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Original Article

Reliability Analysis of a System Operating at Reduced Capacity with Repair Priority to Boiler

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Abstract - *The essential need of any industry to raise productivity is to make the system available all the time without any obstructions. In this study, the main focus is on continued production from the system with the mechanism of different functioning modes. For the intended concept, the author studied the steam generation plant of the fertilizer industry with the presumption of operating the system at full or reduced capacity. The novelty of this research is to offer the provision of a repair facility for boiler over fans based on corresponding functioning modes. The above system having boiler and FD fans can't function at actual capacity on fan failure, so the facility provided to operate the system at reduced capacity can enhance availability and productivity. Also, numerical evaluation for MTSF, availability and profit analysis summed up using the theory of semi-Markov processes and the regenerative point technique. Furthermore, graphical plotting for MTSF, availability concerning different failure rates, and the effects of various rates/costs on profit are provided.*

Keywords - *Reduced capacity, Regenerative processes, Reliability modelling, Semi-Markov processes.*

1. Introduction

The engineers and researchers have made various efforts in reliability analysis to enhance system performance. The stochastic analysis of multiple unit systems with different constraints on repair facilities has been done in [1-3]. Many researchers have carried out various reliability measures on different situations of technological systems depending upon several failure modes and different repair patterns [4–9]. Several methodologies demonstrate the optimal design to maximize the reliability of a non-repairable system with standby redundancy [10], the availability of a system with an unreliable repair facility and reboot delay [11], and the availability of redundant systems under perfect repair [12], and the effect of random shocks having priority for maintenance over repair [13]. Reliability analysis of repairable wireless transmission systems was done by [14]. Various redundant systems were studied under various conditions, such as operation based on varying demand [15], provision of concurrent work [16], and [17] additional units to increase functionality. Reference [18-19] found the reliability and availability of the standby systems. A new reliability method [20] was proposed [21] for repairable components to analyse the system at different temperatures with a repair facility provided at night hours. Reliability measures for the water treatment plant were carried out by [22]. A three-unit system consisting of induced draft fans and warm standby has been considered under study [23] that produces low power on fan failure. The concept of profit evaluation of the cold standby system, which comprises a boiler, turbine, and fans, was analyzed by [24]. But in both attempts, the repair priority was not managed adequately to increase the system availability. Although the reference [25] concentrated on milk plants operating under reduced capacity, none of them explained the provision of a repair facility depending upon different functioning modes. Extending the above concept, the Steam Generation Plant of National Fertilizer Limited Bathinda has been studied under several repair facilities based on the various functioning modes.

Initially, the system involves one boiler and two forced-draft fans. For continuous functioning, a boiler and two FD fans should function adequately. If the boiler fails, the system stops working immediately. But if any fan fails, the system can't operate at its actual capacity. Provision to work at reduced capacity is considered in the case of a fan that fails to overcome the losses associated with shutting down. Thus, system availability increases in comparison to a complete shutdown. Over the fans, a repair pattern is given to the boiler to maintain the system for a long time. Also, the fan's repair pattern is on FCFS. The model has been developed on the following assumptions:

- The nature of all the random variables is independent.
- Failure time's distribution is exponential, whereas repair time's distribution is arbitrary.
- After each repair, the system functions as if it were new.
- Repairman waiting time is negligible on any failure.

2. Material and Methods

The present study consists of a boiler and forced draft fans of the Steam Generation plant of National Fertilizer Limited, Bathinda. The reliability model is developed to enhance the availability and productivity of the system. The semi-Markov processes and regenerative point techniques have been used to evaluate reliability measures such as MTSF, availability, busy period, and expected repairs. Also, the graphic study shows the effects of failure rates on profit and MTSF.

