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# Durability Assessment of Replacement and Maintenance of Equipment in Active Propulsion System

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***Abstract*:-** In this manuscript, we analyse that the replacement and maintenance of the equipment in an active propulsion system, even if they have good materials, eventually stops working due to many reasons, one of which is that it is not able to be maintained on time; many other reasons for performance slowing down. Making the cost-effective option to replace or maintain the facilities is one of the most important ones, and a lot of research is being done to improve the reliability of a component and reduce the cost of any active propulsion system. It helps to make an existing system more reliable and less expensive, and with the active propulsion system analysis, the equipment has been used up to the average annual cost. To balance raising costs and completing the work, this suite also determines the lowest cost value while evaluating a component's reliability regarding replacement time. The active propulsion system's operational efficiency is greatly reduced when there is wear and tear or duplication, which increases the average cost, and maintaining operational efficiency requires low maintenance costs, as replacing the original propulsion system too soon can diminish its value.

***Keywords*:** *Depreciation Cost, Analysis, Average Annual Cost, Maintenance Cost, Replacement Cost, Reliability*

## 1. Introduction

Industry production is profit-making, and businesses must receive minimum investment. Cost and dependability are related, with initial equipment costs increasing due to procedures. Manufacturers bear these costs to avoid losing significant clients. Asiedu, *et al.*, [1] discuss the concurrent engineering, or life cycle engineering, is a strategy used to reduce design changes, cost, and time to market in the competitive global market. It involves life cycle cost analysis and tools to provide engineers with cost information for design. Stewart, *et al.*, [2] present a thorough rundown of the ideas, procedures, and practical uses of risk-based bridge evaluations. In particular, life-cycle cost analysis and risk ranking are two real-world uses for reliability-based bridge evaluation. Michel, *et al.*, [3] introduce of challenger units with higher performance necessitates an optimal strategy combining corrective and preventive replacements to minimize the total cost induced by this change in component generation. Kleyner, *et al.*, [4] discuss the outcomes of application-specific optimal product validation plans and assess a program's effectiveness from a life cycle cost perspective, focusing on product warranties and validation costs. Jodejko-Pietruczuk, *et al.*, [5] describe the Mean residual lifetime and hazard rate are key factors in estimating machine removal time, with durability being a crucial criterion for strategic decisions affecting company results. Sharma, *et al.*, [6] & Kumar, *et al.*, [7] analyze the probable failure modes in a system and their causes, failure mode analysis involves examining as many components, assemblies, and subsystems as feasible. Failure rate models are then integrated with a statistical failure mode ratio data source. Ardente, *et al.*, [8] shows that the extending product lifetimes offers environmental benefits, but these benefits depend on the chosen impact category, lifetime extension, repair impact, and substitute product effectiveness. Shi, *et al.*, [9] contribute to a more thorough comprehension of this remanufacturing in relation to replacement and maintenance schedules.

Dependability cost depends on system cost and failure significance, increasing business volume and profit. Traditional replacement models overlook maintenance impact, requiring engineering economics, imperfect maintenance, and reliability analysis for cost-effective schedules. Tyagi, *et al.*, [10] discuss the research concentrated on how many elements, such as belt pricing, splicing costs, belt durability and joint durability, kind of splicing, time and cost of scheduled and emergency replacements, affect the overall expenses of belting. Zakeri, *et al.*, [11] analyze an updated database for cost aspects of power storage systems, critically reviews existing literature, and provides a comprehensive cost-benefit study for techno-economic analysis. Wang, *et al.*, [12] comprehensively discuss the maintenance plans for aging concrete tunnels using performance and lifetime cost benchmarks to optimize facility use and minimize costs. Sajedi, *et al.*, [13] assess the life cycle costs of several corrosion control techniques using a reliability-based methodology. Sharma, *et al.*, [14, 15] discuss the dependability of a component system all the way to the simple three-phase mission block diagram's unreliability. Bovea, *et al.*, [16] presents a process assesses the environmental impact of two end-of-life scenarios for electrical and electronic equipment: replacement vs. repair & reuse, to determine the optimal end-of-life situation. Plebankiewicz, *et al.*, [17] analyses lead us to infer that, in spite of the greater cost of materials, the most cost-effective solutions prove to be the most beneficial throughout the course of the building's life cycle.

