Reliability, Availability, Maintainability, and Dependability (RAMD) Analysis of Computer Based Test (CBT) Network System

Abdullahi Sanusi *[1], Ibrahim Yusuf[2] and Na'fiu Hussain[3]

•

[1]School of Continuing Education, Bayero University, Kano, Nigeria
[2]Department of Mathematical Sciences, Bayero University, Kano, Nigeria
[3]Department of Mathematical Sciences, Bayero University, Kano, Nigeria
asanusi.sce@buk.edu.ng
iyusuf.mth@buk.edu.ng
nafiu_hussaini@yahoo.com

Abstract

Computer Based Test System also known as an e-examinations system, is software that can be used to administer examinations for distant or in-house applicants via internet or in an internet. Computer Based Test System/Software comprises of many components. So, it is vital to ensure its smooth operation, which can be achieved by the proper operation of its components/subcomponents. It is necessary to improve components/subcomponents operational availability. For this reason, the present research proposes to explore Computer Based Test System reliability indices using a RAMD technique at the component/subcomponent level. As a result, all subsystem/component transition diagrams are constructed, and the Chapman-Kolmogorov differential equations are formulated using the Markov birth-death process. For various subsystems/components of the system, numerical findings for reliability, availability, maintainability, and dependability, all of which are crucial to system performance, have been obtained and given in tables and figures. Other measurements, such as MTTF, MTBF, dependability ratio, and dependability minimum have also been obtained. Based on the numerical results, the most significant subsystem/component has been determined and the significance of the research has been emphasized.

Keywords: Reliability, availability, maintainability, dependability, Subsystem/component, Computer Based Test (CBT).

I. Introduction

Examination is one of the most important aspect of educational sectors or institutions for evaluating student performance. One of the elements for determining the standard and efficiency of an educational institution is the regularity and integrity with which examinations are conducted. The computerization of many test operations improves the examination system.

Different types of Computer Based Test (CBT) Software Systems are being used by many educational institutions and examination bodies. The advantages of these technologies over the old technique (Traditional/Convectional) of examination cannot be over stressed as they aid in achieving efficiency and error-free outcomes and computations.

In many nations, there has been an increasing interest in developing and employing computer-based assessments in educational evaluation in recent years. Therefore, it is important to stay up with technological advancements.

Every Computer Based Test Software System must have high levels of reliability, availability, and dependability to be effective. These dimensions mentioned above can be used extensively to assess service quality in a variety of ways. Each subsystem/component of Computer Based Test (CBT) Software System has its own functions or characteristics and it is necessary to analyze the features of these subsystems/components to identify the subsystems/components that mainly influence the performance of the system. To achieve this, RAMD technique is mostly used by system engineers.

RAMD analysis is a critical step in assuring successful operations and production, as it identifies components or subsystems that can be improved. RAMD assesses the system at different stages using various performance modeling methods. RAMD evaluation can be used to derive important performance indicators. These indicators include, MTBF, MTTR, availability, reliability, maintainability, dependability ratio, and dependency minimum. These performance indicators are widely used for planning of maintenance policies to enhance the performance of the system.

Researchers have used different methods to evaluate the performance of various systems in the literature. Aggarwal et al. [1] have used RAMD technique to build a performance model of a dairy plant's skim milk powder production system. Aggarwal et al. [2] applied RAMD analysis to construct a mathematical model for evaluating the performance of serial processes in sugar plant's refining system. Choudhary et al. [3] proposed a way for increasing cement plant reliability. The system's MTBF and MTTR were obtained during a two-year period, and RAMD indices were analyzed. Corvaro et al. [4] have used RAM model to evaluate the operating performance of reciprocating compressors used in the gas and oil industries. De Sanctis et al. [5] provided a methodology for enhancing industry performance and suggested to engineers some maintenance strategies for handling issues such as high costs, safety, and environmental protection. For this, RAMD analysis was performed using equipment from the oil and gas sector as a case study object. Dahiya et al. [6] adopted the RAMD method to evaluate the performance of the sugar industry's A-Pan crystallization system. Garg [8] used a soft computing-based hybridized technique to analyze the performance of an industrial system. Kumar et al. [9] have recently discussed reliability and maintainability investigation of a sewage treatment plant's power producing unit. Kumar et al. [10] have used reliability and availability analysis to estimate the profit of an engineering system with several subsystems arranged in series connection. Malik and Tewari [11] have built a mathematical model for evaluating the performance of a water flow system and suggested some maintenance priorities. Mehta et al. [12] have discussed availability analysis of an industrial system applying supplementary variable technique. Qiu and Cui [13] approved a system reliability performance based on a dependable two-stage failure process, which includes the defect initialization stage and the defect development stage, both of which have competing failures. Based on the cost-free warranty policy, Niwas and Garg [14] proposed a methodology for measuring the reliability and profit of an industrial system. Saini and Kumar [15] analyzed the performance of an evaporation system in the sugar sector via RAMD analysis. Sanusi et al. [16] recently presented performance evaluation of an industrial arranged as series-parallel system. Velmurugan et al. [18] have provided reliability, availability, and maintainability analysis in forming industry. Yusuf, I [19] investigated the availability modelling and evaluation of repairable system subject to minor deterioration under imperfect repairs.

Singh et al. [17] have recently discussed probabilistic assessment of CBT network system consisting four subsystems connected in series using Copula technique. In their work, they evaluated the performance of the CBT network system without taking into account its components or subsystems. They investigated two types of repairs: Copula and General repairs to see how failure and repair affected reliability measures. Their findings showed that when Copula repair is used, the performance of the CBT network system can be improved. This study therefore addressed the gap left by Singh et al. [17] by investigating Computer Based Test (CBT) Software System reliability measures utilizing a RAMD technique at the component level in order to identify the most critical subsystem/component in the system and to build maintenance plans for this subsystem/component.

