International Journal of Applied Research 2024; 10(11): 90-95

ISSN Print: 2394-7500
ISSN Online: 2394-5869
Impact Factor (RJIF): 8.4
IJAR 2024; 10(11): 90-95
www.allresearchjournal.com
Received: 21-09-2024
Accepted: 22-10-2024

Sanju Kumari
Research Scholar, Department of Mathematics, Baba Mastnath University Asthal Bohar, Rohtak, Haryana, India

Dr. Sangeeta Malik
Professor, Department of Mathematics, Baba Mastnath University Asthal Bohar, Rohtak, Haryana, India

Dr. Jai Bhagwan
Department of Mathematics, Government PG Nehru College, Jhajjar, Haryana, India

Corresponding Author:
Sanju Kumari
Research Scholar, Department of Mathematics, Baba Mastnath University Asthal Bohar, Rohtak, Haryana, India

Sensitivity analysis of Non-Markovian repairable systems with warm standby system

Sanju Kumari, Dr. Sangeeta Malik and Dr. Jai Bhagwan

DOI: https://doi.org/10.22271/allresearch.2024.v10.i11b.12124

Abstract
In this paper system parameters of a Non-Markovian repairable systems with warm standby system with priority in repair to failed units under steady state are modeled using machine learning. A single server is available 24x7 and carries out all type of repairs inn the system. Failed unit after repair is supposed to be as if new. Various disappointment/repair rates of elements stand occupied as exponential and statistically independent.

Keywords: RPGT, availability, machine learning

Introduction

Studies on redundant systems are gaining importance day by day due to fact that several researchers in reliability and operation research have contributed a lot on the study of redundant systems to improve the system effectiveness to optimize system parametric values of different types of systems with different repair policies. These systems have broad range of applications in real world especially in industries. The objective of this paper is to study the organization reliability done redundant section and additional preventive maintenance of working and standby units. Main units of the system have two modes *viz*., operable, and abortive and standby unit of the structure has three modes *viz*. practicable, degraded and failed. Following a failure, both units undergo inspections to determine the nature of failure and choose the appropriate course of action for repair. There are exponential and generic time distributions for the failure and repair times, respectively. In order to determine the system's dependability, availability, downtime, busy period, and cost efficiency, Laplace transformation and RPGT are used in the study. Finally, a few systemic exceptional instances have been covered. A unit or system is made up of several parts, and we need to utilize dependable parts in order to provide the system a high level of reliability. In certain cases, building extremely dependable components is either not feasible or too expensive. In these cases, integrating redundant parts and offering maintenance and repair when necessary might lead to a higher degree of reliability. Redundancy also contributes significantly to increased system reliability. Standby redundancy is one of the most widely used types of redundancy. Standby systems are frequently used in a variety of industrial and other settings. Some extra paths are made in a redundant system to ensure the system runs correctly. Parallel redundancy occurs when all of the redundant components begin operating simultaneously. Using the Markov Process approach, a transition state diagram system has been created where it might remain. When a failure occurs, the standby unit is switched in and the malfunctioning unit is switched out by a single, always-available repairman. The repairman is expected to be on call around-the-clock. The failed unit on repair is supposed to be as good as if a new one. If the server is repairing a down unit and a one more unit fails in the meantime, then it joins end of the queue of the failed units. Additionally, a general non-Markovian system with two primary units and two redundant units-units designated as A and B primary units and C and D redundant units-whose working capacities are less than those of the primary units-is modelled for the system parameters in this paper using RPGT, accounting for the exponential failure and repair rates of the units. Using the Markov Process approach, a transition state diagram system has been created where it might remain. Kumar *et al.* [2018] discussed the behavior investigation of a bread plant exhausting RPGT.

In order to do a sensitivity analysis on a standby framework made up of dual identical units with server disappointment and ordered for preventative upkeep, Kumar *et al.* [2019] [8] used RPGT. Two halves make up the current paper, one of which is in use and the other of which is in cold standby mode. The good and fully failed modes are the only differences between online and cold standby equipment. A case study of an EAEP manufacturing facility was examined by Rajbala *et al.* [2019] [1] in their work on system modeling and analysis in [2019]. A study of the urea fertilizer industry's behavior was conducted by Kumar *et al.* [2017] [9]. Mathematical formulation and profit function of a comestible oil refinery facility were investigated by Kumar *et al.* in [2017] [9]. In a paper mill washing unit, Kumar *et al.* [2019] investigated scientific formulation and performance study. In their study, Kumar *et al.* [2018] investigated a 3:4: outstanding system plant's sensitivity analysis. Using a heuristic methodology, Rajbala *et al.* [2022] [3] investigated the RAP in the cylinder plant.