The system's failure to replace items is often blamed on factors like broken down items, short replacement times, and ignored issues. Reservoir facilities' effectiveness is influenced by material deterioration, maintenance, and operation. Wittocx, *et al.*, [18] discuss the aging stock of buildings presents challenges, with a rise in reinforced concrete structures requiring maintenance, replacement, or repair, leading to increased waste and material demand. Singh, *et al.*, [19] define the component needs to remain consistent throughout the process when the failure rate is constant, and the process to continue after each failure, just one component is examined and repairable. Ekpenyong, *et al.*, [20] analyze real-time data from a commercial photocopier operator's spending logbook to develop analytical and intelligent replacement models for optimal industrial equipment maintenance. Dui, *et al.*, [21] define technological advancements complicate leased equipment structures, making maintenance programs challenging. A condition-based maintenance policy considering hybrid preventive and periodic inspections is suggested to avoid excessive or inadequate maintenance. He, *et al.*, [22] discuss the wise maintenance choices for cutters based on their economic life, using economic income index and actuarial theory. Sensitivity and stress tests are conducted on various parameters. Yazdi, [23] explains the various maintenance strategies businesses can employ to ensure asset efficiency and long-term sustainability, including preventive, predictive, reactive, and proactive methods. Soleimani, *et al.*, [24] proposes the proportional hazard model is used to capture the dynamic impacts of climate change on reliability characteristics, and an approach is used to evaluate the implications of climate change on the life cycle cost of railway infrastructure assets. Karagiannopoulos, *et al.*, [25] focuses on the methodology for PCB repair is a sequential quadratic programming problem, and focusing on maintenance and recycling of printed circuit boards and domestic electrical appliances.

In Section 2, define the objective of this article. Section 3: Discuss the basics of cost reliability functions of different categories and discuss the effect of reliability on cost and its depreciation cost with replacement policies. In Section 4, we define the methodology of average annual cost of equipment with data analysis. In Section 5, we discuss the observation of the depreciation cost of equipment in continuous years, and in Section 6, we conclude our discussion and talk about the future scope of the cost reliability of equipment.

## 2. Objective

Our objective of the current study is to analyze for improve the reliability of an active propulsion system and reduce the cost of replacing equipment when the average yearly cost above the minimum.

## 3. Basics of Cost Reliability Functions

Generally, five categories may be used to categorize reliability costs, as Fig. (1), illustrates.

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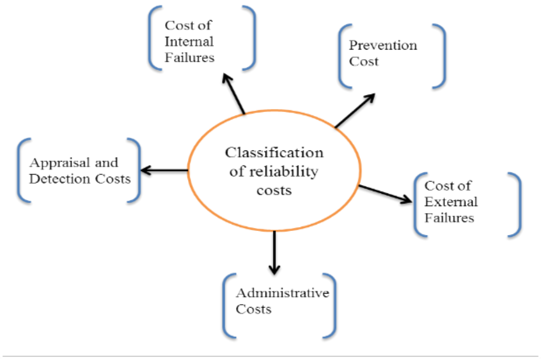


**Figure 1: Classification of Reliability-cost**

Each classification's constituent parts are explained as below:

### 3.1 *Classification I*

All costs associated with internal malfunctions fall under this category, or to put it another way, costs associated with materials, commodities, components, and other items that don't live up to expectations. Moreover, these costs take place prior to the client receiving the merchandise. These expenses are related to shown as in Fig. (2),

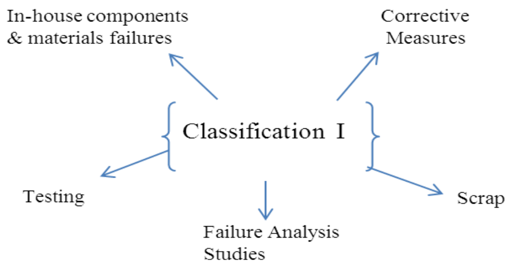


**Figure 2: Classification I (Internal Malfunctions)**

### 3.2 *Classification II*

The costs of prevention are the focus of this categorization. These expenses are related to the steps done to stop the use of faulty materials, parts, and finished goods. Costs of prevention are related to things like these are related to shown as in Fig. (3),