This paper is composed of 7 Sections. The first Section contains an introduction and a few brief reviews that are required for this study. The materials and methods are discussed in Section 2. Section 3 is devoted to the description of the system. The results of the RAMD analysis of the system are summarized in Section 4. Numerical simulation is covered in Section 5. The outcome discussion was presented in Section 6, and the paper was concluded in Section 7.

II. Materials and Methods

The tools for computing RAMD measures for the model under consideration are described in this section. All of the data in this study is valid only during a steady-state period when all the failure and repair rates are exponentially distributed and statistically independent.

I. Reliability function

In terms of failure rate, the reliability of a component can be represented as:

$$R(t) = \int_t^\infty f(t_0)dt_0. \quad (1)$$

For a component with an exponentially distributed failure rate, equation (1) is reduced to:

$$R(t) = e^{-\lambda t}. \quad (2)$$

II. Availability function

Mathematically, availability is expressed as:

$$A(t) = limA(T) = \frac{MTBF}{MTBF+MTTR}. \quad (3)$$

III. Maintainability

System maintainability can be expressed mathematically as:

$$M(t) = P(T \le t) = 1 - e^{\left(\frac{-t}{MTTR}\right)} = 1 - e^{-\mu t}. \quad (4)$$

where μ is the constant system's repair rate.

IV. Dependability

The dependability ratio for exponentially distributed random variables is given below:

$$d = \frac{\mu}{\theta} = \frac{MTBF}{MTTR}. \quad (5)$$

The following formula calculates the minimum value of dependability:

$$D_{min} = 1 - \left(\frac{1}{d-1}\right)\left(e^{-Ind/d-1} - e^{-dInd/d-1}\right). \quad (6)$$

V. MTTR

Mean Time To Repair is mathematically expressed as:

$$MTTR = \frac{1}{\alpha}. \tag{7}$$

where α is the system's repair rate.

VI. MTBF

The Mean Time Before Failure for an exponentially dispersed system is as follows:

$$MTBF = \int_0^\infty R(t)\,dt = \int_0^\infty e^{-\mu t}\,dt = \frac{1}{\mu} \tag{8}$$

Where μ is the failure rate.

VII. Exponential distribution.

A random variable X is said to obey an exponential distribution with parameter $\theta > 0$, if its probability density function is given by:

$$f(x,\theta) = \begin{cases} \theta e^{-\theta x}, if\ x \ge 0 \\ 0,\ otherwise \end{cases} \tag{9}$$

VIII. Constant failure rate

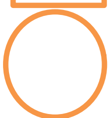
The constant hazard rate function can be written as follows:

$$f(t,\theta) = \begin{cases} \theta e^{-\theta t}, if\ t \ge 0 \\ 0,\ otherwise \end{cases} \tag{10}$$

Where θ is constant with probability density function, with $F(t) = 1 - e^{-\theta t}$ & $R(t) = e^{-\theta t}$.

IX. Notations

 Failure state of all subsystems.

 Operative state of all subsystems.

G, H, I, J, K, L, and M: Represent states in which a subsystem is operating at maximum efficiency.
P, q, r and s: Represent the failure states of subsystem A, B, C, and D, respectively.
$\mu_i, i = 1,2,3,4$: Rate of failure of subsystems A, B, C, and D, respectively.
$\alpha_i, i = 1,2,3,4$: Rate of repair of subsystems A, B, C and D, respectively.
$P_0(t)$: Probability that the system is operating at maximum capacity when it starts up.
$P_i;\ i = 0,1,2,3$: Steady-state probability that the system is in i^{th} state.

X. System description

The Computer Based Test system studied in this research work consists of four distinct subsystems/components. The brief description of the subsystems/components is given below:

Subsystem A (Clients): This subsystem is made up of three active clients. For the system to work, two clients must be operational. When one client of subsystem A fails, the system's capacity is lowered.
Subsystem B (Load Balancer): This subsystem has only one unit, failure of this unit leads to a complete system failure.
Subsystem C (Distributed Database Servers): This subsystem consists of two active servers arranged

in parallel. When one of the two active servers in this subsystem fails, the system operates at a reduced capacity. While failure of the two servers bring the system to a total failure.
Subsystem D (Centralized Distributed Server): There is only one unit of centralized distributed server in this subsystem. When this server fails, the system as a whole fail. Figure 1 below depicts a visual representation of the Computer Based Test system.

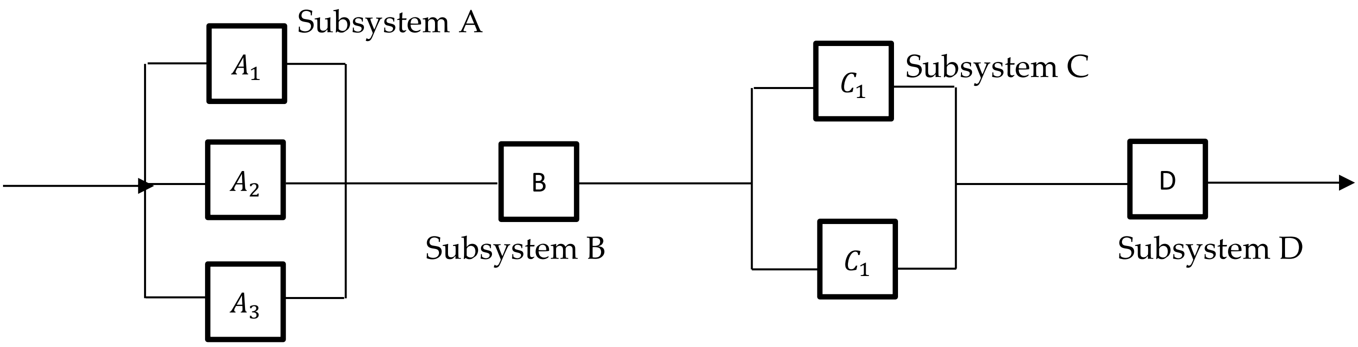


Figure 1: *Reliability block diagram of CBT software system*

III. RAMD analysis of the system

For mathematical modeling of a Computer Based Test Network System, Chapman Kolmogorov differential equations for each subsystem were developed utilizing the Markov birth-death process in this section. Figures 2, 3, 4, and 5 represent transition diagrams for all four subsystems, using the notation from section 2.1 above. System performance indicators such as availability, reliability, maintainability, and dependability have been obtained by solving the appropriate Chapman-Kolmogorov differential equations in a steady-state and employing normalization conditions simultaneously. Table 1 depicts various subsystem failure and repair rates.

