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SENSITIVITY ANALYSIS OF FOUR UNIT SYSTEM WITH PREVENTIVE MAINTENANCE USING MACHINE LEARNING

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Abstract: The sensitivity analysis of a four-unit system with preventive maintenance and degradation is covered in this work. Using the Regenerative Point Graphical Technique (RPGT), one permanent repairman is available around-the-clock in a single unit. Units A, B, C, and D are initially operating at full capacity. Unit A may experience two sorts of failures: a direct failure and a partial failure mode. However, units B, C, and D may experience direct failures. One server handles all system repairs and is accessible around-the-clock. After repair, a malfunctioning unit should function like new. Tables for rising failure/repair rates and graphs are used to analyse different path probabilities mean sojourn duration.

Keywords:- Availability, Preventive Maintenance, Busy Period Of The Server, Sensitivity Analysis, Machine Learning

1. Introduction:

Reliability and operation researchers have made significant contributions to the study of redundant systems in order to increase system effectiveness and optimize system parametric values of various system types with various repair policies, which has led to an increasing interest in these studies. These systems are widely used in the real world, particularly in industry. This article describes a system consisting of four units, one of which has been repaired flawlessly using the RPGT, while the other unit has undergone preventative maintenance before to complete failure, with one unit experiencing degeneration after failure. Initially, all four units (A, B, C, and D) are running at full capacity. While units B, C, and D might have a direct failure, unit A might have a partial failure mode.

A system with four units is subjected to preventive maintenance, and the principal unit degrades. Several parts are put together to create various systems. Four unit systems are used in numerous process sectors, including the textile and utensil industries. If one component breaks down, the entire system fails. Given the importance of a single unit in the overall system, in this chapter we have studied a system with four subunits, where the first unit is degraded upon total failure and the primary single unit is undergoing preventative maintenance. Where it might stay, a transition state diagram system has been developed using the Markov Process technique.

A single, always-available repairman replaces the problematic unit and switches in the standby unit when a breakdown occurs. It is anticipated that the repairman will be available at all times. The repaired item should function as well as a brand-new one. In the event that another unit fails while the server is fixing a downed unit, it joins the back of the queue of failed units. A primary, secondary, and tertiary cycle table is generated from this diagram. All system fixes are handled by a single server that is available 24/7. A broken unit should work like new after being repaired. The mean sojourn duration of various path probabilities is analyzed using graphs and tables with increasing failure/repair rates. In [2018], Kumar et al. investigated the behaviour of a bread plant. Kumar et al. [2019] used RPGT to do a sensitivity analysis on a cold standby architecture consisting of dual identical units by server failure and prioritized for PM. The current paper is divided into two parts, one of which is in cold standby mode and the other is in use. The sole distinction between online and cold standby equipment is between the good and utterly failed states. In their 2019 work on system modelling and analysis, Rajbala et al. [2019] looked at a case study of an EAEP manufacturing facility. Kumar et al. [2017] studied the behaviour of the urea fertiliser business. Kumari et al. [2021] investigated limited cases using PSO. Rajbala et al. [2022] looked at the redundancy allocation issue in the cylinder manufacturing factory using a heuristic technique. Kumar et al. (2017) looked into the profit function and mathematical formulation of an edible oil refinery facility. Kumar et al. [2019] looked at mathematical formulation and behaviour study in a paper mill washing unit. Kumar et al. [2018] examined the sensitivity analysis of a 3:4:: G outstanding system plant. Regression analysis is one method for figuring out how adjustments to each variable affect the system's overall dependability and effectiveness.

Using machine learning techniques to model the system's performance in various scenarios would be an additional strategy. This would entail building a model of the system that takes into account the previously mentioned variables and applying the model to forecast the system's performance in various scenarios. To make sure the model appropriately depicts the behaviour of the system under actual circumstances, it could be trained using historical data. All things considered, sensitivity analysis on complicated systems, such as a three-unit standby system with an imperfect switch-over mechanism, can be effectively accomplished with machine learning techniques. These algorithms can be used to determine which factors most affect the system's performance and to create plans to increase efficiency and dependability. One would normally change each system input parameter one at a time while holding all other parameters constant in order to conduct a sensitivity analysis. The system's output is then monitored to examine how it responds to changes in each of the input parameters.

