# Profit Analysis of a Two Unit Standby Oil Delivering System with off line Repair Facility when Priority is given to Partially Failed Unit over the Completely Failed Unit for Repair and System having a Provision of Switching over to Another System

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**Abstract**— Profit analysis of two unit standby oil delivering system with three types of failure complete failure, normal to partial failure and partial to complete failure is analysed. Initially one unit is operative and the other is standby. In case of partial failure, repair of unit is done by switching off the unit. When both the units fail then for repairing, priority is given to partially failed unit over completely failed unit. The system is in down state if one unit is completely failed and other is partially failed On the complete failure of both the units there is a provision of switching over to the other similar system. This practical situation may be observed in an oil refinery plant. The system is analyzed by making use of semi-Markov processes and regenerative point technique.

**Index Terms**— Oil delivering system, Semi Markov process, Regenerative point technique, measures of system effectiveness and profit analysis.

## 1 Introduction

In the field of reliability standby systems have been discussed by various researchers including [1-4] under various assumptions/considerations. For graphical study, they have taken assumed valuesfor failure and repair rates, and not used the observed values. However, some researchers including [5-8] studied some reliability models collecting real data on failure and repair rates of the units used in such systems. The concept of another line facility in case of failure of operating system has been introduced by Sharma et. al. [9]which can be seen in an oil refinery plant wherein on the failure of one standby oil delivering system, the supply is done by switching over to another system .This is done by changing a valve. A valve is a device which is used for switching over to another system. But the concept of three types of failures for such oil delivering system has not been considered so far and in this paper authors have tried to bridge this gap. There may be situations where a unit may fail due to complete failure, normal to partial failure and partial to complete failure. On the complete failure of the operative unit, it is repaired or it's component is replaced depending on the type of failure. In case of partial failure repair is done by switching off the unit and for repair of the units priority is given to partially failed unit over completely failed unit. The present study is based on the data collected on the failure and repair rates for the oil delivering system working in the oil refinery plant.

Initially one unit is operative and the other is standby. On the failure of the operative unit, it is repaired depending on type of failure or its component is replaced with a new one according as it is repairable or irreparable. The standby unit becomes operative at this stage If one unit is completely failed and other is partially failed unit then the system will be in down states and in the situation of complete failure of both the units, we switch over to the other system to avoid down time as the company may have other line facilities. Failure time is assumed to have exponential distribution. Repair/replacement times have been taken as arbitrary

## Notations

| | |
|---|---|
| s | stand by |
| Fr | unit is under repair |
| Fwr | failed unit is waiting for repair |
| $F_R$ | repair is continuing from previous state |
| Frep | unit is under replacement |
| Fwrep | failed unit is waiting for replacement |
| Frs | repair of failed units is kept under suspension |
| CV | valve change for being connected |

| | |
|---|---|
| $\lambda$ | rate of direct complete failure of main pump |
| $\lambda_1$ | failure rate of normal to partial failure |
| $\lambda_2$ | failure rate of partial to complete failure |
| $\alpha_1$ | repair rate of unit |
| $\alpha_2$ | replacement rate of unit |
| $\beta$ | rate of change of valve |
| p | prob. that unit is under repair |
| q | prob. that unit is under replacement |
| p | prob. of switching over to another line |
| q | prob. of failure of switching over to another line |
| $G_1(t), g_1(t)$ | c.d.f. and p.d.f. of the repair time of unit. |
| $G_2(t), g_2(t)$ | c.d.f. and p.d.f. of the replacement time of unit. |
| $G_3(t), g_3(t)$ | c.d.f. and p.d.f. of repair time of partially failed unit |

## TRANSITION PROBABILITIES AND MEAN SOJOURN TIMES

A transition diagram showing the various states of the system is shown in **Fig 1.** The epochs of entry into states 0, 1, 2,3,5,7,10,12,17,18,19 and20 are regenerative points. The transition probabilities are given below:

$p_{01} = p\lambda e^{-(\lambda+\lambda_1)t}\,dt$

$p_{02} = q\lambda\, e^{-(\lambda+\lambda_1)t}\,dt$

$p_{03} = \lambda_1\, e^{-(\lambda+\lambda_1)t}\,dt$

$p_{10} = g_1(t)\, e^{-(\lambda+\lambda_1)t}\,dt$

$p_{11}^{(4)} = p\, q_1(\lambda e^{-(\lambda+\lambda_1)t}$ ©1$)g_1(t)\,dt$

$$p_{14} = \frac{pq_1\lambda}{\lambda+\lambda_1}\left\{1-g_1^*(\lambda+\lambda_1)\right\}$$

$$p_{30} = g_3*(\lambda+\lambda_1)$$

$$p_{3,14} = \frac{q\lambda}{\lambda+\lambda_1}\left\{1-g_3^*(\lambda+\lambda_1)\right\}$$

$$p_{3,1}^{(15)} = \frac{p\lambda}{\lambda+\lambda_1}\left\{1-g_3^*(\lambda+\lambda_1)\right\}$$

