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Machine Repair System On Two Units With Imperfect Coverage, Unreliable Servers And Common Cause Failure

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Abstract: In many ongoing repairable frameworks, when a unit fizzles, it could be quickly recognized, found and supplanted with coverage factor likelihood by a backup on the off chance that one is accessible. When developing reliability models for repairable systems, some of the most important considerations that should be taken into account include the availability of standbys, the coverage factor, and common cause failure. Coverage factor is used to study measures of the reliability of a backup system, which is a combination of primary and backup equipment. Provisioning has been made for the proper functioning of the framework. In case the main unit's reserve units are down, the reserve units will take over the base units, and in case the backup units fall, the frame will go into bombardment completely. The frustrations and remedies of each unit follow general circulation and are notable individually. Under the conditions of inadequate coverage and common cause failure, the entire system has been analyzed. To determine the probabilities of state transients, a Markov model has been created. Using Laplace transformation, various reliability metrics like availability and MTTF have been evaluated. A few graphical outlines have been taken for better comprehension of the model.

Keywords- Reliability, Availability, Common cause failure, MTTF, Laplace transforms

I. Introduction

Repairable multi-component machining systems' availability and reliability prediction has become increasingly important in a variety of industries, including power plants, manufacturing and production systems, computer networks, and telecommunications. Such machining frameworks are frequently requiring a pre-determined least required degree of unwavering quality and accessibility. A repairable framework is typically characterized as one that will be fixed to recuperate its capabilities after every disappointment. The machining system's maintainability is essential for designing, operating, and maintaining the desired level of reliability and availability at a predetermined performance level. The prediction of the availability and reliability indices of repairable systems is required for the design of optimal maintenance strategies. The quality of the product, business costs, customer service, and, consequently, the organization's profit can all be directly impacted by the performance of repairable systems. The backup overt repetitiveness is one of the resources to accomplish profoundly solid framework with less trustworthy units at the least conceivable expense. For a repairable system with spares, reliability and availability should be precisely evaluated as a common performance indicator.

With the headway of current innovation, it is turning out to be more muddled to machine frameworks. At the expense of system complexity, these methods enable a system to operate with high reliability under unavoidable techno economic constraints. The majority of real-time systems are also repairable, despite their complexity. In numerous commonsense applications, we have a huge complex framework which is made out of a large number which are inclined to disappointment. For such frameworks, the accessibility investigation might be useful to distinguish the shortcoming of the framework and to evaluate the effect of part disappointments. The unwavering quality models can give a quantitative evaluation to figure out what parts are more vital to framework dependability improvement or more basic to framework disappointment. The provision of spare parts support and a repair facility is common in machining systems in order to boost their dependability and effectiveness.

When a server goes down, Chowdhary and Tadj (2009) talked about a two-step maintenance system. There are two types of services that servers can provide: optional and basic. The device receives optional service after completion of the first main service. System performance has been greatly improved with additional services. Yang and Wu (2015) explored an N strategy for an M/M/1 queuing model that works by thinking about server failures. They used molecular swarm evolution calculations to improve economic capability and determine ideal boundaries. Jane and Meena (2017) focused on modeling the performance of fault-tolerant systems using operational modules and combinations of hot and cold spares as support. To discover transition probabilities associated with system states, they developed a Markov model. The Runge-Kutta strategy is used to estimate the probabilities of frame state and queuing measures. Ke et al. (2018) investigated machine repair issues related to unreliable technicians and imperfect standby mode transitions. They obtained fixed likelihood variances for useful variable strategies. Chen et al. (2018) analyzed the system reliability of a machine repairable system with M work units, S hot standby units and a single N-strategy patch server. Kumar et al. (2019) eliminated machine issues with an F-strategy with two unreliable servers and a service office with hot backups. We also provided a cost function to describe the usefulness of the system at the lowest possible cost. Arora et al. (incorporating the idea of incomplete coverage in 2020) examined the performance of maintainable systems in the backup and repair business. We also focused on appropriate levels of inclusion, focusing on the critical components of consistent quality indicators: availability, reliability, and reliability of a system that works for cost reduction. Liu et al. (2021) managed a multi-server retest system with faulty power-ups and delayed reboots highlighted. They also used heuristic research methods to get expected improvements at all costs. Liu et al. (2023) considers the active need to get out of the queue when one server might crash due to incorrect inclusion. I also created a set of progress bars and provided a simple math reference to demonstrate these activities. Kumar and Gupta (2023) explored unshakable quality measures of multi-device soft fault control (FTC) schemes in which devices rely on frustration and can be eliminated by two different servers.

II. DESCRIPTION OF THE SYSTEM

The following hypotheses serve as the basis for the organization of the system:

(i) The system is initially in good working order.

(ii) After disappointment on fundamental unit, reserve unit begins working.

