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Analysis of Two Unit Standby Oil Delivering System with Two Types of Repair Facility and Priority is Given to Partially Failed Unit with Provision of Switching Over to Another System

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Abstract

This paper develops a model for two unit standby oil delivering system. The system can be failed with three types of failure complete failure, normal to partial failure and Partial to complete failure. Initially one unit is operative and the other is standby. In case of partial failure, inspection is carried out to check whether online or off line repair can be done and priority is given to partially failed unit for repair. 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

Keywords: Oil delivering system, Semi Markov process, Regenerative point technique, measures of system effectiveness and profit analysis.

Introduction

Increasing Reliability of units has become important and urgent with the complex mechanization and automation of industrial process. Standby redundancy plays an important role in enhancing system reliability Standby systems have been discussed by various researchers including [1-12] in the field of reliability under various assumptions/considerations. most of these studies are not based on the real data. however, some researchers 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 the operating system has been introduced by Sharma et. al. [12] 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 situation that unit may fail completely either directly from normal mode or via partial failure. In case of partial failure priority is given to partial failed unit for repair and the repair can be done off line as well as online after inspecting the unit such systems where priority for repair is given to partially failed unit may generate more revenue and hence may be more profitable because it can be operable earlier as compare to completely failed unit. In this system When one unit is under repair and other gets partially failed, then keeping the repair of the former in abeyance , the inspection is carried out to check whether the partially failed unit can be repaired offline or online. If an online repair can be done, priority is given over the repair of the former unit. It is also assumed that in the case of online repair no further damage can occur. This time system will be inoperative state but if the repair of partially failed unit cannot be done online then at that time repair of completely failed unit is kept under suspension and the repair of partially failed unit is done first by switching off the unit. Under such situation system will be in down state and no demand of switching over to second line is given. On complete failure of both the units switching over to another system takes place

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Notations and states of system

O	operative unit
S	stand by
Fr	unit is under repair
Fwr	failed unit is waiting for repair
FR	repair is continuing from previous state
Frep	unit is under replacement
Fwrep	failed unit is waiting for replacement
FRp	replacement is continuing from previous state
Frs	repair of failed units is kept under suspension
Frps	replacement of failed unit is kept under suspension
Pf	unit is under partial failure
Pfi	partially failed unit is under inspection
Pfofr	partially failed unit is under offline repair
Pfonr	partially failed unit is under online repair
Pfwr	partially failed unit is waiting for repair
PfR	repair of partially failed unit is continuing from previous state
Pfrs	repair of partially failed unit is kept under suspension
C	system gets connection
CV	valve change for being connected
λ	rate of direct complete failure of main pump
λ_1	failure rate of normal to partial failure
λ_2	failure rate of partial to complete failure
α	inspection rate of unit
α_1	repair rate of completely failed unit
α_2	replacement rate of completely failed unit
α_3	offline repair rate of partially failed unit
α_4	online repair rate of partially failed unit
β	rate of change of valve
β_1	inspection rate of partially failed unit
p	prob. that unit goes for repair
q	probability that unit is goes for replacement
p	probability of switching over to another line
q_1	probability of failure of switchingover to another line
p_2	probability that on line repair can be done
q_2	probability of online repair cannot be done
I(t),i(t)	c.d.f. and p.d.f. of inspection time of partially failed unit
$G_1(t),g_1(t)$	c.d.f. and p.d.f. of the repair time of completely failed unit.
$G_2(t),g_2(t)$	c.d.f .and p.d.f. of the replacement time of completely failed unit.
$G_3(t),g_3(t)$	c.d.f. and p.d.f. of off line repair time of partially failed unit.
$G_4(t),g_4(t)$	c.d.f. and p.d.f. of on line 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.** The epochs of entry into states 0, 1, 2,3,5,7,10,12,17,18,19,20,21,22and 23 are regenerative points. The transition probabilities are given below:

The mean sojourn time (μ_i) in the regenerative state 'i' is given by

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p_{01} $\dfrac{p\lambda}{\lambda+\lambda_1}$,

p_{02} $\dfrac{q\lambda}{\lambda+\lambda_1}$,

p_{03} $\dfrac{\lambda_1}{\lambda+\lambda_1}$

p_{10} $g_1^*(\lambda+\lambda_1)$

$p_{11}^{(4)}$ $\dfrac{pq_1\lambda}{\lambda+\lambda_1}\left\{1-g_1^*(\lambda+\lambda_1)\right\}$

$p_{12}^{(6)}$ $\dfrac{qq_1\lambda}{\lambda+\lambda_1}\left\{1-g_1^*(\lambda+\lambda_1)\right\}$

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

p_{15} $\dfrac{p_1p\lambda}{\lambda+\lambda_1}\left\{1-g_1^*(\lambda+\lambda_1)\right\}$

p_{16} $\dfrac{q_1q\lambda}{\lambda+\lambda_1}\left\{1-g_1^*(\lambda+\lambda_1)\right\}$