Notations & Assumptions

To discuss the system following notations and assumptions are taken:-

- The system has four units out of which two units are operating and the rest are in cold standby mode.
- The system fails if there are more than two failed units.

: Working State

: Reduced State

: Failed State

β_i constant repair rates of units

α_i constant failure rates of units

System transition state diagram

Accounting the above expectations & notations in study, Transition State Diagram of system using Markov Process is given in Figure 1.

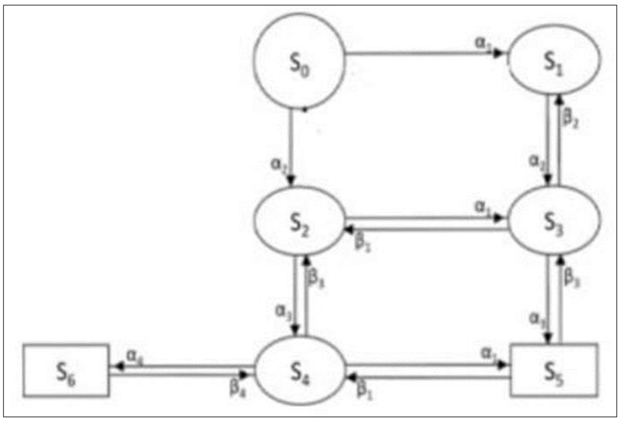

Fig 1: System Transition State Diagram

States: S0[AB(D)(E), S1[aBDE)], S2[AbD(E), S3[abDE], S4[AbdE], S5[abdE], S6[Abde]

Model Description

The system consists of four units: units D and E are in cold standby while units A and B, which are primary units, operate at maximum capacity when they are first online. When one or both standby units are brought online in the event that units A or B fail, the system operates at a reduced capacity because units D and E have a lower operating capacity than units A and B. Perfect switching exists.

The online units whenever fail, the repair priority order is A > B > D > E. Once the online unit "A" fails at a transition rate of α_1, the system will switch to the standby unit "D" and begin the repair of unit "A." This will bring the system back to the initial state S_0, but it will also enter a reduced working state (where unit "A" repair begins right away, while unit "E" is in cold standby). Once unit "A" is repaired at a transition rate of β_1 by the repairman, the system will return to the full capacity working state S_0. In a similar vein, in state S_2, unit "E" is in cold standby and failed unit "B" is promptly repaired by the repairman after the unit fails at transition rate α_2. The failed unit is replaced by a perfect switching device and switched in the standby unit "D." If one additional working unit fails from the states S_1 or S_2, the system joins the reduced working state S_3 or S_4, from which it returns to the states S_1 or S_2 once the failed unit has been repaired. If one more working unit fails, the system moves from the state S_3 or S_4, where failed units are being repaired, to the corresponding state S_5 or S_6. After the failing unit is repaired, the system returns to either S_3 or S_4 depending on the state of the repaired unit. Previously, it was in either S_5, or S_6. The system's potential states are depicted in figure 1 above.

