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Reliability, Availability, Maintainability, and Dependability Analysis of Cold Standby Series-Parallel System

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Abstract: This paper dealt with the evaluation reliability, availability, maintainability, dependability, mean time between failures, and mean time to failure of series-parallel system. The system under investigation has four subsystems, namely subsystem A containing two units in cold standby, subsystem B and C possess one unit each, and subsystem D has two units in cold standby. Through the transition diagram of each subsystem and the Markov birth–death process, Chapman Kolmogorov forward equations are derived. Both failure and repair rates of units in each subsystem are assumed to follow exponential distribution. The objective is to derive the corresponding reliability models of dependability, availability, maintainability, and reliability and capture the effect of system parameters on reliability, availability, maintainability, and dependability and to determine the critical subsystems. On the basis of numerical results obtained, the system's performance has been evaluated. Moreover, the outcome of this study shows that the ideal system reliability can be achieved when the overall system failure rate is low and the supporting units are activated.

Keywords: repair rate, failure rate, RAMD, standby, series-parallel

1. Introduction

Some industrial and manufacturing system consists of various units/components/subsystems configured or arranged or connected in series-parallel. The subsystems in series-parallel systems consist of units working in either active parallel, standby, or in the form of k-out-of-n arrangement. Failure of any one of the subsystems may lead to the catastrophic failure of the system leading to high cost of maintenance. Because of the importance of series-parallel systems, in the quality of the product, production output as well as revenue mobilization, reliability analysis of such systems has gained the attention of various researchers. Garg (2021) developed and analyzed the bi-objectives reliability cost interactive optimization model for series-parallel system. Yusuf et al. (2021) analyzed the reliability and performance of series-parallel system using copula. Malhotra and Taneja (2015) developed and compared reliability models of varying demand cold standby systems. Malhotra et al. (2021) analyzed the reliability of redundant cold standby two-unit system with preventive maintenance. Singh and Ayagi (2018) developed models for performance analysis under preemptive resume repair of complex repairable system. Lado and Singh (2019) dealt with the assessment of cost of complex system attended by human operator.

Reliability, availability, maintainability, and dependability (RAMD) are some of the performance measures used in testing and enhancing the effectiveness and strength of the systems. RAMD analysis enables plant management to identify the most critical components or subsystems within the system that need adequate maintenance in order to enhance its performance. RAMD evaluates the system at various phases using various performance modeling methods. The significant performance measures can be derived via RAMD evaluation. These measures include MTBR, MTTR, availability, reliability, maintainability, dependency ratio, and dependency minimum. In order to ensure system reliability and availability, as well as to improve system features, RAMD approach is commonly used by engineers.

Sequel to the above assertion, researchers have developed different maintenance models and strategies in enhancing the system performance and optimizing the system RAMD. Few of such are Taleb-Berrouane et al. (2019) who used probabilistic approach to evaluate the reliability, availability, and maintainability of system. Saini et al. (2020) studied RAMD of microprocessor systems. Monika and Ashish (2019) analyzed the performance of evaporating unit in sugar manufacturing plant through RAMD approach. Mohamed et al. (2018) developed models for evaluating the performance of industrial systems through RAMD approach. Kumar and Tewari (2018) review some approaches of evaluating systems performance via reliability, availability, and maintainability. Reena and Basotia (2020) developed some performance models of testing the strength of cement manufacturing plant. Saini et al. (2020) analyzed the performance evaporating unit in sugar industry through

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RAMD approach. Sanusi and Yusuf (2021) have used RAMD technique to study the performance of a computer-based test at subsystem level. Tsarouhas (2018) analyzed the reliability, availability, and maintainability of a cheese (feta) production line in a Greek medium-sized company. Choudhary et al. (2019) analyzed the reliability, availability, and maintainability of a cement plant. Corvaro et al. (2017) dealt with the reliability, availability, and maintainability of study on reciprocating compressor. Gupta et al. (2021) investigate the reliability and maintainability of generator in steam turbine power plant. Jagtap et al. (2021) analyzed the reliability and availability optimization of thermal power plant. Tsarouhas (2018) analyzed the reliability, availability, and maintainability of wine packaging production system. Khan et al. (2022) dealt with performance measure decision-making approach on T-spherical operators. Garg and Garg (2022) discussed the optimization of profit and availability of a single-unit system with imperfect switch over. Barma and Modibbo (2021) presented multi-objective optimization model for solid waste management system.