3. Model Discription and Nomenclature

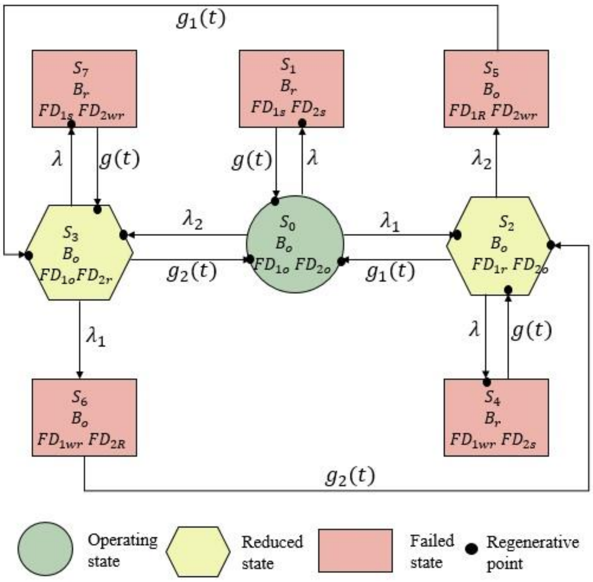

Fig. 1 State Transition Diagram

The above transition diagram shows various states of the system. The epoch of entry into the states S_0, S_1, S_2, S_3, S_4, *and* S_7 are regenerative points; thus, these states are called regenerative states. The states S_0, S_2, *and* S_3, are operating states, while states S_1, S_4, S_5, S_6, *and* S_7 are failed states.

λ: Constant failure rate of the boiler,
λ_1: Constant failure rate of FD fan 1,
λ_2 : Constant failure rate of FD fan 2,
α: Repair rate of the boiler,
α_1 : Repair rate of FD fan 1,
α_2 : Repair rate of FD fan 2,
$G(t), g(t)$: c.d.f. & p.d.f of repair time of Boiler,
$G_1(t), g_1(t)$: c.d.f. & p.d.f of repair time of FD fan 1,
$G_2(t), g_2(t)$: c.d.f. & p.d.f of repair time of FD fan 2,

Symbols for the states of the system:-
B_0, FD_{10}, FD_{20} : Boiler, FD fans 1 and 2 are operating, respectively,
B_r : Boiler under repair.
B_s, FD_{1s}, FD_{2s} : Boiler, FD fans 1 and 2 in the standby state.
FD_{1r}, FD_{2r} : FD fans 1 and 2 are under repair.
FD_{1wr}, FD_{2wr}: FD fans 1 and 2 are waiting for repair.
FD_{1R}, FD_{2R}: FD fans 1 and 2 are under repair from the previous state.

4. Transition Probabilities and Mean Sojourn Times

The non-zero elements p_{ij}, are given by

$p_{01} = \frac{\lambda}{\lambda+\lambda_1+\lambda_2}$, $\quad p_{02} = \frac{\lambda_1}{\lambda+\lambda_1+\lambda_2}$,
$p_{03} = \frac{\lambda_2}{\lambda+\lambda_1+\lambda_2}$, $\quad p_{10} = 1$,
$p_{20} = g_1^*(\lambda+\lambda_2)$, $\quad p_{24} = \frac{\lambda}{\lambda+\lambda_2}[1-g_1^*(\lambda+\lambda_2)]$,
$p_{25} = p_{23^5} = \frac{\lambda_2}{\lambda+\lambda_2}[1-g_1^*(\lambda+\lambda_2)]$,
$p_{30} = g_2^*(\lambda+\lambda_1)$, $\quad p_{37} = \frac{\lambda}{\lambda+\lambda_1}[1-g_2^*(\lambda+\lambda_1)]$,
$p_{36} = p_{32^6} = \frac{\lambda_1}{\lambda+\lambda_1}[1-g_2^*(\lambda+\lambda_1)]$,
$p_{42} = 1$, $\quad p_{53} = 1$,
$p_{62} = 1$, $\quad p_{73} = 1$

It can be verified by these transition probabilities that
$p_{01} + p_{02} + p_{03} = 1$ $\quad p_{10} = 1$
$p_{20} + p_{24} + p_{25} = 1$ $\quad p_{20} + p_{24} + p_{23^5} = 1$,
$p_{30} + p_{36} + p_{37} = 1$ $\quad p_{30} + p_{37} + p_{32^6} = 1$,
$p_{42} = p_{53} = 1$, $\quad p_{62} = p_{73} = 1$,