Transition Probabilities $q_{i,j}(t)$

$q_{0,1}(t) = \alpha_1 e{-}(\ \alpha_{2+}\alpha_2)\ t$

$q_{0,2}(t) = \alpha_2 e{-}(\ \alpha_{2+}\alpha_2)\ t$

$q_{1,3}(t) = \alpha_2 e{-}(\alpha_2)\ t$

$q_{2,3}(t) = \alpha 1 e{-}(\alpha_1 + \alpha_3)\ t$

$q_{2,4}(t) = \alpha 3 e{-}(\alpha 1 + \alpha_3)\ t$

$q_{3,1}(t) = \beta_2 e{-}(\beta_2 + \beta_1 + \alpha_3)t$

$q_{3,2}(t) = \beta_1 e{-}(\beta_2 + \beta_1 + \alpha_3)\ t$

$q_{3,5}(t) = \alpha_3 e{-}(\beta_2 + \beta_1 + \alpha_3)\ t$

$q_{4,2}(t) = \beta_3 e{-}(\beta_3 + \alpha_1 + \alpha_4)\ t$

$q_{4,5}(t) = \alpha_1 e{-}(\beta_3 + \alpha_1 + \alpha_4)\ t$

$q_{4,6}(t) = \alpha_4 e{-}(\beta_3 + \alpha_1 + \alpha_4)\ t$

$q_{5,3}(t) = \beta_3 e{-}(\beta_3 + \beta_1)\ t$

$q_{5,4}(t) = \beta_1 e{-}(\beta_3 + \beta_1)\ t$

$q_{6,4} = \beta 4 e{-}\beta 4 t$

$P_{ij} = q^*_{i,j}(0)$

$p_{0,1}=1$

$p_{0,2}=1$

$p_{1,3}=1$

$p_{2,3}= \alpha_1/(\alpha_1+\alpha_3)$

$p_{2,4}= \alpha_3/(\alpha_1+\alpha_3)$

$p_{3,1}= \beta_2/(\beta_2+\beta_1+\alpha_3)$

$p_{3,2}= \beta_1/(\beta_2+\beta_1+\alpha_3)$

$p_{3,5}= \alpha_3/(\beta_2+\beta_1+\alpha_3)$

$p_{4,2}= \beta_3/(\beta_3+\alpha_1+\alpha_4)$

$p_{4,5}= \alpha_1/(\beta_3+\alpha_1+\alpha_4)$

$p_{4,6}= \alpha_4/(\beta_3+\alpha_1+\alpha_4)$

$p_{5,3}= \beta_3/(\beta_3+\beta_1)$

$p_{5,4}= \beta_1/(\beta_3+\beta_1)$

$p_{6,4}= 1$

Mean Sojourn Times $R_i(t)$

$R_0(t)= e{-}(\ \alpha_{1\,+}\ \alpha_2)\ t$

$R_1(t)= e{-}(\alpha_2)\ t$

$R_2(t)= e{-}(\alpha_1 + \alpha_3)\ t$

$R_3(t)= e{-}(\beta_2 + \beta_1 + \alpha_3)\ t$

$R_4(t)= e-(\beta_3 +\alpha_1 +\alpha_4)\ t$
$R_5(t)= e-(\beta_3 +\beta_1)\ t$
$R_6(t)= e^{-\beta_4}\ t$
$\mu_i=R_i*(0)$
$\mu_0 = 1/(\alpha_{2} + \alpha_2)$
$\mu_1 = 1/(\alpha_2)$
$\mu_2 = 1/(\alpha_1+\alpha_3)$
$\mu_3 = 1/(\beta_2+\beta_1+\alpha_3)$ $\mu_4 = 1/(\beta_3+\alpha_1+\alpha_4)$ $\mu_5 = 1/(\beta_3+\beta_1)$
$\mu_6 = 1/\beta_4$

Evaluation of Parameters

Using RPGT and ‘0’ as initial state and base state ‘ξ = 4’ the transition path probabilities of working system are obtained

$V_{4,1}$=(4,5,3,1)/{(1-(1,3,1))/(1-(3,5,3))/(1-(5,4,5))/(1-4,6,4))}{(1-(3,1,3))(1-(3,5,3))/(1-(5,4,5))/(1-4,6,4))}{(1-(4,6,4))(1-(4,5,4)/(1-(5,3,5)/(1-(3,2,3)(1-(3,1,3)))}{(1-(5,3,5))/(1-(3,2,3))(1-(2,4,2))/(1-(4,6,4))(1-(3,1,3))+(4,2,3,1)/{(1-(1,3,1))/(1-(3,5,3))/(1-(5,4,5))/(1-4,6,4))}{(1-(3,1,3))(1-(3,5,3))/(1-(5,4,5))/(1-4,6,4))}{(1-(4,6,4))(1-(4,5,4)/(1-(5,3,5)/(1-(3,2,3)(1-(3,1,3)))}