$p_{3,1}^{,(15,16)}$

$$= \frac{p\lambda_1\lambda_2}{\lambda_2-\lambda_1-\lambda}\left\{\frac{1-g_3*(\lambda+\lambda_1)}{\lambda+\lambda_1}-\frac{1-g_3*(\lambda_2)}{\lambda_2}\right\}$$

$$p_{3,2}^{,(14,16)} = \frac{p}{q}\,p_{3,1}^{(15,16)}$$

$$p_{3,3}^{(16)} = \frac{\lambda_1}{\lambda_2-\lambda_1-\lambda}\left\{g_3^*(\lambda_2)-g_3^*(\lambda+\lambda_1)\right\}$$

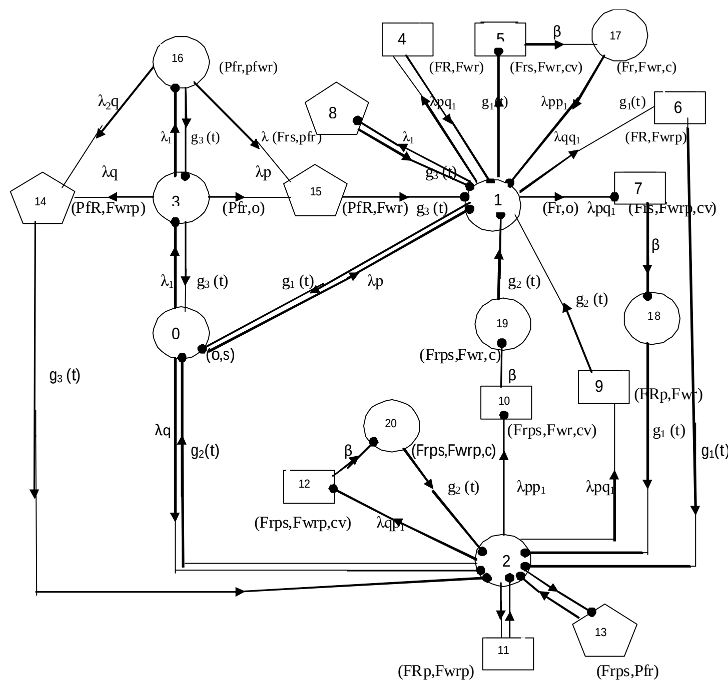
The mean sojourn time ($\mu_i$) in the regenerative state 'i' is given by

$$\mu_i = \int_0^\infty P(T_i > t)\,dt$$

The unconditional mean time taken by a system to transits' to any regenerative state 'j' when time is counted from epoch of entrance into state 'i' is mathematically stated as

$$m_{ij} = \int_0^\infty t\,d\,Q_{ij}(t) = -q_{ij}^{\,*}(s)$$

Fig:1. Transition Diagram




### MEAN TIME TO SYSTEM FAILURE

Let $\phi_i(t)$ be the c.d.f. of the first passage time from regenerative state i to a failed state .To determine the mean time to system failure (MTSF) of the system, considering the failed state as absorbing states. By probabilistic arguments, we obtain the following recursive relation for $\phi_i(t)$ :

$\phi_0(t) = Q_{01}(t)\,(s)\,\phi_1(t) + Q_{02}(t)\,(s)\,\phi_2(t) + Q_{03}(t)\,(s)\,\phi_3(t)$

$\phi_1(t) = Q_{10}(t)\,(s)\,\phi_0(t) + Q_{14}(t) + Q_{15}(t) + Q_{16}(t) + Q_{17}(t) + Q_{18}(t)\,(s)\,\phi_8(t)$

$\phi_2(t) = Q_{20}(t)\,(s)\,\phi_0(t) + Q_{2,9}(t) + Q_{2,10}(t) + Q_{2,11}(t) + Q_{2,12}(t) + Q_{2,13}(t)\,(s)\,\phi_{13}(t)$

$\phi_3(t) = Q_{30}(t)\,(s)\,\phi_0(t) + Q_{3,3}^{(16)}(t)\,\phi_3(t) + Q_{3,1}^{(15)}(t)\,(s)\,\phi_1(t) + Q_{3,1}^{(15,16)}(t)\,(s)\,\phi_1(t) + Q_{3,2}^{(14)}(t)\,(s)\,\phi_2(t) + Q_{3,2}^{(14,16)}(t)\,(s)\,\phi_2(t)$