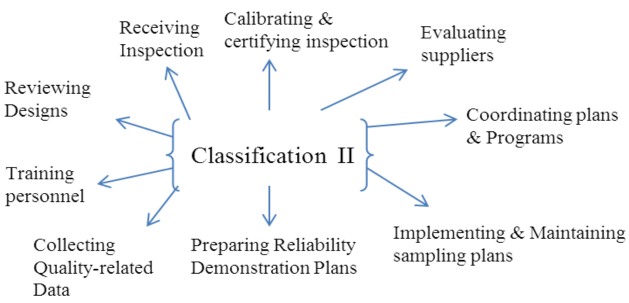


**Figure 3: Classification II (Costs of Prevention)**

### 3.3 *Classification III*

Costs related to external failures, or expenses resulting from faulty items supplied to customers, fall under this category. These costs are associated with item shown as in Fig. (4),

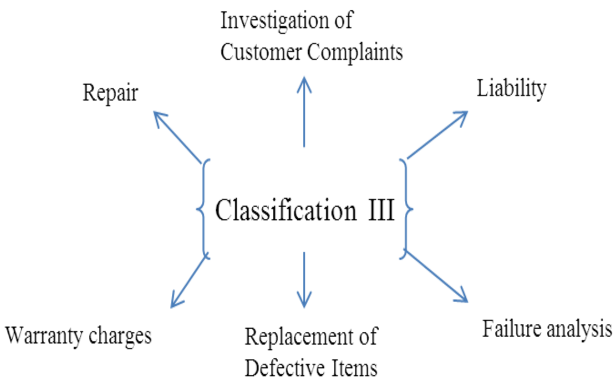


**Figure 4: Classification- III (Costs of External Failures)**

### 3.4 *Classification IV*

All expenses related to administration fall under this category. These costs are associated with item shown as in Fig. (5),

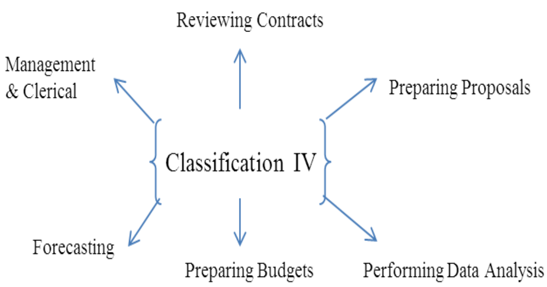


**Figure 5: Classification-IV (Administration Fall)**

### 3.5 *Classification V*

Detection and assessment expenditures are included in this category. The main elements of such costs are associated with item shown as in Fig. (6),

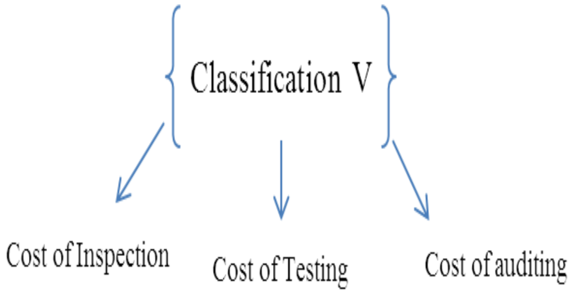


**Figure 6: Classification-V (Detection & Assessment)**

### 3.6 *Effect of Reliability on Depreciation Cost*

The manufacturer's endeavors to enhance the dependability of his merchandise will inevitably result in more expenses for reliability design and internal failure. On the other hand, internal failure costs will begin to decline with time. While external expenses like as transportation remain independent of dependability, higher reliability will result in lower installation, commissioning, and maintenance costs.