2. Material and Methods

2.1. Assumptions and model description

The study looked at a repairable system made up of four subsystems connected in series: A, B, C, and D as shown in Figure 1.

Because Systems B and C are single units, if one of them fails, the entire system fails. Subsystem A consists of two units, one of which is operating and the other in cold standby. Subsystem A will fail fully if one active unit and one standby unit fail at the same time, or Subsystem D and Subsystem C will collapse totally. This set includes four pieces. The system might be repaired in any case. Failures are repaired without fail; thus, every system is as good as new after the repair. Failure and repair rates are expected to be.

2.2. Notation

□: Represent a system that has failed.

○: Represent that the system is up and running.

t: Time scale.

β_i: Failure rates of the system, where i = 1, 2, 3, 4.

γ_j: Repair rates of the system, where j = 1, 2, 3, 4.

s_0: All four units are in good working condition. The system is working.

s_1: All four units are in good working condition, due to the standby unit of subsystem A.

s_2: The system is in failed state due to failure of subsystem B, the system failed.

s_3: The system is in failed state due to failure of subsystem C, the system failed.

s_4: All four units are in good working condition, due to the standby unit of subsystem D, the system is working.

s_5: The system is in failed state due to the failure of subsystem C and active unit of subsystem D, the system failed.

s_6: The system is in failed state due to the complete failure of subsystem D, the system failed.

s_7: The system is in failed state due to the failure of subsystem B and active unit of subsystem D, the system failed.

s_8: The system is in failed state due to the complete failure of subsystem A, the system failed.

s_9: The system is in failed state due to the failure of subsystem B and active unit of subsystem A.

s_{10}: The system is in failed state due to the failure of subsystem C and active unit of subsystem A, the system failed.

s_{11}: All four units are in good working condition, due to the standby units of subsystems A and D, the system is working.

s_{12}: The system is in failed state due to the failure of subsystem A and active unit of subsystem D, the system failed.

s_{13}: The system is in failed state due to the failure of subsystem B and active unit of subsystem D, the system failed.

s_{14}: The system is in failed state due to the failure of subsystem C and active unit of subsystem D, the system failed.

s_{15}: The system is in failed state due to the complete failure of subsystem D, the system failed.

The following assumptions are associated with the model:

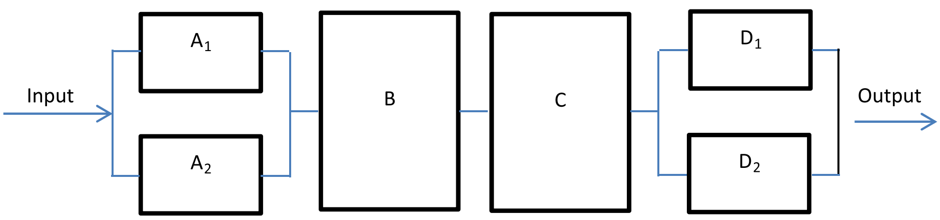
Initially, the system is in good state. The system has two states, working and failed states. The system has completely failed after the failure of system B and C, and failure of the unit of system A and D. All failure and repair rates are constant. The system can be repaired when it is in complete failed mode. The repaired system works like a new one.

2.3. Exponential distribution

The technique in which things are spread is referred to as dispersion.