Mean sojourn times μ_i in the state S_i are
$\mu_0 = \frac{1}{\lambda+\lambda_1+\lambda_2}$, $\quad \mu_1 = -g^{*'}(0)$,
$\mu_2 = \frac{1}{\lambda+\lambda_2}[1-g_1^*(\lambda+\lambda_2)]$,
$\mu_3 = \frac{1}{\lambda+\lambda_1}[1-g_2^*(\lambda+\lambda_1)]$,
$\mu_4 = -g^{*'}(0)$, $\quad \mu_5 = -g_1^{*'}(0)$,
$\mu_6 = -g_2^{*'}(0)$, $\quad \mu_7 = -g^{*'}(0)$,

The unconditional mean time taken by the system to transit for any regenerative state 'j' when it (time) is counted from the epoch of entrance into state' i' is mathematically stated as

$$m_{ij} = \int_0^\infty t\, dQ_{ij}(t) = -q_{ij}^{*'}(0)$$

$m_{01} + m_{02} + m_{03} = \mu_0$,

$m_{10} = \mu_1$,

$m_{20} + m_{24} + m_{25} = \mu_2$,

$m_{20} + m_{23^5} + m_{24} = \mu_2 + K_1$

$m_{30} + m_{36} + m_{37} = \mu_3$,

$m_{30} + m_{32^6} + m_{37} = \mu_3 + K_2$

$m_{42} = \mu_4$,

$m_{53} = \mu_5$,

$m_{62} = \mu_6$,

$m_{73} = \mu_7$,

where,

$$K_1 = \frac{\lambda_2}{\lambda}\int_0^\infty t\, g_1(t)dt,$$

$$K_2 = \frac{\lambda_1}{\lambda}\int_0^\infty t\, g_2(t)dt \qquad (say)$$

5. Measure of System Effectiveness

5.1. Mean Time to System Failure (MTSF)

The mean time to system failure (MTSF) of the system is determined by considering the failed state as an absorbing state when the system starts from the initial state S_0 is

$$5.1.2.\text{MTSF}= T_0 = \lim_{s\to 0}\frac{1-\phi_0^{**}(s)}{s}$$

Using L' Hospital Rule & putting the value of $\phi_0^{**}(s)$, we have

$$T_0 = \frac{N}{D}$$

where

$$N = \mu_0 + \mu_2 p_{02} + \mu_3 p_{03}$$

$$\& \ D = 1 - p_{02}p_{20} - p_{03}p_{30}$$

5.2. Availability Analysis at Full Capacity

Using the theory of regenerative processes, the availability A_0 of the system at full capacity is given by

$$A_0 = \lim_{s\to 0}\left(sA_0^*(s)\right) = \frac{N_1}{D_1}$$

where

$$N_1 = \mu_0[1 - p_{37} - p_{24} - p_{23}^{(5)}p_{32}^{(6)} + p_{24}p_{37}]$$

$$\begin{aligned} D_1 = \mu_0&\left(p_{20} - p_{20}p_{37} + p_{30}p_{23}^{(5)}\right) \\ &+ \mu_1 p_{01}\left(p_{20} - p_{20}p_{37} + p_{30}p_{23}^{(5)}\right) \\ &+ (\mu_2 + K_1)\left(p_{02} - p_{02}p_{37} + p_{03}p_{32}^{(6)}\right) \\ &+ (\mu_3 + K_2)\left(p_{03} - p_{03}p_{24} + p_{02}p_{23}^{(5)}\right) \\ &+ \mu_4 p_{24}((1 - p_{01})(1 - p_{37}) - p_{03}p_{30}) \\ &+ \mu_7 p_{37}((1 - p_{01})(1 - p_{24}) - p_{02}p_{20}) \end{aligned}$$

5.3. Availability Analysis at Reduced Capacity

Using the theory of regenerative processes, the availability R_0 of the system at reduced capacity is given by

$$R_0 = \lim_{s\to 0}\left(sR_0^*(s)\right) = \frac{N_2}{D_1}$$

where

$$\begin{aligned} N_2 = \mu_2&\left[p_{02} + p_{03}p_{32}^{(6)} - p_{02}p_{37}\right] \\ &+ \mu_3\left[p_{03} + p_{02}p_{23}^{(5)} - p_{03}p_{24}\right] \end{aligned}$$

& D_1 is already specified.