$\phi_8(t) = Q_{8,1}(t)\,(s)\,\phi_1(t)$

$\phi_{13}(t) = Q_{13,2}(t)\,(s)\,\phi_2(t)$

Now the mean time to system failure (MTSF) when the system starts from state '0' is

$$\text{MTSF} = \lim_{s\to 0} \frac{1-\phi_0{}^{**}(s)}{s} = \frac{N}{D}$$

Where

$N = \mu_0\{(1-p_{33}^{(16)})(1-p_{18})(1-p_{2,13})\} + \mu_2 [\{1-p_{18}p_{81}\}\{p_{02}(1-p_{33}^{(16)}) + (p_{3,2}^{(14)} + p_{3,2}^{(14,16)})\ p_{03}\}] + K_3\{p_{03}(1-p_{18})(1-p_{2,13})\} + \mu_8\ p_{18}(1-p_{2,13})\{(1-p_{3,3}^{(16)})(1-p_{02}) - p_{03}p_{30} - p_{03}(p_{3,2}^{(14)} + p_{3,2}^{(14,16)})\} + \mu_{13}\ p_{2,13}(1-p_{18})\{(1-p_{3,3}^{(16)})(1-p_{01}) - p_{03}p_{30} - p_{03}(p_{3,1}^{(15)} + p_{3,1}^{(15,16)})\}$

$D = (1-p_{3,3}^{(16)})\{-p_{01}p_{10} + 1 - p_{18})(1-p_{2,13}) - p_{02}p_{20}(1-p_{18})\} - p_{03}\{p_{10}(p_{3,1}^{(15)} + p_{3,1}^{(15,16)}) + p_{30}(1-p_{18})(1-p_{2,13}) + p_{20}(p_{3,2}^{(14)} + p_{3,2}^{(14,16)})(1-p_{18})\}$

## AVAILABILITY ANALYSIS

Let $A_i(t)$ be the probability that the system is in up state at instant t given that the system entered regenerative state i at t=0. The availability $A_i(t)$ is see to satisfy the following recursive relations:

$A_0(t) = M_0(t) + q_{01}(t)\copyright A_1(t) + q_{02}(t)\copyright A_2(t) + q_{03}\copyright A_3(t)$

$A_1(t) = M_1(t) + q_{10}(t)\copyright A_0(t) + q_{11}^{(4)}(t)\copyright A_1(t) + q_{12}^{(6)}(t)\copyright A_2 + q_{15}(t)\copyright A_5(t) + q_{17}(t)\copyright A_7(t) + q_{18}(t)\copyright A_8(t)$

$A_2(t) = M_2(t) + q_{20}(t)\copyright A_0(t) + q_{2,1}^{(9)}(t)\copyright A_1(t) + q_{2,2}^{(11)}(t)\copyright A_2(t) + q_{2,10}(t)\copyright A_{10}(t) + q_{2,12}(t)\copyright A_{12}(t) + q_{2,13}(t)\copyright A_{13}(t)$

$A_3(t) = M_3(t) + q_{30}(t)\copyright A_0(t) + q_{3,1}^{(15)}(t)\copyright A_1(t) + q_{3,1}^{(16,15)}\copyright A_1(t) + q_{3,2}^{(14)}\copyright A_2(t) + q_{3,2}^{(16,14)}\copyright A_2(t) + q_{3,3}^{(16)}(t)\copyright A_3(t)$

$A_5(t) = q_{5,17}(t)\copyright A_{17}(t)$

$A_7(t) = q_{7,18}(t)\copyright A_{18}(t)$

$A_8(t) = q_{8,1}(t)\copyright A_1(t)$

$A_{10}(t) = q_{10,19}(t)\copyright A_{19}(t)$

$A_{12}(t) = q_{12,20}(t)\copyright A_{20}(t)$

$A_{13}(t) = q_{13,2}(t)\copyright A_2(t)$

$A_{17}(t) = M_{17}(t) + q_{17,1}(t)\copyright A_1(t)$

$A_{18}(t) = M_{18}(t) + q_{18,2}(t)\copyright A_2(t)$

$A_{19}(t) = M_{19}(t) + q_{19,1}(t)\copyright A_1(t)$

$A_{20}(t) = M_{20}(t) + q_{20,2}(t)\copyright A_2(t)$

where

$M_0(t) = e^{-(\lambda+\lambda_1)t}$

$M_1(t) = e^{-(\lambda+\lambda_1)t}\,\overline{G_1}(t)$

$M_2(t) = e^{-(\lambda+\lambda_1)t}\,\overline{G_2}(t)$

$M_3(t) = e^{-(\lambda+\lambda_1)t}\,\overline{G_3}(t) + \lambda_1(e^{-(\lambda+\lambda_1)t}\copyright e^{-\lambda_2 t})\overline{G_3}(t)$