2. Assumptions and Notations

- A single repair facility is available 24*7.
- Repairs are perfect.
- Repaired unit works like a new one.
- A,B,C,D/a,b,c,d: Working State/ failed state.
- $w_i/\boldsymbol{\lambda}_i$ – respective mean constant repair/failure rates.; I = 0 to 6

3. Model Description

The system's transition diagram is depicted in Figure 1 below, taking into account the different scenarios and adhering to the assumptions and notations.

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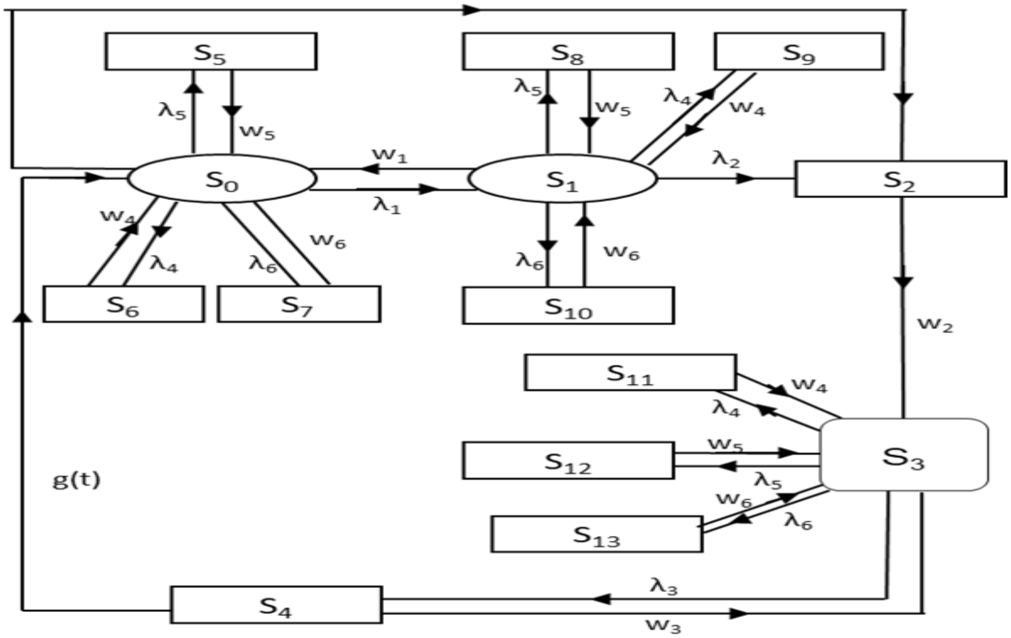

Figure 1: Transition Diagram

S_0	=	ABcD	S_1	=	$\bar{A}$BCD	S_2	=	aBCD
S_3	=	$\bar{A}_1$BCD	S_4	=	a_1BcD	S_5	=	ABcD
S_6	=	AbCD	S_7	=	ABCd	S_8	=	$\bar{A}$BcD
S_9	=	$\bar{A}$bCD	S_{10}	=	$\bar{A}$BCd	S_{11}	=	$\bar{A}_1$bCD
S_{12}	=	$\bar{A}_1$BcD	S_{13}	=	$\bar{A}_1$BCd			

Transition Probability and the Mean sojourn times.

