CHAPTER 7

COMPARATIVE STUDY OF THE MODELS DEVELOPED FOR INDUSTRIAL PROCESS WATER SYSTEMS

In the preceding chapters, several stochastic models have been discussed for one/two-unit industrial process water systems considering different aspects and practical situations including occurrences of minor/ major fault, two types of inspection, proper/ improper repairs, faults during repairs, automatic/ random switching etc. The water systems considered here have several redundant and non-redundant subsystems wherein the redundant subsystems are considered of two types viz. 1-out-of-2 (Type-I) and 2-out-of-3 (Type-II). The models have been analysed by computing various measures of system effectiveness. A model developed for some particular situations cannot be good for all the situations i.e for different situations different models may be better. Therefore in the present chapter the comparative analyses of the models that have been discussed in the preceding chapters (taking two at a time) have been made to judge which model is better in what situation. The comparisons have been made on the basis of their mean times to system failure and profits through the graphs. Various conclusions have been drawn about the models observing the trends of the graphs as well as the cut-off points obtained.

The chapter presents comparative analyses of various models discussed in the preceding chapters in two sections. In the first section, i.e. Section-A comparative analyses of the models discussed within the chapters are presented whereas in second section, i.e. Section-B comparative analyses of the models discussed between the chapters are given.

For the purpose of comparisons of the various models discussed in the thesis, following notations are taken:

Let $T_{ij}$ and $P_{ij}$, respectively denote the mean time to system failure (MTSF) and profit of the $j^{th}$ model discussed in the $i^{th}$ chapter.
Further comparisons of various models with respect to their mean times to system failure and profits have been made here for the particular case, i.e. assuming all the general distributions as exponential distributions as already mentioned for the concerned models. The numerical values assumed/given for various rates/costs have been mentioned along with the respective graphs.

Section-A: Comparative Analyses of the Models Discussed Within the Chapters

Comparative Analysis of the Models Discussed in Chapter 3

In Chapter 3, two stochastic models have been developed for the process water systems that consist of several redundant and non-redundant subsystems where redundant subsystems are considered of two types, i.e. “1-out-of-2” (say, Type-I) and “2-out-of-3” (say, Type-II). Two types of faults and inspections are considered here. In the first model, on occurrence of major fault in any redundant subsystem, switching of the standby subsystem within the redundant subsystems is not taken to avoid losses due to switching whereas in the second model, in that situation, automatic and instantaneous switching of the cold standby subsystem within the similar type of redundant subsystems is taken in to account. In any case, on occurrence of a minor fault, switching of the redundant subsystems is not considered to avoid losses.

Fig. 7.1 shows the graph of difference between the mean times to system failure of the Model-II and Model-I of the Chapter 3, i.e. $T_{32} - T_{31}$ with respect to the rate of minor faults ($\lambda_2$) for different values of rate of major faults ($\lambda_1$).

From the graph, it has been concluded that the mean time to system failure of the Model-II is higher than the Model-I for fixed values of rate of minor faults. It has also been concluded from the graph that the difference of mean times to system failure ($T_{32} - T_{31}$) increases with increase in the values of rate of minor faults and has lower values for higher values of the rate of major faults.
The graph in **Fig. 7.2** indicates the pattern of difference between the mean times to system failure of the **Model-II** and **Model-I** of the **Chapter 3**, i.e. $T_{32} - T_{31}$ with respect to...
the rate of major faults ($\lambda_1$) for different values of probability of faults in Type-I redundant subsystem (a).

From the graph, it has been concluded that the mean time to system failure of the Model-II is higher than the Model-I for fixed values of rate of major faults. It has also been concluded from the graph that the difference of mean times to system failure of the models decreases with increase in the values of probability of faults in Type-I redundant subsystem and has lower values for higher values of the rate of major faults.

\[ \text{DIFFERENCE OF MTSF V/S REPAIR RATE OF TYPE-I REDUNDANT SUBSYSTEM (}\beta_2\text{) FOR DIFFERENT VALUES OF INSPECTION RATE (}\alpha_1\text{)} \]

\[ \lambda_1 = 0.0028, \lambda_2 = 0.0082, \alpha_1 = 2, \beta = 0.0409, \beta_1 = 0.404, \]
\[ \beta_2 = 0.428, \beta_3 = 0.392, a = 0.8895, x = 0.65 \]

Fig. 7.3

The graph in fig. 7.3 shows the pattern of difference between the mean times to system failure of Model-II and Model-I of the Chapter 3, i.e. $T_{32}$-$T_{31}$ with respect to the repair rate of Type-I redundant subsystem ($\beta_2$) for different values of inspection rate ($\alpha_1$).

It has been concluded from the graph that the mean time to system failure of the Model-II is higher than the Model-I for fixed values of repair rate of Type-I redundant subsystem. It has also been concluded from the graph that the difference of mean times to system failure of the models decreases with increase in the values of repair rate of minor faults in Type-I redundant subsystem and has lower values for higher values of the inspection rate.
The curves in fig. 7.4 depicts the pattern of difference between the mean times to system failure of the Model-II and Model-I of the Chapter 3, i.e. $T_{32} - T_{31}$ with respect to the repair rate of Type-II redundant subsystem ($\beta_3$) for different values of probability of faults in non-redundant subsystem ($x$).

From the graph, it has been concluded that the mean time to system failure of Model-II is higher than Model-I for fixed values of repair rate of Type-II redundant subsystem. It has also been concluded from the graph that the difference of mean times to system failure of the models decreases with increase in the values of repair rate of Type-II redundant subsystem and has higher values for higher values of the probability of faults in non-redundant subsystem.

The graph in fig. 7.5 shows the pattern of difference between the mean times to system failure of the Model-II and Model-I of the Chapter 3, i.e. $T_{32} - T_{31}$ with respect to the rate of major faults ($\lambda_1$) for different values of repair rate of the non-redundant subsystem ($\beta_1$).

It has been concluded from the graph that the mean time to system failure of the Model-II is higher than the Model-I for fixed values of rate of major faults. It has also
been concluded from the graph that the difference of mean times to system failure of the models decreases with increase in the values of rate of major faults and has higher values for higher values of repair rate of the non-redundant subsystem.

**Fig. 7.5**

**DIFFERENCE OF MTSF V/S RATE OF MAJOR FAULTS ($\lambda_2$) FOR DIFFERENT VALUES OF REPAIR RATE OF NON-REDUNDANT SUBSYSTEM ($\beta_2$)**

$\lambda_2 = 0.0082, \alpha_1 = 6, \alpha_2 = 2, \beta = 0.0409, \beta_2 = 0.428,$

$\beta_1 = 0.392, a = 0.8895, x = 0.65$

**Fig. 7.6**

**DIFFERENCE OF PROFIT V/S REVENUE PER UNIT UPTIME WITH FULL CAPACITY ($C_0$) OF THE SYSTEM FOR DIFFERENT VALUES OF RATE OF MAJOR FAULTS ($\lambda_1$)**

$\lambda_2 = 0.0082, \alpha_1 = 6, \alpha_2 = 2, \beta = 0.0409, \beta_2 = 0.428,$

$\beta_1 = 0.392, a = 0.8895, x = 0.65,$

$C_1 = 3500, C_2 = 2500, C_3 = 1000, C_4 = 3000$
The curves in fig. 7.6 present the pattern of difference between the profits of the Model-II and Model-I of the Chapter 3, i.e. $P_{32} - P_{31}$ with respect to the revenue per unit uptime with full capacity of the system ($C_0$) for the different values of rate of major faults ($\lambda_1$).

![Ddifference of profit vs revenue per unit uptime with full capacity ($C_0$) for different values of rate of minor faults ($\lambda_2$)]

\(\lambda_1 = 0.0028, a_1 = 6, a_2 = 2, \beta = 0.0409, \beta_1 = 0.404, \beta_2 = 0.428, \beta_3 = 0.392, a = 0.8895, x = 0.65, C_1 = 3500, C_2 = 2500, C_3 = 1000, C_4 = 3000\)

**Fig. 7.7**

Following conclusions have been made from the graph:

(i) The difference of profits ($P_{32} - P_{31}$) decreases with the increase in the values of the revenue per unit uptime with full capacity and has higher values for higher values of the rate of major faults.

(ii) For $\lambda_2 = 0.004$, the difference of profits ($P_{32} - P_{31}$) is positive or zero or negative according as $C_0$ is $< \text{or} = \text{or} > 4300$. Hence, in this case, the **Model-II** is better or equally good or worse than the **Model-I** whenever $C_0 < \text{or} = \text{or} >$ Rs.4300.

(iii) For $\lambda_2 = 0.005$, the difference of profits ($P_{32} - P_{31}$) is positive or zero or negative according as $C_0$ is $< \text{or} = \text{or} > 5000$. Hence, in this case, the **Model-II** is better or equally good or worse than the **Model-I** whenever $C_0 < \text{or} = \text{or} >$ Rs.5000.
(iv) For $\lambda_2 = 0.006$, the difference of profits ($P_{32}-P_{31}$) is positive or zero or negative according as $C_0$ is $< \text{ or } = \text{ or } > 5700$. Hence, in this case, the Model-II is better or equally good or worse than the Model-I whenever $C_0 < \text{ or } = \text{ or } > Rs.5700$.

The graph in fig. 7.7 exhibits the behaviour of difference between the profits of the Model-II and Model-I of the Chapter 3, i.e. $P_{32}-P_{31}$ with respect to the revenue per unit uptime with full capacity of the system ($C_0$) for the different values of rate of minor faults ($\lambda_2$).

