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Comparative Analysis of Reliability Models of a Cable Plant Portraying Summer and Winter Operating Strategy

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Abstract. The paper presents a comparative analysis between the profits of two reliability models of a plant, manufacturing electrical cables. Model-I is based on operating the plant for 24 hours without resting machines during summer season, whereas, Model-II is based on 16 hours of operation followed by 8 hours of rest period during winter season. Specific season based operational strategies being adopted to address the demand based production of the cables. Real maintenance data are used for estimating the optimized reliability indices and comparison of profits. Semi-Markov processes and regenerative point techniques are used to carry out the analysis. Essential graphs are plotted to demonstrate the results.

Keywords: cable plant, regenerative processes, reliability, semi-Markov processes.

1 Introduction

Significant contribution has been made to the field of reliability by a number of researchers while analysing various complex industrial systems. Tuteja et al. [1-3] performed cost-benefit analysis of 2-unit system with different types of standby, failures and repairman. Rizwan et al. [4-9] carried out reliability analysis of 1-unit PLC system with hot standby; waste water treatment plant with inspection; and 2-unit system with various categories of repairman. Mathew et al. [10-16] estimated important reliability indices of 1-unit and 2-unit CC plant wherein different installation capacities and maintenance policies were considered. Padmavathi et al. [17-22] extensively analysed desalination plant focussing on major and minor failure, emergency shutdown, online repair, and priority to repair over maintenance. Rizwan et al. [23-24] extended the work for reliability analysis of desalination plant with season based shutdown and repair/maintenance on FCFS basis. Taneja et al. [25-26] discussed profit analysis of system with varying demand. Yaqoob Al Rahbi et al. [27-30] worked on the reliability and maintainability of three different systems in the aluminium industry. Taj et al. [31-35] studied the performance of 1-unit, 2-unit and 3-unit subsystems of a cable plant considering various maintenance categories and priority to repair over preventive maintenance. Recently, Taj et al. [36-37] proposed two reliability models of a cable plant portraying specific season based operating strategies. The summer operating strategy, where the plant operates for 24 hours without resting machines, was discussed in Model-I [36]. Model-II [37] presented the winter operating strategy, where the plant operates for 16 hours followed by 8 hours rest period for the machines. Real maintenance data of the plant were used to estimate important reliability indices such as mean time to plant failure, availability of the plant, expected number of repairs, expected busy period of the repairman and profit incurred to the plant. Semi-Markov processes [38] and regenerative point techniques [39] were used to carry out the analysis. Simulated results were presented to demonstrate the effect of varying plant parameters on the reliability indices. There is scope of performing comparative analysis between the two reliability models of the cable plant.

Thus, this paper presents comparative analysis between the profits of the two reliability models of the cable plant, Model-I and Model-II. The behaviour of difference of profits of the two models with respect to various costs and different values of failure rate is demonstrated through graphs. The analysis is useful in deducing the suitability of one model over the other, under the following operating conditions and assumptions:

- The plant consists of five subsystems (A, B, C, D and E) operating in series.
- If a particular subsystem fails, the succeeding subsystems enter into the down state whereas the preceding subsystems continue to operate.
- The entire plant enters into the failed state once the first subsystem of the plant, arranged in series, fails.
- Repair is carried out upon failure.
- Repair work is completed before the plant enters into the rest state (for Model-II).
- Repair rates are taken as arbitrary.
- Failure rates are taken as exponential.

2 Model-I

For Model-I, the rates of transition from state S_i to state S_j are given in Table 1.

Table 1. Rates of transition for Model-I

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_0	0	λ_A	λ_B	λ_C	λ_D	λ_E	0	0	0	0	0
S_1	$g_A(t)$	0	0	0	0	0	0	0	0	0	0
S_2	$g_B(t)$	0	0	0	0	0	λ_A	0	0	0	0
S_3	$g_C(t)$	0	0	0	0	0	0	0	0	0	0
S_4	$g_D(t)$	0	0	0	0	0	0	λ_A	λ_B	0	0

S_5	$g_E(t)$	0	0	0	0	0	0	0	0	λ_B	λ_D
S_6	0	$g_B(t)$	0	0	0	0	0	0	0	0	0
S_7	0	$g_D(t)$	0	0	0	0	0	0	0	0	0
S_8	0	0	$g_D(t)$	0	0	0	0	0	0	0	0
S_9	0	0	$g_E(t)$	0	0	0	0	0	0	0	0
S_{10}	0	0	0	0	$g_E(t)$	0	0	0	0	0	0

Following measures of plant effectiveness in steady state are obtained (refer [36] for details):

Mean time to plant failure, $\mathrm{MTPF} = \frac{N}{D}$

Availability of the plant, $A_0 = \frac{N_1}{D_1}$

Expected busy period of the repairman, $B_0 = \frac{N_2}{D_1}$

Expected number of repairs, $R_0 = \frac{N_3}{D_1}$

Profit incurred to the plant, $P_1 = C_0A_0 - C_1B_0 - C_2R_0$

3 Model-II

For Model-II, the rates of transition from state S_i to state S_j are given in Table 2.

