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Research paper

Performance Analysis of a Rod Breakdown System

S Z Taj[1*], S M Rizwan[2], B M Alkali[3], D K Harrison[4], G Taneja[5]

[1&2]Department of Mathematics & Statistics, Caledonian College of Engineering, Sultanate of Oman
[3&4]Department of Mechanical Engineering, Glasgow Caledonian University, Scotland, UK
[5]Department of Mathematics, Maharshi Dayanand University, India
**Corresponding author E-mail: syed@caledonian.edu.om*

Abstract

The paper presents performance analysis of a rod breakdown system consisting of two machines operating in parallel. Ten years maintenance data of the system depicts three maintenance practices: repair, major preventive maintenance and minor preventive maintenance. Machines are repaired on normal failures, whereas major/minor preventive maintenance is carried out at scheduled basis. The machines are queued for major preventive maintenance. An operative machine requires a cooling period of half hour before undergoing major preventive maintenance. Repair is prioritized over major preventive maintenance. The system is analysed using semi-Markov processes and regenerative point techniques. Performance indices namely mean time to system failure, system availability, no. of system repairs and busy period of the repairman are obtained. Simulated results are presented to demonstrate the effect of varying failure/repair rates on the system performance.

Keywords: *performance analysis; regenerative point technique; rod breakdown; semi-Markov process; simulation*

1. Introduction

Performance analysis of various complex industrial systems operating under different conditions and assumptions has been widely discussed by a number of researchers [1-26, 31-37]. Recently, Taj et al. [27-30] carried out performance analysis of four different subsystems of a cable plant. However, analysis of subsystems does not completely contribute to the plant effectiveness in terms of overall performance; it only gives the subsystem effectiveness, and therefore opens up a scope of complete plant performance as a case study.

Thus, this paper presents performance analysis of a system called rod breakdown system which is commonly used in electrical cables manufacturing plants. To facilitate the analysis, ten years maintenance data of a rod breakdown system has been collected from an electrical cables manufacturing plant currently operational in the Sultanate of Oman. The system consists of two machines operating in parallel. The machines undergo three maintenance practices as depicted in the data: repair, major preventive maintenance (MAPM) and minor preventive maintenance (MIPM). Repair is carried out upon failure, whereas MAPM/MIPM is performed as per schedule. The two machines are queued for MAPM. An operative machine requires a cooling period of half hour before undergoing MAPM. Priority is given to repair over MAPM. Transition states of the system are shown in Table2. Detailed system analysis has been carried out using semi-Markov processes and regenerative point techniques. Performance indices namely mean time to system failure (MTSF), system availability, no. of system repairs and busy period of the repairman have been estimated. Simulated results have also been presented to demonstrate the effect of varying failure/repair rates on the system performance.

1.1 Notations

MIPM	minor preventive maintenance
MAPM	major preventive maintenance
MTSF	mean time to system failure
S_i	state i
pdf	probability density function
cdf	cumulative distribution function
$g_1(t)$	pdf of repair times for machine1
$g_2(t)$	pdf of repair times for machine2
$h_1(t)$	pdf of MIPM times for machine1
$h_2(t)$	pdf of MIPM times for machine2
$f_1(t)$	pdf of MAPM times for machine1
$f_2(t)$	pdf of MAPM times for machine2
α_1	estimated rate of requirement of MIPM
μ	estimated rate of performing MIPM for machine1
η	estimated rate of performing MIPM for machine2
β_1	estimated rate of requirement of MAPM
φ	estimated rate of performing MAPM for machine1
ν	estimated rate of performing MAPM for machine2
γ	estimated rate of cooling
λ_1	estimated failure rate for machine1
λ_2	estimated failure rate for machine2
δ	estimated repair rate for machine1
ω	estimated repair rate for machine2
Q_{ij}	cdf from S_i to S_j
q_{ij}	pdf from S_i to S_j
©	Laplace convolution
Ⓢ	Laplace Stieltje's convolution
*	Laplace transform
**	Laplace Stieltje's transform
A_0	system availability