Table 1: Transition Probabilities

$q_{i,j}^{(t)}$	$P_{ij} = q^*_{i,j}{}^{(t)}$
$q_{4,0}= g(t)e^{-w_3(t)}$ $q_{4,3}= w_3e^{-w_3t}\overline{g(t)}$	$p_{4,0}= g^*(w_3)$ $p_{4,3}= 1-g^*(w_3)$
$q_{5,0}= w_5e^{-w_3t}$	$P_{5,0} = 1$
$q_{6,0}= w_4e^{-w_4t}$	$P_{6,0} = 1$
$q_{7,0}= w_6e^{-w_6t}$	$P_{7,0} = 1$
$q_{8,1}= w_5e^{-w_5t}$	$P_{8,1} = 1$
$q_{9,1}= w_4e^{-w_4t}$	$P_{9,1} = 1$
$q_{10,1}= w_6e^{-w_6t}$	$P_{10,1} = 1$
$q_{11,3}= w_4e^{-w_4t}$	$P_{11,3} = 1$
$q_{12,3}= w_5e^{-w_5t}$	$P_{12,3} = 1$
$q_{13,3}= w_6e^{-w_6t}$	$P_{13,3} = 1$

Table 2: Mean Sojourn Times

$R_i(t)$	$\mu_i=R_i^*(0)$
$R_0^{(t)}= e^{-(\lambda_1+\lambda_4+\lambda_5+\lambda_6+\lambda)t}$	$\mu_0 = 1/(\lambda_1+\lambda_4+\lambda_5+\lambda_6+\lambda)$
$R_1^{(t)}= e^{-(w_1+\lambda_5+\lambda_4+\lambda_6+\lambda_2)t}$	$\mu_1 = 1/(w_1+\lambda_5+\lambda_4+\lambda_6+\lambda_2)$
$R_2^{(t)}= e^{-w_2t}$	$\mu_2 = 1/w_2$
$R_3^{(t)}= e^{-(\lambda_3+\lambda_4+\lambda_5+\lambda_6)t}$	$\mu_3 = 1/(\lambda_3+\lambda_4+\lambda_5+\lambda_6)$
$R_4^{(t)}= e^{-w_3t}\overline{g(t)}$	$\mu_4 = (1-g^*\ w_3)/w_3$
$R_5^{(t)}= e^{-w_5t}$	$\mu_5 = 1/w_5$
$R_6^{(t)}= e^{-w_4t}$	$\mu_6 = 1/w_4$
$R_7^{(t)}= e^{-w_6t}$	$\mu_7 = 1/w_6$
$R_8^{(t)}= e^{-w_5t}$	$\mu_8 = 1/w_5$
$R_9^{(t)}= e^{-w_4t}$	$\mu_9 = 1/w_4$
$R_{10}^{(t)}= e^{-w_6t}$	$\mu_{10} = 1/w_6$
$R_{11}^{(t)}= e^{-w_4t}$	$\mu_{11} = 1/w_4$
$R_{12}^{(t)}= e^{-w_5t}$	$\mu_{12} = 1/w_5$
$R_{13}^{(t)}= e^{-w_6t}$	$\mu_{13} = 1/w_6$

4. Path Probability

$V_{0,0} = 1$ (verified)

$V_{0,1} = p_{0,1} = \lambda_1/(\lambda_1+\lambda_4+\lambda_5+\lambda_6+\lambda)$

$V_{0,2} = \lambda_1\lambda_2/(\lambda+\lambda_1+\lambda_4+\lambda_5+\lambda_6)(w_1+\lambda_2+\lambda_4+\lambda_5+\lambda_6)\div(w_1+\lambda_2+\lambda_4+\lambda_6)(w_1+\lambda_2+\lambda_5+\lambda_6)$

$(w_1+\lambda_2+\lambda_4+\lambda_5)/(w_1+\lambda_2+\lambda_4+\lambda_5+\lambda_6)^3+\lambda/(\lambda+\lambda_1+\lambda_4+\lambda_5+\lambda_6)$

$V_{0,3}$ = …….continuous

$V_{3,0} = \lambda_3 g^*(w_3)/(\lambda_3+\lambda_4+\lambda_5+\lambda_6)\div 1-\ \lambda_1 w_1/(\lambda+\lambda_1+\lambda_4+\lambda_5+\lambda_6)(w_1+\lambda_2+\lambda_4+\lambda_5+\lambda_6)(\lambda+\lambda_1+\lambda_4+\lambda_6)$

