CHAPTER-VII

Availability and Profit Analysis of B-Pan Crystallization System in Sugar Industry

7.1 Introduction

After concentration of the juice in multiple effect evaporators the subsequent process is to turn into yellow crystal sugar/magma through crystallization (‘A-Pan’ and ‘B-Pan’). As most of the part of massecuite is used in ‘A-Pan’ crystallization system as A-Massecuite and the remaining part of massecuite along with molasses derived from ‘A-Pan’ is used as B-Massecuite in ‘B-Pan’ crystallization system that results in molasses as final product.

Keeping in view, in this chapter; performance analysis of ‘B-Pan’ Crystallization system in sugar industry is done. The system is composed of three subsystems namely Crystallizer, Centrifugal machine and Melter. These subsystems are working in series. The failure times of the subsystems is assumed to be exponentially distributed whereas repair times of the subsystems follow arbitrary distribution. The analysis of the system is done by using supplementary variable technique to determine the various reliability measures. A particular case is also considered to show the behavior of availability and profit of the ‘B-Pan’ crystallizer system. Numerical results are obtained to explicate the effect of subsystems. Also, conclusion drawn from analysis is discussed.

![Fig.7.1 Configuration diagram](image-url)
7.2 System description

In the B-Pan crystallization system in sugar industry, B massecuite is heated in subsystem crystallizer (subsystem A) gradually slow heating. The massecuite (semi-solid juice) converted into magma (molasses) contains yellow sugar crystals. Then the molasses is sent to subsystem centrifugal machine (subsystem B) to separate out B-sugar contents from it. After that remaining syrup from subsystem B, magma (melt) is made in subsystem melter. As described above, the B-Pan crystallization system consists of three subsystems and detail descriptions of the subsystems are as follows:

1. **Subsystem A** (crystallizer)
   Subsystem A consists of five identical crystallizers working in parallel. In this subsystem the semi-solid form of the juice is heated by gradually slow heating. The failure of any one of the crystallizer reduces the capacity of the system. Complete failure occurs when any two crystallizers fail. It connected with subsystems B and C in series.

2. **Subsystem B** (Centrifugal machine)
   This subsystem consists of three centrifugal machines in which one is working in standby. Standby unit is in working when one centrifugal machine is fail. This subsystem is connected in series with subsystems A, C. The failure of this subsystem causes complete failure of the system.

3. **Subsystem C** (Melter)
   This subsystem consists of one melter unit. It is working in series with subsystems A and B. The failure of this subsystem causes the failure of complete system. This subsystem is connected in series with subsystems B and C.

7.3 Assumptions

1. Repairmen are always available with the system.
2. Unit works as new after repair.
3. The distribution of failure times of the subsystems is taken as exponential while the distribution of repair times is arbitrary.
4. There is no simultaneous failure in parallel units.
7.4 Notations

The following symbols are associated with the system.

A, B, C : Units working with full capacity.

B₁ : Standby units

a, b : Units working with reduce capacity.

\( \bar{A}, \bar{B}, \bar{B}_1, \bar{C} \) : Failed units.

\( \alpha_i \) (1 ≤ i ≤ 3),  \( \lambda_i \) : Failure rates of subsystems A, B, C, a, b, and B₁ respectively.

\( \beta_i(x), (1 ≤ i ≤ 6) \) : Repair rates of subsystems A, B, C, a, b, and B₁ respectively.

\( p_0(t) \) : Probability that at time \( t \) the system is in good state.

\( p_i(x, t), (i = 1, ..., 13) \) : Probability that at time \( t \) the system is in \( i \)th state and has an elapsed repair time \( x \).

\( S_i \) (i=0, 1, ..., 13) : States of the system.