Table 2. Rates of transition for Model-II

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_A	λ_B	λ_C	λ_D	λ_E	0	0	0	0	0	γ
S_1	$g_A(t)$	0	0	0	0	0	0	0	0	0	0	0
S_2	$g_B(t)$	0	0	0	0	0	λ_A	0	0	0	0	0
S_3	$g_C(t)$	0	0	0	0	0	0	0	0	0	0	0
S_4	$g_D(t)$	0	0	0	0	0	0	λ_A	λ_B	0	0	0
S_5	$g_E(t)$	0	0	0	0	0	0	0	0	λ_B	λ_D	0
S_6	0	$g_B(t)$	0	0	0	0	0	0	0	0	0	0
S_7	0	$g_D(t)$	0	0	0	0	0	0	0	0	0	0
S_8	0	0	$g_D(t)$	0	0	0	0	0	0	0	0	0
S_9	0	0	$g_E(t)$	0	0	0	0	0	0	0	0	0

S_{10}	0	0	0	0	$g_E(t)$	0	0	0	0	0	0	0
S_{11}	σ	0	0	0	0	0	0	0	0	0	0	0

Following measures of plant effectiveness in steady state are obtained (refer [37] for details):

Mean time to plant failure, $\text{MTPF} = \frac{N}{D}$

Availability of the plant, $A_0 = \frac{N_1}{D_1}$

Expected busy period of the repairman, $B_0 = \frac{N_2}{D_1}$

Expected number of repairs, $R_0 = \frac{N_3}{D_1}$

Profit incurred to the plant, $P_1 = C_0A_0 - C_1B_0 - C_2R_0$

4 Comparison between the Two Models

Comparison of profits of Model-I and Model-II is done graphically for the particular cases and various conclusions are drawn.

Fig. 1 shows the behavior of difference of profits (P_1-P_2) with respect to revenue per unit up time (C_0) for different values of failure rate (λ_A).

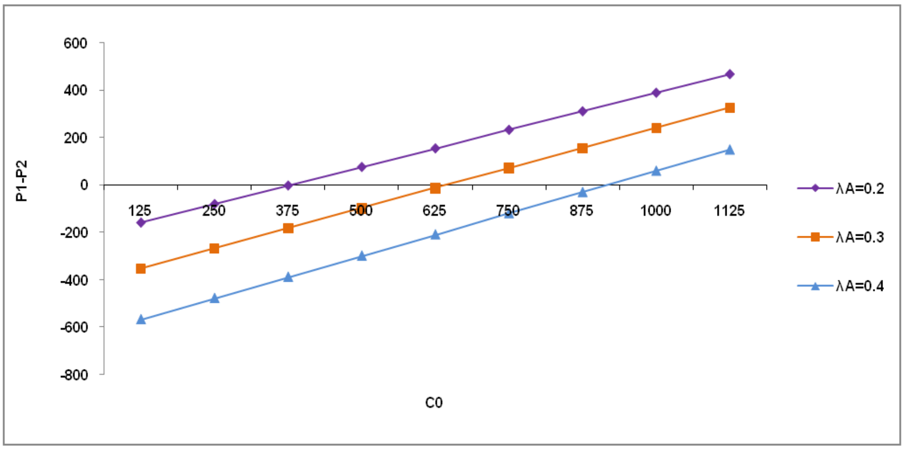

Fig. 1 Difference of profits (P_1-P_2) with respect to revenue per unit up time (C_0) for different values of failure rate (λ_A).

From the graph, the following can be concluded:

(i) The difference of profits (P_1-P_2) increases as the revenue per unit up time (C_0) increases.

(ii) The difference of profits (P_1-P_2) is higher for lower values of failure rate (λ_A).

(iii) For $\lambda_A = 0.2$, P_1-P_2 > or = or < 0 accordingly as C_0 > or = or < 375. So, Model-I is better or worse than Model-II if C_0 > or < 375. Both models are equally good if $C_0 = 375$.

