ABSTRACT

This study aimed to increase textile manufacturing system dependability, reliability, maintainability, availability, and metrics like MTBF and MTTF by boosting RAMD. The textile system under investigation is a serial system consisting of five subsystems, which are: subsystem A is weaving section, subsystem B is the dry clean section, subsystem C is the cross cut section, subsystem D is the side seam section and subsystem E is the cleaning section. Each of the subsystem consist of main unit, warm standby unit and cold standby unit. For design and prediction, the Markovian birth-death method is employed to assemble the system governing the differential difference equation from the state-to-state transition diagram. The rates of repair and failure of each subsystem are exponentially distributed and statistically independent. For several subsystems of the system, the findings for RAMD, all of which are crucial to system performance, have been acquired and shown in figures and tables. Furthermore, the results of this study reveal that the highest system performance and dependability may be achieved when the overall system failure rate is low. The findings of this research are thought to be valuable for analyzing performance and determining the best system design and feasible maintenance strategies that may be used in the future to improve system performance, strength, effectiveness, production output as well as revenue mobilization.

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Markovian process is used to evaluate measures such as maintainability, reliability, dependability, and availability in determining its capability and reliability. [3] concentrate on increasing the profit of engineering systems with serial sub-systems by improving system performance indicators like availability and reliability. [4] investigate the reciprocating unit's system availability, maintainability, and dependability in the oil and gas industries in order to improve the unit's operating performance. [5] uses particle swarm optimization and fuzzy techniques to assess industrial reliability, maintainability, and availability. [6] investigated the efficiency of the forming industry by assessing system maintainability, dependability, and availability. [7] developed Markov models for RAM performance estimation of circulation system of water. [8] discuss the RAM evaluation of Load Haul Dumpers.

Available studies either neglects or overlooks the importance of warm and cold standby in strengthening system reliability, availability, mean time to failure, and MTBF. Most previous studies focused solely on system availability and effectiveness evaluation, paying little attention to the influence of warm and cold standby units on reliability, availability, mean time to failure, and generated revenue. More advanced designs with mixed standby units should indeed be established to reduce the likelihood of a complete breakdown, expenditures, overall reliability, availability, mean time to failure, and revenue generated (profit).

The aforementioned literature review presented in Table 1 above reveals that the RAMD evaluation of some industrial and manufacturing system having mixture of warm and cold standby units when failure and repair rates as Lindley and Exponentiated Weibull distribution has not been explored so far. Motivated by the aforementioned studies in Table 1 above, the objective of this work is to perform RAMD analysis of textile system with mixed standby unit when failure rates follows Lindley and Exponentiated Weibull distribution. As a result, this study considers a textile manufacturing system that consists of five distinct sub-systems equipped as a series-parallel system, each consisting of a combination of primary units, warm standby units, and cold standby units. The system’s effectiveness is investigated via first order differential difference equations. Availability as one of the performance measures of system strength and effectiveness have been computed for each configuration. The present work will perform RAMD analysis of textile system with mixed standby unit when failure rates follows Lindley and Exponentiated Weibull distribution.

The following are the paper's contributions:

- To formulated novel models of RAMD analysis of textile manufacturing system considering models; main,

Table 1. Some related research on availability, maintainability, reliability and dependability of some complex systems

<table>
<thead>
<tr>
<th>Reference</th>
<th>System</th>
<th>Standby used</th>
<th>Exponential distribution</th>
<th>Lindley distribution</th>
<th>Exponentiated Weibull distribution</th>
<th>Reliability</th>
<th>Availability</th>
<th>Maintainability</th>
<th>Dependability</th>
</tr>
</thead>
<tbody>
<tr>
<td>[9]</td>
<td>Sewage treatment plant</td>
<td>N/A</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>[10]</td>
<td>Series-parallel</td>
<td>Cold</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>[11]</td>
<td>Cement</td>
<td>Cold</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>[12]</td>
<td>Steam turbine power plant</td>
<td>N/A</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>No</td>
</tr>
<tr>
<td>[13]</td>
<td>Water treatment plant</td>
<td>N/A</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>Yes</td>
</tr>
<tr>
<td>[14]</td>
<td>Tube-well</td>
<td>N/A</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>Yes</td>
</tr>
<tr>
<td>[15]</td>
<td>Sugar Plant</td>
<td>N/A</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>[16]</td>
<td>Microprocessor</td>
<td>N/A</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>[17]</td>
<td>Sugar manufacturing plant</td>
<td>N/A</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>[18]</td>
<td>Hot standby database systems</td>
<td>N/A</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>[19]</td>
<td>Automotive manufacturing</td>
<td>N/A</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>[20]</td>
<td>Power generating unit of sewer treatment plant</td>
<td>N/A</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>yes</td>
</tr>
</tbody>
</table>