5.4. Busy Period Analysis of a Repairman

A busy period analysis of a repairman is given by

$$B_0 = \lim_{s\to 0}\left(sB_0^*(s)\right) = \frac{N_3}{D_1}$$

where

$$\begin{aligned} N_3 = \mu_2&\left(p_{02} - p_{02}p_{37} + p_{03}p_{32}^{(6)}\right) \\ &+ \mu_3\left(p_{03} - p_{03}p_{24} + p_{02}p_{23}^{(5)}\right) \\ &+ K_3\left(p_{01} - p_{01}p_{24} - p_{02}p_{24} - p_{01}p_{37}\right. \\ &- p_{03}p_{37} + p_{01}p_{24}p_{37} - p_{02}p_{24}p_{37} \\ &- p_{03}p_{24}p_{37} + p_{02}p_{37}p_{23}^{(5)} + p_{03}p_{24}p_{32}^{(6)} \\ &\left.- p_{01}p_{23}^{(5)}p_{32}^{(6)}\right) \end{aligned}$$

& D_1 is already specified.

5.5. Expected no. of Repairs

Expected no. repairs per unit time for the system is given by

$$V_0 = \lim_{s\to 0}\left(sV_0^{**}(s)\right) = \frac{N_4}{D_1}$$

where

$$N_4 = 1 - p_{24} - p_{37} - p_{37}p_{24} - p_{23}^{(5)}p_{32}^{(6)}$$

& D_1 is already specified.

6. Cost-Benefit Analysis

The expected total profit acquired for the system is

$$P = C_0A_0 + C_1R_0 - C_2B_0 - C_3V_0$$

where

$C_0 =$ Revenue per unit up time at full capacity.
$C_1 =$ Revenue per unit up time at reduced capacity.
$C_2 =$ Cost per unit up-time when the repairman is busy repairing.
$C_3 =$ Cost per repair.

7. Particular Case

For the graphical representation, the following particular cases are considered. Let us suppose that $g(t) = \alpha e^{-\alpha t}$, $g_1(t) = \alpha_1 e^{-\alpha_1 t}, g_2(t) = \alpha_2 e^{-\alpha_2 t}$. Therefore, we have

$p_{01} = \frac{\lambda}{\lambda+\lambda_1+\lambda_2}$, $p_{02} = \frac{\lambda_1}{\lambda+\lambda_1+\lambda_2}$,
$p_{03} = \frac{\lambda_2}{\lambda+\lambda_1+\lambda_2}$, $p_{10} = 1$,
$p_{20} = \frac{\lambda_1}{\lambda+\alpha_1+\lambda_2}$, $p_{24} = \frac{\lambda}{\lambda+\alpha_1+\lambda_2}$,
$p_{25} = \frac{\lambda_2}{\lambda+\alpha_1+\lambda_2}$, $p_{23^5} = \frac{\lambda_2}{\lambda+\alpha_1+\lambda_2}$,
$p_{30} = \frac{\lambda_2}{\lambda+\alpha_2+\lambda_1}$, $p_{37} = \frac{\lambda}{\lambda+\alpha_2+\lambda_1}$,
$p_{36} = \frac{\lambda_1}{\lambda+\alpha_2+\lambda_1}$, $p_{32^6} = \frac{\lambda_1}{\lambda+\alpha_2+\lambda_1}$,
$p_{42} = 1$, $p_{53} = 1$,
$p_{62} = 1$, $p_{73} = 1$
$\mu_0 = \frac{1}{\lambda+\lambda_1+\lambda_2}$, $\mu_1 = \frac{1}{\alpha}$,
$\mu_2 = \frac{1}{\lambda+\alpha_1+\lambda_2}$, $\mu_3 = \frac{1}{\lambda+\alpha_2+\lambda_1}$,
$\mu_4 = \frac{1}{\alpha}$, $\mu_5 = \frac{1}{\alpha_1}$,
$\mu_6 = \frac{1}{\alpha_2}$, $\mu_7 = \frac{1}{\alpha}$

Table 1. Data collected from the industry regarding various rates/costs

Various rates/costs associated	corresponding values
Failure rate of Boiler (λ)	.0001186/hr
Failure rate of FD fan 1 (λ_1)	.0001171/hr
Failure rate of FD fan 1 (λ_2)	.000101295/hr
Repair rate of Boiler (α)	.00738/hr
Repair rate of FD fan 1 (α_1)	.024272/hr
Repair rate of FD fan 1 (α_2)	.048544/hr
Expected cost per repair (C_3)	Rs. 14282

For the remaining rates/costs, hypothetical values have been taken, and various measures of system effectiveness are computed in Table 2 based on the particular cases by putting the values from Table 1.

