2 + \alpha_3)\}]
\]

and \(D'_1(0) = D'_2(0)\) is same as obtained in availability analysis.

## 5 Expected Number of Repairs

Let us define \(V_i(t)\) as the expected no. of repairs of the unit during the time interval \((0, t)\) when the system initially starts from regenerative state \(S_i\). Using probabilistic arguments, taking the Laplace transform and solving the resultant set of equations for \(\tilde{V}_0(s)\), we get

\[\tilde{V}_0(s) = \frac{N_4(s)}{D_4(s)},\]

where

\[N_4(s) = [\tilde{Q}_{03} \tilde{Q}_{12} - \tilde{Q}_{02} \tilde{Q}_{13}][\{\tilde{Q}_{21} + \tilde{Q}_{23}^5\} \{\tilde{Q}_{41}(\tilde{Q}_{34} + \tilde{Q}_{34}^6) + \tilde{Q}_{31}\} - (\tilde{Q}_{31} + \tilde{Q}_{32}^6) \{\tilde{Q}_{41}^6\}
\]

\[\{\tilde{Q}_{24} + \tilde{Q}_{24}^5\} + \tilde{Q}_{21} + \tilde{Q}_{41} \{\tilde{Q}_{31} \tilde{Q}_{24} + \tilde{Q}_{24}^5\} - \tilde{Q}_{21}(\tilde{Q}_{34} + \tilde{Q}_{34}^6)\} + [\tilde{Q}_{02} + \tilde{Q}_{03} \tilde{Q}_{32}^6]
\]

\[\{\tilde{Q}_{21} + \tilde{Q}_{23}^5\} \{1 - \tilde{Q}_{14} \tilde{Q}_{41}\} + \tilde{Q}_{41}(\tilde{Q}_{21} \tilde{Q}_{14} + \tilde{Q}_{24} + \tilde{Q}_{23}^5)\} + \tilde{Q}_{01}[\tilde{Q}_{12} + \tilde{Q}_{13} \tilde{Q}_{32}^6]
\]

\[\tilde{Q}_{41}(\tilde{Q}_{31} \tilde{Q}_{14} + \tilde{Q}_{34} + \tilde{Q}_{34}^6)\} + \tilde{Q}_{01}[\tilde{Q}_{13} + \tilde{Q}_{12} \tilde{Q}_{23}^5]\{\tilde{Q}_{31} + \tilde{Q}_{32} + \tilde{Q}_{41}(\tilde{Q}_{34} + \tilde{Q}_{34}^6)\}
\]

\[\tilde{Q}_{01} \tilde{Q}_{14} \tilde{Q}_{41}(1 - \tilde{Q}_{23} \tilde{Q}_{32}^6)
\]

and \(D_4(s) = D_2(s)\) is same as obtained in availability analysis.

In steady state, the number of visits per unit time is given by

\[V_0 = \lim_{t \to \infty} \frac{V_0(t)}{t} = \frac{N_4(0)}{D_4(0)},\]

where

\[N_4(0) = (\alpha_1 + \alpha_3)(\alpha_2 + \alpha_3)[\alpha_2 + \alpha_1 g_1^*(\alpha_3) - g_1^*(\alpha_2 + \alpha_3)]\{\alpha_1 + \alpha_2 + \alpha_3 - \alpha_3\{g_2^*(\alpha_3) - g_2^*(\alpha_1 + \alpha_3)\}\}[\alpha_1 + \alpha_2 + \alpha_3 - \alpha_3\{g_2^*(\alpha_3) - g_2^*(\alpha_1 + \alpha_3)\}\]

\[\alpha_2 + \alpha_3 - \alpha_3\{g_1^*(\alpha_3) - g_1^*(\alpha_2 + \alpha_3)\}\{\alpha_1 + \alpha_2 + \alpha_3\}][\alpha_1 + \alpha_2 + \alpha_3 - \alpha_3\{g_2^*(\alpha_3) - g_2^*(\alpha_1 + \alpha_3)\}\]

\[g_1^*(\alpha_2 + \alpha_3)\}][\alpha_1 + \alpha_2 + \alpha_3]\]

and \(D'_4(0) = D'_2(0)\) is same as obtained in availability analysis.
6 Cost Benefit Analysis

Two profit functions $P_1(t)$ and $P_2(t)$ can easily be obtained for the system model under study with the help of characteristics obtained earlier. The expected total profits incurred during $(0,t]$ are:

\[ P_1(t) = \text{Expected total revenue in } (0,t] - \text{expected total repair in } (0,t] \]

and

\[ P_2(t) = \text{Expected total revenue in } (0,t] - \text{expected cost of repairs in } (0,t] \]

The expected total profit per unit time, in steady state, is

\[ P = \lim_{t \to \infty} \frac{P(t)}{t} = \lim_{s \to 0} s^2 P^*(s) \]

where

\[ K_0 = \text{Revenue per unit up time of the system,} \]
\[ K_1 = \text{Cost per unit time for which the repairman is busy,} \]
\[ K_2 = \text{Cost per unit repair.} \]

7 Graphical Study of System Behaviour

The behaviour of MTSF, Availability and Profit function of the system is studied graphically in this section and to plot their graphs, the failure and repair time distributions are assumed to be distributed exponentially.
Fig. 3 Behavior of Availability w.r.t. $\alpha_1$ for different values of $\beta_2$

Fig. 4 Behavior of Profit function w.r.t. $\alpha_1$ for different values of $\beta_2$

Fig.2, Fig.3 and Fig.4 shows the variations in MTSF, Availability analysis and Profit function respectively in respect of $\alpha_1$ (failure rate of 1st unit) for three different values of $\beta_2$ (repair rate of 2nd unit) as 0.10, 0.30 and 0.50 while the other parameters are kept fixed as $\alpha_2 = 0.69$, $\alpha_3 = 0.005$, $\gamma = 0.05$ $\beta_1 = 0.06$, $\beta_3 = 0.085$, $K_0 = 1500$, $K_1 = 150$ and $K_2 = 50$. It is observed from the graph that all the three characteristics i.e. MTSF, Availability analysis and profit function decreases with the increase in the failure parameter $\alpha_1$.

Similarly Fig.5, Fig.6 and Fig.7 shows the variations in MTSF, Availability analysis and Profit function respectively in respect of $\beta_2$ for three different values of $\alpha_1$ as 0.25, 0.50 and 0.75 while the other parameters are kept fixed as $\alpha_2 = 0.69$, $\alpha_3 = 0.005$, $\gamma = 0.05$ $\beta_1 = 0.06$, $\beta_3 = 0.085$, $K_0 = 1500$, $K_1 = 150$ and $K_2 = 50$. It is observed from the graph that all the three characteristics i.e. MTSF, Availability analysis and profit function increases with the increase in the repair parameter $\beta_2$. 
Fig. 5  Behavior of MTSF w.r.t. $\beta_2$ for different values of $\alpha_1$

Fig. 6  Behavior of Availability w.r.t. $\beta_2$ for different values of $\alpha_1$
8 Conclusion

In the present paper we study the Fruit Juice manufacturing system with the concept of emergency repair and various characteristics of Reliability like MTSF, Availability and Profit Function has been determined along with their graphical analysis. From the analysis we conclude that the value of the MTSF, Availability and Profit Function increases with the increase in the value of the repair parameters and the value of the MTSF, Availability and Profit Function decreases with the increase in the value of the failure parameters.

References


