Enhancing System Predictability and Profitability: The Importance of Reliability Modelling in Complex Systems and Aviation Industry

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Abstract: - Predicting the future has always been a human endeavor, ranging from antiquated methods such as monitoring aquariums for indications of earthquakes to contemporary techniques that evaluate system probabilities and capacities. Taking into account the current emphasis on improving product reliability by customer demands and global competitiveness, we introduce the idea of reliability in the context of the Airbus A320 airplane in this paper. When it comes to business and commercial aircraft, timetable compliance and punctuality are critical components of an aircraft's profitability. For many operators of commercial aircraft, reaching the 98% reliability criterion is a typical objective. This study examines the Airbus A320 in great detail, concentrating on a particular system scenario that has two possible failure modes, one where gears do not retract after takeoff and the other being when landing, the gears fail to extend. The organization bears specific costs as a result of these shortcomings. The purpose of the study is to examine these expenses and offer insights into the financial ramifications by performing a profit analysis. We examine the failure and repair patterns by utilizing the Markov Process and Regenerative Point method. This study adds to our understanding of the reliability issues facing the aviation sector and has applications for improving the Airbus A320 aircraft's operational effectiveness and financial performance.

Key-Words: - aircraft reliability, Markov process in aviation, regenerative point technique, availability analysis, failure rate, aircraft maintenance, profit analysis, and repair patterns.

Received: August 7, 2023. Revised: March 21, 2024. Accepted: April 14, 2024. Published: May 15, 2024.

1 Introduction

The demands of society are increasing day by day, so to fulfill them, a good amount of technology is put on the forefront by businesses, and many advanced, complicated, and highly developed systems are being introduced. To be at par with international standards, industries are being more responsive to the necessity to provide reliable equipment. Failures are minimized, operational use of systems is improved, and available operational time is increased with the help of reliability and maintainability. Reliability modeling was started during World War II. Reliability program increases the initial cost of every device, instrument, or system, and it is also true that reliability decreases as the system is made more complicated. To create, plan, and execute the duty of the framework with its arbitrary predominance of disappointments, reliability is essential. The possibility that a component, piece of equipment, or system will be able to carry out its intended function as assigned over a predetermined period under predetermined conditions is known as its unwavering quality. Researchers in [1], [2], found that reliability modeling is a helpful method for predicting a system's reliability by abstracting its dynamic behavior. Understanding the system's numerical representation is crucial to understanding its dependability. The numerical representation of the system reliability function describes the system reliability in terms of the reliabilities of its constituent elements. Later, [3], [4], [5], discussed predicting model reliability, which has always been a human endeavor, progressing from ancient methods based on observational techniques to contemporary approaches that can evaluate the probability and capacities of complex systems. Improving product reliability [6], discussed machine learning techniques that are becoming increasingly important in the current environment to meet consumer needs and remain globally competitive. Moreover, [7], [8], studied and explored the complex field of reliability in the particular context of the Airbus A320 airplane. In business and commercial aviation, [9], [10], an aircraft's capacity to make a profit is closely correlated with how well it arrives on time and follows its schedule. When mechanical problems, [11], [12], [13], discussed causes that affect the reliability of a system and compromise its availability. Therefore, demonstrating excellent reliability indices by [14] is essential to any aircraft to guarantee its availability when needed. Many commercial aircraft operators share the objective of attaining a 98% dependability standard. The Airbus A320, a mainstay of the aviation industry, researchers, [15], [16], used Markov regenerative techniques to further dive into this area, and with insight into these findings, the paper performs a thorough investigation. In examining two crucial failure modes by [17], [18], gears failing to down lock themselves during landing and gears failing to up lock themselves after takeoff—the study focuses on a particular system situation. These mistakes have more repercussions for the company than only disrupting operations; they also incur additional expenses. Researchers, [19], [20], studied the field of dependability, failure analysis, mean time to system failure, and availability has seen tremendous advancements and breakthroughs in recent years, which have had a significant impact on aviation systems. Cost-benefit study of standby systems with waiting times aimed at repair was studied by [21], by taking a cold standby unit under consideration. reliability analysis and life cycle cost optimization on Indian industrial models was done by [22], and also studied the cost optimization of the models. Researchers, [23], [24], calculated and analyzed reliability, availability, and maintainability of models already in working, and studies also show that what kind of maintenance techniques are good for similar system models. The advances in intelligent reliability and maintenance techniques of energy infrastructure assets were discussed by [25]. Understanding that this field is dynamic, our research incorporates these new developments into examining the Airbus A320, paying particular attention to the failure modes found craft platform.