(iv) For $\lambda_A = 0.3$, P_1-P_2 > or = or < 0 accordingly as C_0 > or = or < 643. So, Model-I is better or worse than Model-II if C_0 > or < 643. Both models are equally good if $C_0 = 643$.

(v) For $\lambda_A = 0.4$, P_1-P_2 > or = or < 0 accordingly as C_0 > or = or < 916. So, Model-I is better or worse than Model-II if C_0 > or < 916. Both models are equally good if $C_0 = 916$.

Fig. 2 shows the behavior of difference of profits (P_1-P_2) with respect to cost per unit time for which the repairman is busy (C_1) for different values of cost per unit repair (C_2).

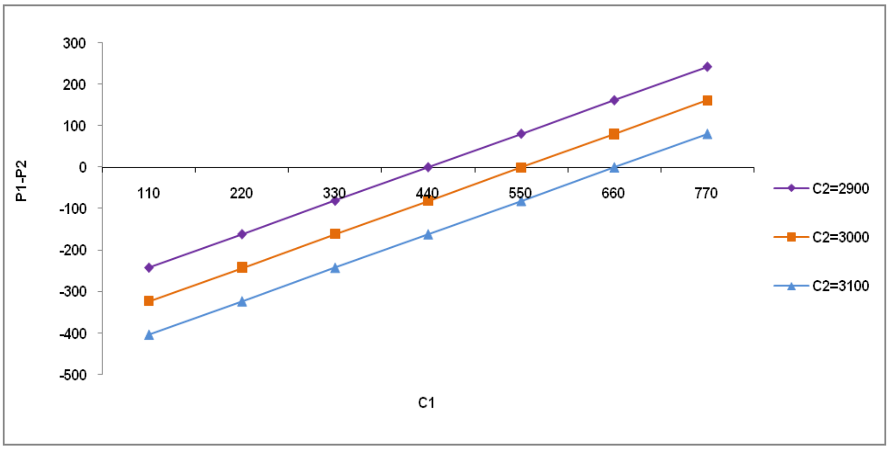

Fig. 2 Difference of profits (P_1-P_2) with respect to cost per unit time for which the repairman is busy (C_1) for different values of cost per unit repair (C_2).

From the graph, the following can be concluded:

(i) The difference of profits (P_1-P_2) increases as the cost per unit time for which the repairman is busy (C_1) increases.

(ii) The difference of profits (P_1-P_2) is higher for lower values of cost per unit repair (C_2).

(iii) For $C_2 = 2900$, P_1-P_2 > or = or < 0 accordingly as C_1 > or = or < 440. So, Model-I is better or worse than Model-II if C_1 > or < 440. Both models are equally good if $C_1 = 440$.

(iv) For $C_2 = 3000$, P_1-P_2 > or = or < 0 accordingly as C_1 > or = or < 550. So, Model-I is better or worse than Model-II if C_1 > or < 550. Both models are equally good if $C_1 = 550$.

(v) For $C_2 = 3100$, P_1-P_2 > or = or < 0 accordingly as C_1 > or = or < 660. So, Model-I is better or worse than Model-II if C_1 > or < 660. Both models are equally good if $C_1 = 660$.