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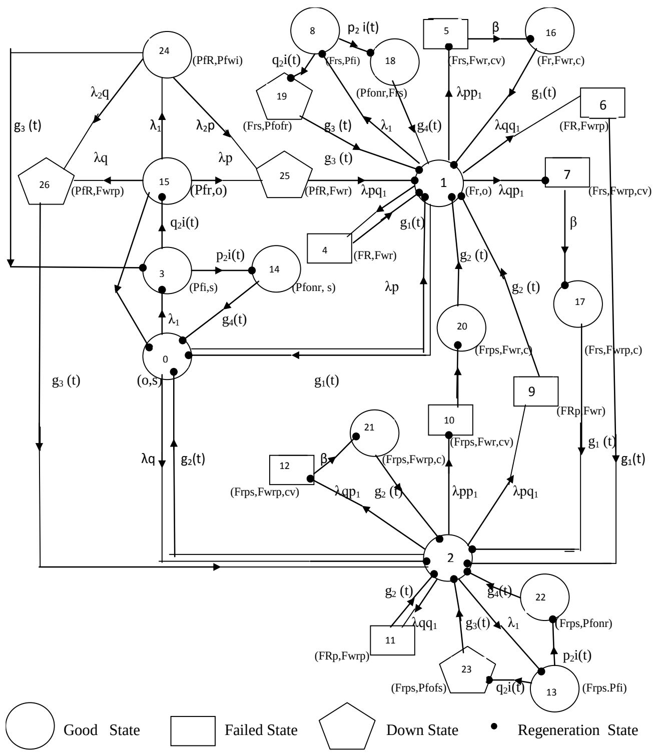
p_{17} $\quad \dfrac{p_1 q\lambda}{\lambda+\lambda_1}\left\{1-g_1^{*}(\lambda+\lambda_1)\right\}$



State Transition Diagram

Fig

p_{18} $\quad \dfrac{\lambda_1}{\lambda+\lambda_1}\left\{1-g_1^{*}(\lambda+\lambda_1)\right\}$

p_{20} $\quad g_2^{*}(\lambda+\lambda_1)$

$p_{2,1}^{(9)}$ $\quad \dfrac{pq_1\lambda}{\lambda+\lambda_1}\left\{1-g_2^{*}(\lambda+\lambda_1)\right\}$

$p_{2,2}^{(11)}$ $\quad \dfrac{qq_1\lambda}{\lambda+\lambda_1}\left\{1-g_2^{*}(\lambda+\lambda_1)\right\}$

$p_{2,9}$ $\quad \dfrac{pq_1\lambda}{\lambda+\lambda_1}\left\{1-g_2^{*}(\lambda+\lambda_1)\right\}$

$p_{2,10}$ $\quad \dfrac{pp_1\lambda}{\lambda+\lambda_1}\left\{1-g_2^{*}(\lambda+\lambda_1)\right\}$

$p_{2,11}$ $\quad \dfrac{qq_1\lambda}{\lambda+\lambda_1}\left\{1-g_2^{*}(\lambda+\lambda_1)\right\}$

$p_{2,12}$ $\quad \dfrac{qp_1\lambda}{\lambda+\lambda_1}\left\{1-g_2^{*}(\lambda+\lambda_1)\right\}$

$p_{3,14} = p_{13,22} = p_2\, i(t)$

$p_{3,15} = p_{13,23} = q_2\, i(t)$

$p_{15,0}$ $\quad g_3{*}(\lambda+\lambda_1)$

$p_{15,1}^{(25)}$ $\quad \dfrac{\lambda p}{\lambda+\lambda_1}\left\{1-g_3^{*}(\lambda+\lambda_1)\right\}$

$p_{15,2}^{(26)}$ $\quad \dfrac{\lambda q}{\lambda+\lambda_1}\left\{1-g_3^{*}(\lambda+\lambda_1)\right\}$

μ_0 $\quad \dfrac{1}{\lambda+\lambda_1}$

μ_1 $\quad \dfrac{1-g_1^{*}(\lambda+\lambda_1)}{\lambda+\lambda_1}$

μ_2 $\quad \dfrac{1-g_2^{*}(\lambda+\lambda_1)}{\lambda+\lambda_1}$

$\mu_3 = \mu_{13} = -i^{*\prime}(o)$

μ_{15} $\quad \dfrac{1-g_3^{*}(\lambda+\lambda_1)}{\lambda+\lambda_1}$

$\mu_5 = \dfrac{1}{\beta} = \mu_7 = \mu_{10} = \mu_{12}$

μ_{17} $\quad -g_1^{*\prime}(0)$

$\mu_{14} = \mu_{18} = \mu_{24} = -g_4^{*\prime}(0)$

$\mu_{19} = \mu_{23} = -g_3^{*\prime}(0)$

$\mu_{21} = \mu_{20} = -g_2^{*\prime}(0)$

Mean time to system failure

To determine the mean time to system failure (MTSF) of the system, considering the failed state as absorbing states. The expression obtained for it

T = MTSF =

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

where

N = μ_0 (1- $p_{15,3}^{(24)}$ $p_{3,15}$)(1- p_{18})(1 - $p_{2,13}$) + μ_1(1-$p_{2,13}$ ($p_{13,23}$ + $p_{13,22}$)) (p_{01} (1 -$p_{3,15}$ $p_{15,3}^{(24)}$)-p_{03} (-$p_{3,15}$($p_{15,1}^{(24)}$ + $p_{15,1}^{(24,26)}$)))+ μ_2 (1- $p_{1,8}$($p_{8,19}$ + $p_{8,18}$))(p_{02} (1- $p_{3,15}$ $p_{15,3}^{(24)}$)-p_{03} (-$p_{3,15}$($p_{15,1}^{(24)}$ +