$M_{17}(t) = \overline{G_1}(t)$

$M_{18}(t) = \overline{G_1}(t)$

$M_{19}(t) = \overline{G_2}(t)$

$M_{20}(t) = \overline{G_2}(t)$

$M_8(t) = \overline{G_3}(t)$

$M_{13}(t) = \overline{G_3}(t)$

In steady-state, availability of the system is given by

$$A_0 = \lim_{s\to 0} s\ A_0{}^*(s) = \frac{N_1}{D_1}$$

$A = N_1/D_1$

where

$\mathbf{N_1} = p_{03}[(\mu_1 + \mu_{17}\ p_{15} + \mu_{18}\ p_{17})\{(-p_{2,1}^{(9)} - p_{2,10})(-p_{3,2}^{(14)} - p_{3,2}^{(14,16)}) - (1-p_{2,2}^{(11)} - p_{2,13} - p_{13,2} - p_{2,12})(-p_{3,1}^{(15)} - p_{3,1}^{(15,16)})\} - (1-p_{11}^{(4)} - p_{18} - p_{15})\{(\mu_2 + \mu_{19}\ p_{2,10} + \mu_{20}\ p_{2,12})(-p_{3,2}^{(14)} - p_{3,2}^{(14,16)}) - (1-p_{2,2}^{(11)} - p_{2,13} - p_{13,2} - p_{2,12})\mu_3\} + (-p_{1,2}^{(6)} - p_{17})\{(\mu_2 + \mu_{19}\ p_{2,10} + \mu_{20}\ p_{2,12})(-p_{3,1}^{(15)} - p_{3,1}^{(15,16)}) - (-p_{2,1}^{(9)} - p_{2,10})\mu_3\}] + (1-p_{3,3}^{(16)})[\mu_0\{(1-p_{11}^{(4)} - p_{18} - p_{15})(1-p_{2,2}^{(11)} - p_{2,13} - p_{13,2} - p_{2,12}) - (-p_{1,2}^{(6)} - p_{17})(-p_{2,1}^{(9)} - p_{2,10})\} + p_{01}\{(\mu_1 + \mu_{17}\ p_{15} + \mu_{18}\ p_{17})(1-p_{2,2}^{(11)} - p_{2,13} - p_{13,2} - p_{2,12}) - (-p_{1,2}^{(6)} - p_{17})(\mu_2 + \mu_{19}\ p_{2,10} + \mu_{20}\ p_{2,12})\} - p_{02}\{(\mu_1 + \mu_{17}\ p_{15} + \mu_{18}\ p_{17})(-p_{2,1}^{(9)} - p_{2,10}) - (1-p_{11}^{(4)} - p_{18} - p_{15})$
$(\mu_2 + \mu_{19}\ p_{2,10} + \mu_{20}\}]$