Table 1: *Failure and Repair rates of subsystems of CBT network system*

Subsystem	Failure rate	Repair rate
SSA	$\delta_1 = 0.002$	$\eta_1 = 0.35$
SSB	$\delta_2 = 0.0015$	$\eta_2 = 0.40$
SSC	$\delta_3 = 0.005$	$\eta_3 = 0.082$
SSD	$\delta_4 = 0.032$	$\eta_4 = 0.95$

The following are RAMD analysis of subsystems for Computer Based Test (CBT) Network System:

I. RAMD analysis of subsystem A (Clients)

This subsystem has three active clients. The failure rate of all three clients is the same, and the failure of two clients\units causes the entire subsystem to fail. Figure 2 is used to formulate the differential equations for subsystem A, which are stated as follow:

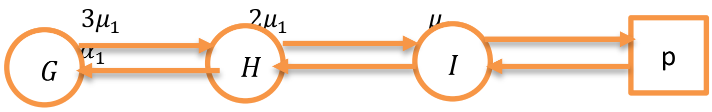


Figure 2: Transition diagram of subsystem A

$$P_0^1(t) = -3\mu_1 P_0 + \alpha_1 P_1, \quad (11)$$

$$P_1^1(t) = -(2\mu_1 + \alpha_1)P_1 + 3\mu_1 P_0 + \alpha_1 P_2, \quad (12)$$

$$P_2^1(t) = -(\mu_1 + \alpha_1)P_2 + 2\mu_1 P_1 + \alpha_1 P_3, \tag{13}$$

$$P_3^1(t) = -\alpha_1 P_3 + \mu_1 P_2. \tag{14}$$

Under steady-state, equations (11)-(14) can be reduced to the following using the initial conditions and taking $t \to \infty$:

$$-3\mu_1 P_0 + \alpha_1 P_1 = 0, \tag{15}$$

$$-(2\mu_1 + \alpha_1)P_1 + 3\mu_1 P_0 + \alpha_1 P_2 = 0, \tag{16}$$

$$-(\mu_1 + \alpha_1)P_2 + 2\mu_1 P_1 + \alpha_1 P_3 = 0, \tag{17}$$

$$-\alpha_1 P_3 + \mu_1 P_2 = 0. \tag{18}$$

Solving equations (15)-(18) recursively and using normalizing condition (i.e., $P_0 + P_1 + P_2 + P_3 = 1$), we have:

$$P_0 = \frac{1}{1+3\frac{\mu_1}{\alpha_1}+6\left(\frac{\mu_1}{\alpha_1}\right)^2+6\left(\frac{\mu_1}{\alpha_1}\right)^3}, P_1 = 3\frac{\mu_1}{\alpha_1}P_0, P_2 = 6\left(\frac{\mu_1}{\alpha_1}\right)^2 P_0, \text{ and } P_3 = 6\left(\frac{\mu_1}{\alpha_1}\right)^3 P_0.$$

Now, the steady-state availability is obtained as the summation of all the working state probabilities as:

$$Av_{sysA}(t) = P_0 + P_1 + P_2. \tag{19}$$

Thus, we have the availability of subsystem A as:

$$Av_{sysA}(t) = \frac{\alpha^2+3\alpha_1\mu_1+6\mu_1^2}{\alpha^2+3\alpha_1\mu_1+6\mu_1^2+\frac{6\mu_1^3}{\alpha_1}} = 0.9999. \tag{20}$$

The reliability of the system is given by equation (1). For a component with an exponentially distributed failure rate, equation (1) is reduced to:

$$R(t) = e^{-\mu t}. \tag{21}$$

Thus, the reliability of subsystem A is obtained as:

$$R_{sysA}(t) = e^{-\mu_1 t}, \tag{22}$$

$$R_{sysA}(t) = e^{-0.002t}. \tag{23}$$

Equation (4) calculates the system's maintainability. Thus, the maintainability of subsystem A is presented by equation (25) below.

$$M_{sysA}(t) = 1 - e^{-\alpha_1 t}, \tag{24}$$

$$M_{sysA}(t) = 1 - e^{-0.35t}. \tag{25}$$

Using equations (4), (5), (6), (7), and (8), other performance indicators of subsystem A are given below:

$MTBF = 500h, MTTR = 2.8571h, d = 175.0026, D_{min(sysA)}(t) = 0.9945.$

II. RAMD analysis of subsystem B (Load Balancer)

There is only one unit of load balancer in this subsystem which is connected to the following units in series. Failure of this unit leads to system failure. The differential equations for subsystem B are written in figure 3, and are as follow:

Figure 3: Transition diagram of subsystem B

$$P_0^1(t) = -\mu_2 P_0 + \alpha_2 P_1, \tag{26}$$

$$P_1^1(t) = -\alpha_2 P_1 + \mu_2 P_0, \tag{27}$$

Under steady-state, equations (26) and (27) can be reduced to the following using the initial conditions and taking $t \to \infty$:

$$-\mu_2 P_0 + \alpha_2 P_1 = 0, \tag{28}$$

$$-\alpha_2 P_1 + \mu_2 P_0 = 0, \tag{29}$$

Solving equations (28) and (29) recursively and using normalizing condition (i.e., $P_0 + P_1 = 1$), we have:

$$P_0 = \frac{\alpha_2}{\alpha_2+\mu_2} \; and \; P_1 = \frac{\mu_2}{\alpha_2} P_0,$$