7.5 Mathematical modeling of the system transient states

In this section, the following set of differential-difference equations associated with the model (Fig. 7.2) can be obtained by using supplementary variable technique.

\[
p_i(t + \Delta t) = [1 - \alpha_i \Delta t - \alpha_2 \Delta t - \alpha_3 \Delta t] p_i(t) + \int_0^\infty \beta_1(x) p_1(x, t) dx + \int_0^\infty \beta_2(x) p_2(x, t) dx + \int_0^\infty \beta_3(x) p_3(x, t) dx
\]

Dividing both sides by \( \Delta t \)

\[
\frac{p_i(t + \Delta t) - p_i(t)}{\Delta t} = [-\alpha_i - \alpha_2 - \alpha_3] p_i(t) + \int_0^\infty \beta_1(x) p_1(x, t) dx + \int_0^\infty \beta_2(x) p_2(x, t) dx + \int_0^\infty \beta_3(x) p_3(x, t) dx
\]

As \( \Delta t \to 0 \)

\[
\left[ \frac{d}{dt} + \alpha_1 + \alpha_2 + \alpha_3 \right] p_0(t) = \int_0^\infty \beta_1(x) p_1(x, t) dx + \int_0^\infty \beta_2(x) p_2(x, t) dx + \int_0^\infty \beta_3(x) p_3(x, t) dx \quad \ldots (7.1)
\]

Similarly,

\[
\left[ \frac{\partial}{\partial t} + \frac{\partial}{\partial x} + \alpha_2 + \lambda_i + \alpha_3 + \beta_1(x) \right] p_i(x, t) = \beta_2(x) p_1(x, t) + \beta_2(x) p_2(x, t) + \beta_3(x) p_3(x, t) + \alpha_1 p_0(t) + \alpha_2 p_1(t) \quad \ldots (7.2)
\]
Fig. 7.2 State changeover diagram of B-Pan crystallization system in Sugar Industry
\[
\left[ \frac{\partial}{\partial t} + \frac{\partial}{\partial x} + \alpha_1 + \lambda_2 + \lambda_3 + \alpha_2(x) \right] p_x(x,t) = \beta_1(x) p_y(x,t) + \beta_2(x) p_y(x,t) + \beta_3(x) p_y(x,t) + \alpha_2 p_y(t) \quad \text{..(7.3)}
\]

\[
\left[ \frac{\partial}{\partial t} + \frac{\partial}{\partial x} + \alpha_3 + \lambda_4 + \lambda_3 + \beta_2(x) \right] p_3(x,t) = \beta_4(x) p_{11}(x,t) + \beta_5(x) p_{10}(x,t) + \beta_6(x) p_{13}(x,t) + \beta_5(x) p_{12}(x,t) + \alpha_2 p_1(x,t) + \alpha_2 p_2(x,t) \quad \text{..(7.4)}
\]

\[
\frac{\partial}{\partial t} + \frac{\partial}{\partial x} + \beta_3(x) \right] p_4(x,t) = \alpha_3 p_5(t) \quad \text{..(7.5)}
\]

\[
\frac{\partial}{\partial t} + \frac{\partial}{\partial x} + \beta_3(x) \right] p_5(x,t) = \alpha_3 p_1(x,t) \quad \text{..(7.6)}
\]

\[
\frac{\partial}{\partial t} + \frac{\partial}{\partial x} + \beta_3(x) \right] p_6(x,t) = \alpha_2 p_2(x,t) \quad \text{..(7.7)}
\]

\[
\frac{\partial}{\partial t} + \frac{\partial}{\partial x} + \beta_4(x) \right] p_7(x,t) = \lambda_1 p_1(x,t) \quad \text{..(7.8)}
\]

\[
\frac{\partial}{\partial t} + \frac{\partial}{\partial x} + \beta_5(x) \right] p_8(x,t) = \lambda_2 p_2(x,t) \quad \text{..(7.9)}
\]

\[
\frac{\partial}{\partial t} + \frac{\partial}{\partial x} + \beta_5(x) \right] p_9(x,t) = \lambda_2 p_2(x,t) \quad \text{..(7.10)}
\]

\[
\frac{\partial}{\partial t} + \frac{\partial}{\partial x} + \beta_3(x) \right] p_{10}(x,t) = \alpha_3 p_3(x,t) \quad \text{..(7.11)}
\]

\[
\frac{\partial}{\partial t} + \frac{\partial}{\partial x} + \beta_4(x) \right] p_{11}(x,t) = \lambda_1 p_3(x,t) \quad \text{..(7.12)}
\]

\[
\frac{\partial}{\partial t} + \frac{\partial}{\partial x} + \beta_5(x) \right] p_{12}(x,t) = \lambda_2 p_3(x,t) \quad \text{..(7.13)}
\]

\[
\frac{\partial}{\partial t} + \frac{\partial}{\partial x} + \beta_6(x) \right] p_{13}(x,t) = \lambda_3 p_3(x,t) \quad \text{..(7.14)}
\]