Research on reliability modeling in the aviation sector frequently ignores particular parts or subsystems in favor of concentrating on the overall reliability of the system. Furthermore, a large portion of the research is still theoretical in nature and lacks empirical support and real-world case studies, which calls into question its validity and usefulness. Finally, a noteworthy deficiency exists in the comparative examination of several reliability modeling techniques, which hinders the determination of the optimal ways for augmenting reliability in intricate aviation systems. This paper depicts the empirical implications and generates cutoff points so the system remains profitable despite the failure taken into consideration.

2 Problem Formulation

2.1 Notations

Table 1. Notations used in the model.

Notation	Meaning
F_N , F'_N	Failure of nose landing gear in takeoff and landing resp.
O_M, O'_M	Main landing gear operative in takeoff and landing resp.
F_M, F'_M	Failure of main landing gear in takeoff and landing resp.
O_N,O'_N	Operative nose landing gear in takeoff and landing resp.
F_{Nr}	Nose landing gear under repair
F_{Mr}	Main landing gear is under repair
F_{Mw}	The main landing gear is waiting for repair
O	Operative unit
λ_1	The failure rate of nose landing gear during takeoff
λ_2	The failure rate of the main landing gear during takeoff
λ'_1	The failure rate of nose landing gear during landing
λ'_2	The failure rate of main landing gear during landing
β_1	Rate of allowed time to get repair started for nose gear after landing
β_2	Rate of allowed time to get repair started for nose and main gear after landing
β_3	Rate of allowed time to get repair started for main gear after landing
p	The probability that landing gear is extended successfully
q	The probability that the landing gear did not extend after applying force
γ_1	Rate of allowed time to extend nose landing gear down using gravity
γ_2	Rate of allowed time to extend nose main landing gear down using gravity
γ_3	Rate of allowed time to extend main gear down using gravity
$g_1(t)$	Repair rate for the nose gear
$g_2(t)$	Repair rate for main gear
$g_3(t)$	Repair rate after total failure
T_F	Total failure of the system
Ⓢ	Stieltjes Convolution
*	Laplace transform

2.2 State Transition Diagram

Assumptions for the system

a. The initial state is considered to be the state of working.
b. All the random variables follow arbitrary distributions.
c. After every repair, the system becomes like a new one.
d. The repairman remains with the system and is immediately available whenever required.
e. The repairman is perfect; therefore, after each repair/replacement, the system regenerates and starts working as effectively as in new condition.
f. If one or both main landing gear fail, then we will take the total failure of the main landing gear.

Figure 1 explains a system's state transition diagram that shows the many operational stages and transitions. When the system boots up, it is completely functional and in state 0. States 1 through 6 are known as down states, denoting situations in which the system is not running as needed and must be repaired. Reduced states are indicated by states 7, 8, and 9, where the system is undergoing repair and will reactivate fully after the work is successfully finished. State 10 denotes a total failure state, implying there is no way to get the system back to its working state. The variables βn, λ_n, and λ'_n are presented to measure certain system elements. The time needed to finish the repair procedure is represented by βn. The failure rates during takeoff and landing are linked to the factors λ_n and ' λ'_n, respectively. The rate at which the system is being repaired is indicated by the repair rate, which is represented as $g_n(t)$, a function of time. The paragraph offers a high-level summary of the behavior and features of the system overall, highlighting its operational and non-operational states, repair procedures, and failure rates during different operating stages. The notations used in the model are in Table 1.

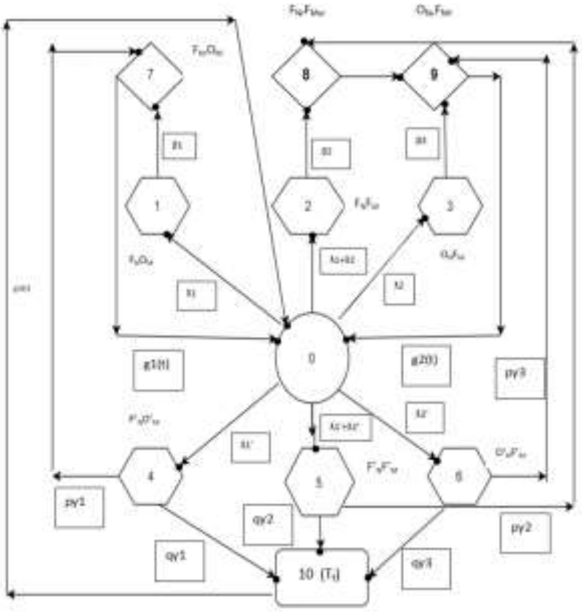


Fig. 1: State transition diagram of the system under consideration

2.3 Transition Times

The transition from a regenerative state 'i' to 'j' or to a failed state 'j' is independent of history before reaching state 'i'. Therefore, from the probabilistic considerations, the distribution function of the transition times can be expressed as:

$q_{01} = \lambda_1 e^{-2(\lambda_1+\lambda_2+\lambda'_1+\lambda'_2)t}$

$q_{02} = (\lambda_1 + \lambda_2)e^{-2(\lambda_1+\lambda_2+\lambda'_1+\lambda'_2)t}$

$q_{03} = \lambda_2 e^{-2(\lambda_1+\lambda_2+\lambda'_1+\lambda'_2)t}$

$q_{04} = \lambda'_1 e^{-2(\lambda_1+\lambda_2+\lambda'_1+\lambda'_2)t}$

$q_{05} = (\lambda'_1 + \lambda'_2)e^{-2(\lambda_1+\lambda_2+\lambda'_1+\lambda'_2)t}$

$q_{06} = \lambda'_2 e^{-2(\lambda_1+\lambda_2+\lambda'_1+\lambda'_2)t}$

$q_{17} = \beta_1 e^{-\beta_1 t}$

$q_{28} = \beta_2 e^{-\beta_2 t}$

$q_{39} = \beta_3 e^{-\beta_3 t}$

$q_{47} = p\gamma_1 e^{-(p\gamma_1+q\gamma_1)t} = p\gamma_1 e^{-\gamma_1 t}$

$q_{4,10} = q\gamma_1 e^{-\gamma_1 t}$

$q_{58} = p\gamma_2 e^{-\gamma_2 t}$

$q_{5,10} = q\gamma_2 e^{-\gamma_2 t}$

$q_{69} = p\gamma_3 e^{-\gamma_3 t}$

$q_{6,10} = q\gamma_3 e^{-\gamma_3 t}$

$q_{70} = g_1(t)$

$q_{89} = g_1(t)$

$q_{90} = g_2(t)$

$q_{10,0} = g_3(t)$

Then, the average amount of time taken by the framework to remain in a specific regenerative state 's' before traveling to some other regenerative state 'j' is :

$\mu_0 = \frac{1}{2(\lambda1+\lambda2+\lambda1`+\lambda2`)}$

$\mu_1 = \int_0^\infty e^{-\beta 1t}\,dt = \frac{1}{\beta 1}$

$\mu_2 = \int_0^{\infty} e^{-\beta 2t}\,dt = \frac{1}{\beta 2}$
$\mu_3 = \int_0^{\infty} e^{-\beta 3t}\,dt = \frac{1}{\beta 3}$
$\mu_4 = \int_0^{\infty} P[T_4 > t]\,dt = \frac{1}{\gamma 1}$
$\mu_5 = \int_0^{\infty} P[T_5 > t]\,dt = \frac{1}{\gamma 2}$
$\mu_6 = \int_0^{\infty} P[T_6 > t]\,dt = \; = \frac{1}{\gamma 3}$
$\mu_7 = \int_0^{\infty} P[T_6 > t]\,dt = -g_1{}^{*\prime}(0)$
$\mu_8 = -g_1{}^{*\prime}(0)$
$\mu_9 = -g_2{}^{*\prime}(0)$
$\mu_{10} = -g_3{}^{*\prime}(0)$

3 Measures of System Effectiveness

3.1 Mean Time to System Failure

Let $\varphi_i(t)$ be the cumulative distribution function of the first passage time from the initial state to a failed state.