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R_0 no. of system repairs
B_0 busy period of the repairman

2.Model Description

Following operating conditions and assumptions are considered:

- Machines undergo three types of maintenances: repair, MIPM and MAPM.
- System consists of two machines operating in parallel.
- Repair is carried out upon failure.
- MIPM/MAPM is carried out as per schedule.
- Machines are queued for MAPM.
- An operative machine requires a cooling period of half hour before undergoing MAPM.
- Priority is given to repair over MAPM.
- Failure rates are taken as exponential.
- Repair rates are taken as arbitrary.

Transition states of the system are described below:
State 0 (S_0): machine1 and machine2, both are operating
State 1 (S_1): machine1 is under repair, machine2 is operating
State 2 (S_2): machine1 is operating, machine2 is under repair
State 3 (S_3): machine1 is under MAPM, machine2 is operating
State 4 (S_4): machine1 is under MIPM, machine2 is waiting for MIPM
State 5 (S_5): machine1 is under repair, machine2 is waiting for repair
State 6 (S_6): machine1 is waiting for repair, machine2 is under repair
State 7 (S_7): machine1 is waiting for MAPM, machine2 is under repair
State 8 (S_8): machine1 is operating, machine2 is waiting for MAPM (cooling period)
State 9 (S_9): machine1 is operating, machine2 is under MIPM
State 10 (S_{10}): machine1 is operating, machine2 is under MAPM
State 11 (S_{11}): machine1 is under repair, machine2 is waiting for MAPM

S_0, S_1, S_2, S_3, S_4, S_7, S_8, S_9, S_{10} and S_{11} are regenerative states whereas S_5 and S_6 are non regenerative as well as failed states.

Estimated values of various rates for the system are given in Table1.

Rates of transition from S_i to S_j are given in Table2. 0 stands for no transition to the mentioned state.

3. Transition Probabilities and Mean Sojourn Times

Using the definition [3] of transition probabilities q_{ij}, we get:

$$dQ_{01}(t) = \lambda_1 e^{-(\lambda_1+\lambda_2+\beta_1+\alpha_1)t}dt$$
$$dQ_{02}(t) = \lambda_2 e^{-(\lambda_1+\lambda_2+\beta_1+\alpha_1)t}dt$$
$$dQ_{03}(t) = \beta_1 e^{-(\lambda_1+\lambda_2+\beta_1+\alpha_1)t}dt$$
$$dQ_{04}(t) = \alpha_1 e^{-(\lambda_1+\lambda_2+\beta_1+\alpha_1)t}dt$$
$$dQ_{10}(t) = e^{-\lambda_2 t}g_1(t)dt$$
$$dQ_{15}(t) = \lambda_2 e^{-\lambda_2 t}\overline{G_1}(t)dt$$
$$dQ_{12}^5(t) = (\lambda_2 e^{-\lambda_2 t} \copyright 1)g_1(t)dt$$
$$dQ_{20}(t) = e^{-\lambda_1 t}g_2(t)dt$$
$$dQ_{26}(t) = \lambda_1 e^{-\lambda_1 t}\overline{G_2}(t)dt$$
$$dQ_{21}^6(t) = (\lambda_1 e^{-\lambda_1 t} \copyright 1)g_2(t)dt$$
$$dQ_{37}(t) = \lambda_2 e^{-\lambda_2 t}\overline{F_1}(t)dt$$
$$dQ_{38}(t) = e^{-\lambda_2 t}f_1(t)dt$$
$$dQ_{49}(t) = h_1(t)dt$$
$$dQ_{73}(t) = g_2(t)dt$$
$$dQ_{8,10}(t) = \gamma e^{-\gamma t}dt$$
$$dQ_{90}(t) = h_2(t)dt$$
$$dQ_{10,0}(t) = e^{-\lambda_1 t}f_2(t)dt$$
$$dQ_{10,11}(t) = \lambda_1 e^{-\lambda_1 t}\overline{F_2}(t)dt$$
$$dQ_{11,10}(t) = g_1(t)dt$$