A random variable X is said to follow an exponential distribution with parameter if its probability density function is given by > 0:

Figure 1
Block diagram of model



$$f(x,\beta) = \begin{cases} \beta e^{-\beta x} & if\ x \geq 0, \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

It is one of the most typical engineering failure patterns. Failures caused solely by chance or random events will follow this pattern.

Reliability

The capacity of a system or device to fulfill its work or function in a set time and under specified conditions is referred to as "reliability." If a device or system performs its purpose without fail for the stipulated period of time, it is termed reliable.

$$R(t) = e^{-\int_0^\infty Z(t)dt} \quad (2)$$

For a component with an exponentially distributed failure rate, (2) is simplified as follows:

$$R(t) = e^{-\beta t}, \quad (3)$$

MTBF

The average time between failures is referred to as this. Most of the time, it is measured in hours. As the MTBF increases, the system's reliability improves. The MTBF of an exponentially distributed system is calculated as follows:

$$\int_0^\infty R(t)dt = \int_0^\infty e^{-\beta t}dt = \frac{1}{\beta} \quad (4)$$

MTTR

This is known as the reciprocal of the system repair rate. Mathematically,

$$\text{MTTR} = \frac{1}{\gamma}, \quad (5)$$

Availability

The chance that a piece of equipment will perform in a specific state for a specified amount of time is known as availability. It is a different way of evaluating how well a piece of equipment, a system, or a component is kept in working order. The probability that a system will be available in a certain condition for a specific period of time, or the duration during which a system will be functional, is defined as system availability. It is the proportion of system uptime to total time spent on the system (i.e., uptime plus downtime).

$$\text{Availability} = \frac{MTBF}{MTBF + MTRR} \quad (6)$$

The mean time between failures (MTBF) is a fundamental metric of a system's robustness. It's almost the same as the average period between failures (MTBF). MTBF refers to the expected time to failure after a component or system has failed and been repaired, whereas MTSF refers to the expected time to failure of a component or system, which is also known as the mean time to failure of components or systems. The mean time to failure (MTTF) is a metric that indicates how long a product can be expected to last in the field based on specific testing. It is also worth noting that Companies' estimates of mean time to failure for specific goods or components may not have been based on continuous testing:

$$\text{MTSF} = \lim_{n\to\infty} \bar{R}(s) \text{ or MTSF} = \int_0^\infty R(t), \quad (7)$$

where $R(t)$ is the system's dependability, defined as $R(t) = (T > t) = \int_t^\infty f(x)dx$, and $\bar{R}(s)$ *is Laplace transform of* $R(t)$.

Maintainability

When maintenance is performed according to the needed protocol, Ebeling defined system maintainability as the ability to repair or restore a failing component to a specified condition within a specific time period. The formula for determining an industrial system's maintainability is

$$M(t) = 1 - e(-t/MTTR) = 1 - e^{(-t\gamma)}, \quad (8)$$

where γ is the constant repair rate.

Dependability

Dependability is a design criterion, according to Wohl. It assesses dependability and availability as well as average failure and repair rates. The beauty of dependability is that it allows you to consider factors such as cost, reliability, and maintenance. The following is the dependability ratio for random variables with exponential distributions:

$$d = \frac{\gamma}{\beta} = \frac{MTBF}{MTTR}, \quad (9)$$

The high value of the dependability ratio demonstrates the importance of maintenance. The dependability value increases when availability exceeds 0.9 and decreases when availability falls below 0.1, according to Aggarwal et al. To get the minimum value of dependability, use the algorithm below:

$$D_{\min} = 1 - (1/(d-1))(e^{(-\ln d/(d-1))} - e^{(-d\ln d/(d-1))}), \quad (10)$$