We have the following recursive relations f or $\varphi_i(t)$:
$\varphi_0(t) = Q_{01}(t) \circledS \varphi_1(t) + Q_{02}(t) \circledS \varphi_2(t) + Q_{03}(t) \circledS \varphi_3(t) + Q_{04}(t) \circledS \varphi_4(t) + Q_{05}(t) \circledS \varphi_5(t) + Q_{06}(t) \circledS \varphi_6(t)$
$\varphi_1(t) = Q_{17}(t) \circledS \varphi_7(t)$
$\varphi_2(t) = Q_{28}(t) \circledS \varphi_8(t)$
$\varphi_3(t) = Q_{39}(t) \circledS \varphi_9(t)$
$\varphi_4(t) = Q_{47}(t) \circledS \varphi_7(t) + Q_{4\,10}(t)$
$\varphi_5(t) = Q_{58}(t) \circledS \varphi_8(t) + Q_{5\,10}(t)$
$\varphi_6(t) = Q_{69}(t) \circledS \varphi_9(t) + Q_{6\,10}(t)$
$\varphi_7(t) = Q_{70}(t) \circledS \varphi_0(t)$
$\varphi_8(t) = Q_{89}(t) \circledS \varphi_9(t)$
$\varphi_9(t) = Q_{90}(t) \circledS \varphi_0(t)$

$$\text{Also, } D(0) = p_{06}p_{6,10} + p_{05}p_{5,10} + p_{04}p_{4,10} \quad (1)$$

$$N(0) = p_{06}p_{6,10} + p_{05}p_{5,10} + p_{04}p_{4,10} \quad (2)$$

$$N1 = m_{01}+m_{02}+m_{03}+m_{05}+m_{06}+p_{06}\mu_6+p_{05}\mu_5+p_{03}\mu_9+p_{03}\mu_3+p_{06}p_{69}\mu_9+p_{01}\mu_7+p_{01}\mu_1+p_{02}\mu_8+p_{02}\mu_9+p_{02}\mu_2+p_{05}p_{58}\mu_9+p_{05}p_{58}\mu_8+p_{4,10}m_{04} + p_{04}m_{04} \quad (3)$$

Using l'Hopital rule, $\text{MTSF} = \frac{D'0 - N'0}{D(0)}$

$$= \frac{\mu 0 + p06\mu 6 + p05\mu 5 + p03\mu 9 + p03\mu 3 + p06p69\mu 9 + p01\mu 7 + p01\mu 1 + p02\mu 8 + p02\mu 9 + p02\mu 2 + p05p58\mu 9 + p05p58\mu 8}{p_{06}p_{6,10} + p_{05}p_{5,10} + p_{04}p_{4,10}} \quad (4)$$

3.2 Availability Analysis

Let $AF_i(t)$ denote the probability that the system is in upstate at instant 't', provided that the system entered regenerative state 'i' at t = 0. After applying the Laplace transform to the equations obtained, we obtain the following recursive relations.

$AF^*_0(s) = M^*_0(s) + q^*_{01}(s) \,.\, AF^*_1(s) + q^*_{02}(s) \,.\, AF^*_2(s) + q^*_{03}(s) \,.\, AF^*_3(s) + q^*_{04}(s) \,.\, AF^*_4(s) + q^*_{05}(s) \,.\, AF^*_5(s) + q^*_{06}(s) \,.\, AF^*_6(s)$
$AF^*_1(s) = M^*_1(s) + q^*_{17}(s) \,.\, AF^*_7(s)$
$AF^*_2(s) = M^*_2(s) + q^*_{28}(s) \,.\, AF^*_8(s)$
$AF^*_3(s) = M^*_3(s) + q^*_{39}(s) \,.\, AF^*_9(s)$
$AF^*_4(s) = M^*_4(s) + q^*_{47}(s) \,.\, AF^*_7(s) + q^*_{4,10}(s) \,.\, AF^*_{10}(s)$
$AF^*_5(s) = M^*_5(s) + q^*_{58}(s) \,.\, AF^*_8(s) + q^*_{5,10}(s) \,.\, AF^*_{10}(s)$
$AF^*_6(s) = M^*_6(s) + q^*_{69}(s) \,.\, AF^*_9(s) + q^*_{6,10}(s) \,.\, AF^*_{10}(s)$
$AF^*_7(s) = q^*_{70}(s) \,.\, AF^*_0(s)$
$AF^*_8(s) = q^*_{89}(s) \,.\, AF^*_9(s)$
$AF^*_9(s) = q^*_{90}(s) \,.\, AF^*_0(s)$
$AF^*_{10}(s) = q^*_{10,0}(s) \,.\, AF^*_0(s)$

$$D_1{}'(0) = \mu_0 + \mu_9(p_{06}p_{69}+p_{05}p_{58}+p_{03}+p_{02}) + \mu_8(p_{05}p_{58}+p_{02}) + \mu_7(p_{01}+p_{04}p_{47}) + \mu_{10}(p_{06}p_{6,10}+p_{05}p_{5,10}+p_{04}p_{4,10}) + \mu_1p_{01}+\mu_2p_{02}+p_{06}\mu_6+p_{05}\mu_5+p_{04}\mu_4 \quad (5)$$