$(\lambda+\lambda_1+\lambda_5+\lambda_6)(\lambda+\lambda_1+\lambda_4+\lambda_5)/(\lambda+\lambda_1+\lambda_4+\lambda_5+\lambda_6)^3$

$V_{3,1} = \lambda_3\lambda_1 g^*(w_3)/(\lambda_3+\lambda_4+\lambda_5+\lambda_6)(\lambda_1+\lambda_4+\lambda_5+\lambda_6+\lambda)\div(\lambda+\lambda_1+\lambda_5+\lambda_6)(\lambda+\lambda_1+\lambda_4+\lambda_6)$

$(\lambda+\lambda_1+\lambda_4+\lambda_5)(\lambda+\lambda_1+\lambda_4+\lambda_5+\lambda_6)^3(w_1+\lambda_2+\lambda_4+\lambda_6)(w_1+\lambda_2+\lambda_5+\lambda_6)(w_1+\lambda_2+\lambda_4+\lambda_5)$

$/(w_1+\lambda_2+\lambda_4+\lambda_5+\lambda_6)^3$

$V_{3,2}$ = …….continued

6. EVALUATION OF PARAMETERS OF THE SYSTEM:

(i). MTSF (T_0): The re-forming un-failed situations to which the classification can transit (initial state '0'), before entering any failed state are: 'i' = 0,1,2,3,4 taking 'ζ' = '0'.

$$\text{MTSF }(T_0) = \left[\sum_{i,sr}\left\{\frac{\left\{pr\left(\xi \xrightarrow{sr(sff)} i\right)\right\}\mu i}{\Pi_{m_1 \neq \xi}\left\{1\text{-}V_{\overline{m_1 m_1}}\right\}}\right\}\right] \div \left[1\text{-}\sum_{sr}\left\{\frac{\left\{pr\left(\xi \xrightarrow{sr(sff)} \xi\right)\right\}}{\Pi_{m_2 \neq \xi}\left\{1\text{-}V_{\overline{m_2 m_2}}\right\}}\right\}\right]$$

$$T_0 = (w_1+\lambda_2+\lambda_4+\lambda_5+\lambda_6)+\lambda_1 \div (w_1+\lambda_2+\lambda_4+\lambda_5+\lambda_6)(\lambda+\lambda_1+\lambda_4+\lambda_5+\lambda_6)\text{-}\lambda_1 w_1$$

Availability of the System: The regenerative states at which the system is available are 'j' = 0, 1, 2, 3, 4 and the regenerative states are 'i' = 0 to 10 taking 'ξ' = '0' the total fraction of time for which the system is available is given by

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

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

Proportional Busy Period of the Server: The regenerative states where server 'j' = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 and regenerative states are 'i' = 0 to 10, taking ξ = '0', the total fraction of time for which the server remains busy is

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

$$B_0 = \left[\sum_j V_{\xi,j}, n_j\right] \div \left[\sum_i V_{\xi,i}, \mu_i^1\right]$$

Expected Fractional Number of repairman's visits: The regenerative states where the repair man do this job j = 1 the regenerative states are i = 0 to 10, Taking 'ξ' = '0', the number of visit by the repair man is given by

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

$$V_0 = \left[\sum_j V_{\xi,j}\right] \div \left[\sum_i V_{\xi,i}, \mu_i^1\right]$$

7. 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 four-unit system with preventive maintenance and degradation Systems, the probability of the switch-over device failing, and the time it takes for the degradation Systems 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.

8. 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:

1. **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 degradation device to function properly, which could have implications for the system's overall performance.

2. **The reliability of the preventive maintenance and degradation device**: This represents the likelihood that the preventive maintenance and degradation device determinations function correctly when it is needed. If the reliability of the preventive maintenance and degradation is low, then the system may not function properly when the main unit fails, which could lead to downtime or other negative consequences.

3. **The period it takes for the preventive maintenance and degradation device to activate**: This represents the period it takings for the preventive maintenance and degradation 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 preventive maintenance and degradation s device: If spare parts for the preventive maintenance and degradation 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.