![Graph showing difference of profit vs revenue per unit uptime with reduced capacity ($C_1$) for different values of major faults ($\lambda_1$)]

**Fig. 7.8**

From the graph, following conclusions can be made:

(i) The difference of profits ($P_{32}-P_{31}$) decreases with the increase in the values of the revenue per unit uptime with full capacity and has lower values for higher values of the rate of minor faults.

(ii) For $\lambda_2 = 0.00330$, the difference of profits ($P_{32}-P_{31}$) is positive or zero or negative according as $C_0$ is $< \text{ or } = \text{ or } > 441$. Hence, in this case, the Model-II is better or equally good or worse than the Model-I whenever $C_0 < \text{ or } = \text{ or } > Rs.441$.  

\[
\lambda_2 = 0.0082, \alpha_1 = 6, \alpha_2 = 2, \beta = 0.0409, \\
\beta_1 = 0.404, \beta_2 = 0.428, \beta_3 = 0.392, \alpha = 0.8895, \\
x = 0.65, C_0 = 6000, C_1 = 2500, C_2 = 1000, C_3 = 3000
\]
(iii) For $\lambda_2 = 0.00331$, the difference of profits ($P_{32} - P_{31}$) is positive or zero or negative according as $C_0$ is < or = or > 398. Hence, in this case, the Model-II is better or equally good or worse than the Model-I whenever $C_0$ < or = or > Rs.398.

(iv) For $\lambda_2 = 0.00332$, the difference of profits ($P_{32} - P_{31}$) is positive or zero or negative according as $C_0$ is < or = or > 357. Hence, in this case, the Model-II is better or equally good or worse than the Model-I whenever $C_0$ < or = or > Rs.357.

The curves fig. 7.8 highlights the pattern of difference between the profits of the Model-II and Model-I of the Chapter 3, i.e. $P_{32} - P_{31}$ with respect to the revenue per unit uptime with reduced capacity of the system ($C_1$) for the different values of rate of major faults ($\lambda_1$).

Following conclusions have been made from the graph:

(i) The difference of profits ($P_{32} - P_{31}$) increases with the increase in the values of the revenue per unit uptime with reduced capacity and has higher values for higher values of the rate of major faults.

(ii) For $\lambda_2 = 0.002$, the difference of profits ($P_{32} - P_{31}$) is negative or zero or positive according as $C_1$ is < or = or > 5711.60. Hence, in this case, the Model-II is worse or equally good or better than the Model-I whenever $C_1$ < or = or > Rs. 5711.60.

(iii) For $\lambda_2 = 0.004$, the difference of profits ($P_{32} - P_{31}$) is negative or zero or positive according as $C_1$ is < or = or > 4438.24. Hence, in this case, the Model-II is worse or equally good or better than the Model-I whenever $C_1$ < or = or > Rs. 4438.24.

(iv) For $\lambda_2 = 0.006$, the difference of profits ($P_{32} - P_{31}$) is negative or zero or positive according as $C_1$ is < or = or > 3632.12. Hence, in this case, the Model-II is worse or equally good or better than the Model-I whenever $C_1$ < or = or > Rs. 3632.12.
Fig. 7.9 gives the graph of difference between the profits of the Model-II and Model-I of the Chapter 3, i.e. \( P_{32} - P_{31} \) with respect to the revenue per unit uptime with reduced capacity of the system \( (C_1) \) for the different values of repair rate of major faults in the system \( (\beta) \).

Following has been concluded from the graph:

(i) The difference of profits \( (P_{32} - P_{31}) \) increases with the increase in the values of the revenue per unit uptime with reduced capacity and has lower values for higher values of the repair rate of major fault in the system.

(ii) For \( \beta = 0.003 \), the difference of profits \( (P_{32} - P_{31}) \) is negative or zero or positive according as \( C_1 \) is \(< or = or > 4132.12 \). Hence, in this case, the Model-II is worse or equally good or better than the Model-I whenever \( C_1 < or = or > \) Rs. 4132.12.

(iii) For \( \beta = 0.005 \), the difference of profits \( (P_{32} - P_{31}) \) is negative or zero or positive according as \( C_1 \) is \(< or = or > 5125.20 \). Hence, in this case, the Model-II is worse or equally good or better than the Model-I whenever \( C_1 < or = or > \) Rs. 5125.20.
For $\beta = 0.007$, the difference of profits ($P_{32} - P_{31}$) is negative or zero or positive according as $C_1$ is $< or = or > 5706.21$. Hence, in this case, the Model-II is worse or equally good or better than the Model-I whenever $C_1 < or = or >$ Rs. 5706.21.

Comparative Analysis of the Models Discussed in Chapter 4

Chapter 4 investigates two stochastic models for the process water systems incorporating the possibilities of improper repairs of the minor faults by the repairman besides the aspects taken in the previous chapter. Here the first model took care of the situations that improper repairs are done by the ordinary repairman when the expert repairman in not available and there is no provision of switching of the standby components within the redundant subsystems whereas the second model considers the situation that improper repair is done by the ordinary repairman when the expert repairman is available and there is automatic switching of the cold standby subsystem within redundant subsystems on occurrence of major faults in the subsystem.

Fig. 7.10 shows the behaviour of difference between the mean times to system failure of the Model-II and Model-I of the Chapter 4, i.e. $T_{42} - T_{41}$ with respect to the rate of major faults ($\lambda_1$) for the different values of probability of faults in Type-I redundant subsystem (a).
It can be concluded from the graph that the mean time to system failure of the Model-II is higher than the Model-I of Chapter 4 for fixed values of rate of major faults ($\lambda_1$). Also the difference of mean times to system failure decreases with the increase in the values of rate of major faults ($\lambda_1$) and has lower values for higher values of the probability of faults in Type-I redundant subsystem (a).

Fig. 7.11 presents the behaviour of difference between the mean times to system failure of the Model-II and Model-I of the Chapter 4, i.e. $T_{42} - T_{41}$ with respect to the rate of minor faults ($\lambda_2$) for the different values of probability of faults in non-redundant subsystem (x).

![Graph showing difference of MTSF vs rate of minor faults for different values of probability of fault in a non-redundant subsystem](image)

**Fig. 7.11**

It has been concluded from the graph that the mean time to system failure of the Model-II is higher than the Model-I of Chapter 4 for fixed values of rate of minor faults ($\lambda_2$). Also the difference of mean times to system failure decreases with the increase in the values of rate of major faults ($\lambda_1$) and has higher values for higher values of the probability of fault in non-redundant subsystem (x).
Fig. 7.12 shows the behaviour of difference between the mean times to system failure of the Model-II and Model-I of the Chapter 4, i.e. $T_{42} - T_{41}$ with respect to the probability of proper repair of non-redundant subsystem ($p_1$) for the different values of rate of major faults ($\lambda_i$).

From the graph, it has been concluded that the mean time to system failure of the Model-II is higher than the Model-I of Chapter 4 for fixed values of probability of proper repair of non-redundant subsystem ($p_1$). Also the difference of mean times to system failure increases with the increase in the values of probability of proper repair of non-redundant subsystem ($p_1$) and has lower values for higher values of rate of major faults ($\lambda_i$).

![Graph showing difference of MTSF vs probability of proper repair of non-redundant subsystem](image)

**Fig.7.12**

The curves in the Fig. 7.13 reveal the behaviour of difference between the mean times to system failure of the Model-II and Model-I of the Chapter 4, i.e. $T_{42} - T_{41}$ with
respect to the probability of proper repair of redundant subsystem \( (p_2) \) for the different values of repair rate of Type-II redundant subsystem \( (\beta_3) \).

**Fig. 7.13**

It can be concluded from the graph that the mean time to system failure of the Model-II is higher than the Model-I of Chapter 4 for fixed values of probability of proper repair of redundant subsystem \( (p_2) \). Also the difference of mean times to system failure increases with the increase in the values of probability of proper repair of redundant subsystem \( (p_2) \) and has lower values for higher values of repair rate of Type-II redundant subsystem \( (\beta_3) \).

The graph in the **fig. 7.14** shows the behaviour of the difference between the profits of the Model-II and Model-I of the Chapter 4, i.e. \( P_{42} - P_{41} \) with respect to the rate of major faults \( (\lambda_1) \) for the different values of the probability of faults in a Type-I redundant subsystem \( (a) \).
Following can be concluded from the graph:

(i) The difference of profits ($P_{42} - P_{41}$) increases with the increase in the rate of major faults and has higher values for higher values of the probability of fault in a Type-I redundant subsystem.

(ii) For $a = 0.001$, the difference of profits ($P_{42} - P_{41}$) is negative or zero or positive according as $\lambda_1$ is $< \text{ or } = \text{ or } > 0.001493$. Hence, in this case, the Model-II is worse or equally good or better than the Model-I whenever $\lambda_1 < \text{ or } = \text{ or } > 0.001493$.

(iii) For $a = 0.041$, the difference of profits ($P_{42} - P_{41}$) is negative or zero or positive according as $\lambda_1$ is $< \text{ or } = \text{ or } > 0.001604$. Hence, in this case, the Model-II is worse or equally good or better than the Model-I whenever $\lambda_1 < \text{ or } = \text{ or } > 0.001604$.

(iv) For $a = 0.071$, the difference of profits ($P_{42} - P_{41}$) is negative or zero or positive according as $\lambda_1$ is $< \text{ or } = \text{ or } > 0.001735$. Hence, in this case, the Model-II is worse or equally good or better than the Model-I whenever $\lambda_1 < \text{ or } = \text{ or } > 0.001735$.  