$$N_1(0) = \mu_6p_{06} + \mu_5p_{05} + \mu_4p_{04} + \mu_3p_{03} + \mu_2p_{02} + \mu_1p_{01} + \mu_0 \quad (6)$$

$$AF_0 = \frac{N1(0)}{D1'(0)}$$
$$= \frac{\mu_6p_{06}+\mu_5p_{05}+\mu_4p_{04}+\mu_3p_{03}+\mu_2p_{02}+\mu_1p_{01}+\mu_0}{\mu_0+p06\,\mu_6+p05\mu_5+p04\mu_4+\mu_9(p06p69+p05p58+p03+p02)+\mu_8(p05p58+p02)+\mu_7(p01+p04p47)+\mu_{10}(p06p6{,}10+p05p5{,}10+p04p4{,}10)+\mu_1p01+\mu_2p02} \quad (7)$$

3.3 Downtime of System

Let us assume that the system entered regenerative state I at t=0. Then, the probability that the system is in down mode at instant t is given by
$DT_0 = \lim_{s \to 0} sDT_0^*(s)$

The recursive relations for downtime after applying Laplace transform are as follows:
$Dt^*_0(s) = q^*_{01}(s) \,.\, Dt^*_1(s) + q^*_{02}(s) \,.\, Dt^*_2(s) + q^*_{03}(s) \,.\, Dt^*_3(s) + q^*_{04}(s) \,.\, Dt^*_4(s) + q^*_{05}(s) \,.\, Dt^*_5(s) + q^*_{06}(s) \,.\, Dt^*_6(s)$
$Dt^*_1(s) = q^*_{17}(s) \,.\, Dt^*_7(s)$
$Dt^*_2(s) = q^*_{28}(s) \,.\, Dt^*_8(s)$
$Dt^*_3(s) = q^*_{39}(s) \,.\, Dt^*_9(s)$
$Dt^*_4(s) = q^*_{47}(s) \,.\, Dt^*_7(s) + q^*_{4,10}(s) \,.\, Dt^*_{10}(s)$
$Dt^*_5(s) = q^*_{58}(s) \,.\, Dt^*_8(s) + q^*_{5,10}(s) \,.\, Dt^*_{10}(s)$
$Dt^*_6(s) = q^*_{69}(s) \,.\, Dt^*_9(s) + q^*_{6,10}(s) \,.\, Dt^*_{10}(s)$
$Dt^*_7(s) = D^*_7 + q^*_{70}(s) \,.\, Dt^*_0(s)$
$Dt^*_8(s) = D^*_8 + q^*_{89}(s) \,.\, Dt^*_9(s)$
$Dt^*_9(s) = D^*_9 + q^*_{90}(s) \,.\, Dt^*_0(s)$
$Dt^*_{10}(s) = q^*_{10,0}(s) \,.\, Dt^*_0(s)$

$D_2'(0)=\mu_0+p_{06}\mu_6+p_{05}\mu_5+p_{04}\mu_4+\mu_9(p_{06}p_{69}+p_{05}p_{58}+p_{03}+p_{02})+\mu_8(p_{05}p_{58}+p_{02})+\mu_7(p_{01}+p_{04}p_{47})+\mu_{10}(p_{06}p_{6,10}+p_{05}p_{5,10}+p_{04}p_{4,10})+\mu_1 p_{01}+\mu_2 p_{02}$ (8)

$N_2(0)=\mu_9(p_{69}p_{06}+p_{58}p_{05}+p_{03})+\mu_8 p_{58}p_{05}+\mu_7(p_{04}p_{47}+p_{01})$ (9)

Finally, $DT_0=\frac{N_{2(0)}}{D_2'(0)}$

$$=\frac{\mu_6 p_{06}+\mu_5 p_{05}+\mu_4 p_{04}+\mu_3 p_{03}+\mu_2 p_{02}+\mu_1 p_{01}+\mu_0}{\mu_0+p06\ \mu_6+p05\mu_5+p04\mu_4+\mu_9(p06p69+p05p58+p03+\ p02)+\mu_8(p05p58+p02\ )+\mu_7(p01+p04p47)+\mu_{10}(p06p6,10+p05p5,10+p04p4,10)+\mu_1 p01+\mu_2 p02} \quad (10)$$