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$$p_{15,1}^{(24,26)}))) + \mu_3\, p_{03}\,(1- p_{1,8}(p_{8,19} + p_{8,18}))(1 - p_{2,13}(p_{13,23}+p_{13,22})) +\mu_8\, p_{18}\,(((1- p_{3,15}p_{15,3}^{(24)}) + p_{03}(-p_{3,14}- p_{3,15}))(1- p_{2,13}(p_{13,23}+ p_{13,22}))+ p_{20}\,(p_{03}\,(-p_{3,15}(p_{15,1}^{(24)}+p_{15,1}^{(24,26)})) -p_{02}(1-p_{3,15}p_{15,3}^{(24)})\,) + (p_{2,9} + p_{2,10} + p_{2,11} +p_{2,12})(-p_{03}\, p_{3,15}(p_{15,1}^{(24)} + p_{15,1}^{(24,26)}) - p_{02}\,(1- p_{3,15}p_{15,3}^{(24)}))) + \mu_{13}\, p_{2,13}\,(p_{10}\,(-p_{01}(1-p_{3,15}p_{15,3}^{(24)}) -p_{03}\, p_{3,15}\,(p_{15,1}^{(24)}+p_{15,1}^{(24,26)})) + (1-p_{1,8}(p_{8,19} + p_{8,18}))((1- p_{3,15}p_{15,3}^{(24)})+ p_{03}(-p_{3,14} - p_{3,15}))+ (p_{14} + p_{15} + p_{16} +p_{17})\,(-p_{01}(1- p_{3,15}p_{15,3}^{(24)})- p_{03}\, p_{3,15}(p_{15,1}^{(24)}+p_{15,1}^{(24,26)}))) + \mu_{14}\, p_{314}\, p_{03}\,(1- p_{1,8}(p_{8,19} + p_{8,18}))(p_{2,13}(p_{13,23} + p_{13,22}))+ p_{3,15}\, p_{03}\,(1- p_{1,8}(p_{8,19} + p_{8,18}))(1-p_{2,13}(p_{13,23}+p_{13,22})) + \mu_{18}\, p_{818}\, p_{18}((1-p_{2,13}\,(p_{13,23}+ p_{13,22}))((1- p_{3,15}p_{15,3}^{(24)}\,) + p_{03}(-p_{3,14}-p_{3,15})) + p_{20}(-p_{02}\,(1- p_{3,15}p_{15,3}^{(24)})-p_{03}\, p_{3,15}\,(p_{15,1}^{(24)}+p_{15,1}^{(24,26)})) + (p_{2,9} + p_{2,10} + p_{2,11} +p_{2,12})\,(-p_{03}\, p_{3,15}\,(p_{15,1}^{(24)} + p_{15,1}^{(24,26)}) - p_{02}(1 - p_{3,15}p_{15,3}^{(24)}))) + \mu_{19}\, p_{819}\, p_{18}\,((1-p_{2,13}(p_{13,23}+p_{13,22}))((1 - p_{3,15}\, p_{15,3}^{(24)})+ p_{03}(-p_{3,14}-p_{3,15})) + p_{20}(-p_{02}(1- p_{3,15}p_{15,3}^{(24)}) - p_{03}\, p_{3,15}(p_{15,1}^{(24)}+p_{15,1}^{(24,26)}))+ (p_{2,9} + p_{2,10} + p_{2,11} +p_{2,12})\,(-p_{03}\, p_{3,15}(p_{15,1}^{(24)}+p_{15,1}^{(24,26)})- p_{02}(1 - p_{3,15}\, p_{15,3}^{(24)}))) + (\mu_{22}+\mu_{23})\, p_{213}(p_{10}(-p_{01}(1 - p_{3,15}p_{15,3}^{(24)})-p_{03}p_{3,15}(p_{15,1}^{(24)}+p_{15,1}^{(24,26)}))+ (1-p_{1,8}(p_{8,19}+p_{8,18}))(-p_{01}\,(1- p_{3,15}p_{15,3}^{(24)})+ p_{03}(-p_{3,14}-p_{3,15}))+ (p_{14} + p_{15} + p_{16} +p_{17})\,((1 - p_{3,15}p_{15,3}^{(24)}) - p_{03}\, p_{3,15}(p_{15,1}^{(24)}+p_{15,1}^{(24,26)})))$$

$$\mathbf{D} = (1-p_{2,13}(p_{13,23} + p_{13,22}))\,(p_{10}\,(- p_{01}(1-p_{3,15}p_{15,3}^{(24)}) - p_{03}\, p_{3,15}\,(p_{15,1}^{(24)} + p_{15,1}^{(24,26)})) + (1-p_{18}\,(p_{8,19} + p_{8,18}\,))\,((\,1- p_{3,15}\, p_{15,3}^{(24)}) + p_{03}\,(-p_{3,14} - p_{3,15}))) + (1- p_{18}(\,p_{8,19} + p_{8,18}))\,(p_{20}\,(-p_{02}\,(1- p_{3,15}\, p_{15,3}^{(24)}) - p_{03}\, p_{3,15}\,(p_{15,1}^{(24)} + p_{15,1}^{(24,26)})))$$

and $R^*(s)$ is the Laplace transform of the reliability $R(t)$: The reliability $R(t)$ of the system at time t can be obtained taking inverse Laplace transform of $R^*(s)$

Availability Analysis

Let $A_i(t)$ be the probability that the system is in upstate at instant t given that the system entered regenerative state i at t = 0. The obtained expression for availability is given by