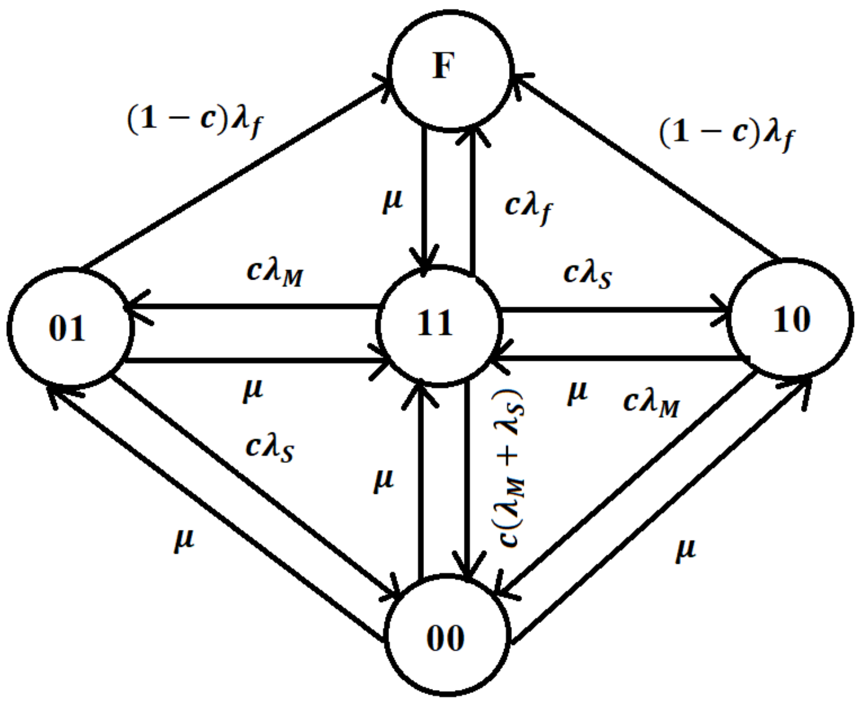
(iii) Framework has been totally fizzled when backup bombed before fix of the principal unit and because of normal reason disappointment.

(iv) It has been assumed that all repair rates would remain constant.

(v) After fix framework proceeds as another framework.

The current model is considered a usable two-unit system with a primary processor and a backup processor. The frame has three fast states, i.e. bombed and big. The system is in good condition at first as each unit is working properly. When the primary unit fails, the backup unit is immediately installed and the primary unit repaired. In the event that the bombarded main unit is repaired before the reserve forces fool, the reserve unit will receive a save pile and the reserve unit will go into reserve mode. If a backup device fails before the primary unit is repaired, the system will be in a complete failure state. The system also fails when it fails due to common causes at any stage of operation. Expect no delays between exchanges. With c coverage, the system will be repaired immediately in the event of a problem. However, the system will most likely fall into a complete failure state with probability $(1-c)$ if the fault is not detected. Figure (1) depicts each state transition that the model may encounter.

Figure 1: Transition rate diagram of the two unit repairing system



III. FORMULATION OF THE MODEL

To formulate the problem, we perform transient and stationary analysis to understand the feasibility of implementing the proposed model.

3.1 Transient state analysis:

$$P_{11}'(t) = \mu(P_{01} + P_{10} + P_{00} + P_F) - c(2\lambda_M + 2\lambda_S + \lambda_f)P_{11} \quad (1)$$

$$P_{10}'(t) = c\lambda_S P_{11} + \mu P_{00} - [c\lambda_M + \mu + (1-c)\lambda_f]P_{10} \quad (2)$$

$$P_{01}'(t) = c\lambda_M P_{11} + \mu P_{00} - [c\lambda_S + \mu + (1-c)\lambda_f]P_{01} \quad (3)$$

$$P_{00}'(t) = c(2\lambda_M + 2\lambda_S)P_{11} - 3\mu P_{00} \quad (4)$$

$$P_F'(t) == (1-c)\lambda_f P_{01} + (1-c)\lambda_f P_{10} + c\lambda_f P_{11} - \mu P_F \quad (5)$$

Since initially the system has both active units as good state, the initial conditions are given by

$$P_{11}(0) = 1, P_{01}(0) = 0, P_{10}(0) = 0, P_{00}(0) = 0, P_F(0) = 0 \quad (6)$$

Taking Laplace transform of (1),(2),(3),(4) and (5) on both sides

$$sp_{11}(s) - P_{11}(0) = \mu[p_{10}(s) + p_{10}(s) + p_{00}(s) + p_F(s)] - c(2\lambda_M + 2\lambda_S + \lambda_f)p_{11}(s) \quad (7)$$

$$sp_{10}(s) - P_{10}(0) = c\lambda_S p_{11}(s) + \mu p_{00}(s) - [c\lambda_M + \mu + (1-c)\lambda_f]p_{10}(s) \quad (8)$$

$$sp_{01}(s) - P_{01}(0) = c\lambda_M p_{11}(s) + \mu p_{00}(s) - [c\lambda_S + \mu + (1-c)\lambda_f]p_{01}(s) \quad (9)$$

$$sp_{00}(s) - P_{00}(0) = c(2\lambda_M + 2\lambda_S)p_{11}(s) - 3\mu p_{00}(s) \quad (10)$$

$$sp_F(s) - P_F(s) = (1-c)\lambda_f p_{01}(s) + (1-c)\lambda_f p_{10}(s) + c\lambda_f p_{11}(s) - \mu p_F(s) \quad (11)$$

$$p_{11}(s) = \frac{1+\mu[p_{01}(s)+p_{10}(s)+p_{00}(s)+p_F(s)]}{k_1} \quad (12)$$

$$p_{10}(s) = \frac{c\lambda_S}{k_2}p_{11}(s) + \frac{\mu k_4}{k_2(s+3\mu)}p_{11}(s) \quad (13)$$

$$p_{01}(s) = \frac{c\lambda_M}{k_3}p_{11}(s) + \frac{\mu k_4}{k_3(s+3\mu)}p_{11}(s) \quad (14)$$

$$sp_{00}(s) - P_{00}(0) = c(2\lambda_M + 2\lambda_S)p_{11}(s) - 3\mu p_{00}(s)$$

$$p_{00}(s) = \frac{k_4}{s+3\mu}p_{11}(s) \quad (15)$$

$$p_F(s) = \frac{(1-c)\lambda_f}{s+\mu}\left\{\frac{c\lambda_M}{k_3}p_{11}(s) + \frac{\mu k_4}{k_3(s+3\mu)}p_{11}(s)\right\} + \frac{(1-c)\lambda_f}{s+\mu}\left\{\frac{c\lambda_S}{k_2}p_{11}(s) + \frac{\mu k_4}{k_2(s+3\mu)}p_{11}(s)\right\} + \frac{c\lambda_f}{s+\mu}p_{11}(s) \quad (16)$$