Fig.7.14

$\lambda_2 = 0.0082, \alpha_1 = 6, \alpha_2 = 2, \beta = 0.0409, \beta_1 = 0.404, \beta_2 = 0.428, \beta_3 = 0.392, \beta_4 = 0.035, x = 0.65, p_1 = 0.4, p_2 = 0.6, p_3 = 0.7, C_0 = 6000, C_1 = 3500, C_2 = 2500, C_3 = 1000, C_4 = 3000$
The curves in the fig. 7.15 shows the behaviour of difference between the mean times to system failure of the Model-II and Model-I of the Chapter 4, i.e. $P_{42} - P_{41}$ with respect to the rate of minor faults ($\lambda_2$) for the different values of probability of fault in an non-redundant subsystem ($x$).

Following has been concluded from the graph:

(i) The difference of profits ($P_{42} - P_{41}$) increases with the increase in the rate of minor faults and has higher values for higher values of probability of faults in a non-redundant subsystem.

(ii) For $x = 0.04$, the difference of profits ($P_{42} - P_{41}$) is negative or zero or positive according as $\lambda_2$ is $< \text{or} = \text{or} > 0.00517$. Hence, in this case, the Model-II is worse or equally good or better than the Model-I whenever $\lambda_2 < \text{or} = \text{or} > 0.00517$.

(iii) For $x = 0.05$, the difference of profits ($P_{42} - P_{41}$) is negative or zero or positive according as $\lambda_2$ is $< \text{or} = \text{or} > 0.00582$. Hence, in this case, the Model-II is worse or equally good or better than the Model-I whenever $\lambda_2 < \text{or} = \text{or} > 0.00582$. 

Fig. 7.15
(iv) For $x = 0.06$, the difference of profits ($P_{42} - P_{41}$) is negative or zero or positive according as $\lambda_2$ is $< or = or > 0.00671$. Hence, in this case, the Model-II is worse or equally good or better than the Model-I whenever $\lambda_2 < or = or > 0.00671$.

The curves in the fig. 7.16 shows the behaviour of difference between the mean times to system failure of the Model-II and Model-I of the Chapter 4, i.e. $P_{42} - P_{41}$ with respect to the revenue per unit uptime with full capacity of the system ($C_0$) for the different values of repair rate of the Type-I redundant subsystem ($\beta_2$).

![DIAGRAM](image)

**Fig. 7.16**

Following conclusions have been made from the graph:

(i) The difference of profits ($P_{42} - P_{41}$) increases with the increase in the values of the revenue per unit uptime with full capacity of the system and has higher values for higher values of the repair rate of the Type-I redundant subsystem.

(ii) For $\beta_2 = 0.031$, the difference of profits ($P_{42} - P_{41}$) is negative or zero or positive according as $C_0$ is $< or = or > 937.306$. Hence, in this case, the Model-II is worse or equally good or better than Model-I if $C_0 < or = or > Rs.937.306$. 

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(iii) For \( \beta_2 = 0.041 \), the difference of profits \((P_{42}-P_{41})\) is negative or zero or positive according as \( C_0 \) is \(<\) or \(=\) or \(>\) 613.729. Hence, in this case, the Model-II is worse or equally good or better than Model-I if \( C_0 <\) or \(=\) or \(>\) Rs.613.729.

(iv) For \( \beta_2 = 0.051 \), the difference of profits \((P_{42}-P_{41})\) is negative or zero or positive according as \( C_0 \) is \(<\) or \(=\) or \(>\) 314.927. Hence, in this case, the Model-II is worse or equally good or better than Model-I if \( C_0 <\) or \(=\) or \(>\) Rs.314.927.

The graph shown in Fig. 7.17 reveals the pattern of difference between the profits of the Model-II and Model-I of the Chapter 4, i.e.\(P_{42}-P_{41}\) with respect to the revenue per unit uptime with full capacity of the system \((C_0)\) for the different values of rate of major faults \((\lambda_1)\).

![Graph of differences of profits vs revenue per unit uptime with full capacity](image)

Fig. 7.17

From the graph, following conclusions have been made:

(i) The difference of profits \((P_{42}-P_{41})\) increases with the increase in the values of the revenue per unit uptime with full capacity of the system and has higher values for higher values of the rate of major faults.
For $\lambda_1 = 0.0011$, the difference of profits ($P_{42} - P_{41}$) is negative or zero or positive according as $C_0$ is $<$ or $=$ or $>$ 780.785. Hence, in this case, the Model-II is worse or equally good or better than Model-I if $C_0$ $<$ or $=$ or $>$ Rs.780.785.

For $\lambda_1 = 0.0511$, the difference of profits ($P_{42} - P_{41}$) is negative or zero or positive according as $C_0$ is $<$ or $=$ or $>$ 736.336. Hence, in this case, the Model-II is worse or equally good or better than Model-I if $C_0$ $<$ or $=$ or $>$ Rs.736.336.

For $\lambda_1 = 0.1011$, the difference of profits ($P_{42} - P_{41}$) is negative or zero or positive according as $C_0$ is $<$ or $=$ or $>$ 695.927. Hence, in this case, the Model-II is worse or equally good or better than Model-I if $C_0$ $<$ or $=$ or $>$ Rs.795.927.

Fig. 7.18 reveals the pattern of difference between the profits of the Model-II and Model-I of the Chapter 4, i.e. $P_{42} - P_{41}$ with respect to the revenue per unit uptime with reduced capacity of the system ($C_1$) for the different values of repair rate of non-redundant subsystem ($\beta$).
Following conclusions have been made from the graph:

(i) The difference of profits \((P_{42} - P_{41})\) increases with the increase in the values of the revenue per unit uptime with reduced capacity of the system and has lower values for higher values of the repair rate of non-redundant subsystem.

(ii) For \(\beta = 0.210\), the difference of profits \((P_{42} - P_{41})\) is negative or zero or positive according as \(C_1\) is \(< or = or > 0.0557\). Hence, in this case, the Model-II is worse or equally good or better than Model-I if \(C_1 < or = or > Rs.0.0557\).

(iii) For \(\beta = 0.215\), the difference of profits \((P_{42} - P_{41})\) is negative or zero or positive according as \(C_1\) is \(< or = or > 0.0598\). Hence, in this case, the Model-II is worse or equally good or better than Model-I if \(C_1 < or = or > Rs.0.0598\).

(iv) For \(\beta = 0.220\), the difference of profits \((P_{42} - P_{41})\) is negative or zero or positive according as \(C_1\) is \(< or = or > 0.0632\). Hence, in this case, the Model-II is worse or equally good or better than Model-I if \(C_1 < or = or > Rs.0.0632\).

**Comparative Analysis of the Models Discussed in Chapter 5**

In Chapter 5, considering the situations of occurrence of faults during online repairs in the non-redundant subsystem and random switching of the standby subsystem within the similar redundant subsystems, two stochastic models for the systems have been studied. The models consider the situations of occurrence of a fault in the non-redundant subsystem during online repairs of the subsystem the system goes to complete failure and also when random switching of the subsystem of the redundant subsystems has been done on occurrence of faults. In fact, the first model is an extension of the first model of Chapter 3 taking above practical situations along with different rates of occurrences of major/minor faults during repairs of redundant subsystems whereas the second model is the extension of second model of Chapter 3 taking the above practical situations.

**Fig. 7.19** shows the behaviour of difference between the mean times to system failure of the Model-II and Model-I of the Chapter 5, i.e. \(T_{52} - T_{51}\) with respect to the rate of faults during repair \((\lambda_r)\) for the different values of rate of major faults \((\lambda_1)\).

It has been concluded from the graph that the mean time to system failure of the Model-II is higher than the Model-I of Chapter 5 for fixed values of rate of faults.
during repair \((\lambda_r)\). Also the difference of mean times to system failure increases with the increase in the values of rate of faults during repair and has higher values for higher values of rate of major faults.

![Fig.7.19](image1)

![Fig.7.20](image2)
The curves in the fig. 7.20 show the behaviour of difference between the mean times to system failure of the Model-II and Model-I of the Chapter 5, i.e. $T_{52}-T_{51}$ with respect to the rate of minor faults ($\lambda_2$) for the different values of repair rate of Type-I redundant subsystem ($\beta_2$).

From the graph, it has been concluded that the mean time to system failure of the Model-II is higher than the Model-I of Chapter 5 for fixed values of rate of minor faults ($\lambda_2$). Also the difference of mean times to system failure decreases with the increase in the values of rate of minor faults and has higher values for higher values of repair rate of a Type-I redundant subsystem ($\beta_2$).

The graph shown in fig. 7.21 reveals the pattern of difference between the mean times to system failure of the Model-II and Model-I of the Chapter 5, i.e. $T_{52}-T_{51}$ with respect to the repair rate of non-redundant subsystem ($\beta_1$) for the different values of the switching rate ($\eta_2$).
From the graph, following conclusions have been made:

(i) The difference of the mean times to system failure ($T_{52} - T_{51}$) increases with the increase in the values of the repair rate of non-redundant subsystem and has lower values for higher values of the switching rate.

(ii) For $\eta_2 = 0.45$, the difference of profits ($T_{52} - T_{51}$) is negative or zero or positive according as $\beta_1$ is $< or = or > 0.008361$. Hence, in this case, the **Model-II** is worse or equally good or better than **Model-I** if $\beta_1 < or = or > \text{Rs.0.008361}$.