$\mathbf{D_1} = \mu_0\ [p_{10}\{(-p_{2,1}^{(9)} - p_{2,10})(-p_{3,2}^{(14)} - p_{3,2}^{(14,16)}) - (1-p_{2,2}^{(11)} - p_{2,13} - p_{13,2} - p_{2,12})(-p_{3,1}^{(15)} - p_{3,1}^{(15,16)})\} - p_{20}\{(1-p_{11}^{(4)} - p_{18} - p_{15})(-p_{3,2}^{(14)} - p_{3,2}^{(14,16)}) - (-p_{1,2}^{(6)} - p_{17})(-p_{3,1}^{(15)} - p_{3,1}^{(15,16)})\} + p_{30}\{(1-p_{11}^{(4)} - p_{18} - p_{15})\ p_{2,2}^{(11)} - p_{2,13} - p_{2,12}) - (-p_{1,2}^{(6)} - p_{17})(-p_{2,1}^{(9)} - p_{2,10})\} + K_1\ [p_{03}\{(-p_{2,1}^{(9)} - p_{2,10})(-p_{3,2}^{(14)} - p_{3,2}^{(14,16)}) - (1-p_{2,2}^{(11)} - p_{2,13} - p_{2,12})(-p_{3,1}^{(15)} - p_{3,1}^{(15,16)})\} + \{p_{01}(1-p_{2,2}^{(11)} - p_{2,13} - p_{2,12}) - p_{02}(-p_{2,1}^{(9)} - p_{2,10})\}(1-p_{3,3}^{(16)})] + K_2\ [p_{03}\{(-p_{1,2}^{(6)} - p_{17})(-p_{3,1}^{(15)} - p_{3,1}^{(15,16)}) - (1-p_{11}^{(4)} - p_{18} - p_{15})(-p_{3,2}^{(14)} - p_{3,2}^{(14,16)})\} + (1-p_{3,3}^{(16)})\{(1-p_{11}^{(4)} - p_{18} - p_{15})\ p_{02} - (-p_{1,2}^{(6)} - p_{17})\ p_{01}\}] + K_3\ [p_{03}\{(1-p_{11}^{(4)} - p_{18} - p_{15})p_{2,2}^{(11)} - p_{2,13} - p_{2,12}) - (-p_{1,2}^{(6)} - p_{17})(-p_{2,1}^{(9)} - p_{2,10})\} + \mu_5\ p_{20}\ p_{15}[\{(-p_{3,2}^{(14)} - p_{3,2}^{(14,16)})\ p_{03} - p_{02}(1-p_{33}^{(16)})\} + p_{30}\{-(1-p_{2,2}^{(11)} - p_{2,13} - p_{2,12})\ p_{03}\} + (1-p_{2,2}^{(11)} - p_{2,13} - p_{2,12})\{(1-p_{33}^{(16)})\}] + \mu_7\ p_{17}\ [-(-p_{3,1}^{(15)} - p_{3,1}^{(15,16)})p_{03}p_{20} + (-p_{2,1}^{(9)} - p_{2,10})p_{03}p_{30} - (-p_{2,1}^{(9)} - p_{2,10})(1-p_{3,3}^{(16)}) + p_{01}p_{20}(1-p_{3,3}^{(16)})] + \mu_8\ [(-p_{3,2}^{(14)} - p_{3,2}^{(14,16)})p_{03}\ p_{20} - p_{02}\ p_{20}(1-p_{3,3}^{(16)}) - (1-p_{2,2}^{(11)} - p_{2,13} - p_{2,12})\ p_{03}\ p_{30} + (1-p_{2,2}^{(11)} - p_{2,13} - p_{2,12})(1-p_{3,3}^{(16)})] + \mu_{10}\ p_{2,10}[-(-p_{3,2}^{(14)} - p_{3,2}^{(14,16)})\ p_{03}\ p_{10} + \{p_{02}p_{10} - (-p_{1,2}^{(6)} - p_{17})\}\{1-p_{3,3}^{(16)}\} + (-p_{1,2}^{(6)} - p_{17})\ p_{03}\ p_{30}] + \mu_{12}\ p_{2,12}\ [(-p_{3,1}^{(15)} - p_{3,1}^{(15,16)})\ p_{03}\ p_{10} - (1-p_{11}^{(4)} - p_{18} - p_{15})\ p_{03}p_{30} + \{-p_{01}\ p_{10} + (1-p_{11}^{(4)} - p_{18} - p_{15})\}\{1-p_{3,3}^{(16)}\}] + \mu_{13}\ p_{2,13}[\{p_{03}\ (-p_{3,1}^{(15)} - p_{3,1}^{(15,16)}) - p_{01}(1-p_{3,3}^{(16)})\}p_{10} - (1-p_{11}^{(4)} - p_{18} - p_{15})\ p_{03}\ p_{30} + (1-p_{11}^{(4)} - p_{18} - p_{15})\{1-p_{3,3}^{(16)}\}] + \mu_{17}\ p_{15}\ [p_{03}\{p_{20}(-p_{3,2}^{(14)} - p_{3,2}^{(14,16)}) - p_{30}(1-p_{2,2}^{(11)} - p_{2,13} - p_{2,12})\} + \{(1-p_{2,2}^{(11)} - p_{2,13} - p_{2,12}) - p_{02}\ p_{20}\}\{1-p_{3,3}^{(16)}\}] + \mu_{18}\ [\{-p_{20}\ (-p_{3,1}^{(15)} - p_{3,1}^{(15,16)}) + p_{30}(-p_{2,1}^{(9)} - p_{2,10})\}\ p_{03} + \{p_{01}p_{20} - (-p_{2,1}^{(9)} - p_{2,10})\}\{1-p_{3,3}^{(16)}\}] + \mu_{19}\ p_{2,10}\ [\{p_{02}\ p_{10} - (-p_{1,2}^{(6)} - p_{17})\}\{1-p_{3,3}^{(16)}\} + \{p_{30}(-p_{1,2}^{(6)} - p_{17}) - (-p_{3,2}^{(14)} - p_{3,2}^{(14,16)})\ p_{10}\}\ p_{03}] + \mu_{20}\ p_{2,12}\ [\{p_{10}\ (-p_{3,1}^{(15)} - p_{3,1}^{(15,16)}) - p_{30}\ (1-p_{11}^{(4)} - p_{18} - p_{15})\}\ p_{03} + \{(1-p_{11}^{(4)} - p_{18} - p_{15}) - p_{01}p_{10}\}\{1-p_{3,3}^{(16)}\}]$