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

where

$$N_1= p_{03}\,((\mu_1 +\mu_{17}p_{1,7} +\mu_{16}\, p_{1,5} + \mu_8 p_{1,8} +\mu_{18}\, p_{1,8}\,)((-p_{2,1}^{(9)} - p_{2,10})(-p_{3,15}(p_{15,2}^{(26)} + p_{15,2}^{(24,26)}) - (1-p_{2,2}^{(11)} - p_{2,13}(p_{13,23} + p_{13,22}\,) -p_{2,12}\,)(-p_{3,15}(p_{15,1}^{(26)} + p_{15,1}^{(24,26)})) - (1-p_{1,1}^{(4)} - p_{1,5} -p_{1,8}\,(p_{8,18} +p_{8,19}\,))((\mu_2 +\mu_{13}p_{2,13}+ \mu_{22}\, p_{2,13} + \mu_{20}p_{2,10} +\mu_{21}\, p_{2,12}\,)(-p_{3,15}(p_{15,2}^{(26)} + p_{15,2}^{(24,26)})-(1-p_{2,2}^{(11)} -p_{2,13}(p_{13,23} + p_{13,22}\,) -p_{2,12})(\mu_3 + \mu_{14}p_{3,14} +\mu_{15}\, p_{3,15})\,)+ (-p_{1,2}-p_{1,7})((\mu_2 + \mu_{13}p_{2,13}+ \mu_{22}\, p_{2,13}\, p_{13,22} + \mu_{20}p_{2,10}+\mu_{21}\, p_{2,12}\,)\,(-p_{3,15}(p_{15,1}^{(26)} + p_{15,1}^{(24,26)})-(- p_{2,1}^{(9)} - p_{2,10})(\mu_3 + \mu_{14}p_{3,14} +\mu_{15}\, p_{3,15})\,))+ (1-p_{3,15}p_{15,3}^{(24)})(\mu_0((1- p_{1,1}^{(4)} - p_{1,5} -p_{1,8}\,(p_{8,18} +p_{8,19}\,))(1- p_{2,2}^{(11)} -p_{2,13}(p_{13,23} + p_{13,22}\,) -p_{2,12}\,) - (-p_{1,2}-p_{1,7})(- p_{2,1}^{(9)} - p_{2,10}))+p_{01}((\mu_1 +\mu_{17}p_{1,7} + \mu_{16}\, p_{1,5} + \mu_8 p_{1,8} +\mu_{18}\, p_{1,8}\, p_{8,18})\text{`}(1- p_{2,2}^{(11)} - p_{2,13}\,(p_{13,23} + p_{13,22}\,) -p_{2,12}\,)\text{`}- (-p_{1,2}-p_{1,7})(\mu_2 + \mu_{13}p_{2,13}+ \mu_{22}\, p_{2,13}\, p_{13,22} + \mu_{20}p_{2,10}+\mu_{21}\, p_{2,12}\,))-p_{02}((\mu_1 + \mu_{17}p_{1,7} + \mu_{16}\, p_{1,5} + \mu_8 p_{1,8} +\mu_{18}\, p_{1,8}\, p_{8,18})(- p_{2,1}^{(9)} - p_{2,10})-(1-p_{1,1}^{(4)}-p_{1,5} -p_{1,8}\,(p_{8,18} +p_{8,19}\,))(\mu_2 + \mu_{13}p_{2,13}+ \mu_{22}\, p_{2,13}\, p_{13,22} + \mu_{20}p_{2,10}+\mu_{21}\, p_{2,12}\,))$$