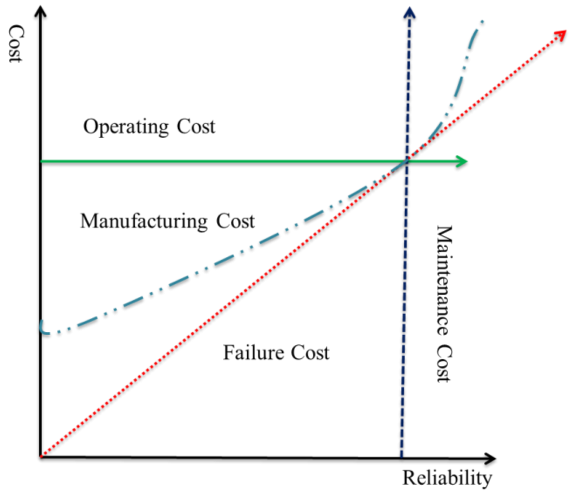


Figure 7: Reliability-Cost Curve

Generally, the aiming for total perfection that is, eradicating every mistake is not advantageous. The reliability cost curves for the different equipment categories shown in Fig. (7), make this evident, at least up to a point, where it makes sense to invest appropriately in reliability. Beyond that point, additional investments are only recommended in situations where reliability is absolutely necessary and where reliability achievement, utility, depreciation, and availability have a significant impact on equipment life-cost. The product's value over time and describe as below:

$$d_c = \frac{c_i - o_c}{n}$$

A product's depreciation cost, or the difference between its original cost $o_c$ and its value after $n$ years of usage, is borne by the consumer. This expense, also known as the use cost for the $n^{th}$ year of operation, is calculated by dividing the total depreciation cost by the user's initial cost $c_i$ .

### 3.7 *Replacement Policies*

Replacement theory explains when corrective action can restore a system to its former efficiency. Effectiveness is measured by age, economic worth, or efficiency and cost functions are decreasing and growing. Rising costs result from wear and age, while declining costs stem from depreciation and the lower average costs can be achieved by distributing capital expenses over longer periods. The current system's minimal overall cost is justified by weighing costs of decaying objects, replacing failed objects, and determining which ones to replace, while considering system downtime and lost life of previously replaced items, and the policies will be conducted under the following presumptions:

***i.*** Things are fully functional until they break down, at which point they become completely ineffective.
***ii.*** Queuing issues caused by multiple objects breaking down are often overlooked due to the belief that there are sufficient maintenance or repair crew members to handle these tasks.
***iii.*** Items that fail are replaced with identical ones, ensuring the new item has the same lifespan distribution as the old one.
***iv.*** There is a restricted replacement time.

## 4. Material and Methods

In this section, we provide a brief methodology of the essential procedures and challenges for the current system analysis; the equipment has been used up to its average yearly cost, making the existing systems more dependable and less costly. This suite also assesses a component`s dependability in terms of replacement time and finds the lowest cost value, all in an attempt to strike a balance between increasing prices and finishing the task. The replacement theory examines situations in which corrective measures can restore a system that has become less effective over time to its previous state. Consider for equipment value, clipping value, and current cost at a time,

$C_p$ = Cost Equipment value (at purchase time $t$ )

$C_v$ = Clipping value of the equipment

$C_c$ = Current cost at a time of $t$

Estimated cost of the equipment, then

= Cost Equipment value + Current cost at a time t – Clipping value of the equipment.

= $C_p + C_c - C_v$

Estimated cost of the equipment (used for $T$ years), then

$$K(T) = \int_0^T C_c(t)dt \quad \text{... (1)}$$

Thus, the total amount spent on the equipment over $T$ years,

= Cost Equipment value + Present estimated cost in $T$ years - Clipping value of the equipment

= $C_p + K(T) - C_v$

The equipment's yearly average cost is given by

$$Avg.\mathrm{Cos}t, A(T) = \frac{C_p + K(T) - C_v}{T} \quad \text{... (2)}$$

Determine the value of $T$ at which $Avg.\mathrm{Cos}t(T)$ is its minimum, so differentiate the Eqn. (2), concerning $T$ and drop it to zero, we have

$$\frac{d}{dt}(A) = \left[\frac{-(C_p - C_v)}{T^2} + \frac{C_c(T)}{T}\right] - \left[\frac{1}{T^2}\int_0^T C_c(t)dt\right] \quad \text{... (3)}$$

Then, $C_c(T) = \dfrac{C_p + K(T) - C_v}{T} = A(T)$

Thus, the replacement and maintenance of the equipment when the annual average cost reaches its lowest point is necessary, and in light of this claim, the decision to forgo system replacement is made with an eye on cost minimization by accounting for both rising and dropping costs. The importance of balance is with the cost of maintaining the old items in running condition against the cost of new goods.