Now, the steady-state availability is obtained as the summation of all the working state probabilities as:

$$Av_{sysB}(t) = P_0. \tag{30}$$

Thus, we have the availability of subsystem B as:

$$Av_{sysB}(t) = \frac{\alpha_2}{\alpha_2+\mu_2} = 0.9963. \tag{31}$$

The reliability of the system is given by equation (1). For a component with an exponentially distributed failure rate, equation (1) is reduced to:

$$R(t) = e^{-\mu t}. \tag{32}$$

Thus, the reliability of subsystem B is obtained as:

$$R_{sysB}(t) = e^{-\mu_2 t}, \tag{33}$$

$$R_{sysB}(t) = e^{-0.0015t}. \tag{34}$$

Equation (4) calculates the system's maintainability. Thus, the maintainability of subsystem B is presented by equation (36) below.

$$M_{sysB}(t) = 1 - e^{-\alpha_2 t}, \tag{35}$$

$$M_{sysB}(t) = 1 - e^{-0.40t}. \tag{36}$$

Using equations (4), (5), (6), (7), and (8), other performance indicators of subsystem B are given below:

$MTBF = 666.6667h, MTTR = 2.5000h, d = 266.6667, D_{min(sysB)}(t) = 0.9963.$

III. RAMD analysis of subsystem C (Distributed Database Servers)

This subsystem consists of two identical active servers that are connected in a parallel configuration. When one of the subsystem's two active servers fails, the system's capacity is reduced. The failure of the two servers, on the other hand, causes the entire system to fail. Figure 4 shows the differential equations for subsystem C, which are as follow:

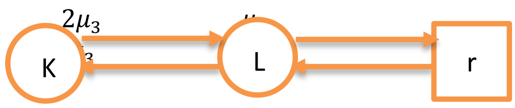


Figure 4: Transition diagram of subsystem C

$$P_0^1(t) = -\mu_3 P_0 + \alpha_3 P_1, \tag{37}$$

$$P_1^1(t) = -(\mu_3 + \alpha_3)P_1 + \mu_3 P_0 + \alpha_3 P_2, \tag{38}$$

$$P_2^1(t) = -\alpha_3 P_2 + \mu_3 P_1. \tag{39}$$

Under steady-state, equations (37)-(39) can be reduced to the following using the initial conditions and taking $t \to \infty$:

$$-\mu_3 P_0 + \alpha_3 P_1 = 0, \tag{40}$$

$$-(\mu_3 + \alpha_3)P_1 + \mu_3 P_0 + \alpha_3 P_2 = 0, \tag{41}$$

$$-\alpha_3 P_2 + \mu_3 P_1. \tag{42}$$

Solving equations (40)-(42) recursively and using normalizing condition (i.e., $P_0 + P_1 + P_2 = 1$), we have:

$$P_0 = \frac{1}{\left(1+\frac{\mu_3}{\alpha_3}+\left(\frac{\mu_3}{\alpha_3}\right)^2\right)}, P_1 = \frac{\mu_3}{\alpha_3}P_0, \text{ and } P_2 = \left(\frac{\mu_3}{\alpha_3}\right)^2 P_0 .$$

Now, the steady-state availability is obtained as the summation of all the working state probabilities as:

$$Av_{sysC}(t) = P_0 + P_1. \tag{43}$$

Thus, we have the availability of subsystem C as:

$$Av_{sysC}(t) = \frac{\alpha_3^2 + \alpha_3\mu_3}{\alpha_3^2 + \alpha_3\mu_3 + \mu_3^2} = 0.9965. \tag{44}$$

The reliability of the system is given by equation (1). For a component with an exponentially distributed failure rate, equation (1) is reduced to:

$$R(t) = e^{-\mu t}. \tag{45}$$

Thus, the reliability of subsystem C is obtained as:

$$R_{sysC}(t) = e^{-\mu_3 t}, \tag{46}$$

$$R_{sysC}(t) = e^{-0.005t}. \tag{47}$$

Equation (4) calculates the system's maintainability. Thus, the maintainability of subsystem C is presented by equation (49) below.

$$M_{sysC}(t) = 1 - e^{-\alpha_3 t}, \tag{48}$$

$$M_{sysC}(t) = 1 - e^{-0.082t}. \tag{49}$$

Using equations (4), (5), (6), (7), and (8), other performance indicators of subsystem C are given below:

$MTBF = 200h, MTTR = 12.1951h, d = 16.4000, D_{min(sysC)}(t) = 0.9492.$

IV. RAMD analysis of subsystem D (Centralized Distributed Server)

There is only one unit in this subsystem. Failure of this unit leads to a complete system failure. The differential equations for subsystem D are written in figure 5, and are as follow:

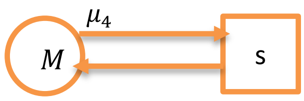


Figure 5: Transition diagram of subsystem D

$$P_0^1(t) = -\mu_4 P_0 + \alpha_4 P_1, \tag{50}$$

$$P_1^1(t) = -\alpha_4 P_1 + \mu_4 P_0. \tag{51}$$

Under steady-state, equations (50) and (51) can be reduced to the following using the initial conditions and taking $t \to \infty$:

$$-\mu_4 P_0 + \alpha_4 P_1 = 0, \tag{52}$$

$$-\alpha_4 P_1 + \mu_4 P_0 = 0. \tag{53}$$

Solving equations (50) and (51) recursively and using normalizing condition (i.e., $P_0 + P_1 = 1$), we have:

$P_0 = \frac{\alpha_4}{\alpha_4+\mu_4}$ and $P_1 = \frac{\mu_4}{\alpha_4} P_0.$

Now, the steady-state availability is obtained as the summation of all the working state probabilities as:

$$Av_{sysD}(t) = P_0. \tag{54}$$

Thus, we have the availability of subsystem D as:

$$Av_{sysD}(t) = \frac{\alpha_4}{\alpha_4+\mu_4} = 0.9674. \tag{55}$$

The reliability of the system is given by equation (1). For a component with an exponentially distributed failure rate, equation (1) is reduced to:

$$R(t) = e^{-\mu t}. \tag{56}$$

Thus, the reliability of subsystem D is obtained as:

$$R_{sysD}(t) = e^{-\mu_4 t}. \tag{57}$$

$$R_{sysD}(t) = e^{-0.032t}. \tag{58}$$

Equation (4) calculates the system's maintainability. Thus, the maintainability of subsystem D is presented by equation (60) below.

$$M_{sysD}(t) = 1 - e^{-\alpha_4 t}. \tag{59}$$

$$M_{sysD}(t) = 1 - e^{-0.95t}. \tag{60}$$

Using equations (4), (5), (6), (7), and (8), other performance indicators of subsystem D are given below:

$MTBF = 31.2500h, MTTR = 1.0526h, d = 29.6884, D_{min(sysD)}(t) = 0.9673.$

V. Numerical simulation

In this section, we present the numerical findings in tables and figures to validate the formulae derived and to provide rapid insight into the system's optimal design.

I. System reliability

Since all four subsystems are connected in a sequential manner. Failure of one subsystem causes the whole system to fail. The following formula calculates the CBT network's overall system reliability:

$$R_{sys}(t) = R_{sysA}(t) \times R_{sysB}(t) \times R_{sysC}(t) \times R_{sysD}(t),$$
$$R_{sysA}(t) = e^{-(0.0405)t} \tag{61}$$

II. System availability

All four subsystems are connected in a sequential manner. One failure causes the entire system to fail. The following formula calculates the CBT network's overall system availability:

$$Av_{sys}(t) = Av_{sysA}(t) \times Av_{sysB}(t) \times Av_{sysC}(t) \times Av_{sysD}(t),$$
$$Av_{sys}(t) = 0.9604. \tag{62}$$

III. System maintainability

All the four subsystems are connected in series; thus, the CBT network's total system maintainability is determined by:

$$M_{sys}(t) = M_{sysA}(t) \times M_{sysB}(t) \times M_{sysC}(t) \times M_{sysD}(t),$$
$$M_{sys}(t) = (1 - e^{-1.7820t}). \tag{63}$$

IV. System dependability

Since all the four subsystems are arranged in series, the CBT network's overall system dependability is given by:

$$D_{min(sys)}(t) = D_{min(sysA)}(t) \times D_{min(sysB)}(t) \times D_{min(sysC)}(t) \times D_{min(sysD)}(t),$$
$$D_{min(sys)}(t) = 0.9097. \tag{64}$$

Table 2 shows a summary of the RAMD results.

Table 2: *RAMD analysis for Computer Based Test (CBT) Network System*

RAMD indices of subsystems	subsystem A	subsystem B	subsystem C	subsystem D
Availability	0.9999	0.9963	0.9965	0.9674
Reliability	$e^{-0.002t}$	$e^{-0.0015t}$	$e^{-0.005t}$	$e^{-0.032t}$
Maintainability	$1-e^{-0.35t}$	$1-e^{-0.40t}$	$1-e^{-0.082t}$	$1-e^{-0.95t}$
Dependability ratio	175.0026	266.6667	16.4000	29.6884
MTBF	$500h$	$666.6667h$	$200h$	$31.2500h$
MTTR	$2.8571h$	$2.5000h$	$12.1951h$	$1.0526h$
Dependability min.	0.9945	0.9963	0.9492	0.9673

Table 3 shows how each subsystem's reliability varies with regard to different time intervals.

Table 3: *Variation in subsystems reliability over time*

Time (t) in (Months)	$R_{sysA}(t)$	$R_{sysB}(t)$	$R_{sysC}(t)$	$R_{sysD}(t)$	$R_{sys}(t)$
0	1.0000	1.0000	1.0000	1.0000	1.0000
10	0.9802	0.9851	0.9512	0.7261	0.6670
20	0.9608	0.9704	0.9048	0.5273	0.4449
30	0.9418	0.9560	0.8607	0.3829	0.2967
40	0.9231	0.9418	0.8187	0.2780	0.1979
50	0.9048	0.9277	0.7788	0.2019	0.1320
60	0.8869	0.9139	0.7408	0.1466	0.0880
70	0.8694	0.9003	0.7047	0.1065	0.0587
80	0.8521	0.8869	0.6703	0.0773	0.0392
90	0.8353	0.8737	0.6376	0.0561	0.0261

Table 4 displays how each subsystem's maintainability varies over time.