$$D_1 = \mu_0((1- p_{3,15}p_{15,3}^{(24)})(1-p_{2,2}^{(11)} -p_{2,13}(p_{13,23} + p_{13,22}\,) -p_{2,12}\,)p_{10}-p_{20}\,(-p_{12} - p_{17})\,p_{3,15}\, p_{15,3}^{(24)}))+P_{51}(p_{03}((- p_{2,1}^{(9)} - p_{2,10})(-p_{3,15}(p_{15,2}^{(26)} + p_{15,2}^{(24,26)})-(1-p_{2,2}^{(11)} -p_{2,13}\,(p_{13,23} + p_{13,22}\,) -p_{2,12}\,)\,(-p_{3,15}(p_{15,1}^{(26)} + p_{15,1}^{(24,26)}))+ (1- p_{3,15}\, p_{15,3}^{(24)})(p_{01}(1-p_{2,2}^{(11)} -p_{2,13}(p_{13,23} + p_{13,22})- p_{2,12}\,) - p_{02}(- p_{2,1}^{(9)} - p_{2,10}))) + p_{52}\,(p_{03}\,((-p_{12} - p_{17})\,(-p_{3,15}(p_{15,1}^{(26)} + p_{15,1}^{(24,26)}) - (1-p_{1,1}^{(4)}-p_{1,5} -p_{1,8}\,(p_{8,18} +p_{8,19}\,))(-p_{3,15}(p_{15,2}^{(26)} + p_{15,2}^{(24,26)}))- (-p_{1,2}-p_{1,7})p_{01}\,(1- p_{3,15}\, p_{15,3}^{(24)}) + p_{02}\,(1-p_{3,15}p_{15,3}^{(24)})(1 - p_{1,1}^{(4)}-p_{1,5} -p_{1,8}\,(p_{8,18} +p_{8,19}\,)))+\mu_3((p_{03}(1-p_{2,2}^{(11)} -p_{2,13}(p_{13,23} + p_{13,22}\,) -p_{2,12}\,)(1-p_{1,1}^{(4)}-p_{1,5} -p_{1,8}\,(p_{8,18} +p_{8,19}\,))(- p_{2,1}^{(9)} - p_{2,10})(-p_{1,2}-p_{1,7})p_{03})) + \mu_5(p_{15}((-p_{3,15}(p_{15,2}^{(26)} + p_{15,2}^{(24,26)})p_{03}p_{20}-p_{02}\,(1 - p_{3,15}p_{15,3}^{(24)})\,p_{20}(1 - p_{2,2}^{(11)} - p_{2,13}(p_{13,23} + p_{13,22}\,) -p_{2,12}\,)p_{03}(-p_{3,15} -p_{3,14}\,) + (1- p_{2,2}^{(11)} -p_{2,13}(p_{13,23} + p_{13,22}\,) -p_{2,12}\,)\,(1-p_{3,15}p_{15,3}^{(24)}))))+(\mu_7+\mu_{17})p_{17}(-(-p_{3,15}(p_{15,1}^{(26)} + p_{15,1}^{(24,26)})p_{03}p_{20}+p_{01}p_{20}\,(1- p_{3,15}p_{15,3}^{(24)})-(- p_{2,1}^{(9)} - p_{2,10})p_{03}(-p_{3,15} -p_{3,14}\,)-(- p_{2,1}^{(9)} - p_{2,10})\,(1-p_{3,15}p_{15,3}^{(24)}))+(\mu_8+\mu_{18})p_{18}(-p_{20}p_{02}\,(1-p_{3,15}p_{15,3}^{(24)})+(-p_{3,15} -p_{3,14}\,)p_{03}(1- p_{2,2}^{(11)} - p_{2,13}(p_{13,23} + p_{13,22}\,) -p_{2,12}\,)+ (1- p_{3,15}p_{15,3}^{(24)})(1- p_{2,2}^{(11)} -p_{2,13}(p_{13,23} + p_{13,22}\,) - p_{2,12}\,)+p_{20}\,(-p_{3,15}(p_{15,2}^{(26)} + p_{15,2}^{(24,26)})p_{03})+(\mu_{10}+\mu_{20})p_{210}(-p_{10}p_{03}(-p_{3,15}(p_{15,2}^{(26)} + p_{15,2}^{(24,26)}) + p_{10}p_{02}\,(1- p_{3,15}p_{15,3}^{(24)})- (-p_{3,15} -p_{3,14}\,)p_{03}\,(-p_{1,2}-p_{1,7})- (1 - p_{3,15}p_{15,3}^{(24)})(-p_{1,2}-p_{1,7}))+(\mu_{12}+\mu_{21})p_{212}\,(p_{10}p_{03}(-p_{3,15}(p_{15,1}^{(26)} + p_{15,1}^{(24,26)})-p_{10}\,(1-p_{3,15}p_{15,3}^{(24)})p_{01}+(-p_{3,15} -p_{3,14}\,)p_{03}(1-p_{1,1}^{(4)}-p_{1,5} -p_{1,8}\,(p_{8,18} +p_{8,19}\,))+ (1- p_{3,15}p_{15,3}^{(24)})(1- p_{1,1}^{(4)}-p_{1,5} -p_{1,8}\,(p_{8,18} +p_{8,19}\,)))+(\mu_{13}+\mu_{22})p_{213}(p_{10}p_{03}(-p_{3,15}(p_{15,1}^{(26)} + p_{15,1}^{(24,26)}) - p_{10}\,(1- p_{3,15}p_{15,3}^{(24)})p_{01}+(-p_{3,15} -p_{3,14}\,)\,p_{03}(1-p_{1,1}^{(4)}-p_{1,5} -p_{1,8}\,(p_{8,18} +p_{8,19}\,))+ (1-$$

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$p_{3,15}p_{15,3}^{(24)})(1- p_{1,1}^{(4)}-p_{1,5} - p_{1,8} (p_{8,18} + p_{8,19})))+P_{15}p_{315}((1-p_{1,1}^{(4)}-p_{1,5} - p_{1,8} (p_{8,18} + p_{8,19}))p_{03}(1-p_{2,2}^{(11)} - p_{2,13}(p_{13,23} + p_{13,22}) - p_{2,12}) - (-p_{2,1}^{(9)} - p_{2,10})(-p_{1,2}-p_{1,7})p_{03})+\mu_{14}p_{314}(p_{03}(1-p_{2,2}^{(11)} - p_{2,13}(p_{13,23}+p_{13,22}) - p_{2,12})(1-p_{1,1}^{(4)}-p_{1,5} - p_{1,8}(p_{8,18}+p_{8,19}))-(-p_{2,1}^{(9)} - p_{2,10})(-p_{1,2}-p_{1,7}) p_{03})+\mu_{16}p_{15}(p_{20}p_{03}(-p_{3,15}(p_{15,2}^{(26)} + p_{15,2}^{(24,26)})-p_{20}p_{02}(1-p_{3,15}p_{15,3}^{(24)}) +(-p_{3,15} - p_{3,14})p_{03}(1-p_{2,2}^{(11)} - p_{2,13}(p_{13,23}+p_{13,22}) - p_{2,12}) + (1-p_{3,15}p_{15,3}^{(24)})(1-p_{2,2}^{(11)} - p_{2,13}(p_{13,23}+p_{13,22}) - p_{2,12})p_{15})+\mu_{19}p_{18}p_{819}(p_{20}p_{03}(-p_{3,15}(p_{15,2}^{(26)}+p_{15,2}^{(24,26)}) - p_{20}p_{02}(`1-p_{3,15}p_{15,3}^{(24)})+(-p_{3,15} - p_{3,14})p_{03}(1-p_{2,2}^{(11)} - p_{2,13}(p_{13,23}+p_{13,22}) - p_{2,12}) + (1-p_{3,15}p_{15,3}^{(24)})(1-p_{2,2}^{(11)} - p_{2,13}(p_{13,23}+p_{13,22}) - p_{2,12}))+\mu_{23}p_{213}(p_{10}+p_{03}(-p_{3,15}(p_{15,1}^{(26)} + p_{15,1}^{(24,26)})-p_{10}(1-p_{3,15}p_{15,3}^{(24)})p_{01}+(-p_{3,15} - p_{3,14})p_{03}(1-p_{1,1}^{(4)}-p_{1,5} - p_{1,8}(p_{8,18}+p_{8,19})) + (1-p_{3,15}p_{15,3}^{(24)})(1-p_{1,1}^{(4)}-p_{1,5} - p_{1,8}(p_{8,18}+p_{8,19})))$