Table 2. Computation of various measures of system effectiveness

Mean time to system failure	8380.65 hours
Availability of the system at full capacity	.9715219/hr
Availability of the system at reduced capacity	.0067098/hr
A busy period of repairman for repair time only	.0224305/hr
Expected no. of repairs	.0003274/hr

Table 3. Data for MTSF vs. Failure rate of boiler (λ)

Data for MTSF vs. Failure rate of boiler (λ) for variation in the Failure rate of FD fan one (λ_1)			
λ	λ_1=.0001171	λ_1=.001171	λ_1=.01171
0.0001186	8380.645	7969.35	6075.088
0.0001286	7732.617	7381.243	5727.469
0.0001386	7177.614	6873.971	5417.479
0.0001486	6696.944	6431.938	5139.321
0.0001586	6276.613	6043.321	4888.332
0.0001686	5905.93	5698.989	4660.716
0.0001786	5576.589	5391.78	4453.354
0.0001886	5282.038	5115.997	4263.658
0.0001986	5017.043	4867.053	4089.462

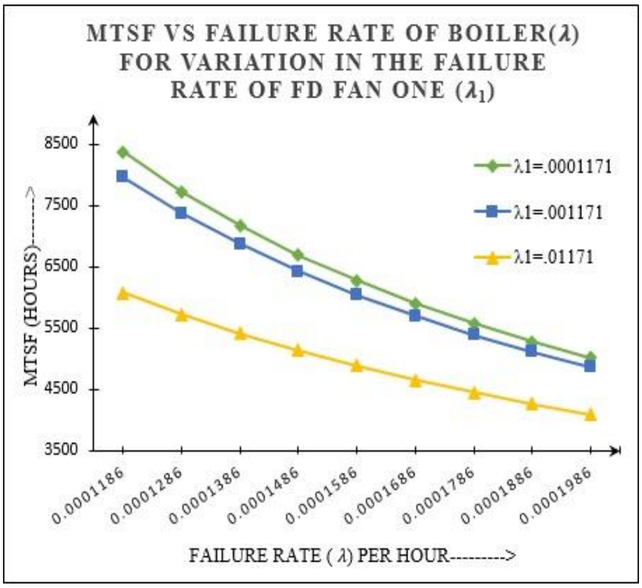

Fig. 2 MTSF vs. Failure rate of the boiler

Table 4. Availability vs. Failure rate of boiler (λ)

Availability vs. Failure rate of boiler (λ)		
λ	Availability at Full Capacity	Availability at Full + Reduced Capacity
0.0001186	0.9715219	0.9782318
0.0001286	0.9706899	0.977394
0.0001386	0.9697939	0.9764918
0.0001486	0.9688474	0.9755388
0.0001586	0.9678605	0.9745451
0.0001686	0.9668411	0.9735186
0.0001786	0.9657951	0.9724654
0.0001886	0.9647273	0.9713902
0.0001986	0.9636414	0.9702968