References

1. Tuteja, R.K., & Taneja, G. (1992). Cost-benefit analysis of a two server, two unit, warm standby system with different types of failure. Microelectron.Reliab., 32(10), 1353-1359.
2. Tuteja, R.K., Rizwan, S.M., & Taneja, G. (1999). *A Two Server System with Regular Repairman Who Is Not Always Available*. Paper presented at the National Symposium on Management Science and Statistics - Applications to Trade and Industry (pp. 231-237). Guru Nanak Dev University, Amritsar, India.
3. Tuteja, R.K., Rizwan, S.M., & Taneja, G. (2000). Profit evaluation of a two unit cold standby system with tiredness and two types of repairman. *Journal of Indian Society of Statistics and Operation Research, 21*(1-4), 1-10.
4. Rizwan, S. M., Khurana, V., & Taneja, G. (2005). *Reliability Modelling of a Hot Standby PLC System*. Paper presented at the International Conference on Communication, Computer and Power (pp. 486-489). Sultan Qaboos University, Sultanate of Oman.
5. Rizwan, S.M., Khurana, V., & Taneja, G. (2007). Modelling and optimization of a single-unit PLC system. *International Journal of Modelling and Simulation, 27*(4), 361-368.
6. Rizwan, S.M., & Thanikal, J.V. (2014). Reliability analysis of a waste water treatment plant with inspection. *i-manager's Journal on Mathematics, 3*(2), 21-26.
7. Rizwan, S.M., Thanikal, J.V., & Torrijos, M. (2014). A general model for reliability analysis of a domestic waste water treatment plant. *International Journal of Condition Monitoring and Diagnostic Engineering Management, 17*(3), 3-6.
8. Rizwan, S.M., Taneja, G., & Tuteja, R.K. (2000). Comparative study between the profits of two models for a two unit system with rest period of repairman. *Journal of Decision and Mathematical Sciences, 5*(1-3), 27-44.
9. Rizwan, S. M. (2007). Reliability analysis of a two unit system with two repairmen. *Caledonian Journal of Engineering, 3*(2), 1-5.
10. Mathew, A. G., Rizwan, S. M., Majumder, M. C., & Ramachandran, K. P. (2009). *MTSF and Availability of a Two Unit CC Plant.* Paper presented at the International Conference on Modelling, Simulation, and Applied Optimization (pp. 1-5). American University of Sharjah, Sharjah, UAE: IEEE.
11. Mathew, A.G., Rizwan, S.M., Majumder, M.C, Ramachandran, K.P., & Taneja, G. (2009). Profit evaluation of a single unit CC plant with scheduled maintenance. *Caledonian Journal of Engineering, 5*(1), 25-33.
12. Mathew, A.G., Rizwan, S.M., Majumder, M.C., Ramachandran, K.P., & Taneja, G. (2009).*Optimization of a Single Unit CC Plant with Scheduled Maintenance Policy*. Paper presented at the International Conference on Recent Advances in Material Processing Technology (pp. 609-613). India.
13. Mathew, A. G., Rizwan, S. M., Majumder, M. C., Ramachandran, K. P., & Taneja, G. (2010, October). *Comparative Analysis between Profits of the Two Models of a CC Plant*. Paper presented at the International Conference on Modelling, Optimization and Computing (pp. 226-231). National Institute of Technology, Durgapur, India: AIP.
14. Mathew, A.G., Rizwan, S.M., Majumder, M.C., Ramachandran, K.P., & Taneja, G. (2010). Reliability modelling and analysis of a two unit parallel CC plant with different installed capacities. *Journal of Manufacturing Engineering, 5*(3), 197-204.
15. Mathew, A. G., Rizwan, S. M., Majumder, M. C., & Ramachandran, K. P. (2011). Reliability modelling and analysis of a two unit continuous casting plant. *Journal of the Franklin Institute, 348*(7), 1488-1505.