2.4. State transition and diagram block of the model

2.5. RAMD indices for subsystems

(a) For subsystem A, RAMD indices

$$P_0 = -\beta_1 P_0(t) + \gamma_1 P_1(t), \quad (11)$$

$$P_1 = -(\beta_1 + \gamma_1)P_1(t) + \beta_1 P_0(\text{t}) + \gamma_1 P_2(t), \quad (12)$$

$$P_2 = -\gamma_1 P_2(t) + \beta_1 P_1(t), \quad (13)$$

In steady state, (11–13) reduces and taking $t \to \infty$

$$-\beta_1 P_0 + \gamma_1 P_1 = 0, \quad (14)$$

$$-(\beta_1 + \gamma_1)P_1 + \beta_1 P_0 + \gamma_1 P_2 = 0, \quad (15)$$

$$-\gamma_1 P_2 + \beta_1 P_1 = 0. \quad (16)$$

Now, using normalization condition:

$$P_0 + P_1 + P_2 = 1. \quad (17)$$

Substituting the values of P_2 and P_3 by solving (14–16) in (17), we get availability of the subsystem as follows:

Availability

$$\textbf{AVsys1} = \frac{1 + \frac{\beta_1}{\gamma_1}}{1 + \frac{\beta_1}{\gamma_1} + \frac{\beta_1^2}{\gamma_1^2}}. \tag{18}$$

Reliability

$$R(t) = e^{(-0.001t)}. \tag{19}$$

Maintainability

$$M(t) = 1 - e(-t/MTTR) = 1 - e^{(-0.6t)} \tag{20}$$

Dependability

$$D_{\min} = 1 - (1/(d_1 - 1))(e(^{-}lnd_1)/(d_1 - 1)) - e(^{-}d_1 lnd_1)/(d_1 - 1))) \tag{21}$$

Other performance indicators of system effectiveness of subsystem A using (18–21) are as follows: MTBF = 1000, MTTR = 1.6667, $d = 600$.

(b) For subsystem B, RAMD indices

$$P_0 = -\beta_2 P_0(t) + \gamma_2 P_1(t), \tag{22}$$

$$P_1 = -\gamma_2 P_1(t) + \beta_2 P_0(t), \tag{23}$$

In steady state, (22) and (23) reduces and taking $t\infty$

$$-\beta_2 P_0(t) + \gamma_2 P_1(t) = 0, \tag{24}$$

$$-\gamma_2 P_1(t) + \beta_2 P_0(t) = 0. \tag{25}$$

Now, using normalization condition:

$$P_0 + P_1 = 1. \tag{26}$$

Substituting the values of P_1 by solving (24–25) in (26), we get availability of the subsystem as follows:

Availability

$$\textbf{AVsys2} = \frac{1}{1 + \frac{\beta_2}{\gamma_2}}. \tag{27}$$

Reliability

$$R(t) = e^{(-0.002t)}. \tag{28}$$

Maintainability

$$M(t) = 1 - e(-t/MTTR) = 1 - e^{(-0.8t)}. \tag{29}$$

Dependability

$$D_{min} = 1 - (1/(d_2 - 1))(e(-lnd_2)/(d_2 - 1)) - e(-d_2 lnd_2)/(d_2 - 1))) = 0.9975. \tag{30}$$

Other performance indicators of system effectiveness of subsystem B using (27–30) are as follows: MTBF = 5000, MTTR = 1.2500, $d = 400$

(c) For subsystem C, RAMD indices

$$P_0 = -\beta_3 P_0(t) + \gamma_3 P_1(t), \tag{31}$$

$$P_1 = -\gamma_3 P_1(t) + \beta_3 P_0(t). \tag{32}$$

In steady state, (31) and (32) reduces and taking $t\infty$

$$-\beta_3 P_0(t) + \gamma_3 P_1(t) = 0, \tag{33}$$

$$-\gamma_3 P_1(t) + \beta_3 P_0(t) = 0. \tag{34}$$

Now, using normalization condition:

$$P_0 + P_1 = 1. \tag{35}$$

Substituting the values of P_1 by solving (33–34) in (35), we get availability of the subsystem as follows:

Availability

$$\textbf{AVsys3} = \frac{1}{1 + \frac{\beta_3}{\gamma_3}}. \tag{36}$$

Reliability

$$R(t) = e^{(-0.002t)}. \tag{37}$$

Maintainability

$$M(t) = 1 - e((-t/MTTR)) = 1 - e^{(-0.8t)}. \tag{38}$$

Dependability

$$D_{min} = 1 - (1/(d_3 - 1))(e(-lnd_3)/(d_3 - 1)) - e(-d_3 lnd_3)/(d_3 - 1))). \tag{39}$$

Other performance measures of subsystem C effectiveness are as follows, using (36–39): MTBF = 333.3333, MTTR = 1.0000, $d = 333.3333$

(d) For subsystem D, RAMD indices

$$-\beta_4 P_0(t) + \gamma_4 P_1(t) = 0, \tag{40}$$

$$-(\beta_4 + \gamma_4) P_1(t) + \beta_4 P_0(t) + \gamma_4 P_2 = 0, \tag{41}$$

$$-\gamma_4 P_2(t) + \beta_4 P_1(t) = 0. \tag{42}$$

In steady state, (40–42) reduces and taking

$$-\beta_4 P_0(t) + \gamma_4 P_1(t) = 0, \tag{43}$$

$$-(\beta_4 + \gamma_4) P_1(t) + \beta_4 P_0(t) + \gamma_4 P_2 = 0, \tag{44}$$

$$-\gamma_4 P_2(t) + \beta_4 P_1(t) = 0. \tag{45}$$

Now, using normalization condition:

$$P_0 + P_1 + P_2 = 1. \tag{46}$$

Substituting the values of P_2 and P_3 by solving (43–45) in (46), we get availability of the subsystem as follows:

Availability

$$\textbf{AVsys4} = \frac{1 + \frac{\beta_4}{\gamma_4}}{1 + \frac{\beta_4}{\gamma_4} + \frac{\beta_4^2}{\gamma_4^2}}. \quad (47)$$

Reliability

$$R(t) = e^{-0.004t}. \quad (48)$$

Maintainability

$$M(t) = 1 - e((-t/MTTR)) = 1 - e^{(-1.2t)}. \quad (49)$$

Dependability

$$D_{min} = 1 - (1/(d_4 - 1))(e(-lnd_4)/(d_4 - 1)) - e(-d_4 lnd_4)/(d_4 - 1))). \quad (50)$$

3. RAMD Indices for Subsystem

System reliability

Because all four subsystems are linked in series, the failure of one causes the entire system to fail. The whole system's dependability is determined by:

$$R_{sys}(t) = R_{sys1}(t)\ R_{sys2}(t)\ R_{sys3}(t)\ R_{sys4}(t)$$

$$R_{sys}(t) = e^{-0.001t}\ e^{-0.002t}\ e^{-0.003t}\ e^{-0.004t}$$

$$R_{sys}(t) = e^{-0.0000024t}. \quad (51)$$

The variation in reliability with respect to time is analyzed using (51) and is shown in Table 2.

System availability

Because all three subsystems are linked in series, the failure of one causes the entire system to fail. The overall availability of the system is determined by:

$$AV_{sys} = \left(\frac{1 + \frac{\beta_1}{\gamma_1}}{1 + \frac{\beta_1}{\gamma_1} + \frac{\beta_1^2}{\gamma_1^2}}\right)\left(\frac{1}{1 + \frac{\beta_2}{\gamma_2}}\right)\left(\frac{1}{1 + \frac{\beta_3}{\gamma_3}}\right)\left(\frac{1 + \frac{\beta_4}{\gamma_4}}{1 + \frac{\beta_4}{\gamma_4} + \frac{\beta_4^2}{\gamma_4^2}}\right) = 0.9999 \quad (52)$$

System maintainability

Because all three subsystems are linked in series, the failure of one causes the entire system to fail. The overall maintainability of the system is determined by:

$$M(t) = (1 - e^{(-0.6t)})(1 - e^{(-0.8t)})(1 - e^{(-1.0t)})(1 - e^{(-1.2t)}),$$

$$M(t) = (1 - e^{(-0.576t)}) \quad (53)$$

Using (53), the variation in maintainability over time is assessed, as illustrated in Table 3.