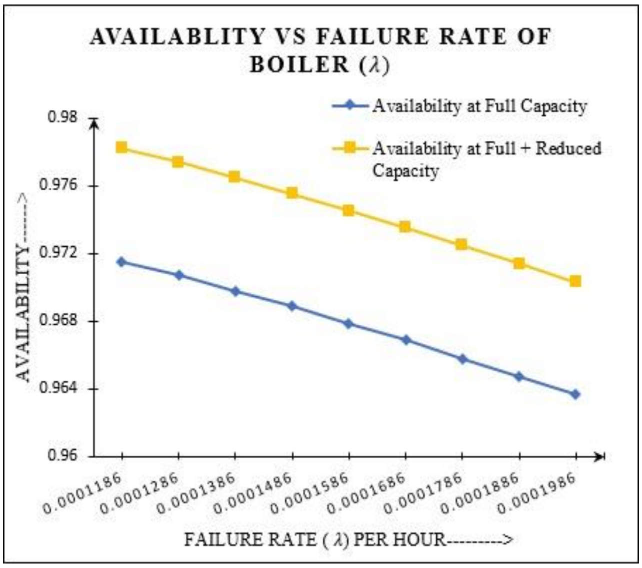

Fig. 3 Availability vs. Failure rate of the boiler

Table 5. Profit vs. Failure rate of boiler (λ)

Profit vs. Failure rate of boiler (λ) for the different values of the Failure rate of FD fan one (λ_1)			
λ	λ_1=.0001171	λ_1=.0001571	λ_1=.0001971
0.0001186	172781.5	172093.9	171411
0.0001286	172474.5	171815.4	171160.6
0.0001386	172156.3	171521.8	170891.1
0.0001486	171829.5	171216.3	170606.7
0.0001586	171495.9	170901.3	170310.2
0.0001686	171156.9	170578.8	170004.1
0.0001786	170813.4	170250.1	169690
0.0001886	170466.5	169916.4	169369.4
0.0001986	170116.7	169578.6	169043.4

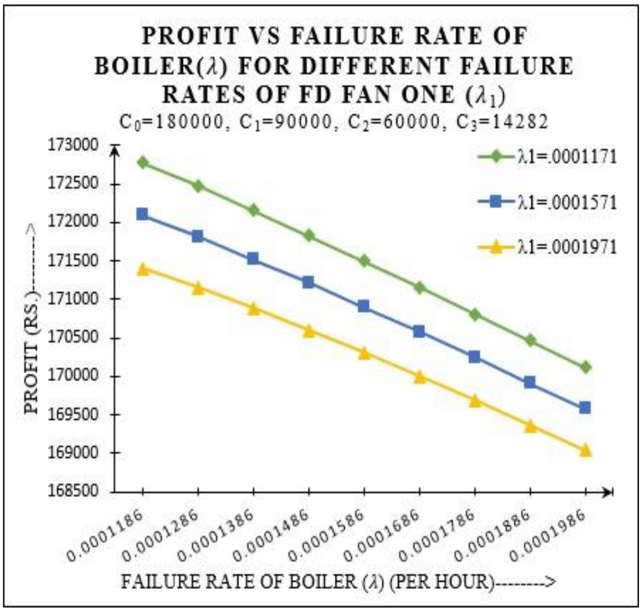

Fig. 4 Profit vs. Failure rate of the boiler

Table 6. Profit vs. Revenue per unit uptime of the system (C_0)

Profit vs. Revenue per unit uptime of the system (C_0) for the different values of the Failure rate of boiler (λ)			
C_0	λ=.0001186	λ=.0006523	λ=.001186
2000	-149.4041	-8112.051	-15089.3
22000	19281.03	10118.54	2013.955
42000	38711.47	28349.14	19117.24
62000	58141.91	46579.73	36220.52
82000	77572.35	64810.33	53323.8
102000	97002.79	83040.92	70427.08
122000	116433.2	101271.5	87530.37
142000	135863.7	119502.1	104633.6
162000	155294.1	137732.7	121736.9
182000	174724.5	155963.3	138840.2
202000	194155	174193.9	155943.5