Boundary conditions:
\[
p_1(0,t) = \alpha_1 p_0(t) \quad \text{and} \quad p_2(0,t) = \alpha_2 p_0(t)
\]

\[
p_3(0,t) = \alpha_3 p_2(t) + \alpha_2 p_1(t) \quad \text{and} \quad p_4(0,t) = \alpha_3 p_8(t) \quad \text{and} \quad p_5(0,t) = \alpha_3 p_4(t)
\]
\[ p_6(0,t) = \alpha_3 p_2(t) \quad p_7(0,t) = \lambda_1 p_1(t) \quad p_8(0,t) = \lambda_3 p_2(t) \]
\[ p_9(0,t) = \lambda_2 p_2(t) \quad p_{10}(0,t) = \alpha_3 p_3(t) \]
\[ p_{11}(0,t) = \lambda_1 p_3(t) \quad p_{12}(0,t) = \lambda_2 p_3(t) \quad p_{13}(0,t) = \lambda_3 p_3(t) \]
\[ \text{..(7.15)} \]

Initial conditions:
\[ p_0(0) = 1 \quad p_i(0) = 0, \quad i = 1 \text{ to } 13 \quad \text{..(7.16)} \]

The system of differential equations (7.1) – (7.14) together with the boundary conditions (7.15) and initial conditions (7.16) is called Chapman- Kolmogorov differential difference equation. Equation (7.1) is linear differential equation of first order and other equations (7.2)-(7.14) are linear partial differential equations. In order to find the reliability of the system, the governing equations (7.1)-(7.14) along with the boundary conditions (7.15) have been solved to get probabilities \( p_i(t) \) (i= 0 to 13) by taking Laplace transformations as
\[ [s + \alpha_1 + \alpha_2 + \alpha_3] p_0(s) = 1 - \int_0^\infty \beta_1(x) p_1(x,s) dx + \int_0^\infty \beta_2(x) p_2(x,s) dx + \int_0^\infty \beta_3(x) p_3(x,s) dx \]
\[ \text{..(7.17)} \]
\[ \left[ \frac{d}{dx} + \alpha_2 + \lambda_1 + \lambda_3 + \beta_1(x) \right] p_1(x,s) = \beta_2(x) p_3(x,s) + \beta_4(x) p_7(x,s) + \beta_5(x) p_3(x,s) + \alpha_1 p_0(s) \]
\[ \text{..(7.18)} \]
\[ \left[ \frac{d}{dt} + s + \alpha_1 + \lambda_2 + \lambda_3 + \beta_1(x) + \beta_2(x) \right] p_2(x,s) = \beta_1(x) p_3(x,s) + \beta_5(x) p_9(x,s) + \beta_6(x) p_8(x,s) + \beta_7(x) p_6(x,s) + \alpha_1 p_0(s) \]
\[ \text{..(7.19)} \]
\[ \left[ \frac{d}{dt} + s + \lambda_3 + \lambda_4 + \lambda_2 + \beta_1(x) + \beta_2(x) \right] p_3(x,s) = \beta_4(x) p_{11}(x,s) + \beta_5(x) p_{10}(x,s) + \beta_6(x) p_9(x,s) + \beta_7(x) p_8(x,s) + \alpha_2 p_1(x,s) + \alpha_3 p_2(x,s) \]
\[ \text{..(7.20)} \]
\[ \left[ \frac{d}{dt} + s + \beta_3(x) \right] p_4(x,s) = \alpha_3 p_0(s) \]
\[ \text{..(7.21)} \]
\[ \left[ \frac{d}{dt} + s + \beta_3(x) \right] p_5(x,s) = \alpha_3 p_1(x,s) \]
\[ \text{..(7.22)} \]
\[ \left[ \frac{d}{dt} + s + \beta_3(x) \right] p_6(x,s) = \alpha_2 p_2(x,s) \]
\[ \text{..(7.23)} \]
\[
\begin{align*}
\frac{d}{dt} + s + \beta_4(x) & \quad p_7(x,s) = \lambda_1 p_1(x,s) \\
\frac{d}{dt} + s + \beta_6(x) & \quad p_8(x,s) = \lambda_3 p_2(x,s) \\
\frac{d}{dt} + s + \beta_5(x) & \quad p_9(x,s) = \lambda_2 p_2(x,s) \\
\frac{d}{dt} + s + \beta_3(x) & \quad p_{10}(x,s) = \alpha_3 p_3(x,s) \\
\frac{d}{dt} + s + \beta_4(x) & \quad p_{11}(x,s) = \lambda_1 p_3(x,s) \\
\frac{d}{dt} + s + \beta_5(x) & \quad p_{12}(x,s) = \lambda_2 p_3(x,s) \\
\frac{d}{dt} + s + \beta_6(x) & \quad p_{13}(x,s) = \lambda_3 p_3(x,s)
\end{align*}
\]