System dependability

Because all three subsystems are linked in series, the failure of one causes the entire system to fail. The total system resiliency is determined by:

Table 1
Rates of failure and repair of subsystems

Subsystem	Failure rate	Repair rate
A	$\beta_1 = 0.001$	$\gamma_1 = 0.6$
B	$\beta_2 = 0.002$	$\gamma_1 = 0.8$
C	$\beta_3 = 0.002$	$\gamma_1 = 1.0$
D	$\beta_4 = 0.003$	$\gamma_1 = 1.2$

$$D_{min}D_{min} == 1 - (\frac{1}{d-1})(e^{-lnd/d-1} - e^{-dlnd/d-1})$$

Parameter values in Table 1 are used to validate the models.

$$D_{min} = 0.9984 \times 0.9975 \times 0.9970 \times 0.9999 = 0.9999. \quad (54)$$

The summary of all the RAMD indices is given in Table 2.

4.1. Discussion and conclusion remarks

From Table 2 and Figure 2, it is clear that the reliability of the individual subsystem decreases with passage of time. However, the table has shown that the reliability of the individual subsystem is greater than the reliability of the entire system with passage of time. It is observed from the table that subsystem 4 has lower reliability than the remaining subsystems. Thus,

$$R_1(t) > R_2(t) > R_3(t) > R_4(t) > R(t)$$

Thus, subsystem 4 is said to be behind the lower reliability of the system with passage of time. This called for adequate preventive measures to subsystem 4 in order to avoid failure occurrence and enhanced its reliability which may result in enhancing the reliability of the system.

From Table 3 and Figure 3, it is clear that the maintainability of the individual subsystem increases with passage of time. However, the table has shown that the maintainability of the individual subsystem is equal to the maintainability of the entire system with passage of time. It is observed from the table that none of the subsystem has lower maintainability. Thus, the change of the maintainability of any of the subsystem is said to lower maintainability of the system with passage of time. Offline and online maintenance to the system as well as subsystems be invoked to maintain the system performance at its peak.

Tables 5, 6, 7, and 8 display the variation in system reliability owing to variations in failure rates of each subsystem. From the tables, it is evident that reliability decreases with passage of time. However, the analysis of reliability for different values of failure

Table 2
Variation in subsystem reliability over time

Time	$R_1(t)$	$R_2(t)$	$R_3(t)$	$R_4(t)$	$R_{system}(t)$
0	1.0000	1.0000	1.0000	1.0000	1.0000
20	0.9802	0.9608	0.9518	0.9418	0.8869
40	0.9608	0.9231	0.8979	0.8839	0.7866
60	0.9418	0.8869	0.8453	0.8353	0.6977
80	0.9231	0.8521	0.7966	0.7866	0.6187
100	0.9048	0.8187	0.7508	0.7408	0.5488
120	0.8869	0.7866	0.6977	0.6577	0.4867
140	0.8694	0.7558	0.6471	0.6371	0.4318
160	0.8521	0.7262	0.6188	0.6088	0.3829