Table1: Estimated values of rates for the system

S. No.	Rate (per hour)	Estimated value (per hour)
1	α_1, rate of requirement of MIPM	0.00129
2	μ, rate of performing MIPM for machine1	0.86957
3	η, rate of performing MIPM for machine2	1.01099
4	β_1, rate of requirement of MAPM	0.00045
5	φ, rate of performing MAPM for machine1	0.04729
6	ν, rate of performing MAPM for machine2	0.05079
7	γ, rate of cooling	2.00000
8	λ_1, failure rate for machine1	0.00541
9	λ_2, failure rate for machine2	0.00581
10	δ, repair rate for machine1	0.18868
11	ω, repair rate for machine2	0.20302

Table2: Rates for the system

S_i \ S_j	S_0	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}
S_0	0	λ_1	λ_2	β_1	α_1	0	0	0	0	0	0	0
S_1	$g_1(t)$	0	0	0	0	λ_2	0	0	0	0	0	0
S_2	$g_2(t)$	0	0	0	0	0	λ_1	0	0	0	0	0
S_3	0	0	0	0	0	0	0	λ_2	$f_1(t)$	0	0	0
S_4	0	0	0	0	0	0	0	0	0	$h_1(t)$	0	0
S_5	0	0	$g_1(t)$	0	0	0	0	0	0	0	0	0
S_6	0	$g_2(t)$	0	0	0	0	0	0	0	0	0	0
S_7	0	0	0	$g_2(t)$	0	0	0	0	0	0	0	0
S_8	0	0	0	0	0	0	0	0	0	0	γ	0
S_9	$h_2(t)$	0	0	0	0	0	0	0	0	0	0	0
S_{10}	$f_2(t)$	0	0	0	0	0	0	0	0	0	0	λ_1
S_{11}	0	0	0	0	0	0	0	0	0	0	$g_1(t)$	0
For non-regenerative states (S_5 and S_6)												
S_1 to S_2 via S_5	$dQ_{12}^5(t) = (\lambda_2 e^{-\lambda_2 t} \copyright 1)g_1(t)dt$											
S_2 to S_1 via S_6	$dQ_{21}^6(t) = (\lambda_1 e^{-\lambda_1 t} \copyright 1)g_2(t)dt$											

Using the definition [3] of non zero elements p_{ij}, we get:

$$p_{01} = \frac{\lambda_1}{\lambda_1 + \lambda_2 + \beta_1 + \alpha_1}$$
$$p_{02} = \frac{\lambda_2}{\lambda_1 + \lambda_2 + \beta_1 + \alpha_1}$$
$$p_{03} = \frac{\beta_1}{\lambda_1 + \lambda_2 + \beta_1 + \alpha_1}$$
$$p_{04} = \frac{\alpha_1}{\lambda_1 + \lambda_2 + \beta_1 + \alpha_1}$$
$p_{10} = g_1^*(\lambda_2)$
$p_{15} = 1 - g_1^*(\lambda_2)$
$p_{12}^5 = 1 - g_1^*(\lambda_2)$
$p_{20} = g_2^*(\lambda_1)$
$p_{26} = 1 - g_2^*(\lambda_1)$
$p_{21}^6 = 1 - g_2^*(\lambda_1)$
$p_{37} = 1 - f_1^*(\lambda_2)$
$p_{38} = f_1^*(\lambda_2)$
$p_{49} = h_1^*(0)$
$p_{73} = g_2^*(0)$
$p_{8,10} = 1$
$p_{90} = h_2^*(0)$
$p_{10,0} = f_2^*(\lambda_1)$
$p_{10,11} = 1 - f_2^*(\lambda_1)$
$p_{11,10} = g_1^*(0)$