..(7.24)

..(7.25)

..(7.26)

..(7.27)

..(7.28)

..(7.29)

..(7.30)

Laplace transformations boundary conditions:

\[
\begin{align*}
p_1(0,s) &= \alpha_1 p_0(s) & p_2(0,s) &= \alpha_2 p_0(s) & p_3(0,s) &= \alpha_4 p_2(s) + \alpha_2 p_1(s) \\
p_4(0,s) &= \alpha_3 p_0(s) & p_5(0,s) &= \alpha_3 p_1(s) & p_6(0,s) &= \alpha_2 p_2(s) \\
p_7(0,s) &= \lambda_1 p_1(s) & p_8(0,s) &= \lambda_3 p_2(s) & p_9(0,s) &= \lambda_2 p_2(s) \\
p_{10}(0,s) &= \alpha_6 p_3(s) & p_{11}(0,s) &= \lambda_1 p_3(s) & p_{12}(0,s) &= \lambda_2 p_3(s) \\
p_{13}(0,s) &= \lambda_3 p_3(s)
\end{align*}
\]

..(7.31)

The equations (7.17)-(7.30) have been solved by using boundary conditions to get the transition state probabilities \( p_i(s), \ (i = 0 \ to \ 13) \) of B-Pan crystallization system in the sugar industry as

\[
p_{13}(s) = \int_0^\infty e^{-\int_0^s (r + \beta_6(x)) dx} \left\{ \lambda_3 p_3(s) + \int_0^\infty \lambda_3 p_3(x,s) e^{-\int_0^x (r + \beta_6(x)) dx} dx \right\} dx
\]

..(7.32)
\[ p_{12} (s) = \int_0^\infty e^{-\int (s+\beta_3(x)) dx} \left\{ \lambda_2 p_5 (s) + \int_0^\infty \lambda_2 p_5 (x, s) e^{\beta_3(x)} dx \right\} dx \]  

..(7.33)

\[ p_{11} (s) = \int_0^\infty e^{-\int (s+\beta_4(x)) dx} \left\{ \lambda_1 p_3 (s) + \int_0^\infty \lambda_1 p_3 (x, s) e^{\beta_4(x)} dx \right\} dx \]  

..(7.34)

\[ p_{10} (s) = \int_0^\infty e^{-\int (s+\beta_3(x)) dx} \left\{ \alpha_3 p_3 (s) + \int_0^\infty \alpha_3 p_3 (x, s) e^{\beta_3(x)} dx \right\} dx \]  

..(7.35)

\[ p_{9} (s) = \int_0^\infty e^{-\int (s+\beta_4(x)) dx} \left\{ \lambda_2 p_2 (s) + \int_0^\infty \lambda_2 p_2 (x, s) e^{\beta_4(x)} dx \right\} dx \]  