4. **The cost of the preventive maintenance and degradation device**: If the preventive maintenance and degradation 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.

9. 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 preventive maintenance and degradation device introduces additional delay and uncertainty. In contrast, the disappointment rate of the standby unit may have less impact on system availability because the preventive maintenance and degradation 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 preventive maintenance and degradation, meaning that the units are already partially operational and can quickly be brought up to full capacity. The preventive maintenance and degradation device may have a significant impact on system availability because it introduces additional delay and uncertainty into the system of parameter in Table 3. A longer preventive maintenance and degradation result in 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 below figures 2, 3, 4, and 5.

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Table 3: Table of parameter

W (w1, w2,--------,wn)	$\lambda(\lambda 1, \lambda 2, \ldots \ldots . \lambda n)$	S (s, s2,-------, sn)	P
(0-.100)	(0-.100)	(0-100)	(0-.68)

Table 4: 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

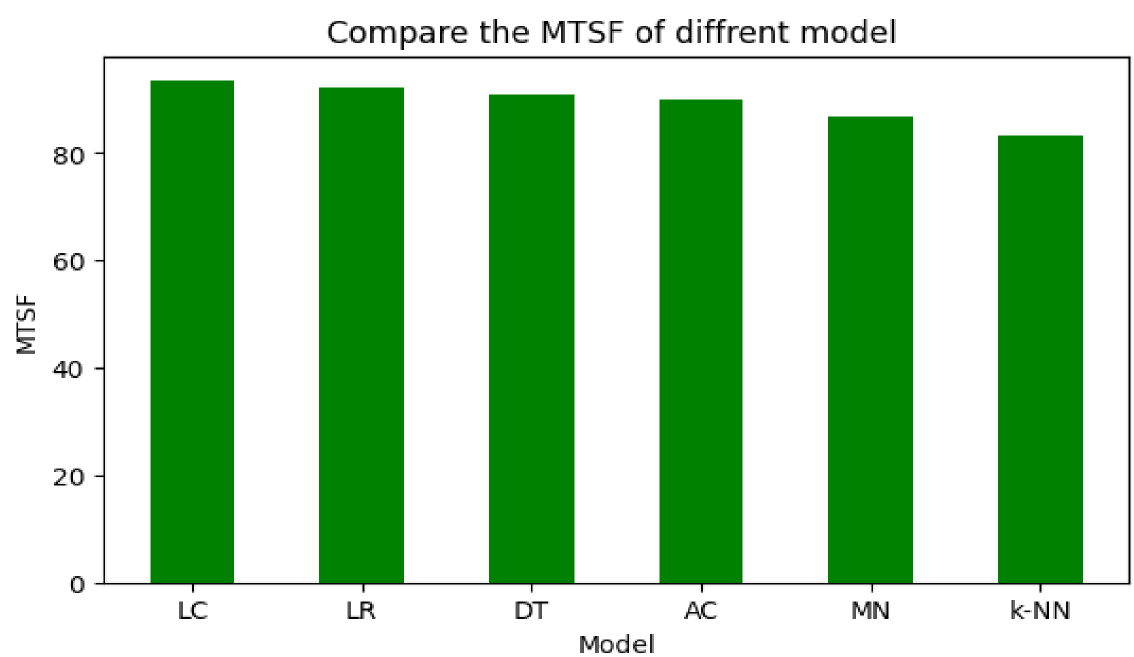

Figure 2: Compare of the MTSF of different Model.