Following relations can easily be verified:
$p_{01} + p_{02} + p_{03} + p_{04} = 1$
$p_{10} + p_{15} = 1$
$p_{10} + p_{12}^5 = 1$
$p_{20} + p_{26} = 1$
$p_{20} + p_{21}^6 = 1$
$p_{37} + p_{38} = 1$
$p_{49} = 1$
$p_{73} = 1$
$p_{8,10} = 1$
$p_{90} = 1$
$p_{10,0} + p_{10,11} = 1$
$p_{11,10} = 1$

Using the definition [3] of mean sojourn time μ_i, we get:

$$\mu_0 = \frac{1}{\lambda_1 + \lambda_2 + \beta_1 + \alpha_1}$$
$$\mu_1 = \int_0^\infty e^{-\lambda_2 t}\overline{G_1}(t)dt$$
$$\mu_2 = \int_0^\infty e^{-\lambda_1 t}\overline{G_2}(t)dt$$
$$\mu_3 = \int_0^\infty e^{-\lambda_2 t}\overline{F_1}(t)dt$$
$$\mu_4 = \int_0^\infty \overline{H_1}(t)dt$$
$$\mu_7 = \int_0^\infty \overline{G_2}(t)dt$$
$$\mu_8 = \frac{1}{\gamma}$$
$$\mu_9 = \int_0^\infty \overline{H_2}(t)dt$$
$$\mu_{10} = \int_0^\infty e^{-\lambda_1 t}\overline{F_2}(t)dt$$
$$\mu_{11} = \int_0^\infty \overline{G_1}(t)dt$$

Using the definition [3] of unconditional mean time m_{ij}, following relations can easily be verified:
$m_{01} + m_{02} + m_{03} + m_{04} = \mu_0$
$m_{10} + m_{15} = \mu_1$
$m_{20} + m_{26} = \mu_2$
$m_{37} + m_{38} = \mu_3$
$m_{49} = \mu_4$
$m_{73} = \mu_7$
$m_{8,10} = \mu_8$
$m_{90} = \mu_9$
$m_{10,0} + m_{10,11} = \mu_{10}$
$m_{11,10} = \mu_{11}$

4. Mathematical Analysis

4.1 MTSF

Using the definition [3] of $\phi_i(t)$ and applying simple probabilistic arguments, we get the following relations:

$$\phi_0(t) = Q_{01}(t)\textcircled{S}\phi_1(t) + Q_{02}(t)\textcircled{S}\phi_2(t) + Q_{03}(t)\textcircled{S}\phi_3(t) + Q_{04}(t)\textcircled{S}\phi_4(t)$$
$$\phi_1(t) = Q_{10}(t)\textcircled{S}\phi_0(t) + Q_{15}(t)$$
$$\phi_2(t) = Q_{20}(t)\textcircled{S}\phi_0(t) + Q_{26}(t)$$
$$\phi_3(t) = Q_{37}(t)\textcircled{S}\phi_7(t) + Q_{38}(t)\textcircled{S}\phi_8(t)$$
$$\phi_4(t) = Q_{49}(t)\textcircled{S}\phi_9(t)$$
$$\phi_7(t) = Q_{73}(t)\textcircled{S}\phi_3(t)$$
$$\phi_8(t) = Q_{8,10}(t)\textcircled{S}\phi_{10}(t)$$
$$\phi_9(t) = Q_{90}(t)\textcircled{S}\phi_0(t)$$
$$\phi_{10}(t) = Q_{10,0}(t)\textcircled{S}\phi_0(t) + Q_{10,11}(t)\textcircled{S}\phi_{11}(t)$$
$$\phi_{11}(t) = Q_{11,10}(t)\textcircled{S}\phi_{10}(t)$$