On putting the values of $p_{10}(s), p_{01}(s), p_{00}(s)$ and $p_F(s)$ from equations (13),(14),(15) and (16) in equation (12), we get

$$p_{11}(s) = \frac{1}{Nk_1}$$

Where

$$N = \left[1 - \frac{\mu}{k_1}\left\{\frac{c\lambda_M}{k_3} + \frac{\mu k_4}{k_1(s+3\mu)} + \frac{c\lambda_S}{k_2} + \frac{\mu k_4}{k_2(s+3\mu)} + \frac{k_4}{s+3\mu} + \frac{c\lambda_M(1-c)\lambda_f}{k_3(s+\mu)} + \frac{\mu k_4(1-c)\lambda_f}{k_3(s+3\mu)(s+\mu)} + \frac{\lambda_f c\lambda_S(1-c)}{k_2(s+\mu)} + \frac{\mu k_4(1-c)\lambda_f}{k_2(s+3\mu)(s+\mu)} + \frac{c\lambda_f}{s+\mu}\right\}\right] \quad (17)$$

where

$$s + c(2\lambda_M + 2\lambda_S + \lambda_f) = k_1, s + c\lambda_M + \mu + (1-c)\lambda_f = k_2$$

$$s + c\lambda_S + \mu + (1-c)\lambda_f = k_3, 2c(\lambda_M + \lambda_S) = k_4$$

The probabilities of the high and low states are as follows:

$$p_{up}(s) = p_{11}(s) + p_{10}(s) + p_{01}(s) \quad (18)$$

$$p_{down}(s) = p_{00}(s) + p_F(s) \quad (19)$$

$$p_{up}(s) = \left[1 + \frac{c\lambda_S(s+3\mu)}{\{s+c\lambda_M+\mu+(1-c)\lambda_f\}\{2c(\lambda_M+\lambda_S)\}} + \frac{\mu\{2c(\lambda_M+\lambda_S)\}}{k_2(s+3\mu)} + \frac{c\lambda_M}{s+c\lambda_S+\mu+(1-c)\lambda_f} + \frac{\mu\{2c(\lambda_M+\lambda_S)\}}{\{s+c\lambda_S+\mu+(1-c)\lambda_f\}(s+3\mu)}\right]p_{11}(s) \quad (20)$$

3.2. Steady state analysis:

The steady state equations are

$$\mu(P_{01} + P_{10} + P_{00} + P_F) = c(2\lambda_M + 2\lambda_S + \lambda_f)P_{11} \quad (21)$$

$$c\lambda_S P_{11} + \mu P_{00} = [c\lambda_M + \mu + (1-c)\lambda_f]P_{10} \quad (22)$$

$$c\lambda_M P_{11} + \mu P_{00} = [c\lambda_S + \mu + (1-c)\lambda_f]P_{01} \quad (23)$$

$$c(2\lambda_M + 2\lambda_S)P_{11} = 3\mu P_{00} \quad (24)$$

$$(1-c)\lambda_f P_{01} + (1-c)\lambda_f P_{10} + c\lambda_f P_{11} = \mu P_F \quad (25)$$

$$P_{11} = \frac{3\mu}{D_1}P_{00} \quad (26)$$

$$P_{01} = \left[\frac{3c\lambda_M}{D_1 D_2} + \frac{1}{D_2}\right]\mu P_{00} \quad (27)$$

$$P_{10} = \left[\frac{3c\lambda_S}{D_1 D_3} + \frac{1}{D_3}\right]\mu P_{00} \quad (28)$$

$$P_F = \left[\frac{(1-c)\lambda_f\{3c\lambda_M D_3 + 3c\lambda_S D_2 + D_1 D_3 + D_1 D_2\} + 3c\lambda_f D_2 D_3}{D_1 D_2 D_3}\right]P_{00} \quad (29)$$

The normalizing conditions is

$$P_{01} + P_{10} + P_{00} + P_F + +P_{11} = 1 \quad (30)$$

On substituting the values of P_{11}, P_{01} P_{10} and P_F from equations (23), (24),(25) and (26) in equation (27), we get

$$P_{00} = \frac{A}{B} \quad (31)$$

Where

$A = D_1 D_2 D_3$

$B = 3c\mu\lambda_M D_3 + \mu D_1 D_3 + 3c\mu\lambda_S D_2 + \mu D_1 D_2 + D_1 D_2 D_3 + (1-c)\lambda_f\{3c\lambda_M D_3 + 3c\lambda_S D_2 + D_1 D_3 + D_1 D_2\} + 3(\mu + c\lambda_f) D_2 D_3$

$D_1 = 2c(\lambda_M + \lambda_S)$

$D_2 = \{c\lambda_S + \mu + (1-c)\lambda_f\}$

$D_3 = \{c\lambda_M + \mu + (1-c)\lambda_f\}$

IV. PERFORMANCE INDICES

In this segment, we give some exhibition measures to investigate the impact of framework boundaries specifically disappointment paces of primary unit, reserve, defective issue inclusion, administration rate and on the unwavering quality files for the repairable two unit framework.