16. Mathew, A.G., Rizwan, S.M., Majumder, M.C., Ramachandran, K.P., & Taneja, G. (2011). Reliability analysis of identical two-unit parallel CC plant system operative with full installed capacity. *International Journal of Performability Engineering, 7*(2), 179-185.
17. Padmavathi, N., Rizwan, S.M., Pal, A., & Taneja, G. (2012). Reliability analysis of an evaporator of a desalination plant with online repair and emergency shutdowns. *Aryabhatta Journal of Mathematics and Informatics, 4*(1), 1-12.
18. Padmavathi, N., Rizwan, S.M., Pal, A., & Taneja, G. (2013). *Comparative Analysis of the Two Models of an Evaporator of a Desalination Plant*. Paper presented at the International Conference on Information and Mathematical Science (pp. 418-422). Punjab, India
19. Padmavathi, N., Rizwan, S.M., Pal, A., & Taneja, G. (2013). Probabilistic analysis of an evaporator of a desalination plant with priority for repair over maintenance. *International Journal of Scientific and Statistical Computing, 4*(1), 1-8.
20. Padmavathi, N., Rizwan, S.M., Pal, A., & Taneja, G. (2014). Probabilistic analysis of a desalination plant with major and minor failures and shutdown during winter season. *International Journal of Scientific and Statistical Computing, 5*(1), 15-23.
21. Padmavathi, N., Rizwan, S.M., Pal, A., & Taneja, G. (2014). Probabilistic analysis of a seven unit desalination plant with minor/major failures and priority given to repair over maintenance. *Aryabhatta Journal of Mathematics and Informatics, 6*(1), 219-230.
22. Padmavathi, N., Rizwan, S.M., & Senguttuvan, A. (2015). Comparative analysis between the reliability models portraying two operating conditions of a desalination plant. *International Journal of Core Engineering and Management, 1*(12), 1-10.
23. Rizwan, S.M., Padmavathi, N., Pal, A., & Taneja, G. (2013). Reliability analysis of a seven unit desalination plant with shutdown during winter season and repair/maintenance on FCFS basis. *International Journal of Performability Engineering, 9*(5), 523-528.
24. Rizwan, S.M., Padmavathi, N., & Taneja, G. (2015). Performance analysis of a desalination plant as a single unit with mandatory shutdown during winter. *Aryabhatta Journal of Mathematics and Informatics, 7*(1), 195-202.
25. Taneja, G., & Malhotra, R. (2013). Cost-benefit analysis of a single unit system with scheduled maintenance and variation in demand. *Journal of Mathematics and Statistics, 9*(3), 155-160.
26. Taneja, G., Malhotra, R., & Chitkara, A.K. (2016). Comparative profit analysis of two reliability models with varying demand. *Aryabhatta Journal of Mathematics and Informatics, 8*(2), 305-314.
27. Yaqoob Al Rahbi, Rizwan, S.M., Alkali, B.M., Andrew Cowell, & Taneja, G. (2017). Reliability analysis of rodding anode plant in aluminium industry. *International Journal of Applied Engineering Research, 12*(16), 5616-5623.
28. Yaqoob Al Rahbi, Rizwan, S.M., Alkali, B.M., Andrew Cowell, & Taneja, G. (2017, September 20-22). *Reliability Analysis of a Subsystem in Aluminium Plant*. Paper presented at the 6th IEEE International Conference on Reliability, Infocom Technologies and Optimization. doi:10.1109/ICRITO.2017.8342424
29. Yaqoob Al Rahbi, Rizwan, S.M., Alkali, B.M., Andrew Cowell, & Taneja, G. (2018). Maintenance analysis of a butt thimble removal station in aluminium plant. *International Journal of Mechanical Engineering and Technology, 9*(4), 695-703.
30. Yaqoob Al Rahbi, Rizwan, S.M., Alkali, B.M., Andrew Cowell, & Taneja, G. (2018). Reliability analysis of rodding anode plant in an aluminum industry with multiple repairmen. *Advances and Applications in Statistics, 53*(5), 569-597.
31. Taj, S.Z., Rizwan, S.M., Alkali, B.M., Harrison, D.K., & Taneja, G. (2017, April 4-6). *Reliability Modelling and Analysis of a Single Machine Subsystem of a Cable*

Plant. Paper presented at the 7thInternational Conference on Modelling, Simulation, and Applied Optimization. doi:10.1109/ICMSAO.2017.7934917

32. Taj, S.Z., Rizwan, S.M., Alkali, B.M., Harrison, D.K., & Taneja, G.L. (2017). Reliability analysis of a single machine subsystem of a cable plant with six maintenance categories. *International Journal of Applied Engineering Research, 1*(8), 2017, 1752-1757.
33. Taj, S.Z., Rizwan, S.M., Alkali, B.M., Harrison, D.K., & Taneja, G. (2017). Probabilistic modelling and analysis of a cable plant subsystem with priority to repair over preventive maintenance. *i-manager's Journal on Mathematics, 6*(3), 12-21.
34. Taj, S.Z., Rizwan, S.M., Alkali, B.M., Harrison, D.K., & Taneja, G. (2018). Performance analysis of a rod breakdown system. *International Journal of Engineering and Technology, 7*(3.4), 243-248.
35. Taj, S.Z., Rizwan, S.M., Alkali, B.M., Harrison, D.K., & Taneja, G. (2018). Reliability analysis of a 3-unit subsystem of a cable plant. *Advances and Applications in Statistics, 52*(6), 413-429.
36. Taj, S.Z., Rizwan, S.M., Alkali, B.M., Harrison, D.K., & Taneja, G. (2018). Performance and cost benefit analysis of a cable plant with storage of surplus produce. *International Journal of Mechanical Engineering and Technology, 9*(8), 814-826.
37. Taj, S.Z., Rizwan, S.M., Alkali, B.M., Harrison, D.K., & Taneja, G. (2018). Profit analysis of a cable manufacturing plant portraying the winter operating strategy. *International Journal of Mechanical Engineering and Technology, 9*(11), 370-381.
38. Ibe, O. (2008). *Markov processes for stochastic modelling*. London: Academic Press.
39. Smith, W.L. (1955). Regenerative stochastic processes. *Proc R Soc Lond A, 232*(1188), 6-31.