Mathematical Modeling and Optimization of System Reliability Analysis Using RPGT-A General Approach

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ABSTRACT

In the present paper, reliability analysis is examined for consistent state. The Processing/Manufacturing industry is isolated into numerous subsystems. Subsystems are either in parallel/equal or in arrangement. Taking failure and repair rates constant. The subsystem may flop totally through partial disappointment. At the point when any subsystem flops then the framework is in bombed state. A state diagram of system portraying the transition rates is drawn. The statistical method analysis is applied. Several models, assuming linear or non-linear relationship between growth and profitability are fitted. Industry-wise as well as inter-industry analysis System with Priority in Repair Using RPGT is carried out. Finally, the variations in profitability ratios are explained by several variables (e.g., capital output ratio, rate of inflation, index number of physical production etc.) with multivariate System with Priority in Repair Using RPGT analysis. Earlier researchers evaluated system problems using. Graphs are prepared to compare and draw the conclusion.

KEYWORDS: RPGT, MTSF, Availability

1. Introduction:

In the present study several statistical tools are applied to examine the structure of profit rates. Inter-Industry variations (each year) and industry-wide variations (over a period of time) are examined by using 'relative and absolute measures of dispersion (Standard Deviation and Coefficient of Variation). Profitability trend Coefficients of each of the manufacturing industries are estimated and examined by regressing profitability over time. Estimates of capital are derived by the methodology adopted by S.R. Hashim and M.M. Dadi in their publication, on 1946-1964. The value of fixed assets has been estimated at constant prices, thereby indicating their value in real terms. These estimates of capital thus derived are used to express the growth of the industry in real terms; Batter on an attempt is made to explore the relationship between growth of the industry and its profitability. The statistical method analysis is applied. Several models, assuming linear or non-linear relationship between growth and profitability are fitted. In the current situation of global competition and liberalization, Indian industries must be aware of the need to produce quality goods that meet global standards. For a company to succeed in a complex environment, it is necessary to know the reliability of its product and manufacture the product at an optimum reliability level. It results in the minimum system and lifecycle cost for the consumer without compromise on the product's quality and reliability. In order for an enterprise to thrive in this complex situation, it is crucial to ensure the consistency of its products and optimize the production processes to accomplish an optimum level of steadfastness. This approach results in minimized organization and lifecycle prices for the end-user, without co-operating on the quality and dependability of the creation.

While challenges associated through the expansion and processes of organizations have been significant in the past, the significances of disappointments were not necessarily catastrophic. However, in premature epochs of engineering phase, reliability concerns were not accorded significant attention. Initially, reliability analysis was confined to mechanical apparatus. Nevertheless, through the evolution of electrification, substantial efforts obligate been undertaken to guarantee a reliable stream of electric power. In the pursuit of global competitiveness, Indian industries are now recognizing the critical role of reliability not only in mechanical systems but across diverse domains, including electrical systems. The emphasis on optimal reliability levels is instrumental in delivering products and services that not only meet global standards but also result in minimal costs throughout the system lifecycle. This strategic focus on reliability, quality, and dependability positions companies to navigate the challenges of a competitive global market while providing users with high-quality, dependable products. As industries evolve, the commitment to reliability becomes an integral aspect of sustainable growth and success in the dynamic global business environment.

In the past, the problems associated with the development and process of the systems was serious, but the consequences of failures were not catastrophic. In the starting period of the industrial age, the reliability problems were not considered much seriously. In the beginning, reliability analysis was only restricted to mechanical equipment. However, with the development of electrification, significant efforts have been made to ensure reliable electric power supply. In the present mechanical world, almost every person depends upon the persistent functioning of a wide array of complex machinery and equipment for their regular health, mobility, and safety. We look ahead to our vehicles, PCs, electrical apparatuses, and TVs to work whenever we need them day after day, year after year.

At the point when they fail, the outcomes can be catastrophic for example injuries and loss of life can happen. More frequent and repeated failures can lead to problems, and lifelong client's dissatisfaction that can play havoc with the responsible company's marketplace position. It requires some investment for a company to develop a reputation for reliable manufacturing. In this competitive world, there is no more time left for unreliable products and low-quality manufacturing units.