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 visits by repairman	N_4/D_1
Expected no of Replacements	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
Busy Period for Inspection	N_8/D_1

Where

$\mathbf{N_2} = p_{03}(W_1 + W_{17}p_{17}+W_{16}p_{1,5} + p_{1,8}(W_{19}p_{8\cdot19} + W_{18}p_{8,18}))((-p_{2,1}^{(9)} - p_{2,10})(-p_{3,15}(p_{15,2}^{(26)} + p_{15,2}^{(24,26)}))-(1-p_{2,2}^{(11)} - p_{2,13}(p_{13,23}+p_{13,22}) - p_{2,12}))(-p_{3,15}(p_{15,1}^{(26)} + p_{15,1}^{(24,26)})) - (1-p_{11}^{(4)}-p_{15} - p_{18}(p_{8,18}+p_{8,19}))((p_{2,13}(W_{23}p_{13,23} + W_{22}p_{13,22}))(-p_{3,15}(p_{15,2}^{(26)} + p_{15,2}^{(24,26)}) - (1-p_{2,2}^{(11)} - p_{2,13}(p_{13,23}+p_{13,22}) - p_{2,12})(W_{15}p_{3,15} + W_{14}p_{3,14})) + (-p_{1,2}-p_{1,7})((p_{2,13}(W_{23}p_{13,23} + W_{22}p_{13,22}))(-p_{3,15}(p_{15,1}^{(26)} + p_{15,1}^{(24,26)}) - (-p_{2,1}^{(9)} - p_{2,10})(W_{15}p_{3,15} + W_{14}p_{3,14}))) + (1-p_{3,15}p_{15,3}^{(24)})(p_{01}((W_1 + W_{17}p_{17}+W_{16}p_{1,5} + p_{1,8}(W_{19}p_{8\cdot19} + W_{18}p_{8,18}))(1-p_{2,2}^{(11)} - p_{2,13}(p_{13,23}+p_{13,22}) - p_{2,12}) - (-p_{1,2}-p_{1,7})(p_{2,13}(W_{23}p_{13,23} + W_{22}p_{13,22}))) - p_{02}((W_1 + W_{17}p_{17}+W_{16}p_{1,5} + p_{1,8}(W_{19}p_{8\cdot19} + W_{18}p_{8,18}))(-p_{2,1}^{(9)} - p_{2,10}) - (1-p_{11}^{(4)}-p_{15} - p_{18}(p_{8,18}+p_{8,19}))(p_{2,13}(W_{23}p_{13,23} + W_{22}p_{13,22}))))$

$\mathbf{N_3} = -p_{03}(W_2+W_{21}p_{2,12}+W_{20}p_{2,10})((1-p_{1,1}^{(4)}-p_{1,5} - p_{1,8}(p_{8,18}+p_{8,19})))(-p_{3,15}(p_{15,2}^{(26)} + p_{15,2}^{(24,26)})-(-p_{1,2}-p_{1,7})(-p_{3,15}(p_{15,1}^{(26)} + p_{15,1}^{(24,26)}))) + (1-p_{3,15}p_{15,3}^{(24)})(W_2 + W_{21}+W_{20}p_{2,10})(-p_{01}(-p_{1,2}-p_{1,7}) + p_{02}(1-p_{1,1}^{(4)}-p_{1,5} - p_{1,8}(p_{8,18}+p_{8,19})))$

$\mathbf{N_4} = (1-p_{3,15}p_{15,3}^{(24)})((1-p_{1,1}^{(4)}-p_{1,5} - p_{1,8}(p_{8,18}+p_{8,19}))(1-p_{2,2}^{(11)} - p_{2,13}(p_{13,23}+p_{13,22}) - p_{2,12}) - (-p_{1,2}-p_{1,7})(-p_{2,1}^{(9)} - p_{2,10}))$

$\mathbf{N_5} = (p_{2,1}^{(9)} + p_{2,2}^{(11)} + p_{2,12} + p_{2,10})(-p_{03}((1-p_{1,1}^{(4)} - p_{1,5} - p_{1,8}(p_{8,18}+p_{8,19})))(-p_{3,15}(p_{15,2}^{(26)} + p_{15,2}^{(24,26)}))-(-p_{1,2}-p_{1,7})(-p_{3,15}(p_{15,1}^{(26)} + p_{15,1}^{(24,26)}))) + (1-p_{3,15}p_{15,3}^{(24)})(-p_{01}(-p_{1,2}-p_{1,7}) + p_{02}(1-p_{1,1}^{(4)} - p_{1,5} - p_{1,8}(p_{8,18}+p_{8,19}))))$