### 4.1 *Data Assessment*

Product value comparisons require a cost-utility analysis. The expenses associated with the customer's investment fall under a number of areas, including purchase price, installation charges, operation costs, failure costs, repair costs, loss of effectiveness costs, damage costs, failure-related income loss, and preventative maintenance costs. Year after year, the consumer must pay for the goods when it is used, but the customer has the option to purchase the product at the lowest cost. We must take into account a piece of equipment as well as its records: the equipment's annual cost, acquisition cost of INR 25,000, and annual resale value are shown in the Table. 1.

Table 1: Analysis of Cost Data Equipment (Yearly)

| Operating Year | Equipment Re-sale price (End of Year) | Equipment Annual Cost | Equipment Annual Maintenance Cost |
|---|---|---|---|
| 1 | 20,000 | 3000 | 300 |
| 2 | 18,000 | 3500 | 500 |
| 3 | 16,000 | 4000 | 700 |
| 4 | 14,000 | 4500 | 1000 |
| 5 | 12,000 | 5000 | 1500 |
| 6 | 10,000 | 6000 | 2000 |
| 7 | 8,000 | 7000 | 2500 |

Draw a Graph to compute the analysis of cost data equipment,

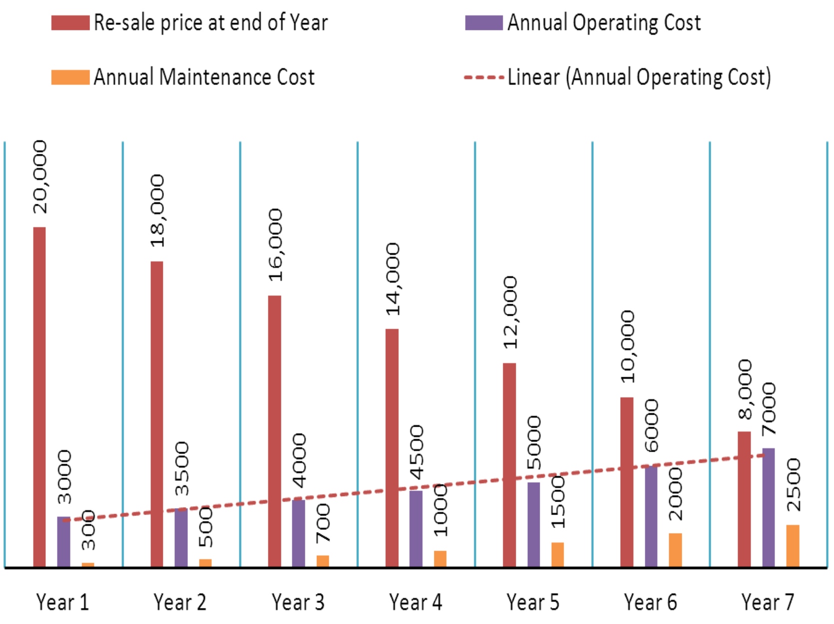


**Figure 8: Cost Data Analysis for Equipment (Yearly)**

A specific sum of money can be used by a system designer to create a system, and there are multiple possibilities for every component. By choosing every element from each of these categories, the system may be able to fulfill the desired dependability level, which is the goal of the system designer within the constraints of the resources at hand, now we analysis of the average annual cost year-by-year of equipment as shown in Table 2,

Table 2: Analysis of the Average Annual Cost

| Operating Year | Re-sale price at (End of Year) INR | Investment cost (INR) | Annual Operating Cost (INR) | Cumulative in Annual Operating Cost Time (INR) | Total Annual cost (INR) | Average Cost (INR) |
|---|---|---|---|---|---|---|
| **I** | **II** | **III** | **IV** | **V** | **VI** | **VII** |
| 1 | 20,000 | 5000 | 3000 | 3000 | 8000 | 8000 |
| 2 | 18,000 | 7000 | 3,500 | 6,500 | 13,500 | 6,750 |
| 3 | 16,000 | **8,500** | 4000 | **10,500** | **19,000** | **6,333** |
| 4 | 14,000 | 11,000 | 4,500 | 15,000 | 26,000 | 6,500 |
| 5 | 12,000 | 13,000 | 5000 | 20,000 | 33,000 | 6,600 |
| 6 | 10,000 | 15,000 | 6000 | 26,000 | 41,000 | 6,833 |
| 7 | 8,000 | 17,000 | 7000 | 33,000 | 50,000 | 7,142 |