Table 4: *Changes in subsystems maintainability over time*

Time (t) in (days)	$M_{sysA}(t)$	$M_{sysB}(t)$	$M_{sysC}(t)$	$M_{sysD}(t)$	$M_{sys}(t)$
0	0.0000	0.0000	0.0000	0.0000	0.0000
10	0.9698	0.9817	0.5596	0.9999	0.9999
20	0.9991	0.9997	0.8060	0.9999	1.0000
30	0.9999	0.9999	0.9146	1.0000	1.0000
40	0.9999	0.9999	0.9623	1.0000	1.0000
50	0.9999	0.9999	0.9834	1.0000	1.0000
60	0.9999	1.0000	0.9927	1.0000	1.0000
70	1.0000	1.0000	0.9968	1.0000	1.0000
80	1.0000	1.0000	0.9986	1.0000	1.0000
90	1.0000	1.0000	0.9986	1.0000	1.0000

Table 5: *Variation in systems reliability as a result of changes in subsystem A's failure rate*

	Subsystem A		System	
Time in (Months)	$\alpha_1 = 0.001$	$\alpha_1 = 0.005$	$\alpha_1 = 0.001$	$\alpha_1 = 0.005$
0	1.00000	1.00000	1.00000	1.00000
10	0.99005	0.95123	0.67368	0.64726
20	0.98020	0.90484	0.45384	0.41895
30	0.97045	0.86071	0.30575	0.27117
40	0.96079	0.81873	0.20598	0.17552
50	0.95123	0.77880	0.13876	0.11361

60	0.94176	0.74082	0.09348	0.07353
70	0.93239	0.70469	0.06298	0.04760
80	0.92312	0.67032	0.04243	0.03081
90	0.91393	0.63763	0.02858	0.01994

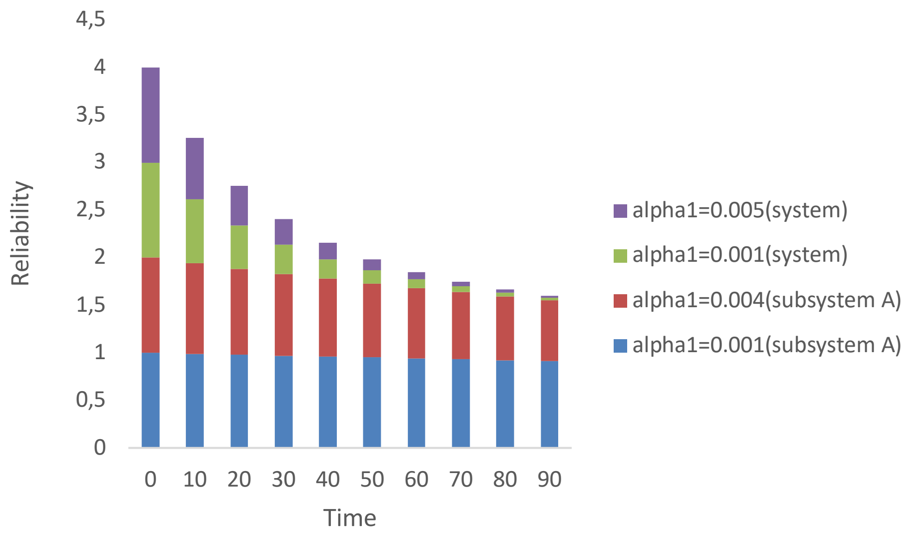


Figure 2: *Effect of α_1 on system reliability and subsystem A reliability*

Table 6: *Variation in systems reliability as a result of changes in subsystem B's failure rate*

	Subsystem B		System	
Time in (Months)	$\alpha_2 = 0.0009$	$\alpha_2 = 0.004$	$\alpha_2 = 0.0009$	$\alpha_2 = 0.004$
0	1.00000	1.00000	1.00000	1.00000
10	0.99104	0.96079	0.67099	0.65051
20	0.98216	0.92312	0.45023	0.42316
30	0.97336	0.88692	0.30210	0.27527
40	0.96464	0.85214	0.20271	0.17907
50	0.95599	0.81873	0.13601	0.11648
60	0.94743	0.78663	0.09126	0.07577
70	0.93894	0.75578	0.06124	0.04929
80	0.93053	0.72615	0.04109	0.03206
90	0.92219	0.69768	0.02757	0.02086

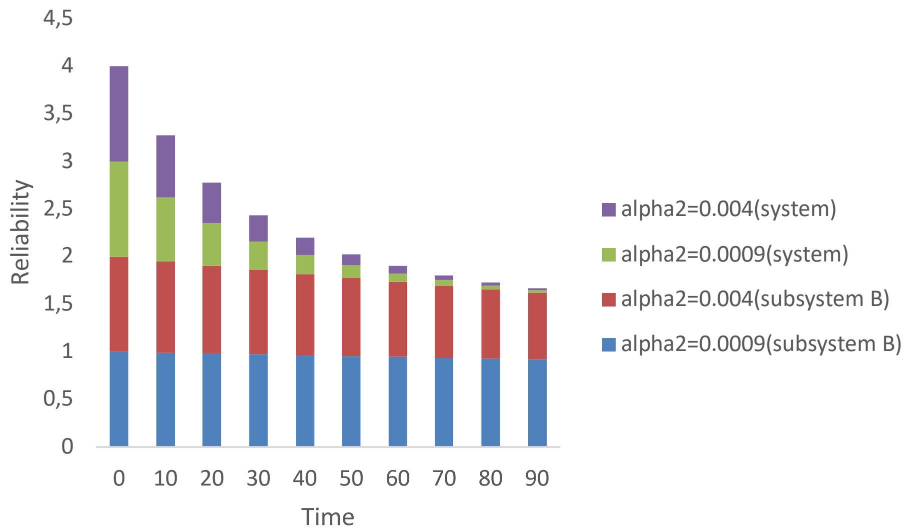


Figure 3: *Effect of α_2 on system reliability and subsystem B reliability*

Table 7: *Variation in systems reliability as a result of changes in subsystem C's failure rate*

	Subsystem C		System	
Time in (Months)	$\alpha_3 = 0.0008$	$\alpha_3 = 0.01$	$\alpha_3 = 0.0008$	$\alpha_3 = 0.01$
0	1.00000	1.00000	1.00000	1.00000
10	0.99203	0.90484	0.69559	0.63445
20	0.98413	0.81873	0.48384	0.40252
30	0.97629	0.74082	0.33655	0.25538
40	0.96851	0.67032	0.23410	0.16203
50	0.96079	0.60653	0.16284	0.10280
60	0.95313	0.54881	0.11327	0.06522
70	0.94554	0.49659	0.07879	0.04138
80	0.93800	0.44933	0.05480	0.02625
90	0.930553	0.40657	0.03812	0.01666