Proposed study

Textile confection plant mixed yes yes yes yes yes yes yes yes
warm and cold standby units. Warm standby unit reduce energy use and recovery period because a standby unit is partly energized and subjected to maximum stress while the primary unit is up and running and completely powered and functional after the primary unit stops working.

- Developing the explicit expressions for the availability, reliability, mean time between failure, maintainability, mean time to failure and dependability for each subsystem.

- To see the performance of the system through ramd models under exponential, Lindley and exponentiated Weibull distributions.

The following is how this paper is structured. The framework for this study is described in Section 2. Section 3 discusses the methods and materials used. Section 4 is dedicated to the modelling approach. Section 5 presents the simulation studies and consequences discussion, and Section 6 concludes the paper.

**DESCRIPTION OF THE SYSTEM AND NOTATIONS**

**Description of The System**

The textile system under investigation is a serial system consisting of five subsystems, which are; weaving section, dry clean section, cross cut section, side seam section and cleaning section. Each of the subsystem consist of main unit, warm standby unit and cold standby unit as shown in Table 2. Warm standby unit are introduced in enhancing the performance of the system. Warm standby units have the capacity to reduce energy use and recovery period because a standby unit is partly energized and subjected to maximum stress while the primary unit is up and running and completely powered and functional after the primary unit stops working. When one of the primary units fails, the warm standby resumes to work with minimal service interruption. Sequel to this, system with warm or mixed standby units have gained the attention of different researchers. To cite few, [21] analysed the cost benefit of warm standby retrial systems with imperfect coverage. Analysis of reliability and availability of a redundant k-out-of-n warm standby system in the presence of common cause failure has been presented in [22]. Evaluation of reliability and performance of power system having warm standby unit is given in [23]. [24] focus on profit optimization of a warm standby non identical system in normal and abnormal environment. [25] analysed reliability of warm standby serial system with switching mechanism and uncertain lifetimes. [26] presented reliability simulation of warm standby two component system having switching and back switching failures. [27] focus on economic analysis of warm standby system attended by single server. [28] analysed the profit of warm standby system attended by single server with priority. [29] analysed the performance of warm standby machine repair problem with servers’ vacation, impatient and controlling F-policy.

The system can be in perfect or initial state when new. At the failure of one of the primary unit, a warm standby unit will shift to take over the failed unit while the cold standby unit will take the position of warm standby unit. This failure is called the partial failure. When all the primary and warm standby failed, the system is down. This called complete failure.

**Subsystem A (Weaving)**

Any machine that weaves yarn into fabric is referred to as a weaving machine. They are used to render upholstery fabric, silk, and ornate carpets. They come in shuttle, circular, and narrow fabric options.

**Subsystem B (Dry Clean):**

A dry cleaning machine is any sanitizing device that uses a solvent other than water to tidy clothing and textiles. Although liquid is still used in dry cleaning, clothes are submerged in a water-free liquid solvent and other detergent, which is the most commonly used solvent.

**Subsystem C (Cross Cut):**

A cross cutter machine is an equipment that cuts both hard and soft wood.

**Subsystem D (Side Seam):**

A seam is a method of joining a number of pieces of garment, typically with thread to form stitches. Seams can be hand-stitched or machine-stitched. A seam is a line that connects pieces of fabric and other materials in a garment.

**Subsystem E (Cleaning):**

Cleaning is the mechanical removal of loosely bound fibers, such as brushing, sueding, or grinding. Cleaning processes that are solvent-free are workable alternatives to the traditional solvent-based regular cleaning. They reduce waste generation and remove potential risks caused by the use and application of toxic, ozone-depleting, and frequently flammable solvents. Sanding, grinding, polishing, brushing / sueding, cropping, and shearing are examples of cleaning operations.