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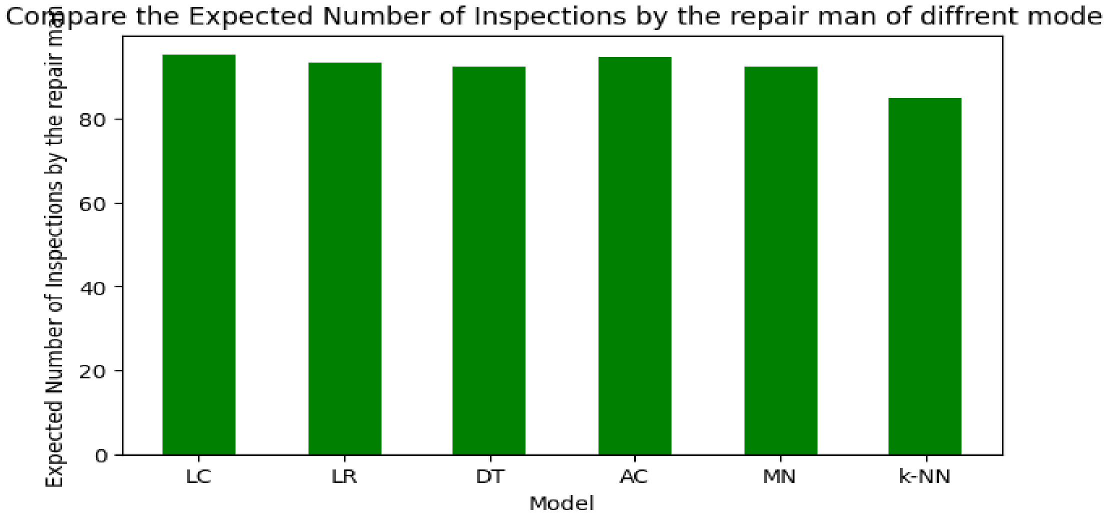

Figure 3: Compared the expected number of inspection by the repair man of different model.

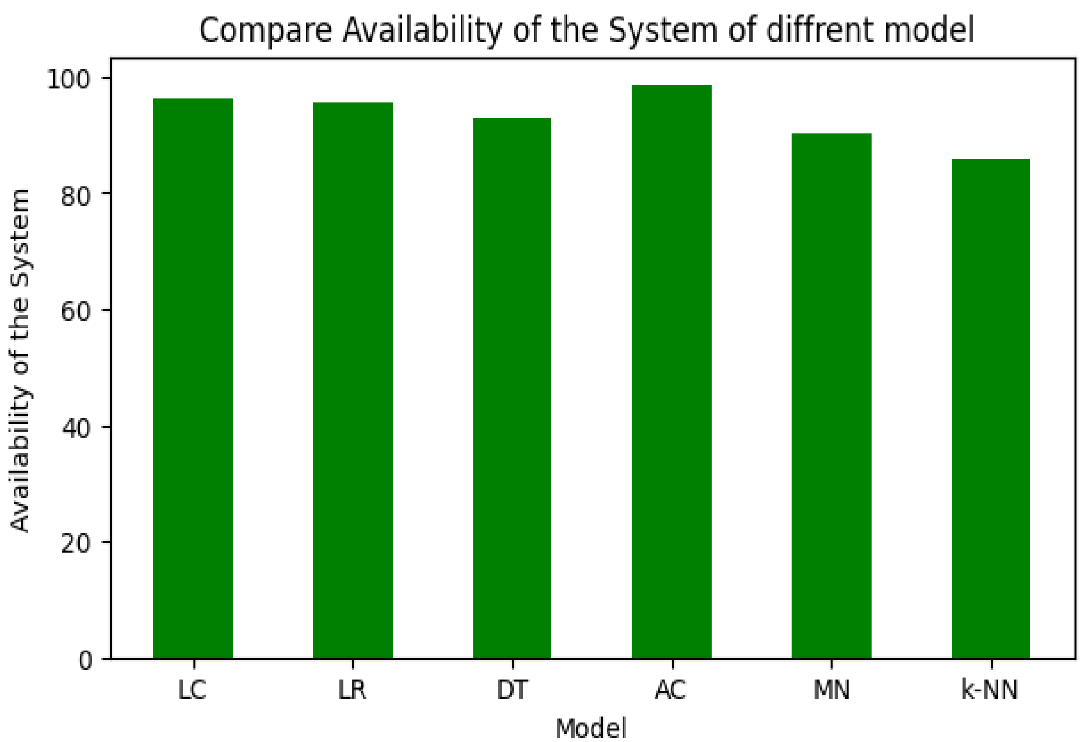

Figure 4: Compare Availability of system of different model.