$V_{4,2}$ = (4,5,3,2)/1-(3,1,3))(1-(3,5,3))/(1-(5,4,5))/(1-4,6,4))(1-(4,2,4))}{(1-(4,6,4))(1-(4,5,4)/(1-(5,3,5)/(1-(3,2,3)(1-(3,1,3)))}{(1-(5,3,5))/(1-(3,2,3))(1-(2,4,2))/(1-(4,6,4))(1-(3,1,3))}{(1-(2,4,2)/(1-(4,6,4))(1-(4,5,4))/(1-(5,3,5))/(1-(3,1,3))}+(4,2)/{(1-(2,4,2)/(1-(4,6,4))(1-(4,5,4))/(1-(5,3,5))/(1-(3,1,3))}{(1-(4,6,4))(1-(4,5,4)/(1-(5,3,5)/(1-(3,2,3)(1-(3,1,3)))}

$V_{4,3}$ =…….continuous

Results and Discussions

MTSF (T_0): The un-failed states to which classification transits, before visiting any failed state are: $0 \le j \le 4$, ‘ξ’= ‘0’, we have

$$\text{MTSF} = \left[\sum_{i,sr}\left\{\frac{\left\{pr\left(\xi \xrightarrow{sr(sff)} i\right)\right\}\mu i}{\prod_{m_1\neq\xi}\left\{1\text{-}V_{\overline{m_1 m_1}}\right\}}\right\}\right] \div \left[1\text{-}\sum_{sr}\left\{\frac{\left\{pr\left(\xi \xrightarrow{sr(sff)} \xi\right)\right\}}{\prod_{m_2\neq\xi}\left\{1\text{-}V_{\overline{m_2 m_2}}\right\}}\right\}\right] \quad (1)$$

$T_0 = (V_{0,1}\mu_1+V_{0,2}\mu_2+V_{0,3}\mu_3 +V_{0,5}\mu_5)$

Availability of System (A_0): The states are where system is available are $0 \le j \le 4$ taking base state ‘ξ’ = ‘4’ is available

$$A_0=\left[\sum_{j,sr}\left\{\frac{\{pr(\xi^{sr\to}j)\}fj,\mu j}{\prod_{m_1\neq\xi}\left\{1\text{-}V_{\overline{m_1 m_1}}\right\}}\right\}\right] \div \left[\sum_{i,s_r}\left\{\frac{\{pr(\xi^{sr\to}i)\}\mu_i^1}{\prod_{m_2\neq\xi}\left\{1\text{-}V_{\overline{m_2 m_2}}\right\}}\right\}\right] \quad (2)$$

$$A_0 = \left[\sum_j V_{\xi,}\ , f_j\ , \mu_j\right] \div \left[\sum_i V_{\xi,i}\ , f_j\ , \mu^1\right]$$

$= (V_{4,0}\mu_0+V_{4,1}\mu_1+V_{4,2}\mu_2+V_{4,3}\mu_3 +V_{4,4}\mu_4)/D$

Where $D = (V_{4,0}\mu_0+V_{4,1}\mu_1+V_{4,2}\mu_2+V_{4,3}\mu_3 +V_{4,4}\mu_4+V_{4,5}\mu_5+V_{4,6}\mu_6)$

Busy Period of Server (B_0): The states where server is busy for maintenance are S_i where $1 \le i \le 6$, taking ξ = 4‘, time in which server remains busy is

$$B_0=\left[\sum_{j,sr}\left\{\frac{\{pr(\xi^{sr\to}j)\},nj}{\prod_{m_1\neq\xi}\left\{1-V_{\overline{m_1 m_1}}\right\}}\right\}\right] \div \left[\sum_{i,s_r}\left\{\frac{\{pr(\xi^{sr\to}i)\}\mu_i^1}{\prod_{m_2\neq\xi}\left\{1-V_{\overline{m_2 m_2}}\right\}}\right\}\right] \quad (3)$$

$B_0 = (V_{4,1}\mu_1+V_{4,2}\mu_2+V_{4,3}\mu_3 +V_{4,4}\mu_4+V_{4,5}\mu_5+V_{4,6}\mu_6)/D$
Where $D = (V_{4,0}\mu_0+V_{4,1}\mu_1+V_{4,2}\mu_2+V_{4,3}\mu_3 +V_{4,4}\mu_4+V_{4,5}\mu_5+V_{4,6}\mu_6)$