<table>
<thead>
<tr>
<th>Machine/Subsystem</th>
<th>Primary Unit</th>
<th>Warm Standby Unit</th>
<th>Cold Standby Unit</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weaving (A)</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Dry Clean (B)</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>Cross Cut (C)</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Side Seam (D)</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Cleaning (E)</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>7</td>
</tr>
</tbody>
</table>
Notations
$q$: time variable
$\lambda_1 / \lambda_2 / \lambda_3 / \lambda_4 / \lambda_5$: main unit failure rate in weaving subsystem, dry clean subsystem, cross cot subsystem, side seam subsystem and cleaning subsystem.
$\alpha_1 / \alpha_2 / \alpha_3 / \alpha_4 / \alpha_5$: warm standby unit failure rate in weaving subsystem, dry clean subsystem, cross cot subsystem, side seam subsystem and cleaning subsystem.
$\mu_1 / \mu_2 / \mu_3 / \mu_4 / \mu_5$: warm standby unit failure rate in weaving subsystem, dry clean subsystem, cross cot subsystem, side seam subsystem and cleaning subsystem.
$\theta_k(q)$: probability that the system is in state $S_k$ at time $q$.

MATERIALS AND METHODS

Reliability Models
The chance that a system/machine will be up and running throughout a period of time $q$ is defined as reliability. Thus, reliability $R(q) = P\{Q > q\}$, where $Q$ is the time when the system is down and not running with $R(q) \geq 0$, $R(q) = 1$. (For a full description, see Ebeling (2000)). Thus,

\begin{equation}
R(q) = \int_{0}^{q} f(q_0) dq_0 \tag{1}
\end{equation}

and

\begin{equation}
R(q) = e^{-\mu q} \tag{2}
\end{equation}

\begin{equation}
R(q) = \left(\frac{1 + m + mq}{1 + m}\right)e^{-\mu q} \tag{3}
\end{equation}

\begin{equation}
R(t) = 1 - \left(1 - e^{-\mu t}\right)^m \tag{4}
\end{equation}

for exponentially, Lindley and exponentiated Weibull distributed rate of failure respectively.

Maintenance

$M(q) = P\{Q \leq q\} = 1 - e^{-\frac{q}{MTTR}} = 1 - e^{-\mu q}$. \tag{6}

where $\mu$ is the constant system’s repair rate.

Dependability
Dependability is a metric given by

$D_{min} = 1 - \left(\frac{1}{h-1}\right)\left(e^{-\log(h)/h-1} - e^{-\log(h)/h-1}\right)$. \tag{7}

where

$h = \frac{\mu}{\theta} = \frac{MTBF}{MTTR}$. \tag{8}

Mean Time Between Failure
The average time between the failures is known as MTBF. It’s usually expressed in hours. As the MTBF increases, so does the system’s reliability. The MTBF is given by

$MTBF = \int_{0}^{h} R(q) dq = \int_{0}^{h} e^{-\mu q} dq = \frac{1}{\mu}$. \tag{9}

Mean Time to Repair
The reciprocal of the system repair rate is specified as MTTR given by

$MTTR = \mu^{-1}$ \tag{10}

where $\mu$ is the system’s repair rate.

FORMULATION OF MATHEMATICAL MODELS FOR RAMD
In this section, Chapman Kolmogorov differential equations for each subsystem have been constructed using the Markov birth-death process for mathematical modeling of textile manufacturing system. Table 3 displays various subsystem failure and repair rates. Table 4 below gives the description of the state of each subsystem.

Table 3. Failure and repair rate

<table>
<thead>
<tr>
<th>Machine/Subsystem</th>
<th>Failure rate ($\lambda$) Operational Units</th>
<th>Failure rate ($\alpha$) Warm standby Units</th>
<th>Repair rate ($\mu$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weaving (A)</td>
<td>0.015</td>
<td>0.015</td>
<td>0.35</td>
</tr>
<tr>
<td>Dry Clean (B)</td>
<td>0.025</td>
<td>0.016</td>
<td>0.20</td>
</tr>
<tr>
<td>Cross Cut (C)</td>
<td>0.010</td>
<td>0.014</td>
<td>0.15</td>
</tr>
<tr>
<td>Side Seam (D)</td>
<td>0.035</td>
<td>0.017</td>
<td>0.40</td>
</tr>
<tr>
<td>Cleaning (E)</td>
<td>0.050</td>
<td>0.013</td>
<td>0.55</td>
</tr>
</tbody>
</table>