For both the manufacture and the buyer, reliability is one of the most significant considerations characterizing the quality of components or systems. High reliability is achieved through the choice of material, design efforts, manufacturer process, and proper maintenance of the manufacturing products.

Developing a reputation for reliable manufacturing is a time-intensive process for any company. In the competitive landscape, there is no room for unreliable products and subpar manufacturing units. Both for the manufacturer and the consumer, reliability stands out as one of the maximum critical considerations important the quality of components or systems. Achieving high reliability involves careful selection of materials, rigorous design efforts, meticulous manufacturing processes, and proper maintenance of the manufactured products. In essence, the pursuit of high reliability is a multifaceted endeavour that spans the entire lifecycle of a product. After the initial design stage to manufacturing and on-going upkeep, every step productions a crucial character in ensuring the reliable functioning of machinery and devices. In a world where technology is deeply integrated into daily life, the emphasis on reliability is paramount, contributing not only to user safety but also to the long-term success and reputation of manufacturing entities. The words 'reliable and reliability' are very commonly used by every one of us, in our daily life, indicating the level of confidence in the person/thing or system. A particular feature of any stochastic system is that in case of failure of a rather limited number of its components/sub-systems, the entire system fails. The failure of an unreliable system may result into very dangerous and serious consequences and an awful disastrous to the people at large and the environment.

For example, the worst industrial accident occurred in the Union Carbide Plant in Bhopal (India) in 1985 where thousands of people died; the space shuttle Challenger had exploded midair in Jan., 1986. In our daily life, we face several problems connected with production, administration, social development and employment etc. if we have a clear-cut idea about the problem and the effective conditions; a solution to the problem is possible using reliability technology. The reliability & technology constitutes the core of economy and the development of the infrastructure of a system. Now-a-days, the technology without reliability is unthinkable. For a country like India with limited resources, it is all the more important to use its resources in a very optimal way to achieve higher production by having increased reliability of the systems.

It was during World War II, when the security was felt because of the problems of maintenance, repairs and the sudden failures of the defense and security equipment's. Then, mathematical models were prepared and researched to overcome the various forms of the breakdowns of the systems. The mathematical shape to this magic word 'reliability' was given during 1943-1945. After realizing the need and importance of the subject, the study of the theory of reliability was initially developed in the western world. There are many journals on reliability form USA, UK, India and other developed countries. IEEE transactions on Reliability (USA), Micro-electronics and Reliability (UK), Reliability Engineering & System Safety (UK), Journal of Mathematics and System Sciences (India) and many others, are doing a remarkable job by disseminating knowledge and experience in the field of reliability. Bhunia et al. (2010) proposed GA for tackling unwavering quality stochastic enhancement issues in a series framework with span part. The review resolved the issue of stochastic unwavering quality streamlining in light of chance imperatives in the series framework. Jieong et al. (2009) utilized a half and half calculation known as GA/PSO for tackling multi-objective streamlining issues. Komal et al. (2009) discussed the reliability, availability, and maintainability analysis gives some plan to carryout structure modification, assuming any required to accomplish superior of the complex mechanical systems. Kumar et al. (2018) talked about the 3:4: G System. Kumari et al. (2021) talked about the benefit examination of an agribusiness harvester plant in consistent state utilizing RPGT. Anchal et al. (2021) examined the SRGM model utilizing differential condition has been proposed, in which two classifications of deficiencies: straightforward and hard as for time in which these happen for disengagement and expulsion after their recognition has been introduced. Kumar et al. (2017) concentrated on the conduct examination in the urea compost industry. Kumar et al. (2019) the primary goal of this paper is to an inspected examination of a washing unit in the paper business using RPGT. Kumar et al. (2018) have concentrated on the conduct examination of a bread framework and eatable petroleum treatment facility plant. The researchers have talked about the reliability and accessibility of numerous stochastic systems and processing industry by utilizing awkward and time-consuming techniques. Goel, P., Goyal, V., Kumar, A., Singh J. what's more, numerous others, have examined and talked about systems under consistent state conditions, utilizing the accompanying formulae of the RPGT to find the key parameters of a stochastic system:

Availability

Availability will be the likelihood that a gadget is going to be in a position to work (i.e. not damaged or even going through repair) when called upon to do it. Much more particularly, it's the likelihood that the device is going to be ready to work within tolerance limits at a certain instant's and it is also known as operational readiness

Failure

Downtime

Downtime is the epochs of time when a framework is inaccessible. Downtime duration means to an epoch of time that a framework fails to work its main function. Down time due to an unexpected occasion or routine upkeep.