Expected fractional number of inspections by the repair man: The states where the repairman do visit’s a fresh are S_1, S_2 taking ‘ξ’= ‘4’, number of repair man’s visit

$$V_0 = \left[\sum_{j,sr}\left\{\frac{\{pr(\xi^{sr\to}j)\}}{\prod_{k_1\neq\xi}\left\{1\text{-}V_{\overline{k_1 k_1}}\right\}}\right\}\right] \div \left[\sum_{i,s_r}\left\{\frac{\{pr(\xi^{sr\to}i)\}\mu_i^1}{\prod_{k_2\neq\xi}\left\{1\text{-}V_{\overline{k_2 k_2}}\right\}}\right\}\right] \quad (4)$$

$= (V_{2,0}\mu_0+ V_{2,1}\mu_1+V_{2,2}\mu_2+V_{2,3}\mu_3+ V_{2,5}\mu_5)/ (V_{2,0}+V_{2,1}+V_{2,2}+V_{2,3}+V_{2,4}+V_{2,5})$
$V_0 = (V_{4,1}\mu_1+V_{4,2}\mu_2)/D$

Where D =
$(V_{4,0}\mu_0+V_{4,1}\mu_1+V_{4,2}\mu_2+V_{4,3}\mu_3 +V_{4,4}\mu_4+V_{4,5}\mu_5+V_{4,6}\mu_6)$

Machine Learning Algorithms

The first step in performing sensitivity analysis is to identify the variables that are likely to have the greatest impact on the performance of the system. In this case, the variables may include the time it takes for the Non-Markovian Repairable Systems, the probability of the switch-over device failing, and the time it takes for the stand-by unit to become fully operational. Once these variables have been identified, machine learning algorithms can be used to analyze the relationships between them and the overall performance of the system. One approach would be to use regression analysis to determine how changes in each variable impact the overall reliability and efficiency of the system. Another approach would be to use machine learning algorithms to simulate the performance of the system under different conditions. This would involve creating a model of the system that considers the variables identified earlier and using the model to predict how the system would perform under different scenarios. The model could be trained using historical data to ensure that it accurately reflects the behaviour of the system in real-world conditions. Overall, machine learning algorithms can be a powerful tool for performing sensitivity analysis on complex systems like a three unit stand-by system with an imperfect switch-over device. By using these algorithms, it is possible to identify the variables that have the greatest impact on the system's performance and develop strategies to improve reliability and efficiency.

Model Evaluation

Sensitivity analysis is a method used to identify how changes in the input parameters of a system affect its output. In the case of a four unit standby system can be modeled and evaluated to identify the key strictures and their impact on the organization's performance.

To evaluate the implementation of our model performance, we have estimated different execution evaluation confusion matrix (Recall, Accuracy Precision, and F1-Measure). The evaluation of the model phase proposes to evaluate the generalization precision accuracy of the design model on an unseen, i.e., test dataset. Here we calculated this accuracy by applying the precision (Availability of the System), accuracy (The Medium-Term Strategic Framework (MTSF)), Recall (Busy Period), f_score function, that are imported from the metrics module available into the Scikit-learn Python library that depends on the following formula. To perform a sensitivity analysis, one would typically vary each input parameter of the system, one at a time, while keeping all other parameters constant. Then, the output of the system is observed to see how it changes in response to the variation in each input parameter. In the case of a single unit warm standby system with an imperfect switch-over maneuver, some of the key parameters that might be varied in a sensitivity analysis could include:

- **The reliability of the main unit**: This represents the probability that the main unit will function properly when it is needed. If the reliability of the main unit is low, then the system may be more reliant on the switch-over device to function properly, which could have implications for the system's overall performance.
- **The reliability of the switch-over device**: This represents the likelihood that the switch-over device determinations function correctly when it is needed. If the reliability of the switch-over device is low, then the system may not function properly when the main unit fails, which could lead to downtime or other negative consequences.
- **The period it takes for the switch-over device to activate:** This represents the period it takings for the switch-over device to detect that the main unit has failed and to switch over to the standby unit. If this time is too long, then the system may experience downtime or other negative consequences.
- **The availability of spare parts for the switch-over device:** If spare parts for the switch-over device are not readily available, then it may be difficult to repair or replace the device if it fails, which could have implications for the system's overall reliability.
- **The cost of the switch-over device:** If the switch-over device is expensive, then it may be cost-prohibitive to implement, which could affect the overall feasibility of the system.