Table 4. Transition rate table for Subsystem A

<table>
<thead>
<tr>
<th>States</th>
<th>$S_0$</th>
<th>$S_1$</th>
<th>$S_2$</th>
<th>$S_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_0$</td>
<td>0</td>
<td>$4\lambda_1 + \alpha_1$</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$S_1$</td>
<td>$\mu_1$</td>
<td>0</td>
<td>$4\lambda_1 + \alpha_1$</td>
<td>0</td>
</tr>
<tr>
<td>$S_2$</td>
<td>0</td>
<td>$2\mu_1$</td>
<td>0</td>
<td>$4\lambda_1$</td>
</tr>
<tr>
<td>$S_3$</td>
<td>0</td>
<td>0</td>
<td>$3\mu_1$</td>
<td>0</td>
</tr>
</tbody>
</table>
RAMD Analysis for Subsystem A (Weaving unit)

This section consists of four primary operation unit (main unit), one warm standby unit and one cold standby unit. When one of the primary units failed, the warm standby unit switch to operation as primary unit and the cold standby unit switch to the position of warm standby unit. Through Table 4 below, the Chapman-Kolmogrov differential difference equations (11)-(14) are derived using Markovian birth-death process.

Where $S_0$ is the perfect state, $S_1$, $S_2$ are partial failure states and $S_3$ is the complete failure state.

$$
\frac{d}{dq} \Phi_0(q) = -(4\lambda_1 + \alpha_1) \Phi_0(q) + \mu_1 \Phi_1(q) \tag{11}
$$

$$
\frac{d}{dq} \Phi_1(q) = -(4\lambda_1 + \alpha_1 + \mu_1) \Phi_1(q) + (4\lambda_1 + \alpha_1) \Phi_0(q) + 2\mu_1 \Phi_2(q) \tag{12}
$$

$$
\frac{d}{dq} \Phi_2(q) = -(4\lambda_1 + 2\mu_1) \Phi_2(q) + (4\lambda_1 + \alpha_1) \Phi_1(q) + 5\mu_1 \Phi_3(q) \tag{13}
$$

$$
\frac{d}{dq} \Phi_3(q) = -3\Phi_3(q) + 4\lambda_1 \Phi_2(q) \tag{14}
$$

The normalizing condition for this problem is

$$
\Phi_0(q) + \Phi_1(q) + \Phi_2(q) + \Phi_3(q) = 1 \tag{15}
$$

Availability of subsystem A is

$$
A_{S_1} = \Phi_0(q) + \Phi_1(q) + \Phi_2(q) \tag{16}
$$

Setting (11) to (14) to zero as $q \to \infty$ in steady state, availability of subsystem A in (16) is now

$$
A_{S_1}(\infty) = \frac{1 + m_1 + \frac{m_1^2}{2}}{1 + m_1 + \frac{m_1^2 + 2\lambda_1 m_1^2}{3\mu_1}} \tag{17}
$$

Where $m_1 = \frac{4\lambda_1 + \alpha_1}{\mu_1}$

The corresponding reliability, maintainability, dependability and MTBF, MTTR for main and warm standby unit of subsystem A are

$$
R_{S_1}(q) = \exp^{-\lambda_1 q} \tag{18}
$$

$$
R_{S_2}(q) = \exp^{-\alpha_1 q} \tag{19}
$$

$$
M_{S_1} = 1 - \exp^{-\lambda_1 q} \tag{20}
$$

Mean time between failure (MTBF) $= \frac{\lambda_1}{\alpha_1} = 66.6667h$ for main unit

Mean time between failure (MTBF) $= \frac{\alpha_1}{\lambda_1} = 66.6667h$ for warm standby unit