$\mathbf{N_6} = p_{03}(1-p_{1,1}^{(4)}-p_{1,5} - p_{1,8}(p_{8,18}+p_{8,19}))(W_{17}p_{1,7} + W_{16}p_{1,5})((-p_{2,1}^{(9)} - p_{2,10})(-p_{3,15}(p_{15,2}^{(26)} + p_{15,2}^{(24,26)}))-(1-p_{2,2}^{(11)} - p_{2,13}(p_{13,23}+p_{13,22}) - p_{2,12})(-p_{3,15}(p_{15,1}^{(26)} + p_{15,1}^{(24,26)})) - (1-p_{1,1}^{(4)}-p_{1,5} - p_{1,8}(p_{8,18}+p_{8,19}))) ((W_{20}p_{2,10} + W_{21}p_{2,12})(-p_{3,15}(p_{15,2}^{(26)} + p_{15,2}^{(24,26)})) + (-p_{1,2}-p_{1,7})((W_{20}p_{2,10} + W_{21}p_{2,12})(-p_{3,15}(p_{15,1}^{(26)} + p_{15,1}^{(24,26)}))) + (1-p_{3,15}p_{15,3}^{(24)})(p_{01}((W_{17}p_{1,7} + W_{16}p_{1,5})(1-p_{2,2}^{(11)} - p_{2,13}(p_{13,23}+p_{13,22}) - p_{2,12}) - (-p_{1,2}-p_{1,7})(W_{20}p_{2,10} + W_{21}p_{2,12}))) - p_{02}((W_{17}p_{1,7} + W_{16}p_{1,5})(-p_{2,1}^{(9)} - p_{2,10}) - (1-p_{1,1}^{(4)}-p_{1,5} - p_{1,8}(p_{8,18}+p_{8,19}))(W_{20}p_{2,10} + W_{21}p_{2,12})))$

$\mathbf{N_7} = -p_{03}(D_{19}p_{1,8}p_{8,19}((-p_{2,1}^{(9)} - p_{2,10})(p_{3,15}(p_{15,2}^{(26)} + p_{15,2}^{(24,26)})) - (1-p_{2,2}^{(11)} - p_{2,13}(p_{13,23}+p_{13,22}) - p_{2,12})(-p_{3,15}(p_{15,1}^{(26)} + p_{15,1}^{(24,26)})) - D_{23}p_{2,13}p_{13,23}((1-p_{1,1}^{(4)}-p_{1,5} - p_{1,8}(p_{8,18}+p_{8,19}))(-p_{3,15}p_{15,2}^{(26)} + p_{15,2}^{(24,26)}) - (-p_{1,2}-p_{1,7})(-p_{3,15}(p_{15,1}^{(26)} + p_{15,1}^{(24,26)})))) + (1-p_{3,15}p_{15,3}^{(24)})(-D_{19}p_{1,8}p_{8,19}(-p_{01}(1-p_{2,2}^{(11)} - p_{2,13}(p_{13,23}+p_{13,22}) - p_{2,12})) + p_{02}(-p_{2,1}^{(9)} - p_{2,10})) + D_{23}p_{2,13}p_{13,23}(-p_{01}(-p_{1,2}-p_{1,7}) + p_{02}(1-p_{1,1}^{(4)}-p_{15} - p_{18}(p_{8,18}+p_{8,19}))))$

$\mathbf{N_8} = p_{03}(W_8p_{1,8}((-p_{2,1}^{(9)} - p_{2,10})(-p_{3,15}(p_{15,2}^{(26)} + p_{15,2}^{(24,26)}) - (1-p_{2,2}^{(11)} - p_{2,13}(p_{13,23}+p_{13,22})p_{2,12})(p_{3,15}(p_{15,1}^{(26)} + p_{15,1}^{(24,26)})) - W_{13}p_{2,13}((1-p_{1,1}^{(4)}-p_{1,5} - p_{1,8}(p_{8,18}+p_{8,19}))(-p_{3,15}(p_{15,2}^{(26)} + p_{15,2}^{(24,26)})) - (-p_{1,2}-p_{1,7})) + W_3((1-p_{1,1}(_4)-p_{1,5} - p_{1,8}(p_{8,18}+p_{8,19}))(1-p_{2,2}^{(11)} - p_{2,13}(p_{13,23}+p_{13,22}) - p_{2,12}) - (-p_{1,2}-p_{1,7})(-p_{2,1}(_9) - p_{2,10}))) + (1-p_{3,15}p_{15,3}^{(24)})(p_{01}W_8p_{1,8}(1-p_{2,2}^{(11)} - p_{2,13}(p_{13,23}+p_{13,22}) - p_{2,12}) - (-p_{1,2}-p_{1,7})W_{13}p_{2,13}) - p_{02}W_8p_{1,8}(-p_{2,1}^{(9)} - p_{2,10}) - (1-p_{1,1}^{(4)}-p_{1,5} - p_{1,8}(p_{8,18}+p_{8,19}))W_{13}p_{2,13}))$

Profit analysis of the system

$$\text{Profit } (P_7) = C_0A_0 - C_1B_0 - C_2BR_0 - C_3R_0 - C_4V_0 - C_5AP_0 - C_6E_0 - C_7I_0$$