Figure 2
System reliability against time *t*

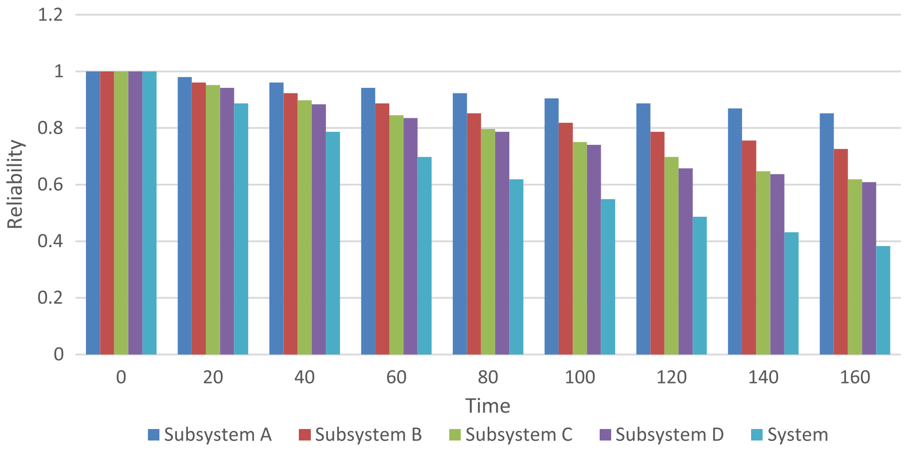


Table 3
Variation in subsystem reliability over time

Time	$M_1(t)$	$M_2(t)$	$M_3(t)$	$M_4(t)$	$M_{system}(t)$
0	0.0000	0.0000	0.0000	0.0000	0.0000
20	0.9999	0.9999	0.9999	0.9999	0.9997
40	1.0000	1.0000	1.0000	1.0000	0.9999
60	1.0000	1.0000	1.0000	1.0000	1.0000
80	1.0000	1.0000	1.0000	1.0000	1.0000
100	1.0000	1.0000	1.0000	1.0000	1.0000
120	1.0000	1.0000	1.0000	1.0000	1.0000
140	1.0000	1.0000	1.0000	1.0000	1.0000
160	1.0000	1.0000	1.0000	1.0000	1.0000

rates has shown reliability is higher at lower failure compared to other failure rates. According to this sensitivity analysis, the ideal system reliability can be achieved when the overall system's failure rate is low and the supporting units have been invoked. As a result, effective maintenance strategies such as regular inspection and preventive maintenance should be chosen, and redundant procedures may be used to improve the system's reliability.

This technique can be used by managers, system designers, and engineers to assess system performance effectively. Managers can use the RAMD analysis of the system at the outer layer to regulate reliability parameters like MTBF, MTTR, and availability when designing maintenance policies.

4.2. Recommendation for feature research

In future, one can extend this research work for more complex industrial systems as well as simple system for improving their production and expected profit. Also, more complex systems can be solved by modern technique like soft computing technique, machine learning technique, etc. to evaluate other important characteristics of the system through which they can:

- ➢ Reduce various failure/repair rates.
- ➢ Identify right cause to system failure.
- ➢ Improve operating conditions.
- ➢ Optimize running cost and maximize profit.
- ➢ Adopt right maintenance policy.

Table 4 above gives the summary of the models with respect to each subsystem.