(iii) For $\eta_2 = 0.65$, the difference of profits ($T_{52} - T_{51}$) is negative or zero or positive according as $\beta_1$ is $< or = or > 0.009187$. Hence, in this case, the **Model-II** is worse or equally good or better than **Model-I** if $\beta_1 < or = or > \text{Rs.0.009187}$.

(iv) For $\eta_2 = 0.85$, the difference of profits ($T_{52} - T_{51}$) is negative or zero or positive according as $\beta_1$ is $< or = or > 0.009849$. Hence, in this case, the **Model-II** is worse or equally good or better than **Model-I** if $\beta_1 < or = or > \text{Rs.0.009849}$.

**Fig. 7.22** reveals the pattern of difference between the profits of the **Model-II** and **Model-I** of the Chapter 5, i.e. $P_{52} - P_{51}$ with respect to the rate of fault during repair ($\lambda_r$) for different values of the inspection rate ($\alpha_1$).

\[
\begin{align*}
\lambda_1 &= 0.0028, \lambda_2 = 0.0082, \lambda_3 = 0.0021, \lambda_4 = 0.0023, \\
\lambda_5 &= 0.0018, \lambda_6 = 0.0039, \alpha_2 = 2, \beta = 0.0409, \beta_1 = 0.404, \\
\beta_2 &= 0.428, \beta_3 = 0.392, \alpha = 0.8895, \eta = 0.65, \eta_1 = 0.6, \eta_2 = 0.4, \eta_3 = 0.7, \\
\mathcal{C}_0 &= 6000, \mathcal{C}_1 = 3500, \mathcal{C}_2 = 2500, \mathcal{C}_3 = 1000, \mathcal{C}_4 = 2000, \mathcal{C}_5 = 3000
\end{align*}
\]

**Fig.7.22**
Following conclusions have been made from the graph:

(i) The difference of the profits ($P_{52} - P_{51}$) increases with the increase in the values of rate of fault during repair and has higher values for higher values of the inspection rate.

(ii) For $\alpha_1 = 1$, the difference of profits ($P_{52} - P_{51}$) is negative or zero or positive according as $\lambda_e$ is $< \; or \; = \; or \; > \; 0.004746$. Hence, in this case, the Model-II is worse or equally good or better than Model-I if $\lambda_e < \; or \; = \; or \; >$ Rs.0.004746.

(iii) For $\alpha_1 = 3$, the difference of profits ($P_{52} - P_{51}$) is negative or zero or positive according as $\lambda_e$ is $< \; or \; = \; or \; > \; 0.003793$. Hence, in this case, the Model-II is worse or equally good or better than Model-I if $\lambda_e < \; or \; = \; or \; >$ Rs.0.003793.

(iv) For $\alpha_1 = 5$, the difference of profits ($P_{52} - P_{51}$) is negative or zero or positive according as $\lambda_e$ is $< \; or \; = \; or \; > \; 0.003179$. Hence, in this case, the Model-II is worse or equally good or better than Model-I if $\lambda_e < \; or \; = \; or \; >$ Rs.0.003179.

The curves in fig.7.23 reveal the pattern of difference between the profits of the Model-II and Model-I of the Chapter 5, i.e. $P_{52} - P_{51}$ with respect to the repair rate of non-redundant subsystem ($\beta_1$) for the different values of the rate of minor faults ($\lambda_2$).

![Graph](image-url)

**Fig.7.23**
Following conclusions have been made from the graph:

(i) The difference of the profits ($P_{52} - P_{51}$) increases with the increase in the values of the repair rate of non-redundant subsystem and has lower values for higher values of the rate of minor faults.

(ii) For $\lambda_2 = 0.0021$, the difference of profits ($P_{52} - P_{51}$) is negative or zero or positive according as $\beta_1$ is $< \text{or} = \text{or} > 0.001775$. Hence, in this case, the Model-II is worse or equally good or better than Model-I if $\beta_1 < \text{or} = \text{or} > Rs.0.001775$.

(iii) For $\lambda_2 = 0.0041$, the difference of profits ($P_{52} - P_{51}$) is negative or zero or positive according as $\beta_1$ is $< \text{or} = \text{or} > 0.001916$. Hence, in this case, the Model-II is worse or equally good or better than Model-I if $\beta_1 < \text{or} = \text{or} > Rs.0.001916$.

(iv) For $\lambda_2 = 0.0061$, the difference of profits ($P_{52} - P_{51}$) is negative or zero or positive according as $\beta_1$ is $< \text{or} = \text{or} > 0.001999$. Hence, in this case, the Model-II is worse or equally good or better than Model-I if $\beta_1 < \text{or} = \text{or} > Rs.0.001999$.

**Fig. 7.24**

**Fig. 7.24** shows the behaviour of difference between the profits of the Model-II and Model-I of the Chapter 5, i.e. $P_{52} - P_{51}$ with respect to the revenue per unit uptime with full capacity of the system ($C_0$) for the different values of rate of major faults ($\lambda_1$).
From the graph, following conclusions have been made:

(i) The difference of profits ($P_{52} - P_{51}$) decreases with the increase in the values of the revenue per unit up time of the system and has higher values for higher values of the rate of occurrence of major faults.

(ii) For $\lambda_1 = 0.0031$, the difference of profits ($P_{52} - P_{51}$) is positive or zero or negative according as $C_0$ is $<$ or $=$ or $>$ 1258.244. Thus, in this case, the Model-II is better or equally good or worse than Model-I of Chapter 5 whenever $C_0 <$ or $=$ or $> Rs. 1258.244$.

(iii) For $\lambda_1 = 0.0051$, the difference of profits ($P_{52} - P_{51}$) is positive or zero or negative according as $C_0$ is $<$ or $=$ or $>$ 1289.35. Thus, in this case, the Model-II is better or equally good or worse than Model-I of Chapter 5 whenever $C_0 <$ or $=$ or $> Rs. 1289.35$.

(iv) For $\lambda_1 = 0.0071$, the difference of profits ($P_{52} - P_{51}$) is positive or zero or negative according as $C_0$ is $<$ or $=$ or $>$ 1320.455. Thus, in this case, the Model-II is better or equally good or worse than Model-I of Chapter 5 whenever $C_0 <$ or $=$ or $> Rs. 1320.455$.

![Diagram showing Difference of Profit vs Cost Per Unit Inspection Time ($C_2$) for different Values of Switching Rate ($\eta_2$)](image)

Fig.7.25
The graph in fig. 7.25 shows the pattern of difference between the profits of the Model-II and Model-I of the Chapter 5, i.e. $P_{52} - P_{51}$ with respect to the cost per unit time of inspection of the system ($C_2$) for the different values of switching rate ($\eta_2$).

Following conclusions have been made from the graph:

(i) The difference of profits ($P_{52} - P_{51}$) decreases with the increase in the values of the cost per unit inspection time and has higher values for higher values of the switching rate.

(ii) For $\eta_2 = 0.0045$, the difference of profits ($P_{52} - P_{51}$) is positive or zero or negative according as $C_2$ is $< or = or > 1545.722$. Thus, in this case, the Model-II is better or equally good or worse than Model-I of Chapter 5 whenever $C_2 < or = or >$ Rs. 1545.722.

(iii) For $\eta_2 = 0.0065$, the difference of profits ($P_{52} - P_{51}$) is positive or zero or negative according as $C_2$ is $< or = or > 2514.402$. Thus, in this case, the Model-II is better or equally good or worse than Model-I of Chapter 5 whenever $C_2 < or = or >$ Rs.2514.402.

(iv) For $\eta_2 = 0.0085$, the difference of profits ($P_{52} - P_{51}$) is positive or zero or negative according as $C_2$ is $< or = or > 3479.414$. Thus, in this case, the Model-II is better or equally good or worse than Model-I of Chapter 5 whenever $C_2 < or = or >$ Rs. 3479.414.

**Comparative Analysis of the Models Discussed in Chapter 6**

Chapter 6 discusses two stochastic models for two-unit cold standby water systems. The provisions of automatic switching of the cold standby unit and also within the similar redundant subsystems on occurrences of major/minor faults in the system have also been taken. The first model, Model-I has been developed taking in to account the situations when the automatic switching of the cold standby unit and within the similar redundant subsystems take place on occurrences of major faults only in the system. On the other hand, the second model, Model–II has been developed considering the situations when the automatic switching of the cold standby unit and within the similar redundant subsystems take place on occurrences of any kind of major/ minor faults.
Fig. 7.26 presents the behaviour of difference between the mean times to system failure of the Model-II and Model-I of the Chapter 6, i.e., $T_{62} - T_{61}$ with respect to the rate of minor faults ($\lambda_2$) for the different values of rate of major faults ($\lambda_1$). The difference of mean times to system failure $T_{62} - T_{61}$ slightly increases with the increase in the values of rate of minor faults and has higher values for higher values of the rate of major faults.

![Difference of MTSF vs Rate of Minor Faults (\lambda_2) for Different Values of Rate of Major Faults (\lambda_1)](image)

\[ \lambda_1 = 0.0028, \lambda_2 = 0.0082, \alpha_1 = 6, \alpha_2 = 2, \beta = 0.0409, \beta_i = 0.404, \]
\[ \beta_2 = 0.428, \beta_1 = 0.392, a = 0.8895, x = 0.65, x_i = 0.6, \eta_i = 0.4, \eta_2 = 0.7 \]

![Difference of MTSF vs Rate of Minor Faults (\lambda_2) for Different Values of Inspection Rate (\alpha_1)](image)

\[ \lambda_1 = 0.0028, \alpha_1 = 2, \beta = 0.0409, \beta_i = 0.404, \]
\[ \beta_2 = 0.428, \beta_1 = 0.392, a = 0.8895, x = 0.65, x_i = 0.6, \eta_i = 0.4, \eta_2 = 0.7 \]
The graph in **fig. 7.27** shows the behaviour of difference between the mean times to system failure of the **Model-II** and **Model-I** of the **Chapter 6**, i.e. $T_{62} - T_{61}$ with respect to the rate of minor faults ($\lambda_2$) for the different values of inspection rate ($\alpha_1$). The difference of mean times to system failure $T_{62} - T_{61}$ increases with the increase in the values of rate of minor faults and has lower values for higher values of the inspection rate.