By varying these and other key parameters one at a time and observing how the output of the system changes in response, it is possible to identify which parameters remain most critical to the organization's performance and to determine the optimal values for each parameter.

Results and Discussion

In contrast, the disappointment rate of the standby unit may have less impact on system availability because the standby unit is not in use until the primary unit bombs. The repair time for each unit may also have less impact because the system is designed to be in a warm standby configuration, meaning that the units are already partially operational and can quickly be brought up to full capacity. Results of sensitivity analysis for this system may indicate that the disappointment rate of the primary unit has the greatest impact on arrangement availability. This is because the primary unit is the active unit and is responsible for providing service. If it fails, the standby unit must take over, and the imperfect switch-over device introduces additional delay and uncertainty. In contrast, the disappointment rate of the standby unit may have less impact on system availability because the standby unit is not in use until the primary unit fails. The repair time for each unit may also have less impact because the system is designed to be in a warm standby configuration, meaning that the units are already partially operational and can quickly be brought up to full capacity. The switch-over time for the imperfect device may have a significant impact on system availability because it introduces additional delay and uncertainty into the system of parameter in Table 1. A longer switch-over time may result in a lower system availability, as there is a greater chance that the system will not be operational when it is needed in performance of model in Table 4as follow and comparison of model in Figure 2, 3, 4, and 5.

Table 1: Table of parameter

W (W1, W2,----,wn)	$\lambda(\lambda 1, \lambda 2, \dots \dots \lambda n)$	S (s, s2,----, sn)	P
(0-.100)	(0-.100)	(0-100)	(0-.68)

Table 2: Table of Performance of Model

Model	Accuracy (MTSF)	F1 Score	Recall (Busy Period)	Precision (Availability)
Linear SVC Classifier (LC)	0.934	0.952	0.931	0.963
Logistic Regression (LR)	0.922	0.933	0.938	0.957
Decision Tree Classifier (DT)	0.911	0.925	0.929	0.930
AdaBoost Classifier(AC)	0.901	0.946	0.921	0.985
Multinomial NB (MN)	0.869	0.923	0.987	0.903
k-nearest neighbors (k-NN)	0.833	0.851	0.853	0.859

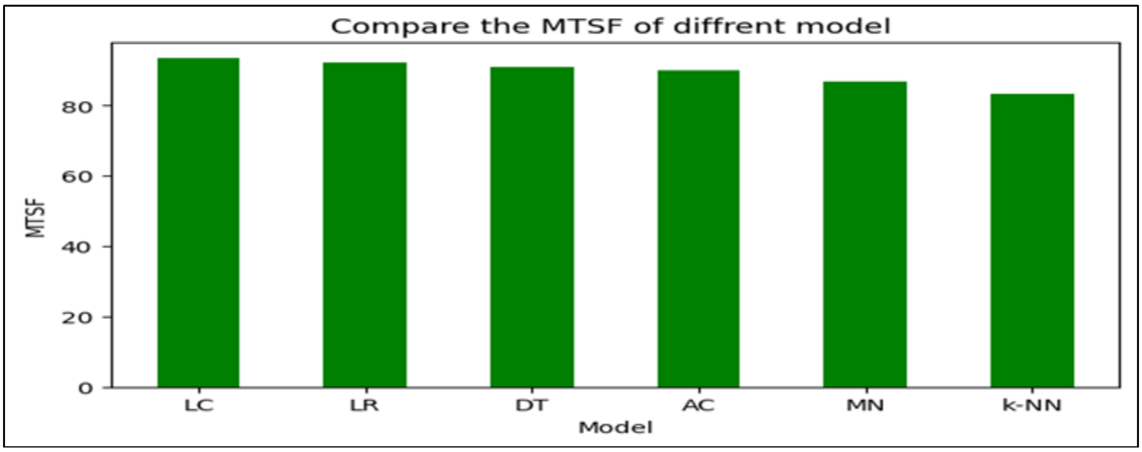

Fig 2: Compare of the MTSF of different Model.