4.1 Availability: The steady state availability is obtained using

$$A(\infty) = 1 - P_{00} - P_F \quad (32)$$

On putting the values of P_F from equation (29) respectively in equation (32) to obtain Availability

$$= 1 - P_{00} - \left[(1-c)\lambda_f\left\{\frac{3c\lambda_M}{D_1 D_2} + \frac{3c\lambda_S}{D_1 D_3} + \frac{1}{D_2} + \frac{1}{D_3}\right\} + \frac{3}{D_1}c\lambda_f\right]P_{00}$$

$$= 1 - \left[1 + (1-c)\lambda_f\left\{\frac{3c\lambda_M}{D_1 D_2} + \frac{3c\lambda_S}{D_1 D_3} + \frac{1}{D_2} + \frac{1}{D_3}\right\} + \frac{3}{D_1}c\lambda_f\right]P_{00} \quad (33)$$

4.2 Reliability: Reliability is a likelihood that concerned how long a framework performs well once it begins works. It is a component of time. The reliability function that follows can be obtained by taking repair rate $\mu = 0$ for equation (20).

$$\bar{R}(s) = \frac{1}{s + c(2\lambda_M + 2\lambda_S + \lambda_f)}\left[1 + \frac{c\lambda_S}{\{s + c\lambda_M + (1-c)\lambda_f\}} + \frac{c\lambda_M}{s + c\lambda_S + \mu + (1-c)\lambda_f}\right] \quad (34)$$

Taking inverse Lapalce transform of equation (34)

$$R(t) = e^{-c(2\lambda_M+2\lambda_S+\lambda_f)t} + \frac{\lambda_S}{c(\lambda_M+2\lambda_S+\lambda_f)}\left[e^{-\{c\lambda_M+(1-c)\lambda_f\}t} - e^{-c(2\lambda_M+2\lambda_S+\lambda_f)t}\right] + \frac{c\lambda_M}{2c\lambda_M+c\lambda_S+2c\lambda_f-\lambda_f}\left[e^{-\{c\lambda_S+(1-c)\lambda_f\}t} - e^{-\{c(2\lambda_M+2\lambda_S+\lambda_f)\}t}\right] \quad (35)$$

4.3 Mean time to failure (MTTF): Mean time to failure (MTTF) of a framework addresses how long a framework can sensibly be anticipated to perform. To get MTTF taking μ = 0 and s will in general focus in equation (20), we get

$$p_{up}(s) = \left[1 + \frac{c\lambda_S(s+3\mu)}{\{s+c\lambda_M+\mu+(1-c)\lambda_f\}\{2c(\lambda_M+\lambda_S)\}} + \frac{\mu\{2c(\lambda_M+\lambda_S)\}}{k_2(s+3\mu)} + \frac{c\lambda_M}{s+c\lambda_S+\mu+(1-c)\lambda_f} + \frac{\mu\{2c(\lambda_M+\lambda_S)\}}{\{s+c\lambda_S+\mu+(1-c)\lambda_f\}(s+3\mu)}\right]p_{11}(s) \quad (20)$$

$$MTTF = \frac{1}{c(2\lambda_M+2\lambda_S+\lambda_f)}\left[1 + \frac{c\lambda_M}{c\lambda_S+(1-c)\lambda_f}\right] \quad (36)$$

V. SENSITIVITY ANALYSIS AND RESULTS

The computer program is developed using the software MATLAB after computing the numerical results. We used the default parameters to provide numerical results for reliability and MTTF.

$\lambda_M = 0.1, \lambda_S = 0.01, \mu = 4, c = 0.5$

By varying the various parameters, the performance indices such as availability, reliability, and MTTF have been graphically presented in graphs 1-10, respectively.

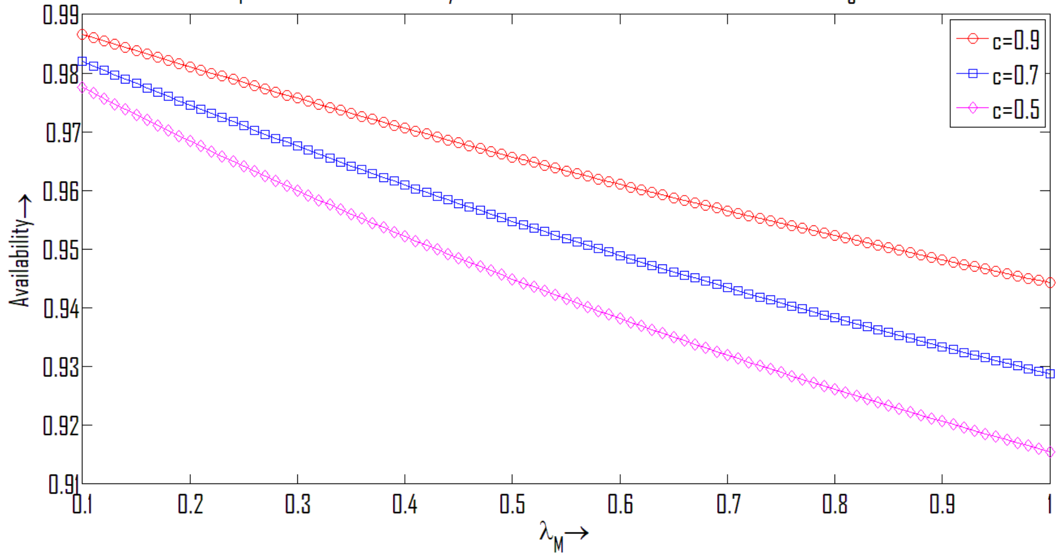
It is found from graph (1) that the availability diminishes as failure rate of fundamental unit increments. It is additionally found that availability appears to the accessibility increments as coverage factor increments. As can be seen from graph 2, an increase in the system's availability is accompanied by an increase in its repair rate. With an increase in the coverage factor, availability also rises. According to graph 3, the availability rises in tandem with the repair rate. At first, we observe a sharp rise in availability, but as time goes on, this rise slows down. Further availability increments as common cause failure rate diminishes.