![DIFERENCE OF MTSF V/S INPECTIONE RATE ($\alpha_2$) FOR DIFFERENT VALUES OF PROBABILITY OF FAULT IN NON-REDUNDANT SUBSYSTEM (x)](image)

**Fig. 7.28**

**Fig. 7.28** shows the behaviour of difference between the mean times to system failure of the **Model-II** and **Model-I** of the **Chapter 6**, i.e. $T_{62} - T_{61}$ with respect to the inspection rate ($\alpha_2$) for the different values of probability of fault in non-redundant subsystem ($x$). The difference of mean times to system failure $T_{62} - T_{61}$ decreases with the increase in the values of inspection rate and has higher values for higher values of the probability of fault in non-redundant subsystem.

The graph presented in **fig. 7.29** reveals the pattern of difference between the profits of the **Model-II** and **Model-I** of the **Chapter 6**, i.e. $P_{62} - P_{61}$ with respect to the rate of minor faults ($\lambda_2$) for different values of rate of major faults ($\lambda_1$). The difference of the
profits $P_{62} - P_{61}$ increases with the increase in the values of rate of minor faults and has higher values for the higher values of rate of major faults.

**Fig. 7.29**

**Fig. 7.30**

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The graph shown in fig. 7.30 reveals the pattern of difference between the profits of the Model-II and Model-I of the Chapter 6, i.e., \( P_{62} - P_{61} \) with respect to the repair rate of non-redundant subsystem (\( \beta_1 \)) for different values of probability of fault in non-redundant subsystem (\( x \)). The difference of the profits \( P_{62} - P_{61} \) increases with the increase in the values of repair rate of non-redundant subsystem and has higher values for the higher values of the probability of fault in non-redundant subsystem.

The curves in fig. 7.31 highlight the pattern of difference between the profits of the Model-II and Model-I of the Chapter 6, i.e., \( P_{62} - P_{61} \) with respect to the revenue per unit uptime with full capacity of the system (\( C_0 \)) for the different values of repair rate of Type-I redundant subsystem (\( \beta_2 \)).

![Graph showing difference of profit vs revenue per unit uptime with full capacity for different values of repair rate.](image)

**Fig. 7.31**

From the graph, following conclusions have been made:

(i) The difference of profits \( (P_{62} - P_{61}) \) increases with the increase in the values of the revenue per unit uptime with full capacity of the system and has higher values for higher values of the repair rate of a Type-I redundant subsystem.

(ii) For \( \beta_2 = 0.0001 \), the difference of profits \( (P_{62} - P_{61}) \) is negative or zero or positive according as \( C_0 \) is < or = or > 3233. Hence, in this case, the Model-II is worse or equally good or better than Model-I if \( C_0 < \text{or } = \text{ or } > \text{Rs.3233.} \)
(iii) For $\beta_2 = 0.0041$, the difference of profits ($P_{62}-P_{61}$) is negative or zero or positive according as $C_0$ is $< \text{or } = \text{or } > 3261$. Hence, in this case, the Model-II is worse or equally good or better than Model-I if $C_0 < \text{or } = \text{or } > Rs.3261$.

(iv) For $\beta_2 = 0.0081$, the difference of profits ($P_{62}-P_{61}$) is negative or zero or positive according as $C_0$ is $< \text{or } = \text{or } > 3307$. Hence, in this case, the Model-II is worse or equally good or better than Model-I if $C_0 < \text{or } = \text{or } > Rs.3307$.

**Fig. 7.32** reveals the pattern of difference between the profits of the Model-II and Model-I of the Chapter 6, i.e. $P_{62}-P_{61}$ with respect to the cost per unit inspection time ($C_2$) for the different values of probability of fault in Type-I redundant subsystem (a).

![Graph](image_url)

Following conclusions have been made from the graph:

(i) The difference of profits ($P_{62}-P_{61}$) decreases with the increase in the values of the cost per unit time of inspection and has higher values for higher values of the probability of fault in Type-I redundant subsystem.

(ii) For $a = 0.451$, the difference of profits ($P_{62}-P_{61}$) is positive or zero or negative according as $C_2$ is $< \text{or } = \text{or } > 19560$. Hence, in this case, the Model-II is better or equally good or worse than the Model-I whenever $C_2 < \text{or } = \text{or } > Rs.19560$. 
(iii) For $a = 0.456$, the difference of profits ($P_{62} - P_{61}$) is positive or zero or negative according as $C_2$ is $< \ or \ = \ or \ > 24350$. Hence, in this case, the Model-II is better or equally good or worse than the Model-I whenever $C_2 < \ or \ = \ or \ >$ Rs.24350.

(iv) For $a = 0.461$, the difference of profits ($P_{62} - P_{61}$) is positive or zero or negative according as $C_2$ is $< \ or \ = \ or \ > 29510$. Hence, in this case, the Model-II is better or equally good or worse than the Model-I whenever $C_2 < \ or \ = \ or \ >$ Rs.29510.

Section-B: Comparative Analyses of the Models Discussed Between the Chapters

Comparative Analysis of the Models Discussed in Chapter 3 and Chapter 4

Fig. 7.33 shows the behaviour of difference between the mean times to system failure of the Model-I of Chapter 4 and Model-II of Chapter 3, i.e. $T_{41} - T_{32}$ with respect to the rate of major faults ($\lambda_1$) for the different values of rate of minor faults ($\lambda_2$).

![Fig.7.33](attachment:image.png)

$\alpha_1 = 6, \alpha_2 = 2, \beta = 0.0409, \beta_1 = 0.404, \beta_2 = 0.428, \beta_3 = 0.392,
\alpha = 0.8895, x = 0.65, x_1 = 0.6, p_1 = 0.4, p_2 = 0.6, p_3 = 0.7$
From the graph, it has been concluded that the mean time to system failure of the Model-I of Chapter 4 is higher than the Model-II of Chapter 3 for fixed values of the rate of major faults ($\lambda_1$). Also the difference of mean times to system failure decreases with the increase in the values of the rate of major faults and has higher values for higher values of rate of minor faults.

The curves in fig.7.34 show the behaviour of difference between the mean times to system failure of the Model-I of Chapter 4 and Model-II of Chapter 3, i.e. $T_{41}-T_{32}$ with respect to the probability of fault in Type-I redundant subsystem (a) for the different values of repair rate of non-redundant subsystem ($\beta_1$).

![Graph](image)

**Fig.7.34**

It has been concluded from the graph that the mean time to system failure of the Model-I of Chapter 4 is higher than the Model-II of Chapter 3 for fixed values of the probability of fault in Type-I redundant subsystem (a). Also the difference of mean times to system failure decreases with the increase in the values of the probability of fault in Type-I redundant subsystem (a) and has higher values for higher values of repair rate of non-redundant subsystem.
Fig. 7.35 shows the behaviour of difference between the mean times to system failure of the Model-I of Chapter 4 and Model-II of Chapter 3, i.e. $T_{41}-T_{32}$ with respect to the repair rate of Type-I redundant subsystem ($\beta_2$) for different values of probability of fault in non-redundant subsystem ($x$).

From the graph, it has been concluded that the mean time to system failure of the Model-I of Chapter 4 is higher than the Model-II of Chapter 3 for fixed values of the repair rate of Type-I redundant subsystem ($\beta_2$). Also the difference of mean times to system failure increases with the increase in the values of the repair rate of Type-I redundant subsystem and has lower values for higher values of probability of fault in non-redundant subsystem.

![DIFERERENCE OF MTSF V/S REPAIR RATE OF TYPE-I REDUNDANT SUBSYSTEM (\(\beta_2\)) OF PROBABILITY OF FAULT IN NON-REDUNDANT SUBSYSTEM (\(x\))](image)

**Fig. 7.35**

The curves in the fig. 7.36 show the behavior of the difference between the profits of the Model-I of Chapter 4 and Model-II of Chapter 3, i.e. $P_{41}-P_{32}$ with respect to the rate of major faults ($\lambda_1$) for the different values of rate of minor faults ($\lambda_2$).
Following conclusions have been made from the graph:

(i) The difference of profits (P_{41}-P_{32}) decreases with the increase in the rate of major faults and has higher values for higher values of the rate of minor faults.

(ii) For $\lambda_2 = 0.026$, the difference of profits (P_{41}-P_{32}) is positive or zero or negative according as $\lambda_1$ is $< \text{or} = \text{or} > 0.0003$. Thus, in this case, the Model-I of Chapter 4 is better or equally good or worse than Model-II of Chapter 3 whenever $\lambda_1 < \text{or} = \text{or} > 0.0003$.

(iii) For $\lambda_2 = 0.031$, the difference of profits (P_{41}-P_{32}) is positive or zero or negative according as $\lambda_1$ is $< \text{or} = \text{or} > 0.000367$. Thus, in this case, the Model-I of Chapter 4 is better or equally good or worse than Model-II of Chapter-3 whenever $\lambda_1 < \text{or} = \text{or} > 0.000367$.