## OTHER MEASURES OF SYSTEM EFFECTIVENESS

Busy period analysis for repair time only = $N_2/D_1$

Busy period analysis for replacement time only = $N_3/D_1$

Expected no of Replacements = $N_4/D_1$

Expected no of visits by repairman = $N_5/D_1$

Expected time during which operation is performed by some other system = $N_6/D_1$

Expected down time = $N_7/D_1$

$\mathbf{N_2} = p_{03}[W_1 + W_8\ p_{18} + W_{17}\ p_{15} + W_{18}\ p_{17}\{(-p_{2,1}^{(9)} - p_{2,10})(-p_{3,2}^{(14)} - p_{3,2}^{(14,16)}) - (1-p_{2,2}^{(11)} - p_{2,13} - p_{2,12})(-p_{3,1}^{(15)} - p_{3,1}^{(15,16)})\} - (1-p_{11}^{(4)} - p_{18} - p_{15})\{W_{13}\ p_{2,13}(-p_{3,2}^{(14)} - p_{3,2}^{(14,16)}) - (1-p_{2,2}^{(11)} - p_{2,13} - p_{2,12})\ W_3\} + (-p_{1,2}^{(6)} - p_{17})\{W_{13}\ p_{2,13}(-p_{3,1}^{(15)} - p_{3,1}^{(15,16)}) - (-p_{2,1}^{(9)} - p_{2,10})\ W_3\}] + (1-p_{33}^{(16)})[p_{01}\{p_{01}\{W_1 + W_8\ p_{18} + W_{17}\ p_{15} + W_{18}\ p_{17}\ p_{7,18}(1-p_{2,2}^{(11)} - p_{2,13} - p_{2,12}) - (-p_{1,2}^{(6)} - p_{17})\ W_{13}\ p_{2,13}\} - p_{02}\{W_1 + W_8\ p_{18} + W_{17}\ p_{15} + W_{18}\ p_{17}\ p_{7,18}(-p_{2,1}^{(9)} - p_{2,10}) - (1-p_{11}^{(4)} - p_{18} - p_{15})W_{13}\ p_{2,13}\}]$

$N_3 = W_2 + W_{20}\ p_{2,12} + W_{19}\ p_{2,10}\ [-p_{03}\{(1-p_{11}^{(4)} - p_{18} - p_{15}\ p_{5,17})(-p_{3,2}^{(14)} - p_{3,2}^{(14,16)}) - (-p_{1,2}^{(6)} - p_{17})(-p_{3,1}^{(15)} - p_{3,1}^{(15,16)})\} + \{1-p_{3,3}^{(16)}\}\{-$

$p_{01}$ (- $p_{1,2}^{(6)}$ - $p_{17}$ ) + $p_{02}$ (1- $p_{11}^{(4)}$ – $p_{18}$ – $p_{15}$ }]
$D_1$ is already specified

$N_4$= $W_2$ + $W_{20}$ $p_{2,12}$ $p_{2,20}$ +$W_{19}$ $p_{2,10}$ $p_{10,19}$ { $p_{2,0}$ + $p_{2,1}^{(9)}$ + $p_{2,2}^{(11)}$ + $p_{2,12}$ + $p_{2,10}$} [ - $p_{03}$ { (1 - $p_{11}^{(4)}$ – $p_{18}$ – $p_{15}$)(-$p_{3,2}^{(14)}$-$p_{3,2}^{(14,16)}$) – (-$p_{1,2}^{(6)}$- $p_{17}$ $p_{7,18}p_{18,2}$)(-$p_{3,1}^{(15)}$ – $p_{3,1}^{(15,16)}$) }+ {1-$p_{3,3}^{(16)}$}{ -$p_{01}$ (-$p_{1,2}^{(6)}$- $p_{17}$ $p_{7,18}p_{18,2}$) + $p_{02}$ (1-$p_{11}^{(4)}$ – $p_{18}p_{8,1}$ – $p_{15}$ $p_{5,17}p_{17,1}$)}]

$N_5$ = (1-$p_{3,3}^{(16)}$)( (1-$p_{11}^{(4)}$ – $p_{18}$ – $p_{15}$)(1-$p_{2,2}^{(11)}$ –$p_{2,13}$ –$p_{2,12}$ )- (-$p_{1,2}^{(6)}$- $p_{17}$)( - $p_{2,1}^{(9)}$ –$p_{2,10}$)