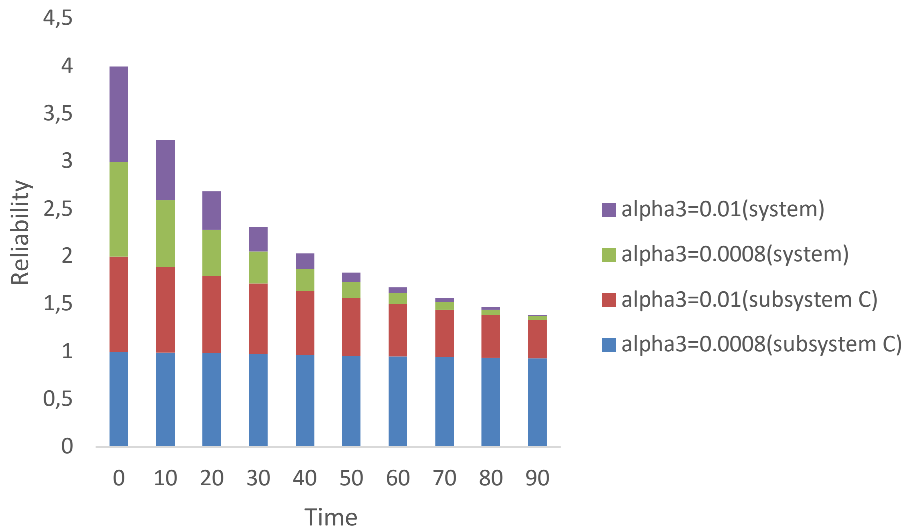


Figure 4: *Effect of α_3 on system reliability and subsystem C reliability*

Table 8: *Variation in systems reliability as a result of changes in subsystem D's failure rate*

	Subsystem D		System	
Time in (Months)	$\alpha_4 = 0.01$	$\alpha_4 = 0.065$	$\alpha_4 = 0.01$	$\alpha_4 = 0.065$
0	1.00000	1.00000	1.00000	1.00000
10	0.90484	0.52205	0.83110	0.47951
20	0.81873	0.27253	0.69073	0.22993
30	0.74082	0.14227	0.57407	0.11025
40	0.67032	0.07427	0.47711	0.05287
50	0.60653	0.03877	0.39653	0.02535
60	0.54881	0.02024	0.32956	0.01255
70	0.49659	0.01057	0.27390	0.00583
80	0.44933	0.00552	0.22764	0.00279
90	0.40657	0.00288	0.18919	0.00134

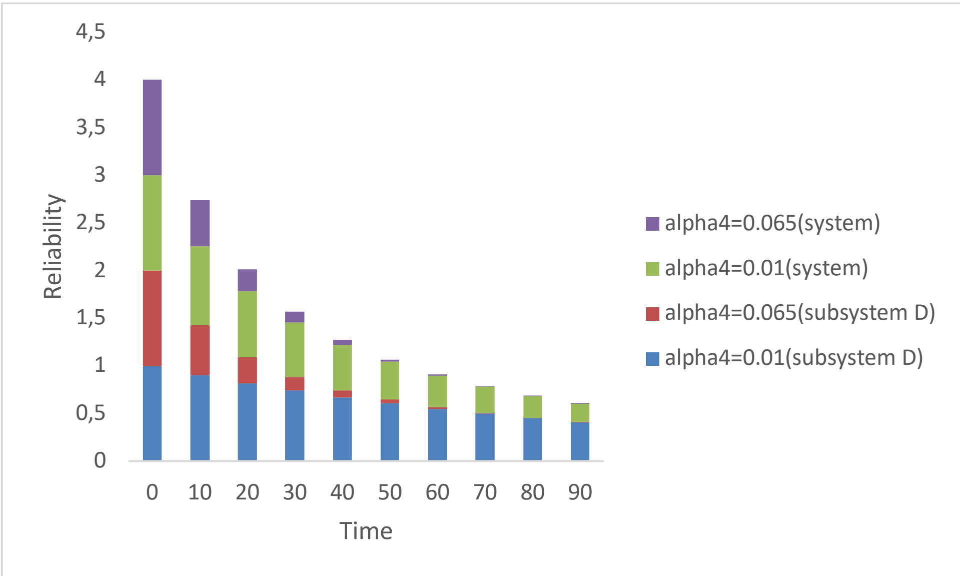


Figure 5: *Effect of α_4 on system reliability and subsystem D reliability*

VI. Result discussion

On the basis of the above analysis, tables 3 and 4 indicate that the reliability and maintainability of the system at time $t = 50$ months are 0.1320 and 1.0000, respectively. At time $t = 50$ months, the system has a comparable value of $R_{sysA}(t) = 0.9048$, $R_{sysB}(t) = 0.9277$, $R_{sysC}(t) = 0.7788$, and $R_{sysD}(t) = 0.2019$. The probability of accomplishing satisfactory maintenance and repair within 50 months is $M_{sys}(t) = 1.0000$, and the maintainability value for the crucial subsystems is $M_{sysA}(t) = 0.9999$, $M_{sysB}(t) = 0.9999$, $M_{sysC}(t) = 0.9834$, and $M_{sysD}(t) = 1.0000$. By exhibiting a form declination, the reliability of the system at time $t = 60$ months is reduced to 0.0880. This is owing to the subsystem D's poor reliability value. This sensitivity study reveals that centralized database server (CDS), which is subsystem D, is the system's most important and sensitive component. This implies that maintaining this subsystem is crucial for increasing overall system reliability. This is supported by this subsystem availability, which is low when compared to the availability of other subsystems. The importance of maintenance is shown in the value of reliability, i.e. the lower the reliability the necessity of the maintenance. For this reason, system designers and maintenance engineers must devise a strategy for the maintenance of this subsystem. Tables 5-6 show how the reliability of key subsystems and the overall system has changed over time and with varying failure rates. We can see from these tables and figures that the entire system reliability is significantly dependent on the failure rate (α_4) of subsystem D, necessitating close attention to this subsystem. This demonstrates that optimal system reliability can be reached when the overall system's failure rate is low and supporting units are included.