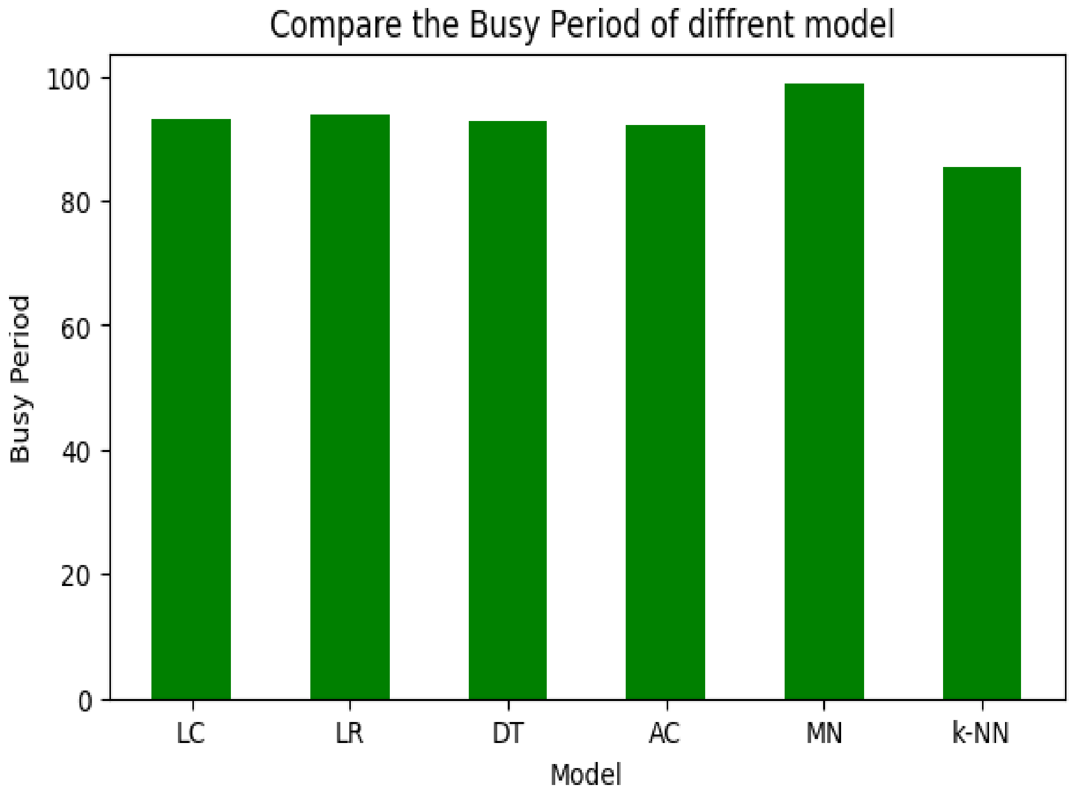

Figure 5: compare of the busy period of different model.

10. Conclusion:

Methods of controlling unit failure along with repair rates relating to financial resources but instead market conditions to obtain optimum values for system parameters. Now, main purpose of our study the system is to optimize the availability of system. The height of system has three parameters as availability of working states of system primary period of server and visits made by the servers. Since the industries have to made a fix investment to set up the system of any type of industry. The system's availability are all observed to decrease with an increase in failure rate and to increase with the repair rate, based on the analytical and figure discussions. In contrast, the letdown rate of the standby unit may have less impact on system availability because the preventive maintenance and degradation 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 preventive maintenance and degradation 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 preventive maintenance and degradation 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 preventive maintenance and degradation 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 3 as follow and comparison of model in figure 2, 3, 4, and 5. By raising the repair rate and lowering the failure rate, the plant's effectiveness and dependability can be enhanced. The system cannot reach production after a limit, i.e. a recession occurs. A degraded state is a state of the system in which the system or units perform a function continuously up to a satisfactory but lower (lower) limit than specified due to its required functions.

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