Uptime

The total amount of time during which the framework is in operating condition. A defect is defined as a departure in the system's attributes from the intended performance. Failure is a phrase used to describe a condition of defect. When the following requirements are met, a system is deemed to be in a failed state:-

1. When it stops working altogether.
2. When substantial degradation has rendered it unfit for continued use, forcing its withdrawal from service for repair or replacement.

Failure

Failure refers to the state or condition of not meeting an intended objective. System failure may be as follows:

- When the system stops working.
- When the system requires repair or replacement.

Phases of Failure

Generally, a gadget might encounter any of three phases of failure throughout the total life cycle of it's of as well as operating.

Initial failure

Initial failures are those that occur at the start of a framework's operation or in its early stages. Variations in the industrial procedure or poor quality control measures through manufacture could be to blame for these failures. These problems are because of manufacturing defects, for example poor assembly, vulnerable areas, defective styles etc.

Random failure (Chance failure)

Chance failures mainly occur during the actual working of the system. Chance failures happen at accidental, brokenly, and unexpectedly, as the term implies. These disappointments are triggered by abrupt stress accumulations that exceed the component's design strength. Nobody knows when a chance failure will happen.

Wear-out failure

These disappointments are affected owing to aging or tiresome out of components. The disappointments occur if the framework is not kept properly or not maintained at all.

Failure Rate

It is characterized as the basic ratio of quantity of disappointments during a specific interval to normal population during that stretch and is communicated in terms of quantity of disappointments per unit time. For the span as $[t, t + \Delta t]$,

Markov Process: A Markov process is a type of stochastic process in which dynamic behavior is such that the probability distribution for its future development depends only on the present state and not on how the process arrived in the present state, if the state space is discrete (finite and countable infinite), then the Markov process is called a Markov chain. The parameter of the Markov chain may be discrete or continuous. If the parameter space (Index set) is also discrete then the chain is called a discrete parameter Markov chain.

Applications of Reliability Technology

- A part of organization will distribute their anticipated steadfast quality numbers to help gain slack over their opponents who either don't convey their numbers or have lower numbers.
- Mechanical designing applications are contained in Dhillon and Singh's book. It might be found in literature. Singh connected the innovation to process businesses which might be found in this book.
- The rural application might be found in the writing.
- Electrical and hardware designing most extreme work has been done which might be found in the writing. Analysis of frameworks and reliability enhancement are given in the writing.
- Applications to non-customary vitality frameworks.
- The product reliability is given in writing.
- In common and concoction building some work has been done on reliability yet not very much. There is extension for work in these fields.
- In the fields of mechanical technology there is degree for work.
- In organic sciences, there is great degree for the work.

STEADY STATE TRANSITION PROBABILITY OF A REACHABLE STATE:

The steady-state transition probability of a state 'j' reachable from the state 'i' is defined as the sum of the steady-state path probabilities of transition from the state 'i' to the state 'j' along all the directed simple paths $(i \xrightarrow{s_r} j)$ for different values of 'r', from the state 'i' to the state 'j'. A simple path $(i \xrightarrow{s_r} j)$ for a given value of 'r' from the state 'i' to the state 'j' in the state transition diagram may have the regenerative state(s) k at which k-cycle(s) are formed. The steady-state transition probability of the state j reachable from the state i(denoted by $V_{i,j}$) is the conditional probability defined by

$$V_{i,j} = \sum_{s_r} \left\{ \frac{pr(i \xrightarrow{s_r} j)}{\prod_k \{1 - \sum pr(k - cycle)\}} \right\} \quad \dots\dots\dots (1)$$

The vital and key parameters like inspection/instructions/repairs/replacements and the number of visits by different servers doing different types of jobs such as inspection/instructions/repairs/replacements; the number of different types of replacements and the number of preventive and corrective maintenance actions can be evaluated by using formulae (2) to (5) explained as follows:

Mean Time to System Failure: - The mean time to system failure is the statistical average time for which the system operates before any failure(s) of the system. The term MTSF is used when the system undergoes either preventive or corrective maintenance actions. On using (1), the mean time to system failure is

$$\text{MTSF} = \left[\sum_{i,s_r} \left\{ \frac{\left\{ pr\left(0 \xrightarrow{s_r(sff)} i\right) \right\} . \mu_i}{\prod_{k_1 \neq 0} \left\{ 1 - V_{\overline{k_1,k_1}} \right\}} \right\} \right] \div \left[1 - \sum_{s_r} \left\{ \frac{\left\{ pr\left(0 \xrightarrow{s_r(sff)} 0\right) \right\}}{\prod_{k_2 \neq 0} \left\{ 1 - V_{\overline{k_2,k_2}} \right\}} \right\} \right] \quad \dots\dots (2)$$

Explanation:

i: a regenerative un-failed state to which the system can transit before entering any failed state while entering the initial 0-state at time t= 0.

k_1 : a regenerative state along the path $\left(0 \xrightarrow{s_r(sff)} i\right)$, at which a $k_1 - \overline{cycle}$ is formed through regenerative un-failed states.

k_2 : a regenerative state along the path $\left(0 \xrightarrow{s_r(sff)} i\right)$, at which a $k_2 - \overline{cycle}$ is formed through regenerative un-failed states.

[In the numerator, the coefficient of μ_i, for $i = 0$, is equal to $pr(0 \to 0) = (0,0) = 1$, and in the denominator the expression also contributes the term $1 - (0,0) = 1 - p_{0,0}$ provided there is a loop at the 0-state].

STEADY STATE AVAILABILITY OF THE SYSTEM: -

It is defined as the proportion of time that the system is operational when the time-interval is very-very large and the corrective, preventive maintenance down times and the waiting times are included.

$$A_0 = \frac{MTBM}{MTBM + MDT}$$

Where, MTBM = mean time between maintenance; MDT (mean down time) = statistical mean of the down times caused due to breakdowns, including supply down time, administrative down time.

The state transition diagram considers all the times under consideration of the stochastic system/process (under steady state conditions). Therefore, $\sum_j V_{0,j} . \mu_j$ is the measure of the numerator and $\sum_i V_{0,i} . \mu_i^1$ is the measure of denominator, where 'j' is a reachable un-failed and 'i' is a regenerative state in the state-transition diagram of the system. μ_i^1 is the total unconditional time spent before transiting to any other regenerative state(s), given that the system entered regenerative state 'i' at t = 0. Thus, steady state availability of a system is given by,

$$A_0 = \left[\sum_j V_{0,j}.\mu_j\right] \div \left[\sum_i V_{0,i}.\mu_i^1\right]$$

In case the system fails partially and is not fully available for its purpose then the availability of the system is discounted according to the proportions to the fuzziness measure of the states that the system can visit. Accordingly, the steady state availability of a system is modified to,

$$A_0 = \left[\sum_j V_{0,j}.f_j.\mu_j\right] \div \left[\sum_i V_{0,i}.\mu_i^1\right]$$

Where f_j is the fuzziness measure of the un-failed state 'j'.
On using (1), the steady state availability of a system is

$$A_0 = \left[\sum_{j,s_r}\left\{\frac{\{pr(0\xrightarrow{s_r}j)\}f_j.\mu_j}{\prod_{k_1\neq 0}\{1-V_{k_1,k_1}\}}\right\}\right] \div \left[\sum_{i,s_r}\left\{\frac{\{pr(0\xrightarrow{s_r}i)\}.\mu_i^1}{\prod_{k_2\neq 0}\{1-V_{k_2,k_2}\}}\right\}\right] \quad \ldots\ldots\ldots(3)$$

Explanation:
j: a reachable state which is an available state (which may be down/reduced state).
i: a regenerative state.
$k_i(\neq 0)$: a regenerative path point (may be an interior or the terminal point of the path) at which a $k_i - cycle$ is formed (may be formed though non-regenerative/failed state). $k_1$is a regenerative state visited along the path $(0 \xrightarrow{s_r} j)$ and k_1 can be equal to j, and k_2 is a regenerative state visited along the path $(0 \xrightarrow{s_r} i)$ and k_2 can be equal to 'i'.