3.4 Busy Period Analysis

Let us assume that the system entered regenerative state 'i' at t=0. Then, the probability that the repairman is busy at instant t is given by

$Bi_0=\lim_{s\to 0} sBi_0^*(s)$

The following recursive relations are obtained after applying the Laplace transform:

$Bi^*_0(s)=q^*_{01}(s).Bi^*_1(s)+q^*_{02}(s).Bi^*_2(s)+q^*_{03}(s).Bi^*_3(s)+q^*_{04}(s).Bi^*_4(s)+q^*_{05}(s).Bi^*_5(s)+q^*_{06}(s).Bi^*_6(s)$

$Bi^*_1(s)=q^*_{17}(s)\ .\ Bi^*_7(s)$

$Bi^*_2(s)=q^*_{28}(s)\ (t)\ .\ Bi^*_8(s)$

$Bi^*_3(s)=q^*_{39}(s)\ (t)\ .\ Bi^*_9(s)$

$Bi^*_4(s)=q^*_{47}(s)\ .\ Bi^*_7(s)+q^*_{4,10}(s)\ .\ Bi^*_{10}(s)$

$Bi^*_5(s)=q^*_{58}(s)\ .\ Bi^*_8(s)+q^*_{5,10}(s)\ .\ Bi^*_{10}(s)$

$Bi^*_6(s)=q^*_{69}(s)\ .\ Bi^*_9(s)+q^*_{6,10}(s)\ .\ Bi^*_{10}(s)$

$Bi^*_7(s)=W^*_7+q^*_{70}(s)\ .\ Bi^*_0(s)$

$Bi^*_8(s)=W^*_8+q^*_{89}(s)\ .\ Bi^*_9(s)$

$Bi^*_9(s)=W_9^*+q^*_{90}(s)\ .\ Bi^*_0(s)$

$Bi^*_{10}(s)=W_{10}^*+q^*_{10,0}(s)\ .\ Bi^*_0(s)$

$D_2'(0)=\mu_0+p_{06}\mu_6+p_{05}\mu_5+p_{04}\mu_4+\mu_9(p_{06}p_{69}+p_{05}p_{58}+p_{03}+p_{02})+\mu_8(p_{05}p_{58}+p_{02})+\mu_7(p_{01}+p_{04}p_{47})+\mu_{10}(p_{06}p_{6,10}+p_{05}p_{5,10}+p_{04}p_{4,10})+\mu_1 p_{01}+\mu_2 p_{02}$ (11)

$N_3(0)=\mu_{10}p_{06}p_{6,10}+\mu_9 p_{06}p_{69}+\mu_7 p_{05}p_{5,10}+\mu_9 p_{05}p_{58}+\mu_{10}p_{04}p_{4,10}+\mu_7 p_{04}p_{47}+\mu_9 p_{03}+\mu_8 p_{02}+\mu_9 p_{02}+\mu_7 p_{01}$ (12)

Finally, $Bi_0=\frac{N_{3(0)}}{D_3'(0)}$

$$=\frac{\mu_{10}p_{06}p_{6,10}+\mu_9 p_{06}p_{69}+\mu_7 p_{05}p_{5,10}+\mu_9 p_{05}p_{58}+\mu_{10}p_{04}p_{4,10}+\mu_7 p_{04}p_{47}+\mu_9 p_{03}+\mu_8 p_{02}+\mu_9 p_{02}+\mu_7 p_{01}}{\mu_0+p06\ \mu_6+p05\mu_5+p04\mu_4+\mu_9(p06p69+p05p58+p03+\ p02)+\mu_8(p05p58+p02\ \mu_{7(p01+p04p47)}\mu_{10}(p06p6,10+p05p5,10+p04p4,10)+\mu_1 p01+\mu_2 p02} \quad (13)$$

4 Results and Findings

4.1 Numerical Outcomes

Equation for profit

$Profit(P)=C_0*AF_0-C_1*DT_0-C_2*BI_0-C_3$ (14)

C_0 : revenue per unit time when the system is at maximum efficiency.

C_1 : loss incurred per unit time when system is in down state.

C_2 : cost per unit time when the repairperson is busy.

C_3 : fixed cost when the system is not working or is down.