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 visit of repairman

C_4 = cost per unit of replacement

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

C_7 = cost per unit time for which repairman is busy

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for inspection

The following particular case is considered for graphical interpretation

$g_1(t) = \alpha_1 e^{-\alpha_1 t}$ $g_2(t) = \alpha_2 e^{-\alpha_2 t}$

$g_3(t) = \alpha_3 e^{-\alpha_3 t}$ $g_4(t) = \alpha_4 e^{-\alpha_4 t}$

Graphical representations of results

MTSF vs partial to complete failure rate (λ_2) for different values of (λ_1)

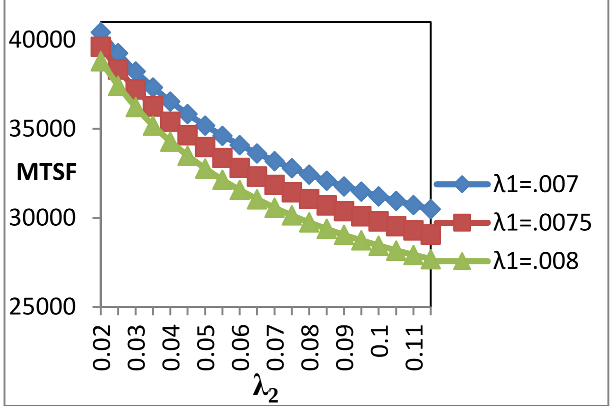

Fig. shows the behaviour of MTSF with respect to partial to complete failure rate (λ_2) for different values of normal to partial failure rate (λ_1). It can be concluded from the graph that MTSF decreases with increase in the values of λ_2 and has higher values for lower values of λ_1.

Profit vs revenue per unit time(C_0) for different values of cost of alternate performance(C_5)

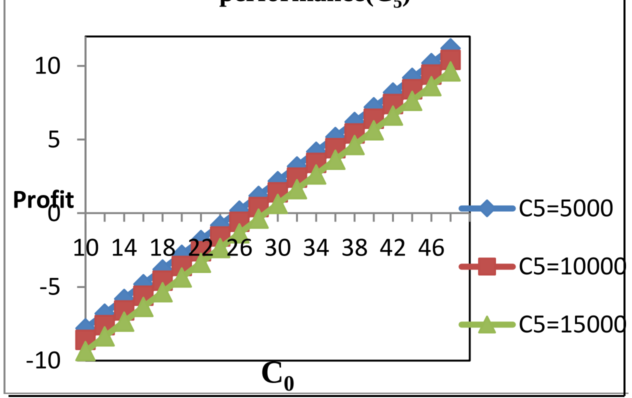

Fig. reveals the behaviour of profit (P_7) with respect to revenue (C_0)for different values of cost per unit time for alternate performance (C_5). It can be interpreted from the graph that profit increases with the increase in the values of C_0 and has lower values for higher values of C_5

Interpretation

(i) For $C_5 = 5000$, the profit is positive or zero or negative according as C_0 > or = or < 25.6147. Hence, for this case the revenue per unit up time should be fixed greater than 25.6147.

(ii) For $C_5 = 10000$, the profit is positive or zero or negative according as C_0 > or = or < 27.1694. Hence, for this case the revenue per unit up time should be fixed greater than 27.1694.

(iii) For $C_5 = 15000$, the profit is positive or zero or negative according as C_0 > or = or < 28.7239. Hence, for this case the revenue per unit up time should be fixed greater than 28.7239.

Profit vs cost per visit of repairman (C_4)for different values of cost for busy period of repairman (C_1)

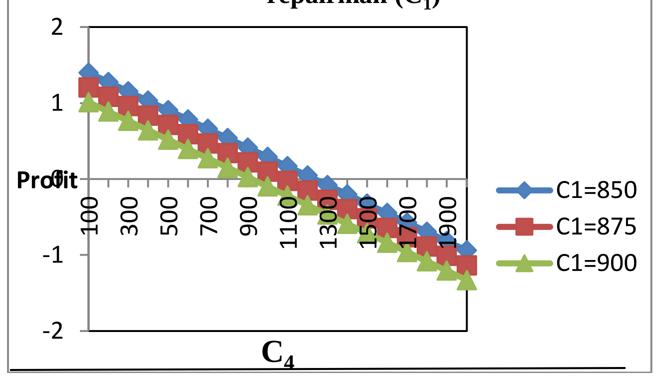

Fig. reveals the behaviour of profit (P_7) with respect to cost per visit of repairman (C_4)for different values of cost per unit time for which the repairman is busy for repair(C_1). It can be interpreted from the graph that profit decreases with the increase in cost per visit of repairman C_4 and has higher values for lower values of C_1.

Interpretation

(i) For $C_1 = 850$, the profit is positive or zero or negative according as C_4 < or = or> 1235.9578. Hence, not more than

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an amount of 1235.9578 per visit should be paid to the repairman.

(ii) For C_1 = 875, the profit is positive or zero or negative according as C_4 < or = or > 1078.1833. Hence, not more than an amount of 1078.1833 per visit should be paid to the repairman.

(iii) For C_1 = 900, the profit is positive or zero or negative according as C_4 < or = or > 920.4545. Hence, not more than an amount of 920.4545 per visit should be paid to the repairman.

Conclusion

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 system on the basis of the graphical interpretation given above.

This fragment should obviously state the foremost conclusions of the exploration and give a coherent explanation of their significance and consequence.

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