$N_6$ = $p_{03}$ [( $W_{17}$ $p_{1,5}$ + $w_{18}$ $p_{1,7}$ ) {( - $p_{2,1}(9)$ –$p_{2,10}$) (-$p_{3,2}^{(14)}$-$p_{3,2}^{(14,16)}$) –(1-$p_{2,2}^{(11)}$ –$p_{2,13}$ – $p_{2,12}$ )(-$p_{3,1}^{(15)}$ – $p_{3,1}^{(15,16)}$)} – (1-$p_{11}(4)$ – $p_{1,8}$ – $p_{15}$ ) {( $W_{20}p_{2,12}$ +$W_{19}$ $p_{2,10}$ )(-$p_{3,2}^{(14)}$-$p_{3,2}^{(14,16)}$) } + (-$p_{1,2}(6)$- $p_{17}$ ) { ( $W_{20}p_{2,12}$ +$w_{19}$ $p_{2,10}$ ) (-$p_{3,1}^{(15)}$ – $p_{3,1}^{(15,16)}$)}] + { 1-$p_{3,3}^{(16)}$}[ $p_{01}$ {( $W_{17}$ $p_{15}$ + $w_{18}$ $p_{17}$ ) (1-$p_{2,2}^{(11)}$ –$p_{2,13}$ –$p_{2,12}$ ) – (-$p_{1,2}(6)$- $p_{17}$ ) ( $W_{20}p_{2,12}$ +$w_{19}$ $p_{2,10}$ ) } –$p_{02}$ { ( $W_{17}$ $p_{15}$ + $w_{18}$ $p_{17}$ ) ( - $p_{2,1}(9)$ –$p_{2,10}$)
– (1-$p_{11}(4)$ – $p_{18}$ – $p_{15}$ )( $W_{20}p_{2,12}$ +$w_{19}$ $p_{2,10}$ ) }]

**$N_7$** = $p_{03}$[$D_8p_{18}${ ( - $p_{2,1}^{(9)}$ –$p_{2,10}$) (-$p_{3,2}^{(14)}$-$p_{3,2}^{(14,16)}$)(-$p_{3,2}^{(14)}$-$p_{3,2}^{(14,16)}$) - (1- $p_{2,2}^{(11)}$ –$p_{2,13}$ $p_{13,2}$ –$p_{2,12}$ )(-$p_{3,1}^{(15)}$ – $p_{3,1}^{(15,16)}$)}-$D_{13}p_{2,13}${ (1- $p_{11}^{(4)}$ – $p_{18}p$ – $p_{15}$ )(-$p_{3,2}^{(14)}$-$p_{3,2}^{(14,16)}$)- (-$p_{1,2}^{(6)}$- $p_{17}$ )(-$p_{3,1}^{(15)}$ – $p_{3,1}^{(15,16)}$)}] + {1- $p_{3,3}^{(16)}$}[$p_{01}$ {$D_8$ $p_{18}$ (1- $p_{2,2}^{(11)}$ –$p_{2,13}$ –$p_{2,12}$ ) – (-$p_{1,2}^{(6)}$- $p_{17}$ $p_{7,18}$)$D_{13}$ $p_{2,13}$} – $p_{02}${ $D_8$ $p_{18}$ ( - $p_{2,1}^{(9)}$ –$p_{2,10}$)- (1-$p_{11}^{(4)}$ – $p_{18}$ – $p_{15}$ $p_{5,17}$)$D_{13}p_{2,13}$}]

## PROFIT ANALYSIS

In steady-state, the expected profit per unit time incurred to the system is given by
Profit (P) = $C_0A_0$– $C_1B_0$ – $C_2BR_0$ – $C_3R_0$ – $C_4$ $V_0$ – $C_5AP_0$ – $C_6$ $D_0$
where
$C_0$ = revenue per unit up time
$C_1$ = cost per unit time for which repairman is busy for repair
$C_2$ = cost per unit time for which repairman is busy for replacement
$C_3$ = cost per unit of replacement
$C_4$ = cost per visit of repairman
$C_5$ = cost per unit time for which operation is performed by other system
$C_6$ = cost per unit time for which system is down

## PARTICULAR CASE

The following particular case is considered for graphical interpretation

$e^{-\alpha_1 t}$
$g_1(t) = \alpha_1 e^{-\alpha_1(t)}$ $e^{-\alpha_1 t}$
$g_1(t) = \alpha_2 e^{-\alpha_2(t)}$ $e^{-\alpha_1 t}$ $e^{-\alpha_1 t}$
$g_3(t) = \alpha_3 e^{-\alpha_3(t)}$