(iv) For $\lambda_2 = 0.036$, the difference of profits (P_{41}-P_{32}) is positive or zero or negative according as $\lambda_1$ is $< \text{or} = \text{or} > 0.000425$. Thus, in this case, the Model-I of Chapter 4 is better or equally good or worse than Model-II of Chapter 3 whenever $\lambda_1 < \text{or} = \text{or} > 0.000425$. 

Fig. 7.36
The graph in fig. 7.37 shows the pattern of difference of profits of the Model-I of Chapter 4 and Model-II of Chapter 3, i.e. \(P_{41}-P_{32}\) with respect to the rate of major faults \((\lambda_1)\) for the different values of repair rate of non-redundant subsystem \((\beta_1)\).

Following can be concluded from the graph:

(i) The difference of profits \((P_{41}-P_{32})\) decreases with the increase in the values of the rate of major faults and has higher values for higher values of repair rate of non-redundant subsystem.

(ii) For \(\beta_1 = 0.051\), the difference of profits \((P_{41}-P_{32})\) is positive or zero or negative according as \(\lambda_1\) is \(<\) or = or > 0.01532. Thus, in this case, Model-I of Chapter 4 is better or equally good or worse than Model-II of Chapter 3 if \(\lambda_1\) is \(<\) or = or > 0.01532.

(iii) For \(\beta_1 = 0.056\), the difference of difference of profits \((P_{41}-P_{32})\) is positive or zero or negative according as \(\lambda_1\) is \(<\) or = or > 0.01677. Thus, in this case, the Model-I of Chapter 4 is better or equally good or worse than Model-II of Chapter 3 if \(\lambda_1\) is \(<\) or = or > 0.01532.

(iv) For \(\beta_1 = 0.061\), the difference of profits \((P_{41}-P_{32})\) is positive or zero or negative according as \(\lambda_1\) is \(<\) or = or > 0.01822. Thus, in this case, the Model-I of Chapter 4 is better or equally good or worse than Model-II of Chapter 3 if \(\lambda_1\) is \(<\) or = or > 0.01532.
The graph in fig. 7.38 shows the pattern of difference between the profits of the Model-I of Chapter 4 and Model-II of Chapter 3, i.e. \( P_{41} - P_{32} \) with respect to the revenue per unit uptime with full capacity of the system \( (C_0) \) for the different values of rate of major faults \( (\lambda_1) \).

Fig. 7.38

Following conclusions have been made from the graph:

(i) The difference of profits \( (P_{41} - P_{32}) \) increases with the increase in the values of the revenue per unit uptime with full capacity of the system and has lower values for higher values of rate of major faults.

(ii) For \( \lambda_1 = 0.25 \), the difference of profits \( (P_{41} - P_{32}) \) is negative or zero or positive according as \( C_0 \) is > or = or < Rs.1111.73. Thus, in this case, the Model-I of Chapter 4 is worse or equally good or better than Model-II of Chapter 3 if \( C_0 > \) or = or < Rs. 1111.73.

(iii) For \( \lambda_1 = 0.27 \), the difference of profits \( (P_{41} - P_{32}) \) is negative or zero or positive according as \( C_0 \) is > or = or < Rs.1199.43. Thus, in this case, the Model-I of Chapter 4 is worse or equally good or better than Model-II of Chapter 3 if \( C_0 > \) or = or < Rs. 1199.43.

(iv) For \( \lambda_1 = 0.29 \), the difference of profits \( (P_{41} - P_{32}) \) is negative or zero or positive according as \( C_0 \) is > or = or < Rs. 1287.13. Thus, in this case, the Model-I of Chapter 4 is worse or equally good or better than Model-II of Chapter 3 if \( C_0 > \) or = or < Rs. 1287.13.
The graph in fig. 7.39 shows the pattern of difference between the profits of the Model-I of Chapter 4 and Model-II of Chapter 3, i.e. $P_{41}-P_{32}$ with respect to the revenue per unit uptime with reduced capacity of the system ($C_0$) for the different values of probability of fault in non-redundant subsystem (x).

From the graph, following conclusions have been made:

(i) The difference of profits ($P_{41}-P_{32}$) increases with the increase in the values of the revenue per unit uptime with reduced capacity of the system and has lower values for higher values of probability of fault in non-redundant subsystem.

(ii) For $x = 0.3$, the difference of profits ($P_{41}-P_{32}$) is negative or zero or positive according as $C_1$ is $> or = or <$ Rs. 236.64. Thus, in this case, the Model-I of Chapter 4 is worse or equally good or better than Model-II of Chapter 3 if $C_1 > or = or <$ Rs. 236.64.

(iii) For $x = 0.6$, the difference of profits ($P_{41}-P_{32}$) is negative or zero or positive according as $C_1$ is $> or = or <$ Rs. 406.35. Thus, in this case, the Model-I of Chapter 4 is worse or equally good or better than Model-II of Chapter 3 if $C_1 > or = or <$ Rs. 406.35.

(iv) For $x = 0.9$, the difference of profits ($P_{41}-P_{32}$) is negative or zero or positive according as $C_1$ is $> or = or <$ Rs. 571.14. Thus, in this case, the Model-I of Chapter 4 is worse or equally good or better than Model-II of Chapter 3 if $C_1 > or = or <$ Rs. 571.14.
Comparative Analysis of the Models Discussed in Chapter 4 and Chapter 5

Fig. 7.40 shows the graph of difference between the mean times to system failure of the Model-I of Chapter 5 and Model-II of Chapter 4, i.e. $T_{51}-T_{42}$ with respect to the rate of minor faults ($\lambda_2$) for different values of rate of major faults ($\lambda_1$).

![Graph showing difference of MTSF vs rate of minor faults for different values of rate of major faults](image)

From the graph, it has been concluded that the mean time to system failure of Model-I of Chapter 5 is higher than that of the Model-II of Chapter 4 for fixed values of rate of minor faults. It is also concluded from the graph that the difference of mean times to system failure ($T_{51}-T_{42}$) increases with increase in the values of rate of minor faults and has higher values for higher values of the rate of major faults.

The curves in fig.7.41 depict the behaviour of difference between the mean times to system failure of the Model-I of Chapter 5 and Model-II of Chapter 4, i.e. $T_{51}-T_{42}$ with respect to the inspection rate ($\alpha_1$) for the different values of the probability of fault in non-redundant subsystem ($x$).

It has been concluded from the graph that the mean time to system failure of the Model-I of Chapter 5 is higher than that of the Model-II of Chapter 4 for fixed values of rate of minor faults. It has also been concluded from the graph that the difference of
mean times to system failure \((T_{51}-T_{42})\) increases with the increase in the values of inspection rate and has lower values for higher values of the probability of fault in non-redundant subsystem.

![Diagram 7.41](image1)

**Fig. 7.41**

![Diagram 7.42](image2)

**Fig. 7.42**

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Fig. 7.42 reveals the pattern of difference between the mean times to system failure of the Model-I of Chapter 5 and Model-II of Chapter 4, i.e. $T_{51} - T_{42}$ with respect to rate of minor faults ($\lambda_2$) for the different values of the repair rate of non-redundant subsystem ($\beta_1$).

Following conclusions have been made from the graph:

(i) The difference of mean times to system failure ($T_{51} - T_{42}$) increases with the increase in the values of rate of minor faults and has higher values for higher values of repair rate of non-redundant subsystem ($\beta_1$).

(ii) For $\beta_1 = 0.0001$, the difference mean times to system failure ($T_{51} - T_{42}$) is positive or zero or negative according as $\lambda_2$ is $\geq$ or $<$ 0.001973. Hence, in this case, the Model-I of Chapter 5 is better or equally good or worse than Model-II of Chapter 4 if $\lambda_2 >$ or $\leq$ or $< 0.001973$.

(iii) For $\beta_1 = 0.0005$, the difference mean times to system failure ($T_{51} - T_{42}$) is positive or zero or negative according as $\lambda_2$ is $\geq$ or $<$ 0.001858. Hence, in this case, the Model-I of Chapter 5 is better or equally good or worse than Model-II of Chapter 4 if $\lambda_2 >$ or $\leq$ or $< 0.001858$.

(iv) For $\beta_1 = 0.0009$, the difference of mean times to system failure ($T_{51} - T_{42}$) is positive or zero or negative according as $\lambda_2$ is $\geq$ or $<$ 0.001751. Hence, in this case, the Model-I of Chapter 5 is better or equally good or worse than Model-II of Chapter 4 if $\lambda_2 >$ or $\leq$ or $< 0.001751$.

The graph in fig. 7.43 shows the behaviour of difference between the profits of the Model-I of Chapter 5 and Model-II of Chapter 4, i.e. $P_{51} - P_{42}$ with respect to the rate of major faults ($\lambda_1$) for the different values of the rate of minor faults ($\lambda_2$).

From the graph, following conclusions have been made:

(i) The difference of profits ($P_{51} - P_{42}$) decreases with the increase in the values of the rate of major faults and has higher values for higher values of the rate of minor faults.

(ii) For $\lambda_2 = 0.004$, the difference of profits ($P_{51} - P_{42}$) is positive or zero or negative according as $\lambda_1$ is $< \leq$ or $> 0.0159$. Hence, in this case, the Model-I of Chapter 5 is better or equally good or worse than Model-II of Chapter 4 if $\lambda_1 <$ or $\geq$ or $> 0.0159$. 