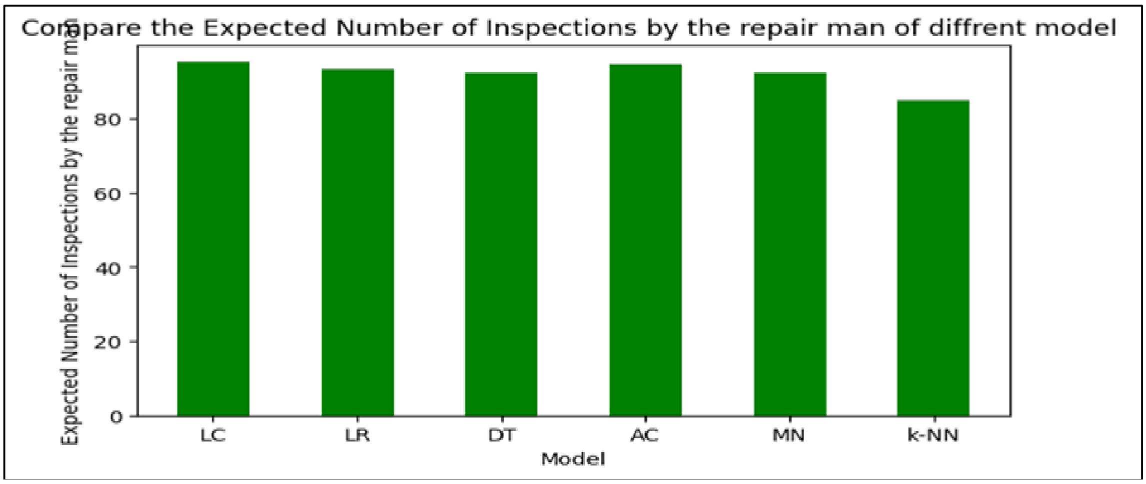

Fig 3: Comapre the expcted number of inspection by the repair man of different model.

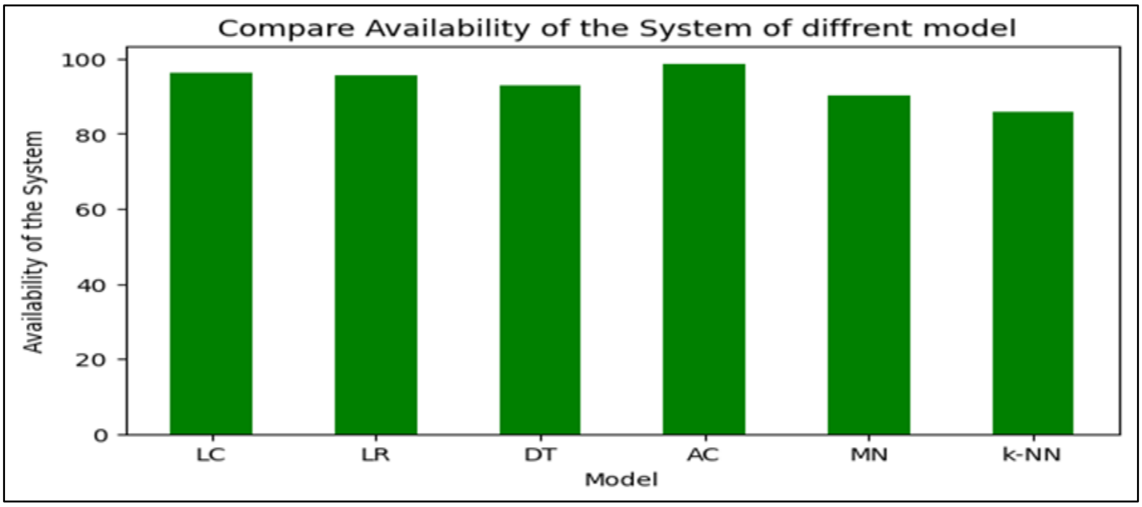

Fig 4: Compare Availability of system of different model.