After using the following values for different parameters calculated from the collected data: -

$\lambda_1=0.000091324, \lambda_2=0.000001826,$

$\lambda'_1=0.000091324, \lambda'_2=0.0000054794,$

$\beta_1=\beta_2=\beta_3=12, \gamma_1=\gamma_2=\gamma_3=171.43,$

$C_0=200000, C_1=300, C_2=5000, C_3=10000$

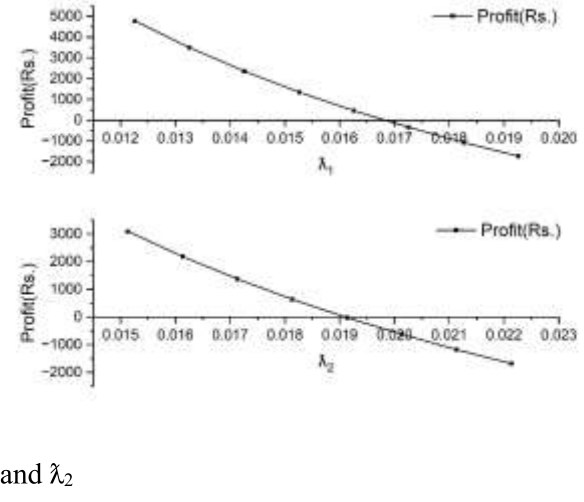
$p=0.99999, q=0.00001, \alpha_1=0.0042, \alpha_2=0.0042$ & $\alpha_3=0.0014$

The various reliability indices obtained are in Table 2 where the system generates a profit of 167157.224 INR with MTSF being 581632667 hours and the value of availability at 0.88804976

Table 2.Table for calculated reliability indices

S.No.	Parameters	Value
1.	Mean Time to System Failure	581632667 hrs
2.	Availability of System	0.88804976
3.	Downtime of the System	0.1011796
4.	Busy period for repairmen	0.084474805
5.	Profit generated	167157.2246

Fig. 2: Profit generated concerning Failure rates ƛ1



and ƛ2

4.2 Graphical Analysis

Figure 2 shows the profit generated by the system with variable failure rates taken one at a time, and it depicts that when the failure rate $ƛ_1$ goes below 0.0191085271, the system stops generating profit, and similarly, for failure rate $ƛ_2$, the profit is negative after it falls below 0.016827519.

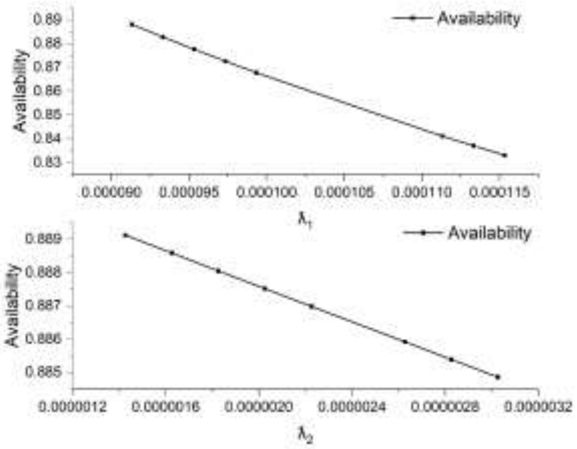


Fig. 3: Full Capacity Availability about Failure Rates at $ƛ_1$ and $ƛ_2$

Figure 3 depicts the graphs plotted for the availability of the system working at full capacity concerning failure rates $ƛ_1$ and $ƛ_2$. It can be seen that the availability of the system decreases with an increase in failure rates ($ƛ_1$ and $ƛ_2$).

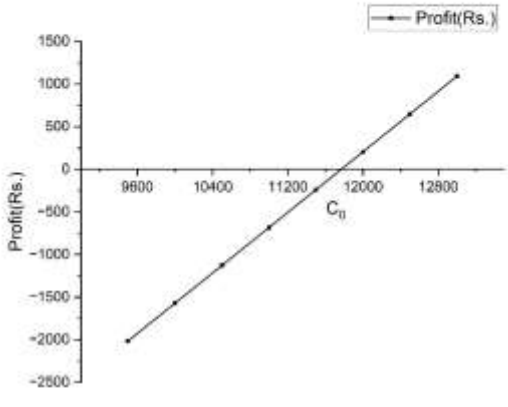


Fig. 4: Profit generated vs revenue generated while the system works at full capacity

Figure 4 represents graphs plotted after finding values of profit generated while the system is working at full capacity considering revenue generated per flying hour, and it shows that revenue generated(C_0) by the system cannot be less than 11,774 INR per flying hour for the airline to generate profit.