Taking Laplace Stieltjes transform of above relations and solving for $\phi_0^{**}(s)$, we get

$$\phi_0^{**}(s) = \frac{N(s)}{D(s)}$$

MTSF when the system started at the beginning of state 0 is given by

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

where

$$N = p_{38}p_{10,0}\{\mu_0 + p_{01}\mu_1 + p_{02}\mu_2 + p_{03}\mu_3 + p_{04}(\mu_4 + \mu_9)\} + p_{03}\{p_{38}(\mu_{10} + p_{10,11}\mu_{11}) + p_{10,0}(\mu_3 + p_{37}\mu_7)\}$$
$$D = p_{38}p_{10,0}(p_{01}p_{15} + p_{02}p_{26})$$

4.2 System Availability

Using the definition [3] of $A_i(t)$ and applying simple probabilistic arguments, we get the following relations:

$$A_0(t) = M_0(t)+q_{01}(t)\copyright A_1(t) \\ +q_{02}(t)\copyright A_2(t)+q_{03}(t)\copyright A_3(t)+q_{04}(t)\copyright A_4(t)$$
$$A_1(t) = q_{10}(t)\copyright A_0(t)+q_{12}^5(t)\copyright A_2(t)$$
$$A_2(t) = q_{20}(t)\copyright A_0(t)+q_{21}^6(t)\copyright A_1(t)$$
$$A_3(t) = q_{37}(t)\copyright A_7(t)+q_{38}(t)\copyright A_8(t)$$
$$A_4(t) = q_{49}(t)\copyright A_9(t)$$
$$A_7(t) = q_{73}(t)\copyright A_3(t)$$
$$A_8(t) = q_{8,10}(t)\copyright A_{10}(t)$$
$$A_9(t) = q_{90}(t)\copyright A_0(t)$$
$$A_{10}(t) = q_{10,0}(t)\copyright A_0(t)+q_{10,11}(t)\copyright A_{11}(t)$$
$$A_{11}(t) = q_{11,10}(t)\copyright A_{10}(t)$$

here, $M_0(t) = e^{-(\lambda_1+\lambda_2+\beta_1+\alpha_1)t}$

Taking Laplace transform of above equations and solving for $A_0^*(s)$, we get

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

In steady state, availability of the subsystem is given by

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

where

$$N_1 = \mu_0 p_{38} p_{10,0}\{1 - p_{12}^5 p_{21}^6\}$$
$$D_1 = \begin{Bmatrix} (1-p_{04})(1-p_{12}^5 p_{21}^6) \\ -p_{01}(p_{10}+p_{12}^5 p_{20}) - p_{02}(p_{20}+p_{21}^6 p_{10}) \end{Bmatrix} \\ \begin{Bmatrix} P_{38}(p_{10,11}\mu_{11}+m_{10,11}) \\ +p_{10,0}(p_{37}\mu_7+m_{37}) \end{Bmatrix} + (1-p_{12}^5 p_{21}^6) \\ \begin{bmatrix} p_{10,0}p_{03}m_{38}+p_{10,0}m_{03}p_{38}+m_{10,0}p_{03}p_{38}+p_{38}p_{10,0} \\ \{p_{03}\mu_8+p_{04}(\mu_4+\mu_9)+m_{04}\} \end{bmatrix} \\ +p_{38}p_{10,0}\begin{bmatrix} p_{01}m_{12}^5 p_{20}+p_{01}p_{12}^5 m_{20}+m_{01}p_{12}^5 p_{20}+ \\ p_{02}m_{21}^6 p_{10}+p_{02}p_{21}^6 m_{10}+m_{02}p_{21}^6 p_{10}+ \\ p_{01}m_{10}+m_{01}p_{10}+p_{02}m_{20}+m_{02}p_{20}+ \\ (p_{01}+p_{02})(p_{12}^5 m_{21}^6+m_{12}^5 p_{21}^6) \end{bmatrix}$$