;
c0=1000,c1=100 , c2=180 , c3=86390.19606
c4=500, c5=5000

## GRAPHICAL INTERPRETATION

Fig 2 shows the behavior of profit vs revenue per unit time for different values of cost of repairman visit

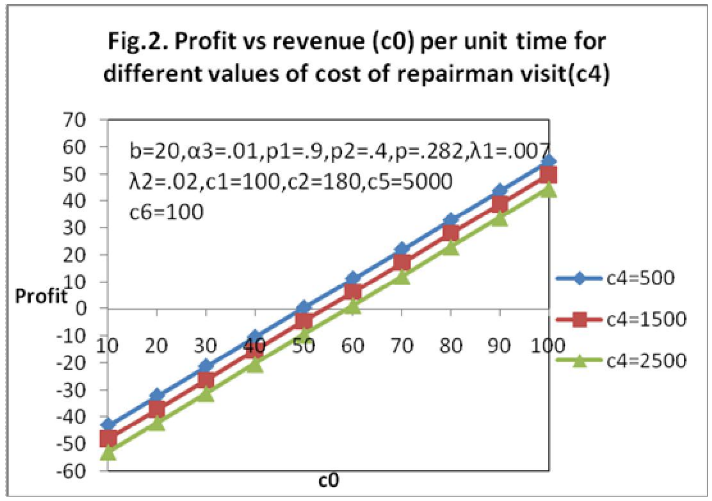


Fig.2. Profit vs revenue (c0) per unit time for different values of cost of repairman visit(c4)

It can be interpretated from the graph that profit increases with increased in the value of revenue per unit up time($C_0$) and has lower values for higher values of cost of visit of repairman($C_4$)

1. For $C_4$ = 500, the profit is positive or zero or negative according as $C_0$ > or = or < 49.5616 and hence the revenue per unit up time should be fixed not less than 49.5616.
2. For $C_4$ = 1500, the profit is positive or zero or negative according as $C_0$ > or = or <54.1666 and hence the revenue per unit up time should be fixed not less than 54.1666
3. For $C_4$ = 2500 the profit is positive or zero or negative according as $C_0$ > or = or < 58.7717 and hence the revenue per unit up time should be fixed not less than 58.7717

Fig 3 shows the behavior of profit vs cost of repairman visit for different values of cost for which the repairman is busy for repair

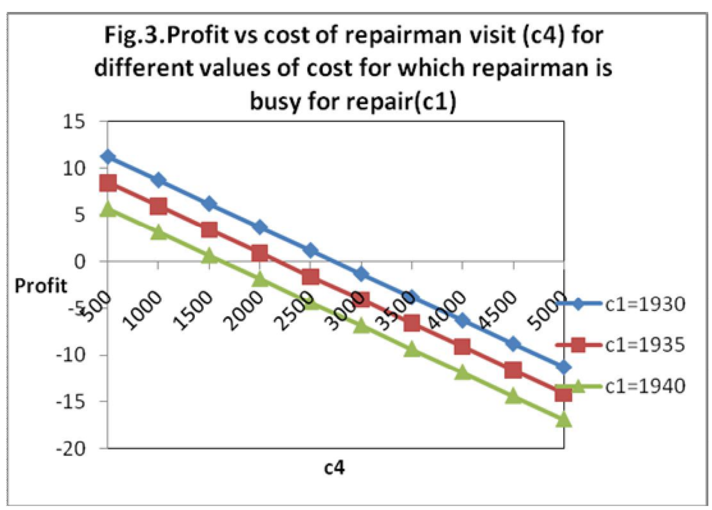


Fig.3.Profit vs cost of repairman visit (c4) for different values of cost for which repairman is busy for repair(c1)

It can be interpretated from the graph that profit decreses with increased in the value of cost of repairman visit($C_4$) and has lower values for higher values of cost for which the repairman is busy for repair($C_1$)

1. For $C_1$ = 1930, the profit is positive or zero or negative according as $C_4$ > or = or < 2752.4790 and hence the cost per visit of repairman should be fixed not be greater than 2752.4790
2. For $C_1$ = 1935, the profit is positive or zero or negative according as $C_0$ > or = or <2194.721 and hence the cost per visit of repairman should be fixed not be greater than 2194.721
3. For $C_1$ = 1940 the profit is positive or zero or negative according as $C_0$ > or = or < 1636.9852 and hence the cost per visit of repairman should be fixed not be greater than 1636.9852

## CONCLUSIONS

So far as the profitability of the system is concerned, minimum amount of revenue and maximum amount to be paid to the repairman for repairing/replacing the failed unit can be suggested by the company using such sytem on the basis of the graphical interpretation given above.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