VII. Conclusion

In this paper, the RAMD indices for each subsystem are critically analyzed to find the most sensitive component of the system under consideration. The basic expressions associated with RAMD measurements for each subsystem were obtained and validated through numerical experiment. Table 1 shows the values of failure and repair rates that are assumed for each subsystem. Table 2 presents all the RAMD measurements for each subsystem. The influence of varying failure rates on subsystems and system reliability is shown in tables 3, 4, 5, and 6 and their corresponding figures 2, 3, 4, and 5. Based on the numerical findings for a given case in tables 2-6 and figures 2-5, it is concluded that the centralized database server is the Computer Based Test (CBT) Software System's significant and delicate component. It is widely accepted that system failure during an examination will have negative impact on educational standards, and that there may even be a catastrophe. As a result, if the models/results given in this paper are modified, management will be able to avoid incorrect evaluations and erroneous decision-making, resulting in unnecessary expenditures and drop in educational standards. Furthermore, the established strategy (RAMD technique) for maintenance policies for the model under consideration may be recommended in order to increase system smooth operation and reduce system failure rate. These are the findings of this present research. In our future research, we will incorporate minimal repair at the failure of each subsystem/component.

References

[1] Aggarwal A, Kumar S, Singh V, (2015). Performance modeling of the skim milk powder production system of a dairy plant using RAMD analysis. Int J Qual Reliab Manag 32(2):167–181.

[2] Aggarwal AK, Kumar S, Singh V, (2017). Performance modeling of the serial processes in refining system of a sugar plant using RAMD analysis. Int J Syst Assur Eng Manag 8(2):1910–1922.

[3] Choudhary D, Tripathi M, Shankar R, (2019). Reliability, availability and maintainability analysis of a cement plant: a case study. Int J Qual Reliab Manag. https ://doi.org/10.1108/IJQRM-10-2017-0215.

[4] Corvaro F, Giacchetta G, Marchetti B, and Recanati M, (2017). "Reliability, Availability, Maintainability (RAM) study, on reciprocating compressors API 618 Petroleum", Vol. 3, 266-272.

[5] De Sanctis I, Paciarotti C, Di Giovine O, (2016). Integration between RCM and RAM: a case study. Int J Qual Reliab Manag 33(6):852–880.

[6] Dahiya O, Kumar A, Saini M, (2019). Mathematical modeling and performance evaluation of A-Pan crystallization system in a sugar industry. SN Appl Sci. https://doi.org/10.1007/s42452-019-0348-0.

[7] Goyal, D., Kumar, A., Saini, M., and Joshi. H. (2019). "Reliability, maintainability and sensitivity analysis of physical processing unit of sewage treatment plant." SN Appl. Sci. 1:1507, https://doi.org/10.1007/s42452-019-1544-7.

[8] Harish Garg (2017). Performance analysis of an industrial system using soft computing based hybridized technique. J Braz Soc Mech Sci Eng 39(4):1441–1451.

[9] Kumar A, Goyal D, and Saini M, (2020). Reliability and maintainability analysis of power generating unit of sewage treatment plant. Int. J. of Stat. and Reliab. Eng. 7(1), 41-48.

[10] Kumar A, Pant S, Singh SB, (2017). Availability and cost analysis of an engineering system involving subsystems in series configuration. Int J Qual Reliabil Manag 34(6):879–894.

[11] Qiu, Q.; Cui, L. (2018). Reliability evaluation based on a dependent two-stage failure process with competing failures. Appl. Math. Model. 64, 699–712.

[12] Ram Niwas and Harish Garg (2018). An approach for analyzing the reliability and profit of an industrial system based on the cost-free warranty policy. Journal of the Brazilian Society of Mechanical Sciences and Engineering, Springer, 40, pp. 1-9.

[13] Malik S, Tewari PC, (2018). Performance modeling and maintenance priorities decision for water flow system of a coal based thermal power plant. Int J Qual Reliabil Manag 35(4):996–1010.

[14] Mehta M., Singh J., and Sharma S, (2018). "Availability Analysis of an Industrial System using Supplementary Variable Technique," Jordan journal of mechanical and industrial engineering, vol. 12, no. 4, pp. 245-251, ISSN 1995-6665.

[15] Saini M, and Kumar A, (2019). "Performance analysis of evaporation system in sugar industry using RAMD analysis". J Braz Soc Mech Sci Eng 41:4.

[16] Sanusi, A., Yusuf, I., Mamuda. B.Y. (2020). Performance evaluation of an industrial configured as series-parallel system, Journal of Mathematical and Computational Science. 10, pp. 692-712.

[17] Singh, V.V., Lado Ismail, A.K., Yusuf, I. and Abdullahi, A.H. (2021). Probabilistic Assessment of Computer-Based Test (CBT) Network System Consists of Four Subsystems in Series Configuration Using Copula Linguistic Approach. Journal of Reliability and Statistical Studies.

[18] Velmurugan K, Venkumar P, and Sudhakarapandian R., (2019). Reliability Availability Maintainability Analysis in Forming Industry. International Journal of Engineering and Advanced Technology; 91S4, 822–828.

[19] Yusuf, I. (2016). Reliability modeling of a parallel system with a supporting device and two types of preventive maintenance. International Journal of Operational Research. 25(3), pp. 269-287.