Figure 3
System maintainability against time *t*

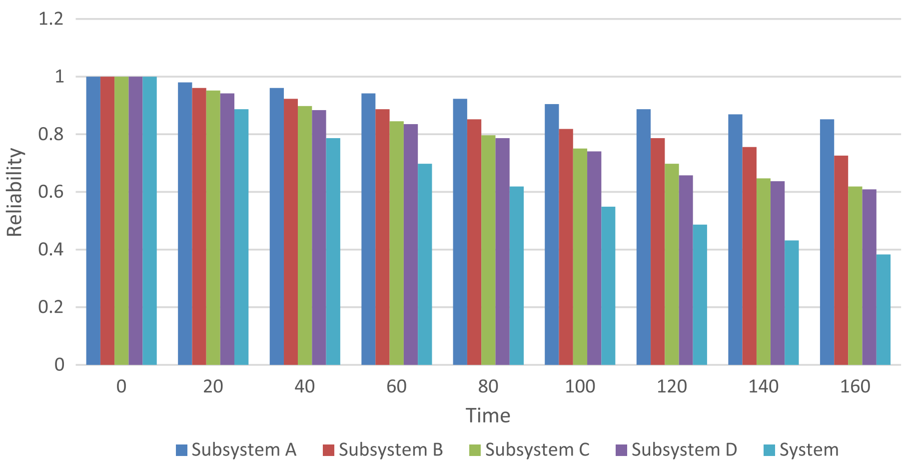


Table 4
RAMD indices for system

Indices	Subsystem A	Subsystem B	Subsystem C	Subsystem D	System
Reliability	$e^{-0.001\,t}$	$e^{-0.002\,t}$	$e^{-0.003\,t}$	$e^{-0.004\,t}$	$e^{-2.4X10^{-8}\,t}$
Availability	1.0000	0.9975	1.0000	1.0000	0.9975
Maintainability	$1-e^{-0.6\,t}$	$1-e^{-0.8\,t}$	$1-e^{-1.0\,t}$	$1-e^{-1.2\,t}$	$1-e^{-0.48\,t}$
Dependability	0.9999	0.9999	0.9999	0.9999	0.9996
MTBF	1000	500	333.3333	333.3333	1666666.65
MTTR	1.6667	1.2500	1.0000	1.0000	2.0834
Dependability ratio	600	400	330	330	

Table 5
Effect of failure rate on subsystem A reliability

Time	$\beta_1 = 0.001$	$\beta_1 = 0.002$	$\beta_1 = 0.003$	$\beta_1 = 0.004$
20	0.9802	0.9608	0.9418	0.9318
40	0.9608	0.9231	0.8869	0.8769
60	0.9418	0.8869	0.8352	0.8252
80	0.9231	0.8521	0.7866	0.7766
100	0.9048	0.8187	0.7408	0.7208
120	0.8869	0.7866	0.6977	0.5977
140	0.8694	0.7558	0.6571	0.5571
160	0.8521	0.7261	0.6188	0.5188

Table 6
Effect of failure rate on subsystem B reliability

Time	$\beta_2 = 0.01$	$\beta_2 = 0.02$	$\beta_2 = 0.03$	$\beta_2 = 0.04$
20	0.8187	0.6703	0.6488	0.5488
40	0.6703	0.4493	0.4012	0.3012
60	0.5488	0.3012	0.2653	0.1653
80	0.4493	0.2019	0.2307	0.0907
100	0.3679	0.1353	0.1998	0.0498
120	0.3012	0.0907	0.1273	0.0273
140	0.2466	0.0608	0.1149	0.0149
160	0.2019	0.0408	0.0183	0.0083

Table 7
Effect of failure rate on subsystem C reliability

Time	$\beta_3 = 0.01$	$\beta_3 = 0.02$	$\beta_3 = 0.03$	$\beta_3 = 0.04$
20	0.1353	0.0183	0.0025	0.0015
40	0.0183	0.0003	0.0000	0.0000
60	0.0024	0.0000	0.0000	0.0000
80	0.0003	0.0000	0.0000	0.0000
100	0.0001	0.0000	0.0000	0.0000
120	0.0000	0.0000	0.0000	0.0000
140	0.0000	0.0000	0.0000	0.0000
160	0.0000	0.0000	0.0000	0.0000

Table 8
Effect of failure rate on subsystem D reliability

Time	$\beta_3 = 0.01$	$\beta_3 = 0.02$	$\beta_3 = 0.03$	$\beta_3 = 0.04$
20	0.1353	0.0183	0.0025	0.0015
40	0.0183	0.0003	0.0000	0.0000
60	0.0024	0.0000	0.0000	0.0000
80	0.0003	0.0000	0.0000	0.0000
100	0.0001	0.0000	0.0000	0.0000
120	0.0000	0.0000	0.0000	0.0000
140	0.0000	0.0000	0.0000	0.0000
160	0.0000	0.0000	0.0000	0.0000

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

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