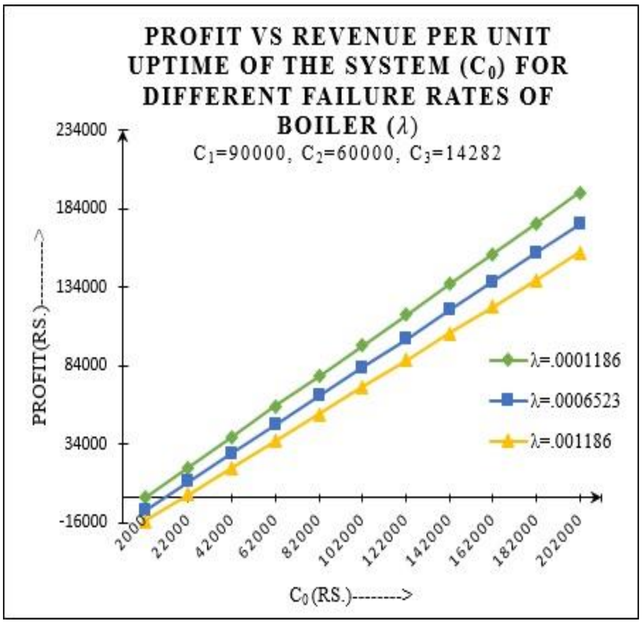

Fig. 5 Profit vs. Revenue per unit up-time

8. Results and Discussion

Fig. 2 shows the influence of MTSF vs. the failure rate of the boiler (λ) for varying values of the failure rate of the FD fan one (λ_1). It demonstrates that MTSF decreases as the failure rate of the boiler (λ) increases. Also, MTSF decreases as the failure rate of FD fan one (λ_1) increases. In Fig. 3, different availabilities are compared with the failure rate of the boiler (λ). As the failure rate of the boiler increases, availability decreases. But an increase in the boiler's failure rate can enhance the system's availability. In Fig. 4, the profit trend is compared with the failure rate of the boiler (λ) and the FD fan (λ_1). It shows that profit decreases with an increase in the failure rate of the boiler and FD fan. Fig. 5 reveals the behaviour of profit w.r.t. cost per unit uptime of the system (C_0) for the different values of the failure rate of the boiler (λ). As the value of C_0 increases, the system's profit also increases. Also, as the failure rate of the boiler increases, profit decreases. Moreover, various cut-points for-profit w.r.t. revenue up-time of the system at full capacity shown in Table 7 reveals that the system is profitable for (C_0) greater than these points.

Table 7. The cut point for profit w.r.t. revenue up-time of the system at full capacity

The failure rate of the boiler (per hr)	**Revenue per unit up-time (Rs.)**	**Profit (Rs.)**
$\lambda = .0001186$	$C_0 > or = or < 2154$	Positive or Zero or Negative
$\lambda = .0006523$	$C_0 > or = or < 10900$	Positive or Zero or Negative
$\lambda = .001186$	$C_0 > or = or < 19645$	Positive or Zero or Negative

9. Conclusion

The paper determines the various reliability measures of the Steam Generation Plant of National Fertilizer Limited, Bathinda. The described model plays a substantial role in operating the system at reduced capacity to achieve maximum availability to make the system profitable. The users/industries may assume the stated model and implement it to conclude various costs like revenue per unit uptime at full and reduced capacity. Also, different cut-off points will assist the user in obtaining the acceptable values of different rates and costs, making the system more reliable and cost-effective.

Conflicts of Interest

"There is no conflict of interest regarding the publication of this paper." This research does not include any help from funding agencies or any govt. Bodies.

References

[1] De, Guo Tong, Stochastic Behaviour of a Two-Unit Cold Standby System with Preparation Time for Repair, Microelectronics Reliability. 29(2) (1989) 125-129.

[2] SK Singh, RP Singh & Sindhu Shukla, Cost-Benefit Analysis of a 2-Unit Priority-Standby System with Patience-Time for Repair, IEEE Transactions on Reliability. 40(1) (1991) 11–14.

[3] Li W, Alfa A. S & Zhao Y. Q, Stochastic Analysis of a Repairable System with Three Units and Two Repair Facilities, Microelectronics Reliability. 38(4) (1998) 585-595.

[4] Rizwan S. M & Taneja G, Profit Analysis of a System with Perfect Repair at Partial Failure or Complete Failure, Pure and applied mathematika ciences. 52(1/2) (2000) 7-14.

[5] Sheu S. H & Griffith W. S, Optimal Age-Replacement Policy with Age-Dependent Minimal-Repair and Random-Leadtime, IEEE Transactions on Reliability. 50(3) (2001) 302-309.

[6] Yanez M, Joglar F & Modarres M, Generalized Renewal Process for Analysis of Repairable Systems with Limited Failure Experience, Reliability Engineering & System Safety. 77(2) (2002) 167-180.