..(7.36)

\[ p_{8} (s) = \int_0^\infty e^{-\int (s+\beta_3(x)) dx} \left\{ \lambda_2 p_2 (s) + \int_0^\infty \lambda_2 p_2 (x, s) e^{\beta_3(x)} dx \right\} dx \]  

..(7.37)

\[ p_{7} (s) = \int_0^\infty e^{-\int (s+\beta_4(x)) dx} \left\{ \lambda_1 p_1 (s) + \int_0^\infty \lambda_1 p_1 (x, s) e^{\beta_4(x)} dx \right\} dx \]  

..(7.38)

\[ p_{6} (s) = \int_0^\infty e^{-\int (s+\beta_3(x)) dx} \left\{ \alpha_3 p_2 (s) + \int_0^\infty \alpha_3 p_2 (x, s) e^{\beta_3(x)} dx \right\} dx \]  

..(7.39)

\[ p_{5} (s) = \int_0^\infty e^{-\int (s+\beta_4(x)) dx} \left\{ \alpha_3 p_1 (s) + \int_0^\infty \alpha_3 p_1 (x, s) e^{\beta_4(x)} dx \right\} dx \]  

..(7.40)

\[ p_{4} (s) = \int_0^\infty e^{-\int (s+\beta_4(x)) dx} \left\{ \alpha_5 p_0 (s) + \int_0^\infty \alpha_5 p_0 (x, s) e^{\beta_4(x)} dx \right\} dx \]  

..(7.41)

\[ p_{3} (s) = \int_0^\infty e^{-\int (s+\alpha_5+\sum \beta_4(x)) dx} \left\{ \alpha_1 p_2 (s) + \alpha_2 p_1 (s) + \int_0^\infty y_1 e^{\beta_4} dx \right\} dx \]  

..(7.42)
\[
p_2(s) = \int_0^\infty e^{-s} \left[ \sum_{i=1}^{3} \lambda_i \right] \frac{1}{x} \left[ \sum_{i=1}^{3} \beta_i \right] p_i(s) + \int_0^\infty y_1 \frac{1}{x} \left[ \sum_{i=1}^{3} \beta_i \right] p_i(s) \, dx \, dx
\]
\tag{7.43}

\[
p_1(s) = \int_0^\infty e^{-s} \left[ \sum_{i=1}^{3} \lambda_i \right] \frac{1}{x} \left[ \sum_{i=1}^{3} \beta_i \right] p_i(s) + \int_0^\infty y_1 \frac{1}{x} \left[ \sum_{i=1}^{3} \beta_i \right] p_i(s) \, dx \, dx
\]
\tag{7.44}

\[
p_0(s) = \frac{1}{s + \alpha_1 + \alpha_2 + \alpha_3} \left[ R(x) p_1(x,s) dx + \int_0^\infty \beta_1(x) p_2(x,s) dx + \int_0^\infty \beta_2(x) p_3(x,s) dx + \int_0^\infty \beta_3(x) p_4(x,s) dx \right]
\]
\tag{7.45}

Where
\[
y_1 = \beta_4(x) p_1(x,s) + \beta_5(x) p_{10}(x,s) + \beta_6(x) p_{13}(x,s) + \beta_7(x) p_{12}(x,s) + \alpha_1 p_1(x,s) + \alpha_4 p_2(x,s)
\]
\[
y_2 = \beta_4(x) p_1(x,s) + \beta_5(x) p_{9}(x,s) + \beta_6(x) p_{8}(x,s) + \beta_7(x) p_{8}(x,s) + \alpha_2 p_0(x,s)
\]
\[
y_3 = \beta_4(x) p_3(x,s) + \beta_5(x) p_{7}(x,s) + \beta_6(x) p_{6}(x,s) + \beta_7(x) p_{6}(x,s) + \alpha_3 p_0(x,s)
\]

Thus, the Laplace transforms of the reliability is given by the following expression:
\[
R(s) = \sum_{i=0}^{3} p_i(s)
\]
\tag{7.46}

The reliability function \(R(t)\) for the system is given by taking Laplace Inverse of \(7.46\).