4.3 No. of System Repairs

Using the definition [3] of $R_i(t)$ and applying simple probabilistic arguments, we get the following relations:

$$R_0(t) = Q_{01}(t)\textcircled{S}\{R_1(t)+1\} \\ +Q_{02}(t)\textcircled{S}\{R_2(t)+1\}+Q_{03}(t)\textcircled{S}R_3(t)+Q_{04}(t)\textcircled{S}R_4(t)$$
$$R_1(t) = Q_{10}(t)\textcircled{S}R_0(t)+Q_{12}^5(t)\textcircled{S}\{R_2(t)+1\}$$
$$R_2(t) = Q_{20}(t)\textcircled{S}R_0(t)+Q_{21}^6(t)\textcircled{S}\{R_1(t)+1\}$$
$$R_3(t) = Q_{37}(t)\textcircled{S}\{R_7(t)+1\}+Q_{38}\textcircled{S}R_8(t)$$
$$R_4(t) = Q_{49}(t)\textcircled{S}R_9(t)$$
$$R_7(t) = Q_{73}(t)\textcircled{S}R_3(t)$$
$$R_8(t) = Q_{8,10}(t)\textcircled{S}R_{10}(t)$$
$$R_9(t) = Q_{90}(t)\textcircled{S}R_0(t)$$
$$R_{10}(t) = Q_{10,0}(t)\textcircled{S}R_0(t)+Q_{10,11}(t)\textcircled{S}\{R_{11}(t)+1\}$$
$$R_{11}(t) = Q_{11,10}(t)\textcircled{S}R_{10}(t)$$

Taking Laplace Stieltjes transform of above equations and solving for $R_0^{**}(s)$, we get

$$R_0^{**}(s) = \frac{N_3(s)}{D_1(s)}$$

In steady state, expected no. of repairs per unit time is given by

$$R_0 = \lim_{s\to 0} s\,R_0^{**}(s) = \frac{N_3}{D_1}$$

where

$$N_3 = p_{03}(1-p_{12}^5 p_{21}^6)(p_{37}p_{10,0}+p_{38}p_{10,11}) \\ +p_{38}p_{10,0}\{p_{01}(1+p_{12}^5)+p_{02}(1+p_{21}^6)\}$$

D_1 is already specified

4.4 Busy Period of the Repairman

Using the definition [3] of $B_i(t)$ and applying simple probabilistic arguments, we get the following relations:

$$B_0(t) = q_{01}(t)\copyright B_1(t) \\ +q_{02}(t)\copyright B_2(t)+q_{03}(t)\copyright B_3(t)+q_{04}(t)\copyright B_4(t)$$
$$B_1(t) = W_1(t)+q_{10}(t)\copyright B_0(t)+q_{12}^5(t)\copyright B_2(t)$$
$$B_2(t) = W_2(t)+q_{20}(t)\copyright B_0(t)+q_{21}^6(t)\copyright B_1(t)$$
$$B_3(t) = q_{37}(t)\copyright B_7(t)+q_{38}(t)\copyright B_8(t)$$
$$B_4(t) = q_{49}(t)\copyright B_9(t)$$
$$B_7(t) = W_7(t)+q_{73}(t)\copyright B_3(t)$$
$$B_8(t) = q_{8,10}(t)\copyright B_{10}(t)$$
$$B_9(t) = q_{90}(t)\copyright B_0(t)$$
$$B_{10}(t) = q_{10,0}(t)\copyright B_0(t)+q_{10,11}(t)\copyright B_{11}(t)$$
$$B_{11}(t) = W_{11}(t)+q_{11,10}(t)\copyright B_{10}(t)$$

here, $W_1(t) = e^{-\lambda_2 t}\overline{G_1}(t)$

$$W_2(t) = e^{-\lambda_1 t}\overline{G_2}(t)$$
$$W_7(t) = \overline{G_2}(t)$$
$$W_{11}(t) = \overline{G_1}(t)$$