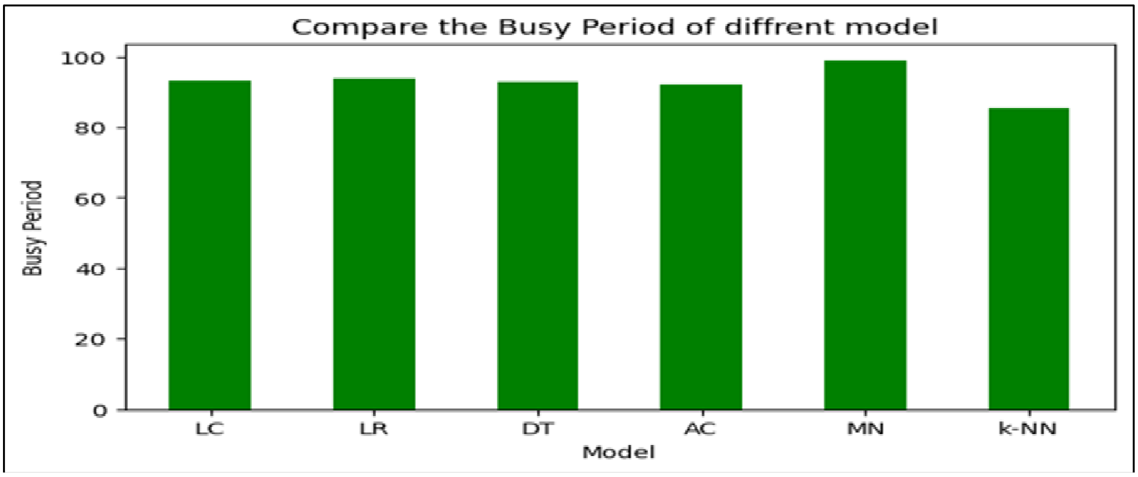

Fig 5: Compare of the busy period of different model.

Conclusion

In contrast, the letdown rate of the standby unit may have less impact on system availability because the standby unit is not in use until the primary unit nosedives. The repair time for each unit may also have less impact because the system is designed to be in a warm standby configuration, meaning that the units are already partially operational and can quickly be brought up to full capacity. This can help to improve the efficiency and profitability of the industry, as well as the quality of the final product. The switch-over time for the imperfect device may have a significant impact on system availability because it introduces additional delay and uncertainty into the system of parameter in Table 2. A longer switch-over time may result in a lower system availability, as there is a greater chance that the system will not be operational when it is needed in performance of model in Table 4 as follow and comparison of model in Figure 2, 3, 4, and 5.

References

1. Rajbala, Kumar A, Garg D. Systems Modelling and Analysis: A Case Study of EAEP Manufacturing Plant. Int J Adv Sci Technol. 2019;28(14):8-18. Available from: http://sersc.org/journals/index.php/IJAST/article/view/1419
2. Kumari S, Khurana P, Singla S, Kumar A. Solution of constrained problems using particle swarm optimization. Int J Syst Assur Eng Manag; c2021, 1-8. DOI: 10.1007/s13198-021-01524-x
3. Rajbala, Kumar A, Khurana P. Redundancy allocation problem: Jayfe cylinder Manufacturing Plant. Int J Eng Sci Math. 2022;11(1):1-7. DOI: 10.6084/m9.figshare.18972917
4. Kumar A, Goel P, Garg D. Behaviour analysis of a bread making system. Int J Stat Appl Math. 2018;3(6):56-61.
5. Kumar A, Garg D, Goel P, Ozer O. Sensitivity analysis of 3:4:: good system. Int J Adv Res Sci Eng. 2018;7(2):851-862.
6. Kumar A, Garg D, Goel P. Mathematical modelling and profit analysis of an edible oil refinery industry. Airo Int Res J. 2017;XIII:1-14.
7. Kumar A, Garg D, Goel P. Mathematical modelling and behavioural analysis of a washing unit in paper mill. Int J Syst Assur Eng Manag. 2019;1(6):1639-45. DOI: 10.1007/s13198-019-00916-4
8. Kumar A, Garg D, Goel P. Sensitivity analysis of a cold standby system with priority for preventive maintenance. J Adv Scholarly Res Allied Educ. 2019;16(4):253-258. Available from: http://ignited.in/I/a/88998
9. Kumar A, Goel P, Garg D, Sahu A. System behaviour analysis in the urea fertilizer industry. In: Data and Analysis. Communications in Computer and Information Science (CCIS), Springer; c2017, p. 3-12. DOI: 10.1007/978-981-10-8527-7_1