According to these indices and statistics, the system is no longer profitable below a certain failure rate for both components. Furthermore, it suggests that component $ƛ_1$ failure rate affects profit creation more than component $ƛ_2$ failure rate. Moreover, Figure 3 illustrates how the system's availability drops as both components' failure rates rise. This suggests that a higher failure rate causes a greater frequency of system outages and a decrease in system performance. Finally, Figure 4 shows that the revenue produced by the system per flying hour (C0) must equal or exceed 11,774 Indian rupees for the airline to turn a profit. This is a critical value that determines the profitability of the system.

5 Conclusion

This study has shown reliability modeling is important for improving complex systems' predictability. Reliability indices have been analyzed, emphasizing downtime, busy periods, and the resulting financial repercussions. This analysis has provided important insights into the optimisation of system failure minimization and maintenance strategy. Organizations can ensure the continuous availability of the system by taking early measures to resolve possible faults, due to the predictability that reliability modeling provides.

The results displayed in Table 1 highlight the financial advantages of efficient reliability modeling. The system's Mean Time Between Failures (MTSF) of 581,632,667 hours, availability of 0.88804976, and profit of 167,157.224 INR. demonstrate the system's beneficial effects on operational and financial aspects.

Moreover, decision-makers can benefit significantly from the documented relationship between profit, failure rates, and availability. Failure rates hurt availability and profitability, as demonstrated. Interestingly, the critical failure rate levels (lambda 1 and lambda 2) that cause profit to turn negative have been determined. This knowledge enables to creation maintenance schedules and performance standards to anticipate problems before they arise.

Through disassembling a system and analyzing its failure rates, researchers can learn more about how it works and what influences success or failure. This information can be applied to the analysis and enhancement of comparable systems in many industries such as healthcare and biomedical engineering, transportation, and logistics, also in energy and utilities resulting in higher manufacturing process profitability and productivity. Further disciplinary advancements and improvements could result from this research. Businesses may reduce downtime, minimize losses, and streamline processes with the help of reliability modeling, which is adaptable and applicable to a range of systems. The information gathered from this research is essential for creating dependability modeling techniques that improve system performance and resilience as technology advances. Reliability modeling ultimately contributes to the strategic objectives of forward-thinking businesses by mitigating losses that arise from system unavailability.

5.1 Limitations of this Study

Its exclusive focus on the financial elements of system failure and profitability is the main shortcoming of this study. The wider ramifications of system reliability are not fully reflected by financial measurements, despite their obvious importance. Additionally, because the study is static, it ignores dynamic elements that over time can have a substantial impact on the profitability and reliability of systems, such as shifting market conditions and technical improvements. Should these dynamic components be disregarded, the analysis might not fully convey the depth of the connection between system profitability and reliability.

5.2 Suggested Improvements of this Work

Several enhancements are proposed to resolve the stated constraints. First and foremost, a more thorough study that takes into account financial measures in addition to a wider range of variables including consumer effect and environmental sustainability should be conducted. Moreover, by evaluating the results' sensitivity to changes in important factors or assumptions, sensitivity assessments would strengthen the results' robustness. Furthermore, adding new data sources and incorporating more sophisticated reliability modeling methods may enhance the analysis's accuracy and dependability. Lastly, carrying out validation research in actual environments would validate the findings' validity and application in a variety of circumstances.

5.3 Future Directions

There are several exciting directions this field may take in the future. An examination of the interactions among system profitability, dependability, and other crucial performance metrics can result in a comprehensive computation of system optimization. Examining how new technologies or market trends affect system profitability and dependability would yield insightful information for modifying plans of action when conditions change. Proactive maintenance techniques like condition-based monitoring and predictive maintenance have the potential to improve system profitability and dependability even more. Maintaining operational effectiveness requires evaluating reliability modeling's long-term effects on system sustainability and resilience, especially under changing regulatory environments. Furthermore, investigating the applicability of dependability modeling methodologies in other industries and their scalability to larger or more complex systems

Acknowledgement:
This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. The authors would like to thank the editor and anonymous reviewers for their comments that helped improve the quality of this work.

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Contribution of Individual Authors to the Creation of a Scientific Article

- Prawar carried out Investigation, Methodology, Software, Writing-Orignal draft, Writing- review & editing
- Anjali Naithani carried out Investigation, Methodology, Software, Resources, Writing- review & editing, Supervision
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Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

No funding was received for conducting this study.

Conflict of Interest

The authors have no conflicts of interest to declare.

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