[7] Coit D. W, Maximization of System Reliability with a Choice of Redundancy Strategies, IEEE Transactions on Reliability. 35(6) (2003) 535-543.

[8] Chen T. C & You P. S, Immune Algorithms-Based Approach for Redundant Reliability Problems with Multiple Component Choices, Computers in Industry. 56(2) (2005) 195-205.

[9] Taneja G, Singh D. V & Minocha A, Profit Evaluation of 2-out-of-3 Unit System for an Ash Handling Plant Wherein Situation of System Failure Did Not Arise, Journal of Information and Optimization Sciences. 28(2) (2007) 195-204.

[10] Amari S. V & Dill G, Redundancy Optimization Problem with Warm-Standby Redundancy, In 2010 Proceedings-Annual Reliability and Maintainability Symposium RAMS, IEEE. (2010) 1-6.

[11] Hsu Y. L, Ke J. C & Liu T. H, Standby System with General Repair, Reboot Delay, Switching Failure and Unreliable Repair Facility-A Statistical Standpoint, Mathematics and Computers in Simulation. 81(11) (2011) 2400-2413.

[12] Yusuf I & Hussaini N, Evaluation of Reliability and Availability Characteristics of 2-out of-3 Standby System Under a Perfect Repair Condition, American Journal of Mathematics and Statistics. 2(5) (2012) 114-119.

[13] Chhillar S. K, Barak A. K & Malik S. C, Analysis of a Parallel System with Priority to Maintenance Over Repair Subject to Random Shocks, American Journal of Mathematics and Statistics. 3(5) (2013) 258-264.

[14] Sattiraju, R., Chakraborty, P., & Schotten, H. D., Reliability analysis of a wireless transmission as a repairable system, In 2014 IEEE Globecom Workshops. (2014) 1397-1401.

[15] Malhotra R & Taneja G, Comparative Study Between a Single Unit System and a Two-Unit Cold Standby System with Varying Demand, Springer Plus. 4(1) (2015) 705

[16] Sharma U and Sharma G, Probabilistic Analysis of a Standby System with Provision of Concomitant Working, International Journal of Engineering Trends and Technology. 40(1) (2016) 32–34.

[17] Sharma U & Kaur J, Study of Two Units Standby System with One Essential Unit to Increase Its Functioning, International Journal of Engineering Trends and Technology. 33(11) (2016) 97-100.

[18] Adlakha N, Taneja G & Batra S, Reliability and Cost-Benefit Analysis of a Two-Unit Cold Standby System Used for Communication through Satellite with Assembling and Activation Time, International Journal of Applied Engineering Research. 12(20) (2017) 9697-9702.

[19] Goyal S & Malhotra R, A Systematical Study of Reliability on Various Models, International Journal of Advance Research in Science and Engineering. 6(4) (2017) 864-876.

[20] Yi X. J, Shi J, Dhillon B. S, Hou P & Dong H. P, A New Reliability Analysis Method for Repairable Systems with Closed Loop Feedback Links, Quality and Reliability Engineering International. 34(3) (2018) 298-332.

[21] Sheetal D. S & Taneja G, Reliability Analysis of a System Working in High Temperature Zones with Fault-Dependent Repair during Night hours, International Journal of Applied Engineering Research. 13(20) (2018) 14650-14656.

[22] Agrawal A, Garg D, Kumar A & Kumar R, Performance Analysis of the Water Treatment Reverse Osmosis Plant, Reliability: Theory & Applications. 16(3(63)) (2021) 16-25.

[23] Bhatia P. K, Naithani A, Parashar B & Taneja G, Reliability Modelling of a 3-Unit (Induced Draft Fan) Cold Standby System Working at Full/Reduced Capacity, International Journal of Mathematical Archive. 3(10) (2012) 3737-3744.

[24] Sharma U & Sharma G, Steady State Behaviour of a Cold Standby System Consisting of Turbine, Boiler and Fans, IOSR Journal of Engineering. 8(8) (2018) 224-230.

[25] Barak M. S, Garg R & Kumar A, Reliability Measures Analysis of a Milk Plant Using RPGT, Life Cycle Reliability and Safety Engineering. 10(3) (2021) 295-302.