Construct the graph to analyze the average annual cost during the year-by-year data collection:

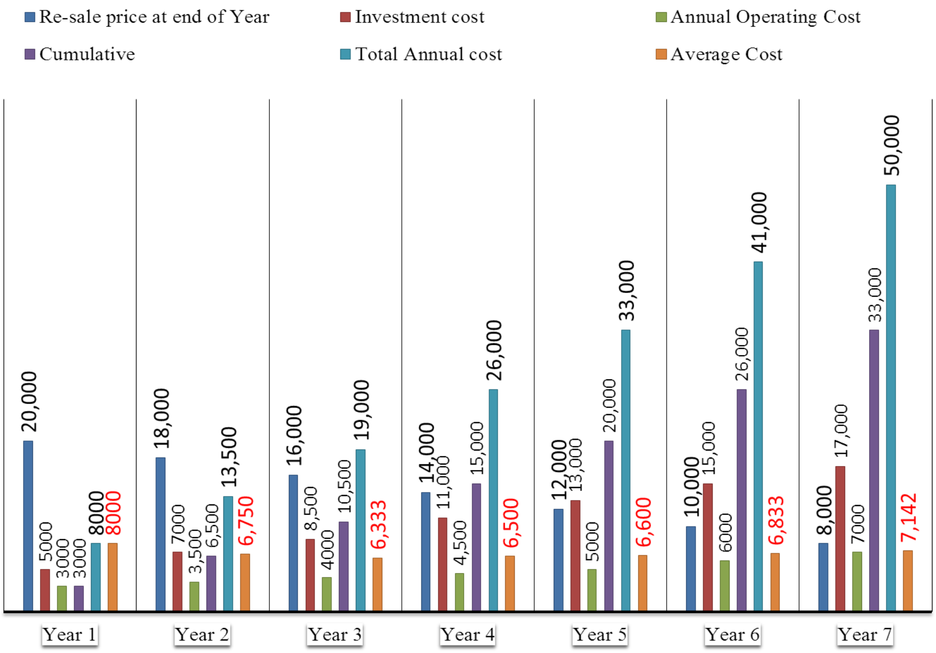


**Figure 9: Assessment of Average Annual Cost of Equipment (Year-by-Year)**

## 5. Observations

Customers invest money in a product, which has ongoing costs and benefits. Manufacturers may have varying prices and return policies. A cost-utility analysis is necessary to determine which options lead to higher system costs and higher reliability for a reliable and reasonably priced system. From Fig. 1 to Fig. 6, we observe the system's improved reliability is supported by all of the classifications for the replacement policies clarify how corrective action can bring a system back to its previous level of efficiency, and the essential classifications calculate the costs of internal and external failure, prevention, administrative, and, from Fig. 7, also observe the depreciation costs at least up to a point where it makes sense to invest appropriately in reliability. Table 1 lists all of the options along with their associated costs and dependability for each component. It should be noted that the scrap value decreases with time, and we also perform analysis to reduce the average cost with time. The equipment's cost data analysis is displayed in Fig.8. The annual maintenance cost of the equipment appears to be rising annually. According to Table 2, assessment of the issue and method, the operational expenses peak in the third year and have the lowest yearly cost, as depicted in Fig. 9. Since the average cost of repairs tends to increase after the third year, we have concentrated on fixing broken items and knowing when to replace them. It's time to replace the equipment when the annual average cost reaches its lowest point.

## 6. Conclusion and Future Direction

Despite the fact that several configurations can attain the same level of reliability, there will always be one that is the least expensive. It has been noted that in two or more configurations, the system may have varying reliability levels at the same cost. System reliability need not be a monotonically increasing function of cost; rather, there will survive a configuration with the highest reliability level among all feasible component groups. The reliability level can be higher for a combination of components that results in lower system cost. Everything about the procedure shows that the value of the operating expenses peaks in the third year with the lowest yearly cost. We have focused the replacing broken things, understanding which ones to replace when, as we have to admit that the average cost starts to rise after the third year. When the annual average cost hits its lowest point, it's time to replace the equipment.