BUSY PERIOD OF THE SERVER: Busy period of the server (under steady state conditions) doing a given job is defined by,

$$B_0 = \frac{MTTR}{MTBM + MDT}$$

Where, MTTR = mean time to repair; MTBM = mean time between maintenance; MDT (mean down time) = statistical mean of the down times caused due to breakdowns, including supply down time, administrative down time. (MDT is replaced by M or MTTR as per the real situation to which the stochastic process is subjected during its operation).
M = mean maintenance down time due to breakdowns and preventive maintenance actions.
On using (1), the busy period of the server (under steady state conditions) doing a given job is given by,

$$B_0 = \left[\sum_j V_{0,j}.\eta_j\right] \div \left[\sum_i V_{0,i}.\mu_i^1\right]$$

$$B_0 = \left[\sum_{j,s_r}\left\{\frac{\{pr(0\xrightarrow{s_r}j)\}.\eta_j}{\prod_{k_1\neq 0}\{1-V_{k_1,k_1}\}}\right\}\right] \div \left[\sum_{i,s_r}\left\{\frac{\{pr(0\xrightarrow{s_r}i)\}.\mu_i^1}{\prod_{k_2\neq 0}\{1-V_{k_2,k_2}\}}\right\}\right] \quad \ldots\ldots\ldots(4)$$

NUMBER OF SERVER'S VISITS/ NUMBER OF REPLACEMENTS:
The expected number of visits of the server/replacements is defined by,

$$V_0 = \left[\sum_j V_{0,j}.\delta_j\right] \div \left[\sum_i V_{0,i}.\mu_i^1\right]$$

Where $\delta_j = 1$ if the visit of the server for the given job or replacement is afresh at the regenerative state i, otherwise $\delta_j = 0$.
On using (1), the expected number of visits of the server/replacements is given by:

$$V_0 = \left[\sum_{j,s_r}\left\{\frac{\{pr(0\xrightarrow{s_r}j)\}}{\prod_{k_1\neq 0}\{1-V_{k_1,k_1}\}}\right\}\right] \div \left[\sum_{i,s_r}\left\{\frac{\{pr(0\xrightarrow{s_r}i)\}.\mu_i^1}{\prod_{k_2\neq 0}\{1-V_{k_2,k_2}\}}\right\}\right] \quad \ldots\ldots\ldots\ldots(5)$$

2. ASSUMPTIONS AND NOTATIONS:-

1. Repaired unit works similar to a new-one.
2. The framework is discussed for consistent state conditions.
3. Failure, repair and treatment time are statistically constant.

pf	: probability factor.
$\underline{k}$	: Non-regenerative state.
$\overline{cycle}$	: Circuit formed through un-failed states.
k-cycle	: a circuit whose termini stand at regenerative state k.
$\left(\xi \xrightarrow{sff} i\right)$	: a fixed simple disappointment freeway from ξ to i-state.
$V_{k,k}$	: pf of state k accessible from incurable state k of k-cycle.
$V_{\overline{k,k}}$	: pf of state k accessible from incurable state k of k-$\overline{cycle}$.
$R_i(t)$	: reliability of framework at time t, given that framework move in the un-failed regenerative state i at t=0.
$V_i(t)$	: expected no. of server visits of server for a given job in (0,t], given that the framework arrived regenerative state i at t=0.
f_j	: Fuzziness measure of j-state.
O	: Unit is Good and in regular mode.
SG	: Server is good.
λ_i	: Constant failure rate of unit's complete failure/ partial failure.
ω	: Constant failure rate of server.
p/q	: Probability that repair of the unit at partial failure is not feasible/feasible.
$G(t)/F(t)$	: Cumulative circulation functions of repair-time of the totally failed unit/treatment time of server.