The variety in likelihood that the framework isn't is working state has been shown is charts (4) and (5), separately. As the system's repair rate rises and the standby's failure rate decreases, this probability decreases. These graphs also show that as the coverage factor rises, so the probability diminishes.

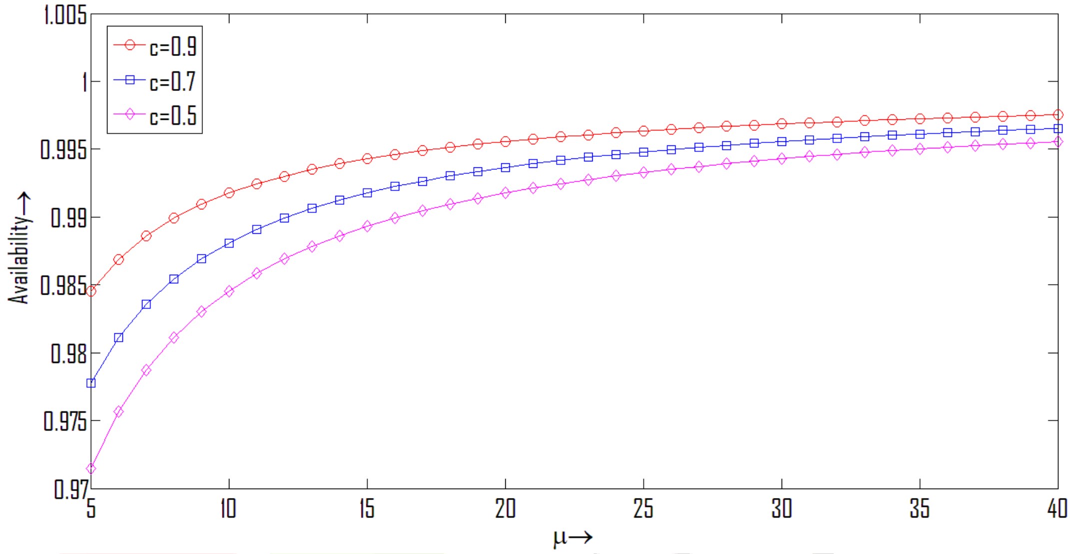
The patterns of Reliability versus time for changing boundaries are portrayed in graphs (6) to (8). The trends of these graphs indicate that the reliability decreases with increasing time (t). This trend is consistent with our expectations for a real-world scenario. The graphs between reliability and time for various coverage factor values are drawn in order to determine the effect of the coverage factor on system reliability. We notice that the Reliability increments as coverage factor increments. We illustrate the impact of standby unit and main unit failure rates on reliability in graphs (7) and (8). We discovered that as standby and main unit failure rates rise, so reliability decreases.

We compute the result in equation (36) and present it in graphs (9) and (10) in order to investigate how various parameters affect the MTTF. We discovered that as the main unit's failure rate rises, so MTTF reduces. This pattern coordinates with the experience on the continuous framework. The MTTF also goes up as the coverage factor goes up, but it goes down as the common cause failure rate goes up.

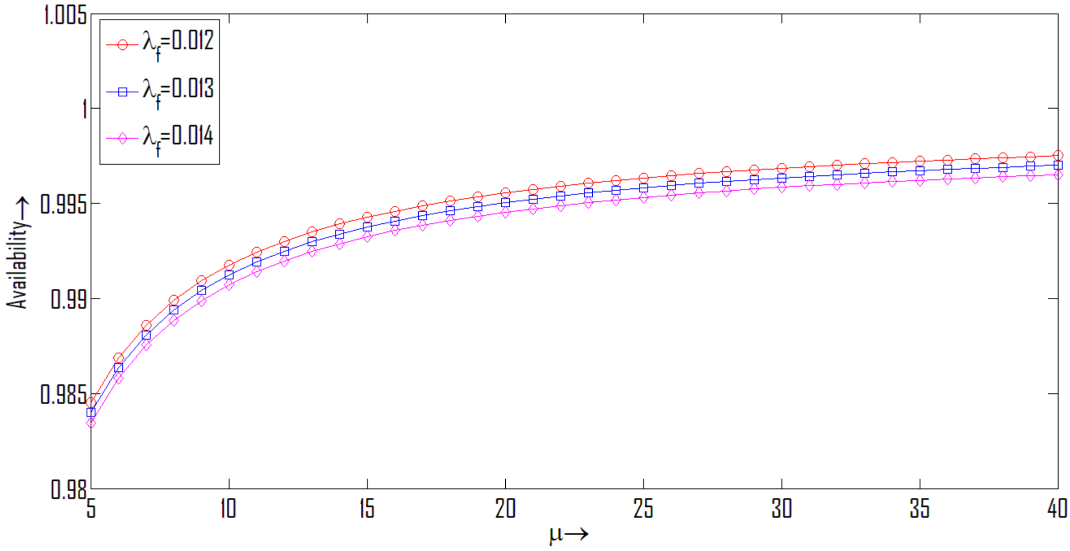
Graph-I: Variation in availability with failure rate of main unit for different coverage factor