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(iii) For $\lambda_2 = 0.005$, the difference of profits ($P_{51} - P_{42}$) is positive or zero or negative according as $\lambda_1$ is $< \text{or} = \text{or} > 0.0209$. Hence, in this case, the Model-I of Chapter 5 is better or equally good or worse than Model-II of Chapter 4 if $\lambda_1 < \text{or} = \text{or} > 0.0209$.

(iv) For $\lambda_2 = 0.006$, the difference of profits ($P_{51} - P_{42}$) is positive or zero or negative according as $\lambda_1$ is $< \text{or} = \text{or} > 0.0258$. Hence, in this case, the Model-II of Chapter 5 is better or equally good or worse than Model-II of Chapter 4 if $\lambda_1 < \text{or} = \text{or} > 0.0258$.

Fig. 7.43

Fig. 7.44 shows the graph of difference between the profits of the Model-I of Chapter 5 and Model-II of Chapter 4, i.e. $P_{51} - P_{42}$ with respect to the inspection rate ($\alpha_2$) for the different values of the repair rate of Type-II redundant subsystem ($\beta_3$).

Following conclusions have been made from the graph:

(i) The difference of profits ($P_{51} - P_{42}$) decreases with the increase in the values of the inspection rate and has higher values for higher values of the repair rate of Type-II redundant subsystem.
For $\beta_3 = 0.051$, the difference of profits ($P_{51} - P_{42}$) is positive or zero or negative according as $\alpha_2$ is $< or = or > 0.1731$. Hence, in this case, the Model-I of Chapter 5 is better or equally good or worse than Model-II of Chapter 4 if $\alpha_2 < or = or > 0.1731$.

For $\beta_3 = 0.061$, the difference of profits ($P_{51} - P_{42}$) is positive or zero or negative according as $\alpha_2$ is $< or = or > 0.1876$. Hence, in this case, the Model-I of Chapter 5 is better or equally good or worse than Model-II of Chapter 4 if $\alpha_2 < or = or > 0.1876$.

For $\beta_3 = 0.071$, the difference of profits ($P_{51} - P_{42}$) is positive or zero or negative according as $\alpha_2$ is $< or = or > 0.2121$. Hence, in this case, the Model-I of Chapter 5 is better or equally good or worse than Model-II of Chapter 4 if $\alpha_2 < or = or > 0.2121$.

The graph presented in fig. 7.45 reveals the pattern of difference between the profits of the Model-II of the Chapter 4 and Model-I of the Chapter 5, i.e. $P_{51} - P_{42}$ with respect to the revenue per unit uptime with full capacity of the system ($C_0$) for the different values of repair rate of Type-I redundant subsystem ($\beta_3$).
Fig. 7.45

From the graph, following conclusions have been made:

(i) The difference of profits ($P_{51} - P_{42}$) increases with the increase in the values of the revenue per unit uptime with full capacity of the system and has higher values for higher values of the repair rate of Type-I redundant subsystem.

(ii) For $\beta_2 = 0.003$, the difference of profits ($P_{51} - P_{42}$) is negative or zero or positive according as $C_0$ is $< or = or > 3981.21$. Hence, in this case, the Model-II of the Chapter 4 is worse or equally good or better than the Model-I of Chapter 5 if $C_0 < or = or > Rs.3981.21$.

(iii) For $\beta_2 = 0.011$, the difference of profits ($P_{51} - P_{42}$) is negative or zero or positive according as $C_0$ is $< or = or > 3971.65$. Hence, in this case, the Model-II of the Chapter 4 is worse or equally good or better than the Model-I of Chapter 5 if $C_0 < or = or > Rs.3971.65$.

(iv) For $\beta_2 = 0.019$, the difference of profits ($P_{51} - P_{42}$) is negative or zero or positive according as $C_0$ is $< or = or > 3959.40$. Hence, in this case, the Model-II of the Chapter 4 is worse or equally good or better than the Model-I of Chapter 5 if $C_0 < or = or > Rs.3959.40$. 

$\lambda_1 = 0.0028, \lambda_2 = 0.0082, \lambda_3 = 0.0016, \lambda_4 = 0.0023, \lambda_5 = 0.0018, \lambda_6 = 0.0039, \alpha_1 = 6, \alpha_2 = 2, \beta = 0.0409, \beta_1 = 0.404, \beta_3 = 0.392, \beta_e = 0.035, a = 0.8895, x = 0.65, x_1 = 0.6, \eta_1 = 0.4, \eta_2 = 0.7, p_1 = 0.4, \eta_2 = 0.6, p_2 = 0.7, C_1 = 3500, C_2 = 2500, C_3 = 1000, C_4 = 2000, C_5 = 3000$
Fig. 7.46 reveals the pattern of difference between the profits of the Model-II of the Chapter 4 and Model-I of the Chapter 5, i.e. $P_{51} - P_{42}$ with respect to the revenue per unit uptime with reduced capacity of the system ($C_1$) for the different values of inspection rate ($\alpha_1$).

Following conclusions have been made from the graph:

(i) The difference of profits ($P_{51} - P_{42}$) increases with the increase in the values of the revenue per unit uptime with reduced capacity of the system and has lower values for higher values of the inspection rate.

(ii) For $\alpha_1 = 1$, the difference of profits ($P_{51} - P_{42}$) is negative or zero or positive according as $C_1$ is $< \text{or} = \text{or} > 306.05$. Hence, in this case, the Model-I of Chapter 5 is worse or equally good or better than Model-II of Chapter 4 if $C_1 < \text{or} = \text{or} > \text{Rs.306.05}$.

(iii) For $\alpha_1 = 2$, the difference of profits ($P_{51} - P_{42}$) is negative or zero or positive according as $C_1$ is $< \text{or} = \text{or} > 323.15$. Hence, in this case, the Model-I of Chapter 5 is worse or equally good or better than Model-II of Chapter 4 if $C_1 < \text{or} = \text{or} > \text{Rs.323.15}$. 

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(iv) For \( \alpha_1 = 3 \), the difference of profits \((P_{51} - P_{42})\) is negative or zero or positive according as \( C_1 \) is \(<\) or \(=\) or \(>\) 336.11. Hence, in this case, the Model-I of Chapter-5 is worse or equally good or better than Model-II of Chapter-4 if \( C_1 < \) or \(=\) or \(>\) Rs.336.11.

**Comparative Analysis of the Models Discussed in Chapter 5 and Chapter 6**

Fig. 7.47 shows the graph of difference between the mean times to system failure of the Model-I of Chapter 6 and the Model-II of Chapter 5, i.e. \( T_{61} - T_{52} \) with respect to the rate of major faults \( (\lambda_1) \) for the different values of rate minor faults \( (\lambda_2) \).

![Graph of difference of MTSF vs rate of major faults for different values of rate of minor faults](image)

**Fig. 7.47**

From the graph, it has been concluded that the mean time to system failure of the Model-I of Chapter 6 is higher than the mean time to system failure of the Model-II of Chapter 5 for fixed values of rate of major faults \( (\lambda_1) \). It has also been concluded from the graph that the difference of mean times to system failure of the models increases with increase in the values of rate of major faults and has lower values for higher values of rate of minor faults.
The curves in **Fig. 7.48** reveal the pattern of difference between the mean times to system failure of the **Model-I of Chapter 6** and the **Model-II of Chapter 5**, i.e. $T_{61}-T_{52}$ with respect to the repair rate of Type-I redundant subsystem ($\beta_2$) for different values of probability of fault in Type-I redundant subsystem ($a$).

**DIFFERENCE OF MTSF V/S REPAIR RATE OF TYPE-I REDUNDANT SUBSYSTEM ($\beta_2$) FOR DIFFERENT VALUES OF PROBABILITY OF FAULT IN TYPE-I REDUNDANT SUBSYSTEM ($a$)**

![Graph showing difference of MTSF vs repair rate of Type-I redundant subsystem](image)

$\lambda_1 = 0.0028, \lambda_2 = 0.0082, \alpha_1 = 6, \alpha_2 = 2, \beta = 0.0409, \beta_1 = 0.404, \beta_3 = 0.392, x = 0.65, x_1 = 0.6, \eta_1 = 0.4, \eta_2 = 0.7$

**Fig. 7.48**

It can be concluded from the graph that the mean time to system failure of the **Model-I of Chapter 6** is higher than the **Model-II of Chapter 5** for fixed values of the repair rate of Type-I redundant subsystem ($\beta_2$). Also the difference of mean times to system failure increases with the increase in the values of the repair rate of Type-I redundant subsystem and has lower values for higher values of probability of fault in Type-I redundant subsystem.

**Fig. 7.49** shows the graph of difference between the mean times to system failure of the **Model-I of Chapter 6** and the **Model-II of Chapter 5**, i.e. $T_{61}-T_{52}$ with respect to the repair rate of non-redundant subsystem ($\beta_1$) for different values of probability of fault in non-redundant subsystem ($x$).
Following conclusions have been made from the graph:

(i)  The difference of profits \((T_{61}-T_{52})\) increases with the increase in the values of the repair rate of non-redundant subsystem and has higher values for higher values of the probability of fault in non-redundant subsystem.

(ii) For \(x = 0.35\), the difference of profits \((T_{61}-T_{52})\) is negative or zero or positive according as \(\beta_1\) is \(<\) or \(=\) or \(>\) 0.004295. Hence, in this case, the Model-I of Chapter 6 is worse or equally good or better than the Model-II of Chapter 5 if \(\beta_1 <\) or \(=\) or \(>\) 0.004295.