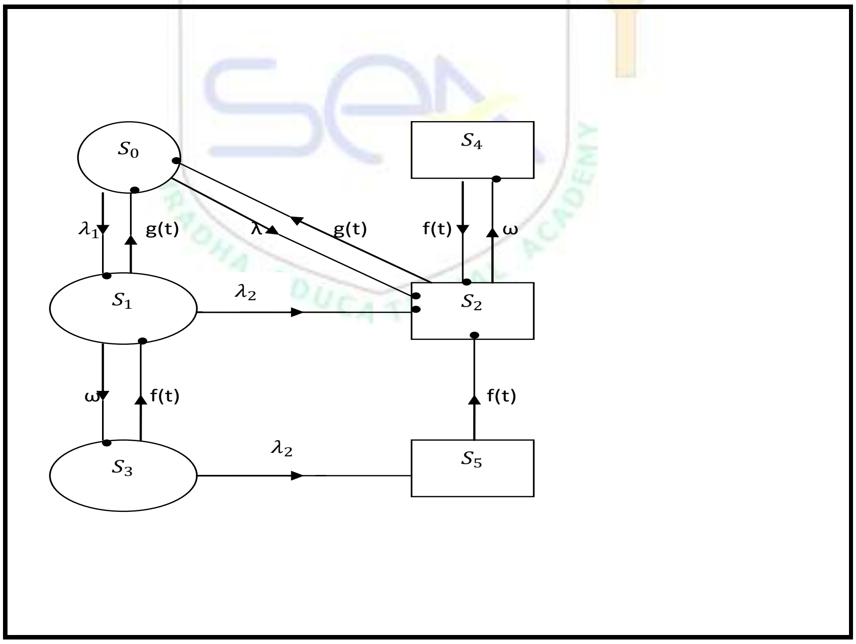

Fig.1 Transition Diagrams

3. METHODOLOGY

Regenerative Point Graphical Technique (Using Base-State 'ξ'):

Mean Time to System Failure: -

It is a positional measure; therefore, it depends upon the initial state of the system from which it is measured. MTSF is measured w. r. t. the un-failed initial state 'ξ' (at t=0).

$$MTSF = \left[\sum_{i,s_r}\left\{\frac{\left\{pr\left(\xi\xrightarrow{s_r(sff)}i\right)\right\}.\mu_i}{\prod_{k_1\neq\xi}\{1-V_{\overline{k_1,k_1}}\}}\right\}\right] \div \left[1-\sum_{s_r}\left\{\frac{\left\{pr\left(\xi\xrightarrow{s_r(sff)}\xi\right)\right\}}{\prod_{k_2\neq\xi}\{1-V_{\overline{k_2,k_2}}\}}\right\}\right] \quad \ldots (6)$$

The busy period of the Server doing any given job:

$$B_o = \left[\sum_{j,s_r}\left\{\frac{\left\{pr\left(\xi\xrightarrow{S_r}j\right)\right\}.\eta_j}{\prod_{k_1\neq\xi}\{1-V_{k_1,k_1}\}}\right\}\right] \div \left[\sum_{i,s_r}\left\{\frac{\left\{pr\left(\xi\xrightarrow{S_r}i\right)\right\}.\mu_i^1}{\prod_{k_2\neq\xi}\{1-V_{k_2,k_2}\}}\right\}\right] \quad \ldots (7)$$

Availability of the system

$$A_0 = \left[\sum_{y,s_r}\left\{\frac{\left\{pr\left(0\xrightarrow{S_r}y\right)\right\}f_y.\mu_y}{\prod_{m1\neq0}\{1-V_{m_1,m_1}\}}\right\}\right] \div \left[\sum_{x,s_r}\left\{\frac{\left\{pr\left(0\xrightarrow{S_r}x\right)\right\}.\mu_x^1}{\prod_{m_2\neq0}\{1-V_{m_2,m_2}\}}\right\}\right] \quad \ldots..(8)$$

The number of the Server's visits/Replacements:

$$V_0 = \left[\sum_{j,s_r}\left\{\frac{\left\{pr\left(\xi\xrightarrow{S_r}j\right)\right\}}{\prod_{k_1\neq\xi}\{1-V_{k_1,k_1}\}}\right\}\right] \div \left[\sum_{i,s_r}\left\{\frac{\left\{pr\left(\xi\xrightarrow{S_r}i\right)\right\}.\mu_i^1}{\prod_{k_2\neq\xi}\{1-V_{k_2,k_2}\}}\right\}\right] \quad \ldots (9)$$