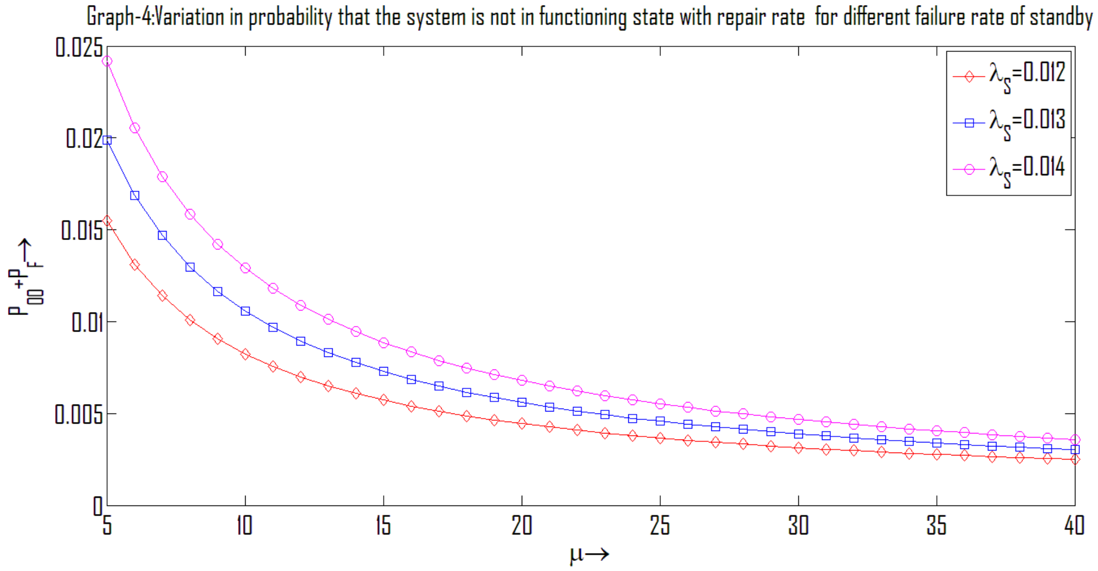


Graph-2: Variation in availability with repair rate of the system for different coverage factor

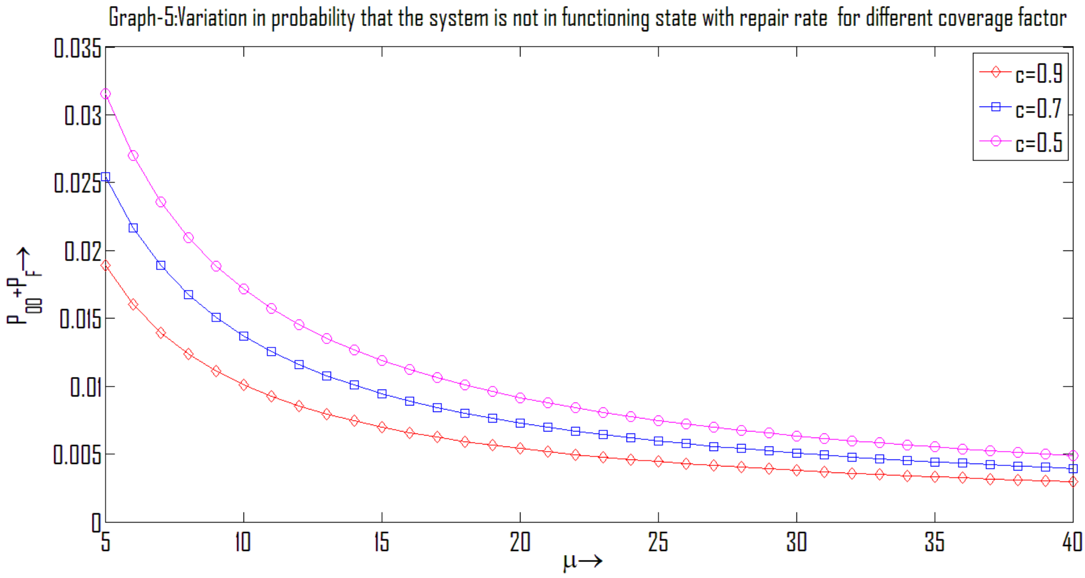


Graph-3:Variation in availability with repair rate of the system for different common cause failure rate