Mean time to repair (MTTR) $= \frac{\alpha_1}{\mu_1} = 2.8571h$

Dependability ratio $= \frac{\mu_1}{\lambda_1} = 23.3345$ for main unit

Dependability ratio $= \frac{\mu_1}{\alpha_1} = 23.3345$ for warm standby unit

Table 5. Transition rate table for Subsystem B

<table>
<thead>
<tr>
<th>$S_0$</th>
<th>$S_1$</th>
<th>$S_2$</th>
<th>$S_3$</th>
<th>$S_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\lambda_2 + 2\alpha_2$</td>
<td>$5\lambda_2$</td>
<td>$5\lambda_2 + \alpha_2$</td>
<td>$5\lambda_2 + \alpha_2$</td>
<td>$5\lambda_2 + \alpha_2$</td>
</tr>
<tr>
<td>$\mu_2$</td>
<td>$0$</td>
<td>$0$</td>
<td>$0$</td>
<td>$0$</td>
</tr>
<tr>
<td>$0$</td>
<td>$2\mu_2$</td>
<td>$3\mu_2$</td>
<td>$4\mu_2$</td>
<td>$0$</td>
</tr>
</tbody>
</table>

$$
\frac{d}{dq} \Phi_0(q) = -(5\lambda_2 + \alpha_2) \Phi_0(q) + \mu_2 \Phi_1(q) \tag{21}
$$

$$
\frac{d}{dq} \Phi_1(q) = -(5\lambda_2 + \alpha_2 + \mu_1) \Phi_1(q) + (5\lambda_2 + 2\alpha_2) \Phi_0(q) + 2\mu_1 \Phi_2(q) \tag{22}
$$

$$
\frac{d}{dq} \Phi_2(q) = -(5\lambda_2 + \alpha_2 + 2\mu_1) \Phi_2(q) + (5\lambda_2 + 2\alpha_2) \Phi_1(q) + 5\mu_1 \Phi_3(q) \tag{23}
$$

$$
\frac{d}{dq} \Phi_3(q) = -(5\lambda_2 + 3\mu_2) \Phi_3(q) + (5\lambda_2 + \alpha_2) \Phi_2(q) + 4\mu_2 \Phi_4(q) \tag{24}
$$

$$
\frac{d}{dq} \Phi_4(q) = -4\mu_2 \Phi_3(q) + 5\lambda_2 \Phi_2(q) \tag{25}
$$

RAMD Analysis for Subsystem B (Dry Clean section)

This section consist of five primary unit, two warm standby and one cold standby unit. Similar to the method described in section 4.1 above, from Table 5 the differential difference equations in (21)-(25) are derived using Markovian birth-death process.

Where $S_0$ is the perfect state, $S_1$, $S_2$, $S_3$ are partial failure states and $S_4$ is the complete failure state
The normalizing condition for this problem is
\[
q \circ \frac{d}{dq} = 1 - \frac{1}{d-1} \left( \exp \frac{\ln d}{d-1} - \exp \frac{d \ln d}{d-1} \right) = 0.9357
\]
for main and warm standby unit

RAMD Analysis for Subsystem C (Cross Cut Unit)
The cross-cut section consists of two primary operation unit, two warm standby unit and two cold standby unit. Using the method described in section 4.1 above, the Chapman-Kolmogrov differential difference equations (32)-(37) are derived using Markovian birth-death process from Table 6 below:

Where \( S_0 \) is the perfect state, \( S_1, S_2, S_3, S_4 \) are partial failure states and \( S_5 \) is the complete failure state

The corresponding reliability, maintainability, dependability and MTBF, MTTR for main and warm standby unit of subsystem B are
\[
R_{S2}(q) = \exp^{-\lambda_2 q}
\]
(29)
\[
R_{S2}(q) = \exp^{-\alpha_2 q}
\]
(30)
\[
M_{S2} = 1 - \exp^{-\mu_2 q}
\]
(31)

Mean time between failure (MTBF) = \( \lambda_2^{-1} = 40 \) h for main unit
Mean time between failure (MTBF) = \( \alpha_2^{-1} = 62.5 \) h for warm standby unit
Mean time to repair (MTTR) = \( \mu_2^{-1} = 5h \)
Dependability ratio \( d = \frac{\mu_2}{\lambda_2} = 8 \) for main unit

The normalizing condition for this problem is
\[
\frac{d}{dq} q \circ \frac{d}{dq} = 1 - \frac{1}{d-1} \left( \exp \frac{\ln d}{d-1} - \exp \frac{d \ln d}{d-1} \right) = 0.8877
\]