### 7.6 Particular case

To show the importance of results and characterize the behavior of availability and profit of the B-Pan crystallization system, here we assume the repair times are exponentially distributed. For this particular case system of equations \((7.1)-(7.14)\) reduces as follows:
\[
\begin{align*}
\frac{d}{dt} + \alpha_1 + \alpha_2 + \alpha_3 \quad p_0(t) &= \beta_1 p_1(t) + \beta_2 p_2(t) + \beta_3 p_4(t) \\
\frac{d}{dt} + \alpha_2 + \lambda_1 + \lambda_2 + \beta_1 \quad p_1(t) &= \beta_2 p_3(t) + \beta_4 p_4(t) + \beta_5 p_5(t) + \alpha_1 p_0(t) \\
\frac{d}{dt} + \alpha_1 + \lambda_2 + \lambda_3 + \beta_2 \quad p_2(t) &= \beta_1 p_3(t) + \beta_5 p_5(t) + \beta_6 p_6(t) + \beta_7 p_7(t) + \beta_1 p_0(t) \\
\frac{d}{dt} + \alpha_3 + \lambda_1 + \lambda_2 + \lambda_3 + \beta_1 + \beta_2 \quad p_3(t) &= \beta_4 p_1(t) + \beta_5 p_10(t) + \beta_6 p_13(t) + \beta_4 p_2(t) + \alpha_2 p_1(t) + \alpha_2 p_2(t)
\end{align*}
\]
\tag{7.47-7.50}
In process industry, systems are required to run for long time, the long run or steady-state availability is defined as the proportion of the time during which an equipment is available for use (Balagurusamy (1984)). So the long-run availability of the Evaporation system in the sugar industry is calculated by taking \( \frac{d}{dt} = 0 \) as \( t \to \infty \), \( p_i(t) = p_i \) in each equation (7.47) to (7.60); we have steady-state probabilities as follows

\[
p_1 = \frac{1}{\alpha_2 + \beta_1} \left( \beta_2 \left( \frac{\alpha_1 \alpha_2}{\alpha_1 + \beta_2} + \frac{\alpha_1 \alpha_3}{\alpha_2 + \beta_1} \right) + \alpha_1 \right) p_0
\]
The long-run availability ($A_v$) of the B-Pan crystallization system in the sugar industry is given as

$$A_v = \sum_{i=0}^{3} p_i$$
7.7 Profit Analysis

Let $K_1$ be the total revenue per unit up time of the system and $K_2$ be the total repair cost then profit incurred to the system model in steady state is obtained by using equation (7.61) as

$$\text{Profit} = K_1 A_v - K_2$$
7.8 Numerical analysis

The effect of failure rates and repair rates on Availability and Profit of B-Pan crystallization system in sugar industry is given in tables 7.1, 7.2, 7.3 and 7.4 as follows:

\[
A_v = \text{Steady state availability of the system.}
\]
Effect of failure rates of subsystems on availability of the B-Pan crystallization system