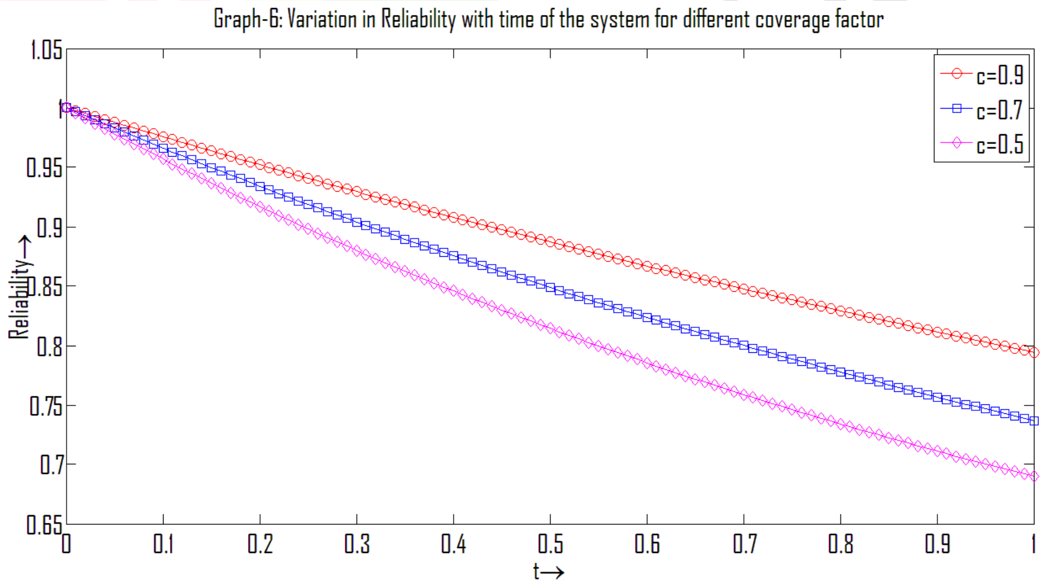




Graph-4:Variation in probability that the system is not in functioning state with repair rate for different failure rate of standby
λ_s=0.012
λ_s=0.013
λ_s=0.014
$P_{00}+P_F$→
μ→

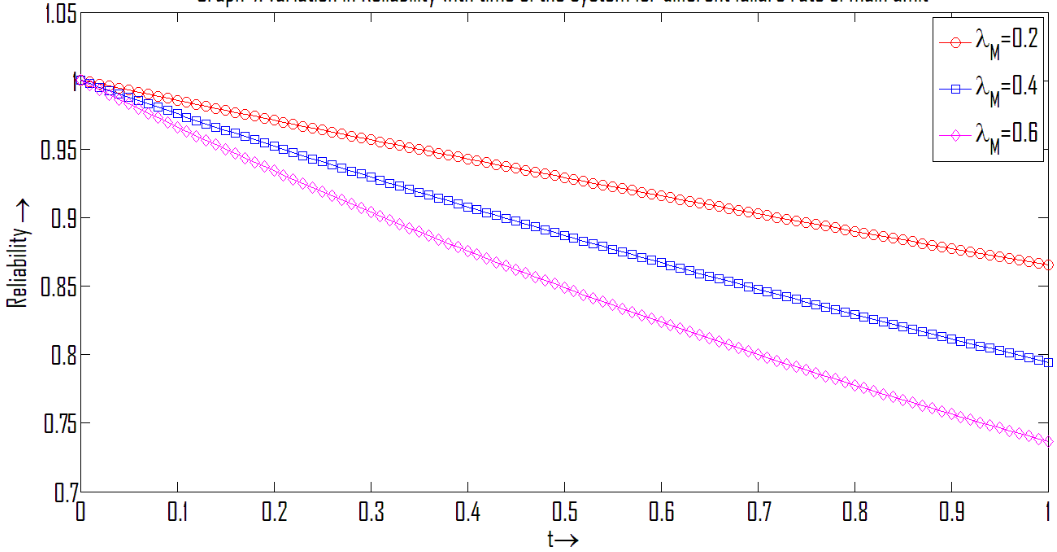


Graph-5:Variation in probability that the system is not in functioning state with repair rate for different coverage factor
c=0.9
c=0.7
c=0.5
$P_{00}+P_F$→
μ→

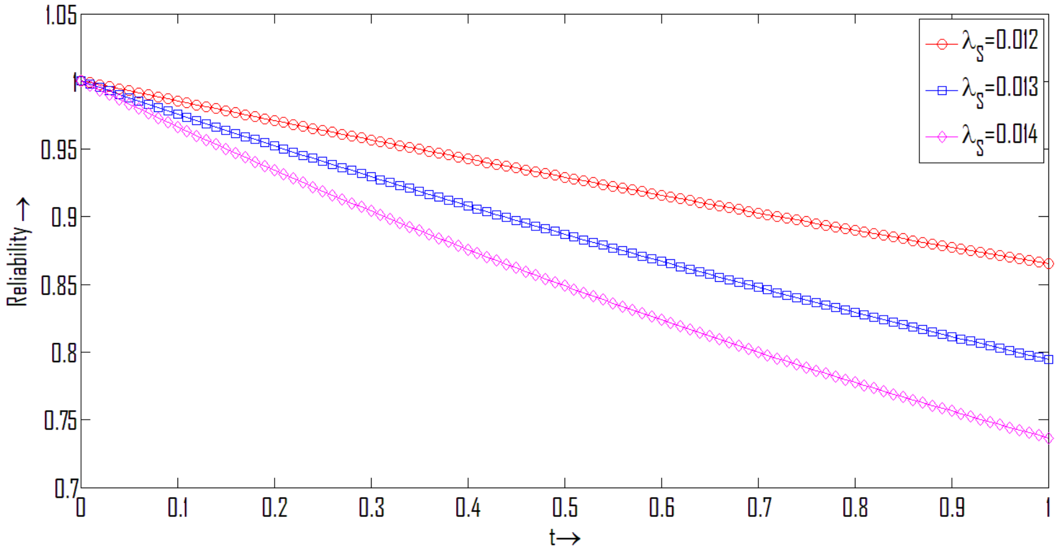


Graph-6: Variation in Reliability with time of the system for different coverage factor
c=0.9
c=0.7
c=0.5
Reliability→
t→