(iii) For \(x = 0.55\), the difference of profits \((T_{61}-T_{52})\) is negative or zero or positive according as \(\beta_1\) is \(<\) or \(=\) or \(>\) 0.003677. Hence, in this case, the Model-I of Chapter 6 is worse or equally good or better than the Model-II of Chapter 5 if \(\beta_1 <\) or \(=\) or \(>\) 0.003677.

(iv) For \(x = 0.75\), the difference of profits \((T_{61}-T_{52})\) is negative or zero or positive according as \(\beta_1\) is \(<\) or \(=\) or \(>\) 0.003057. Hence, in this case, the Model-I of Chapter 6 is worse or equally good or better than the Model-II of Chapter 5 if \(\beta_1 <\) or \(=\) or \(>\) 0.003057.
The graph in fig. 7.50 presents the behavior of difference between the profits of the Model-I of Chapter 6 and the Model-II of Chapter 5, i.e. $T_{61}-T_{52}$ with respect to the rate of minor faults ($\lambda_2$) for the different values of rate major faults ($\lambda_1$).

Following has been concluded from the graph:

(i) The difference of profits ($P_{61}-P_{51}$) decreases with the increase in the rate of minor faults and has higher values for higher values of the rate of occurrence of major faults.

(ii) For $\lambda_1 = 0.0012$, the difference of profits ($P_{61}-P_{51}$) is positive or zero or negative according as $\lambda_2$ is or $< or = or > 0.003565$. Thus, in this case, the Model-I of Chapter 6 is better or equally good or worse than the Model-II of Chapter 5 whenever $\lambda_2 < or = or > 0.003565$.

(iii) For $\lambda_2 = 0.0022$, the difference of profits ($P_{61}-P_{51}$) is positive or zero or negative according as $\lambda_2$ is $< or = or > 0.003706$. Thus, in this case, the Model-I of Chapter 6 is better or equally good or worse than the Model-II of Chapter 5 whenever $\lambda_2 < or = or > 0.003706$.

(iv) For $\lambda_3 = 0.0032$, the difference of profits ($P_{61}-P_{51}$) is positive or zero or negative according as $\lambda_2$ is $< or = or > 0.004178$. Thus, in this case, the Model-I of Chapter 6 is better or equally good or worse than the Model-II of Chapter 5 whenever $\lambda_2 < or = or > 0.004178$. 
Fig. 7.51 gives the graph of difference between the profits of the Model-I of Chapter 6 and the Model-II of Chapter 5, i.e. $P_{61} - P_{52}$ with respect to the inspection rate ($\alpha_2$) for the different values of the repair rate of Type-I redundant subsystem ($\beta_2$).

Following conclusions have been made from the graph:

(i) The difference of profits ($P_{51} - P_{42}$) decreases with the increase in the values of the inspection rate and has higher values for higher values of the repair rate of Type-II redundant subsystem.

(ii) For $\beta_2 = 0.055$, the difference of profits ($P_{51} - P_{42}$) is positive or zero or negative according as $\alpha_2$ is $< \mathrm{or} = \mathrm{or} > 0.022318$. Hence, in this case, the Model-I of Chapter 6 is better or equally good or worse than Model-II of Chapter 5 if $\alpha_2 < \mathrm{or} = \mathrm{or} > 0.022318$.

(iii) For $\beta_2 = 0.065$, the difference of profits ($P_{51} - P_{42}$) is positive or zero or negative according as $\alpha_2$ is $< \mathrm{or} = \mathrm{or} > 0.023768$. Hence, in this case, the Model-I of Chapter 6 is better or equally good or worse than Model-II of Chapter 5 if $\alpha_2 < \mathrm{or} = \mathrm{or} > 0.023768$. 

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(iv) For $\beta_2 = 0.075$, the difference of profits ($P_{51} - P_{42}$) is positive or zero or negative according as $\alpha_2$ is $< or = or > 0.025218$. Hence, in this case, the Model-I of Chapter 6 is better or equally good or worse than Model-II of Chapter 5 if $\alpha_2 < or = or > 0.025218$.

The curves in Fig.7.52 depict the pattern of difference between the profits of the Model-I of Chapter 6 and the Model-II of Chapter 5, i.e. $P_{61} - P_{52}$ with respect to the repair rate of non-redundant subsystem ($\beta_1$) for different values of probability of fault in a Type-I redundant subsystem (a).

![Graph](image)

$\lambda_1 = 0.0028, \lambda_2 = 0.0082, \alpha_1 = 6, \alpha_3 = 2, \beta = 0.0409, \beta_1 = 0.428, \beta_2 = 0.392, x = 0.65, x_1 = 0.6, \eta_1 = 0.4, \eta_2 = 0.7, C_0 = 6000, C_1 = 3500, C_2 = 2500, C_3 = 1000, C_4 = 2000, C_5 = 3000$

**Fig. 7.52**

Following has been concluded from the graph:

(i) The difference of profits ($P_{62} - P_{52}$) increases with the increase in the values of the repair rate of non-redundant subsystem and has lower values for higher values of probability of fault in a Type-I redundant subsystem.

(ii) For $a = 0.15$, the difference of profits ($P_{61} - P_{52}$) is negative or zero or positive according as $\beta_1$ is $< or = or > 0.002375$. Hence, in this case, the Model-I of
Chapter 6 is worse or equally good or better than the Model-II of Chapter 5 if $\beta_1 < \text{ or } = \text{ or } > 0.002375$.

(iii) For $a = 0.35$, the difference of profits ($P_{61} - P_{52}$) is negative or zero or positive according as $\beta_1$ is $< \text{ or } = \text{ or } > 0.002517$. Hence, in this case, the Model-I of Chapter 6 is worse or equally good or better than the Model-II of Chapter 5 if $\beta_1 < \text{ or } = \text{ or } > 0.002517$.

(iv) For $a = 0.55$, the difference of profits ($P_{61} - P_{52}$) is negative or zero or positive according as $\beta_1$ is $< \text{ or } = \text{ or } > 0.002598$. Hence, in this case, the Model-I of Chapter 6 is worse or equally good or better than the Model-II of Chapter 5 if $\beta_1 < \text{ or } = \text{ or } > 0.002598$.

**Fig. 7.53** shows the graph of difference between the profits of the Model-I of Chapter 6 and the Model-II of Chapter 5, i.e. $P_{61} - P_{52}$ with respect to the revenue per unit uptime with full capacity of the system ($C_0$) for the different values of probability of fault in a non-redundant subsystem $(x)$.

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</table>

**Fig. 7.53**
Following conclusions have been made from the graph:

(i) The difference of profits ($P_{61} - P_{52}$) increases with the increase in the values of the revenue per unit uptime with full capacity of the system and has higher values for higher values of the probability of fault in the non-redundant subsystem.

(ii) For $x = 0.45$, the difference of profits ($P_{61} - P_{52}$) is negative or zero or positive according as $C_0$ is $< or = or > 1270.997$. Hence, in this case, the Model-I of Chapter 6 is worse or equally good or better than the Model-II of Chapter 5 if $C_0 < or = or > Rs.1270.997$.

(iii) For $x = 0.65$, the difference of profits ($P_{61} - P_{52}$) is negative or zero or positive according as $C_0$ is $< or = or > 1221.207$. Hence, in this case, the Model-I of Chapter 6 is worse or equally good or better than the Model-II of Chapter 5 if $C_0 < or = or > Rs.1221.207$.

(iv) For $x = 0.85$, the difference of profits ($P_{61} - P_{52}$) is negative or zero or positive according as $C_0$ is $< or = or > 1176.108$. Hence, in this case, the Model-I of Chapter 6 is worse or equally good or better than the Model-II of Chapter 5 if $C_0 < or = or > Rs.1176.108$.
The graph shown in fig.7.54 reveals the pattern of difference between the profits of the Model-I of Chapter 6 and the Model-II of Chapter 5, i.e. \( P_{61} - P_{52} \), with respect to the revenue per unit uptime with reduced capacity of the system \( (C_1) \) for the different values of repair rate of a Type-II redundant subsystem \( (\beta_3) \).

From the graph, following conclusions have been made:

(i) The difference of profits \( (P_{61} - P_{52}) \) increases with the increase in the values of the revenue per unit uptime with reduced capacity of the system and has higher values for higher values of the repair rate of a Type-II redundant subsystem.

(ii) For \( \beta_3 = 0.035 \), the difference of profits \( (P_{61} - P_{52}) \) is negative or zero or positive according as \( C_1 \) is \( < \) or \( = \) or \( > \) 1183.134. Hence, in this case, the Model-I of Chapter 6 is worse or equally good or better than the Model-II of Chapter 5 if \( C_1 < \) or \( = \) or \( > \) Rs.1183.134.

(iii) For \( \beta_3 = 0.055 \), the difference of profits \( (P_{61} - P_{52}) \) is negative or zero or positive according as \( C_1 \) is \( < \) or \( = \) or \( > \) 982.670. Hence, in this case, the Model-I of Chapter 6 is worse or equally good or better than the Model-II of Chapter 5 if \( C_1 < \) or \( = \) or \( > \) Rs.982.670.

(iv) For \( \beta_3 = 0.075 \), the difference of profits \( (P_{61} - P_{52}) \) is negative or zero or positive according as \( C_1 \) is \( < \) or \( = \) or \( > \) 782.206. Hence, in this case, the Model-I of Chapter 6 is worse or equally good or better than the Model-II of Chapter 5 if \( C_1 < \) or \( = \) or \( > \) Rs.782.206.