Table 7.1

| $\alpha_1$ | $\alpha_2=0.025$, $\alpha_3=0.03$, $\lambda_1=0.02$, $\lambda_2=0.035$, $\lambda_3=0.025$ | $\alpha_2=0.035$, $\alpha_3=0.03$, $\lambda_1=0.02$, $\lambda_2=0.035$, $\lambda_3=0.025$ | $\alpha_2=0.025$, $\alpha_3=0.03$, $\lambda_1=0.02$, $\lambda_2=0.035$, $\lambda_3=0.025$ | $\alpha_2=0.025$, $\alpha_3=0.03$, $\lambda_1=0.02$, $\lambda_2=0.035$, $\lambda_3=0.025$ | $\alpha_2=0.025$, $\alpha_3=0.03$, $\lambda_1=0.02$, $\lambda_2=0.035$, $\lambda_3=0.025$ | $\alpha_2=0.025$, $\alpha_3=0.03$, $\lambda_1=0.02$, $\lambda_2=0.035$, $\lambda_3=0.025$ | $\alpha_2=0.025$, $\alpha_3=0.03$, $\lambda_1=0.02$, $\lambda_2=0.035$, $\lambda_3=0.025$ |
|---|---|---|---|---|---|---|
| 0.01 | 0.787858 | 0.773274 | 0.757998 | 0.773999 | 0.779089 | 0.781991 |
| 0.02 | 0.765027 | 0.751269 | 0.736842 | 0.741395 | 0.756757 | 0.759494 |
| 0.03 | 0.746718 | 0.733604 | 0.719842 | 0.715878 | 0.738836 | 0.741445 |
| 0.04 | 0.731707 | 0.719112 | 0.705882 | 0.695364 | 0.724138 | 0.726644 |
| 0.05 | 0.719178 | 0.707006 | 0.694215 | 0.678514 | 0.711864 | 0.714286 |
| 0.06 | 0.708562 | 0.696744 | 0.684318 | 0.664426 | 0.701461 | 0.703812 |
| 0.07 | 0.699451 | 0.687933 | 0.675816 | 0.652472 | 0.692532 | 0.694823 |
| 0.08 | 0.691548 | 0.680286 | 0.668435 | 0.642202 | 0.684783 | 0.687023 |
| 0.09 | 0.684626 | 0.673587 | 0.661966 | 0.633283 | 0.677995 | 0.680191 |
| 0.1  | 0.678514 | 0.667669 | 0.65625  | 0.625465 | 0.672  | 0.674157 |

Availability ($A_v$)

$\beta_1=0.1,\beta_2=0.15,\beta_3=0.2,\beta_4=0.04,\beta_5=0.1,\beta_6=0.15$
Effect of failure rates of subsystems on profit of the B-Pan crystallization system

Table 7.2

<table>
<thead>
<tr>
<th>α₁</th>
<th>α₂=0.025, α₃=0.03, λ₁=0.02, λ₂=0.035, λ₃=0.025</th>
<th>α₂=0.035, α₃=0.03, λ₁=0.02, λ₂=0.035, λ₃=0.025</th>
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β₁=0.1, β₂=0.1, β₃=0.2, β₄=0.04, β₅=0.1, β₆=0.15, K₁=5000, K₂=500
## Effect of repair rates of subsystems on availability of the Evaporation system

### Table 7.3

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<tr>
<th>( \beta_1 )</th>
<th>Availability (( A_v ))</th>
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<td>( \beta_2=0.25 ), ( \beta_3=0.3 ), ( \beta_4=0.04 ), ( \beta_5=0.1 ), ( \beta_6=0.15 )</td>
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### Effect of repair rates of subsystems on profit of the Evaporation system

#### Table 7.4

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<th>$\beta_1$</th>
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<th>$\beta_3$</th>
<th>Profit</th>
<th>$\beta_4$</th>
<th>Profit</th>
<th>$\beta_5$</th>
<th>Profit</th>
<th>$\beta_6$</th>
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</table>

$\alpha_1=0.01, \alpha_2=0.025, \alpha_3=0.03, \lambda_1=0.02, \lambda_2=0.035, \lambda_3=0.025, K_1=5000, K_2=500$
7.9 Conclusion

The effect of failure rates of subsystems on availability and profit of the B-Pan crystallization system has been examined for arbitrary values of various parameters and cost in tables 7.1 and 7.2 respectively. It is observed that availability and profit of the B-Pan crystallization system go on decreasing with the increase of failure rates of the subsystems A, B and C as seen in tables 7.1 and 7.2. However, the effect of failure rates of subsystems A and C is much more as compare to the failure rates of subsystem A. Therefore, there is need to control the failure rates of subsystems A and C in order to make the B-Pan crystallization system of sugar industry more profitable.

Behavior of availability and profit of the B-Pan crystallization system keep on moving up with increase of repair rates of all subsystem as shown in table 3 and 4 respectively. The effect of repair rates of subsystems A and C on availability and profit is more as compare to subsystem B as per tables 7.3 and 7.4. Thus the study reveals that B-Pan crystallization system of a sugar industry can play vital role in improving availability and profit of whole sugar industry provided that subsystem A and subsystem C have to be given more attention as compare to subsystem B.