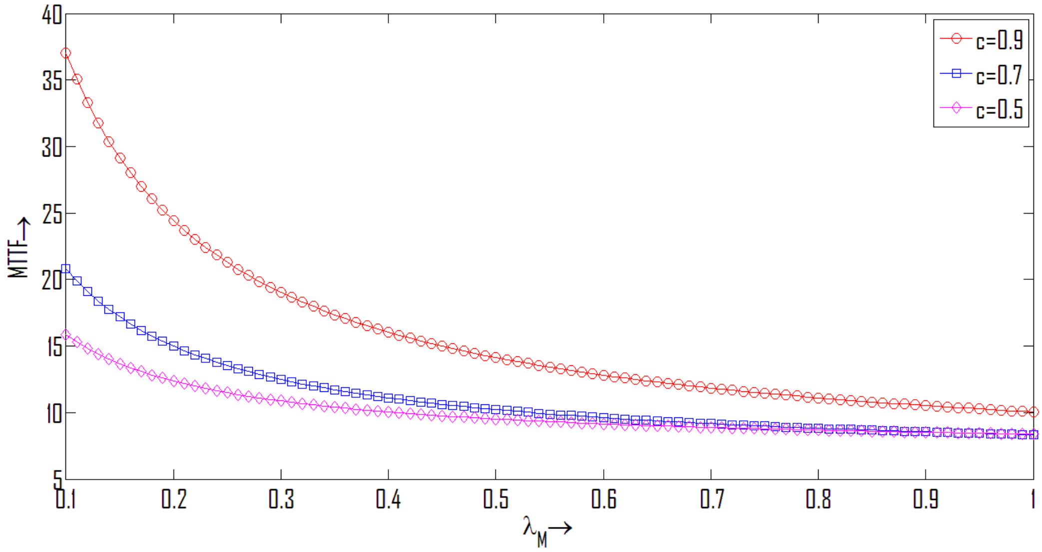
Graph-7: Variation in Reliability with time of the system for different failure rate of main umit

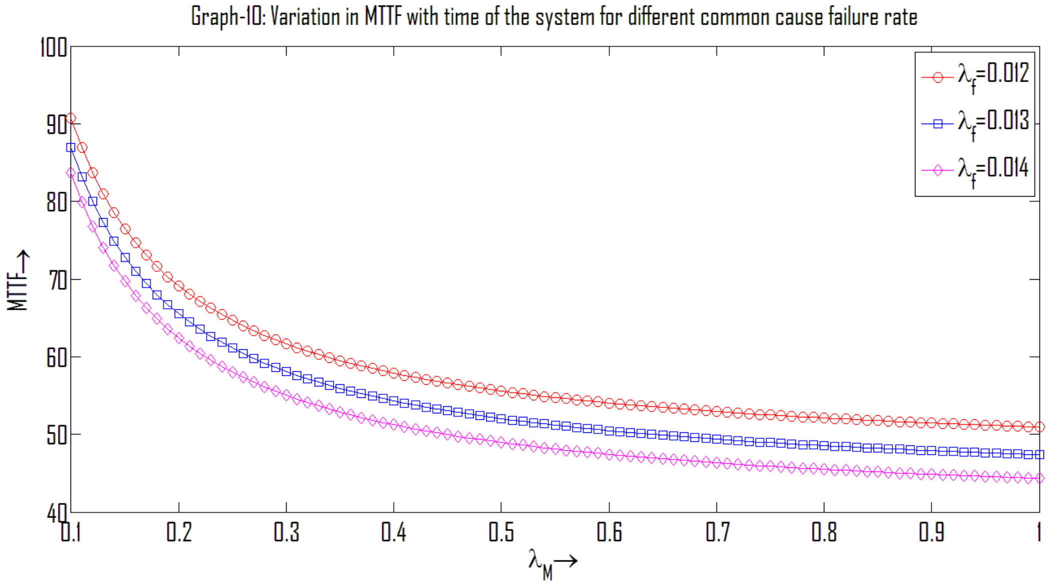


Graph-8: Variation in Reliability with time of the system for different failure rate of standby unit umit



Graph-9: Variation in MTTF with time of the system for different coverage factor





VI. CONCLUDING REMARKS

The viability and Reliability expectation during the plan and activity of repairable framework is of crucial significance to keep a necessary exhibition level. One important method for achieving a highly reliable system with less reliable components is standby redundancy. In this paper we have laid out the unwavering quality and accessibility records to definitively dissect a two unit repairable reserve framework with inclusion component and normal reason disappointment. The examination done gives an understanding to further develop the framework dependability and MTTF for the two unit reparable frameworks.

By combining the concepts of imperfect coverage and common-cause failure, the present work tested the performance of a repairable two-unit system supported by a redundancy facility. and repair. A good measure of comprehensiveness skews in favor of checking the consistency of a framework because it works on accessibility, consistent quality, and cost reduction, which is an essential variable in reliability measure. The Laplace transform is used to evaluate the transient probability of the system state and other measures. In addition, the context is very delicate for human deception. Thus, human deception is a fundamental part of the framework that is hard to steal. Therefore, common-cause failures should be controlled to improve system reliability. This research is also particularly useful for enterprises where the chassis has redundant units such as aircraft, missiles, vehicle transmissions, power supplies supporting the chassis, and more.

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