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### Author Contribution

Chetan Kumar Sharma organized the methodology and managed the work; Ambika and Ruchi wrote the original draft of the simulation, literature review and observations.

### Conflicts Of Interest

On the behalf of all authors, the corresponding author states that there is no conflict of interest.

### Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

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**Appendix I:** ***Description of Standard Definitions***

**Reliability:**

In the simplest of terms, reliability is the probability that a failure won't happen within a specified time frame. "*The* ***probability*** *that a unit (or product) performs its* ***intended function*** *adequately for a given period of* ***time*** *under the stated* ***operating condition*** *or environment*" is a more meticulous definition of reliability. We describe to an element, system, component of a system, or whatever is similar as a unit. Four components are highlighted in the reliability definition, namely:

- Probability
- Intended function
- Time, and
- Operating condition

A failure occurs when a device (or system) loses or changes some or all of its properties to the point where it can no longer function properly or at all. While some components fail with clear indications, others do not. For instance, there are clearly defined failures with switches and electric lamps under all circumstances. In contrast, a variety of operating conditions apply to devices like as resistors and voltage stabilizers. It is expected that there will be a significant number of initial failures when we put a large collection of units into operation. Initial failures or infant mortality resulting from manufacturing faults are the terms used to describe these early failures.

Reliability function for devices/item with continuous lifetime distribution is as follows:

$R(t) = 1 - F(t) = \Pr(T > t)\,;\, t > 0$

*or,*

$$R(t) = 1 - \int_0^t f(x)dx \equiv \int_t^\infty f(x)dx$$

Hence, $R(t)$ define, probability that the item/device operate properly in the time interval $(0, t]$, and $f(x)$ is the probability density function of time to failure, also $F(t)$ is the cumulative density function of lifetime $T$.

**Redundancy Techniques**

Application of redundancy in the system design is found in almost all of systems due to its numerous advantages over the other methods of improving system reliability.

***i.*** Any desired level of reliability can be achieved (if the available sources permit).
***ii.*** Increasing in reliability per unit resource spent is highest when optimal redundancy techniques are employed.
***iii.*** Design through redundancy needs comparatively less skill on the part of the designer.

It provides a quick solution, and this method can be employed in the event of failure of all other methods. The development of miniaturization techniques has made possible the application of redundancy rather conveniently in space vehicles. We find that equipment hierarchy is a special class of redundancy that is often found in systems containing many stages in series, such as communication, data processing, electrical power distribution, and many industrial systems.

**Reliability and Cost**

The cost of various methods of achieving, reliability will vary according to the following:

***i.*** Types of components,
***ii.*** Cost of maintenance,
***iii.*** Accessibility of the products for the maintenance
***iv.*** Time and manpower available for the design,
***v.*** Constraints such as weight, volume, etc.

**Mean Time Between Failures:**

The average amount of time that a system or product lasts between two consecutive failures is called its maximum test-break frequency, or MTBF. A measure of reliability called MTBF is frequently discussed in relation to product development, warranties, and maintenance schedules. Mean Time between Failure (MTBF) is a reliability metric that analyzes the average time between failures, which help inform an asset's reliability. It quantifies the likelihood of an equipment or component failure within a time frame.

The Mean Time between Failures (MTBF) is computed by dividing the total operational hours in a particular period by the total number of failures that happened during that same time. The hours of runtime before technology or equipment malfunctions are revealed by its solution.

$$i.e., \text{ MTBF} = \frac{\text{Number of Operation Hours}}{\text{Number of Failures}}$$

**Design for Reliability**

A system designer has to force certain problems due to automation and the complexity of problems, thus decreasing the overall reliability of the systems. Moreover, an increase in reliability cannot be obtained without investing money, and achieving this objective requires both definite material expenditures and systematic and scientific analyses

The essential tasks of a reliability analyst would be:

***i.*** Evaluation of system reliability and safety characteristics.
***ii.*** Comparison of specific characteristics of alternative designs objectively, and
***iii.*** Location of weak spots (or subsystems) in the design and estimation of their contribution to system unreliability.

The following tools come to rescue the problem of reliability:

***i.*** A concept and procedure for estimating system reliability and comparing alternative designs.
***ii.*** A set of generally applicable mathematical models, and
***iii.*** Efficient computer programs to evaluate reliability models numerically.