Taking Laplace transform of above equations and solving for $B_0^*(s)$, we obtain

$$B_0^*(s) = \frac{N_2(s)}{D_1(s)}$$

In steady state, expected busy period of the repairman is given by

$$B_0 = \lim_{s\to 0} s\,B_0^*(s) = \frac{N_2}{D_1}$$

where

$$N_2 = p_{38}p_{10,0}\{\mu_1(p_{02}p_{21}^6+p_{01})+\mu_2(p_{01}p_{12}^5+p_{02})\} \\ +p_{03}(1-p_{12}^5 p_{21}^6)(p_{10,0}p_{37}\mu_7 \\ +p_{38}p_{10,11}\mu_{11})$$

D_1 is already specified

5. Particular Case

For this particular case, the repair rates are assumed to be exponentially distributed.

$$g_1(t) = \delta e^{-\delta t}$$
$$g_2(t) = \omega e^{-\omega t}$$
$$f_1(t) = \varphi e^{-\varphi t}$$
$$f_2(t) = \nu e^{-\nu t}$$
$$h_1(t) = \mu e^{-\mu t}$$
$$h_2(t) = \eta e^{-\eta t}$$

Using the estimated values from Table1, following performance indices are obtained:

Mean time to system failure = 3475.6 hours
System availability = 0.92523
No. of system repairs = 0.01077
Busy period of the repairman = 0.05362

6. Simulated Results

In this section, the behaviour of system peformance indices viz. MTSF, availability, no. of repairs and busy period is studied with λ_1, λ_2 and ω. Table3 gives the trends of MTSF, availability,

number of repairs and busy period for varying values of λ_2 and ω w.r.t. λ_1. Following observations are evident from Table3.

- MTSF decreases w.r.t. both λ_1 and λ_2 irrespective of other parameters. The trend reverses with increase in the value of ω, for fixed λ_1 and λ_2.
- Availability decreases w.r.t. both λ_1 and λ_2 irrespective of other parameters. The trend reverses with increase in the value of ω, for fixed λ_1 and λ_2.
- No. of repairs increases w.r.t. both λ_1 and λ_2 irrespective of other parameters. The trend remains same with increase in the value of ω, for fixed λ_1 and λ_2.
- Busy period increases w.r.t. both λ_1 and λ_2 irrespective of other parameters. The trend reverses with increase in the value of ω, for fixed λ_1 and λ_2.

Table3: Effect of λ_2 and ω on performance indices w.r.t. λ_1

Performance Index	λ_2=0.0056, ω=0.2000	λ_2=0.0058, ω=0.2000	λ_2=0.0058, ω=0.3100	λ_1
MTSF	3716	3593	4288	0.0052
	3583	3464	4134	0.0054
	3460	3345	3991	0.0056
Availability	0.95551	0.94068	0.95047	0.0052
	0.94062	0.92625	0.93576	0.0054
	0.92619	0.91225	0.92150	0.0056
No. of repairs	0.01070	0.01073	0.01079	0.0052
	0.01073	0.01076	0.01082	0.0054
	0.01076	0.01080	0.01085	0.0056
Busy period	0.05368	0.05385	0.04539	0.0052
	0.05379	0.05396	0.04531	0.0054
	0.05391	0.05407	0.04523	0.0056

7. Conclusion

Performance indices viz. MTSF, availability, number of repairs and busy period of repairman have been estimated by analysing a rod breakdown system using semi-Markov processes and regenerative point techniques. System maintenance practices, queuing of machines for preventive maintenance, cooling period of machines and priority to repair over preventive maintenance, have been considered while carrying out the analysis. Simulated results have been presented to demonstrate the effect of varying failure/repair rates on the system performance. In future, results obtained in the present paper along with the results of [27-30] will be used while carrying out performance analysis of the entire cable manufacturing plant under consideration as a single unit.

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