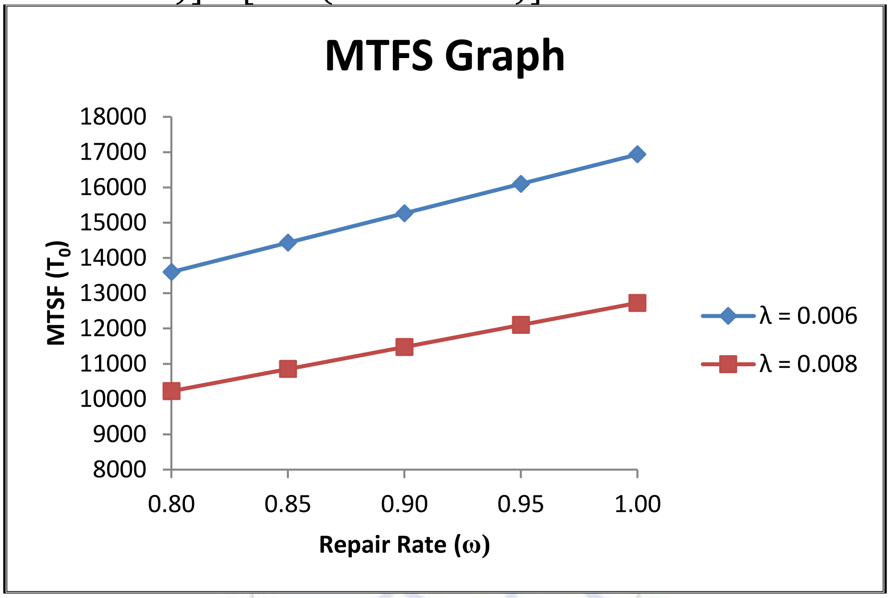

Fig. 2: MTSF Graph

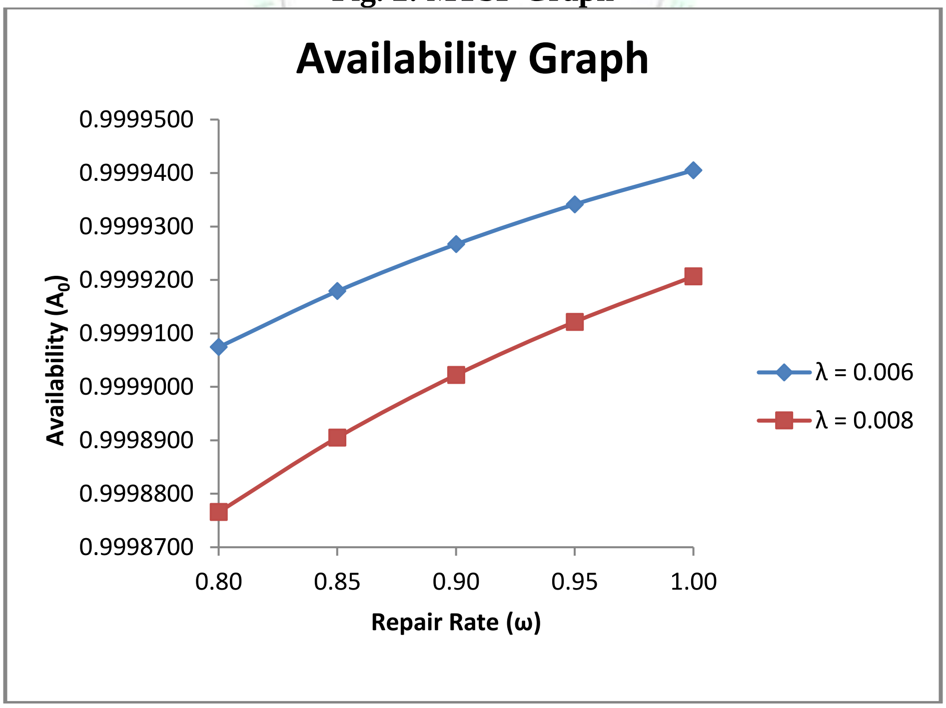

Fig. 3: Availability Graph

4. CONCLUSION:

From the Graphs, we see that as the Repair Rate increases, Availability of the System increases, which should be. The study can be extended for two or more unit system having Perfect and Imperfect Switch-Over devices. The Regenerative-Point Graphical Technique is useful for the evaluation of the parameters in a simple way, without writing any state equations and without doing any lengthy and cumbersome calculations.

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