Availability of subsystem C is

<table>
<thead>
<tr>
<th>( S_0 )</th>
<th>( S_1 )</th>
<th>( S_2 )</th>
<th>( S_3 )</th>
<th>( S_4 )</th>
<th>( S_5 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( S_0 )</td>
<td>0</td>
<td>( 2\lambda_3 + 2\alpha_3 )</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>( S_1 )</td>
<td>( \mu_3 )</td>
<td>0</td>
<td>( 2\lambda_3 + 2\alpha_3 )</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>( S_2 )</td>
<td>0</td>
<td>( 2\mu_3 )</td>
<td>0</td>
<td>( 2\lambda_3 + 2\alpha_3 )</td>
<td>0</td>
</tr>
<tr>
<td>( S_3 )</td>
<td>0</td>
<td>0</td>
<td>( 3\mu_3 )</td>
<td>0</td>
<td>( 2\lambda_3 + \alpha_3 )</td>
</tr>
<tr>
<td>( S_4 )</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>( 4\mu_3 )</td>
<td>0</td>
</tr>
<tr>
<td>( S_5 )</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>( 5\mu_3 )</td>
</tr>
</tbody>
</table>
Setting (32) to (37) to zero as $q \to \infty$ in steady state, availability of subsystem C in (39) is now

$$A_{s3} = \Phi(t) + \theta(t) + \Phi(t) + \Phi(t) + \Phi(t)$$

(39)

The Corresponding reliability, maintainability, dependability and MTBF, MTTR for main and warm standby unit of subsystem C are

$$R_{s3}(q) = \exp^{-\lambda \beta q}$$

(41)

$$R_{s3}(q) = \exp^{-\alpha \gamma q}$$

(42)

$$M_{s3} = 1 - \exp^{-\eta q}$$

(43)

Mean time between failure (MTBF) = $\lambda_{s3}^{-1} = 100h$ for main unit

Mean time between failure (MTBF) = $\alpha_{s3}^{-1} = 71.4286h$ for warm standby unit

Mean time to repair (MTTR) = $\eta^{-1} = 5h$

Dependability ratio $d = \frac{\mu}{\lambda_{s3}} = 14.9999$ for main unit

$$D_{\text{min}}(s_3) = 1 \left(1 - \left(\frac{1}{d-1}\right)\left(\exp^{\frac{d \ln d}{d-1}} - \exp^{\frac{d \ln d}{d-1}}\right)\right) = 0.9451$$

for main unit

Dependability ratio $d = \frac{\mu}{\alpha_{s3}} = 14.2857$ for warm standby unit

$$D_{\text{min}}(s_3) = 1 \left(1 - \left(\frac{1}{d-1}\right)\left(\exp^{\frac{d \ln d}{d-1}} - \exp^{\frac{d \ln d}{d-1}}\right)\right) = 0.9427$$

for main and warm standby unit

RAMD Analysis for Subsystem D (Side Seam)

The side seam section consists of three primary operation unit, two warm standby unit and one cold standby unit. Using the method described in section 4.1 above, the Chapman-Kolmogrov differential difference equations (44)-(48) are derived using Markovian birth-death process from Table 7 below.

$$\frac{d}{dq} \Phi(q) = -(3\lambda_{s4} + 2\alpha_{s4}) \Phi(q) + \mu_s \Phi(q)$$

(44)

$$\frac{d}{dq} \theta(q) = -((3\lambda_{s4} + 2\alpha_{s4}) \theta(q) + 3\lambda_{s4} + 2\alpha_{s4}) \theta(q) + 2\mu_s \theta(q)$$

(45)

$$\frac{d}{dq} \Phi(q) = -(3\lambda_{s4} + 3\mu_s) \Phi(q) + (3\lambda_{s4} + 2\alpha_{s4}) \Phi(q) + 3\mu_s \Phi(q)$$

(46)

$$\frac{d}{dq} \Phi(q) = -(3\lambda_{s4} + 3\mu_s) \Phi(q) + (3\lambda_{s4} + 2\alpha_{s4}) \Phi(q) + 4\mu_s \Phi(q)$$

(47)

$$\frac{d}{dq} \Phi(q) = -4\mu_s \Phi(q) + 3\lambda_{s4} \Phi(q)$$

(48)

The normalizing condition for this problem is

$$\Phi(q) + \Phi(q) + \Phi(q) + \Phi(q) = 1$$

(49)

Availability of subsystem D is

$$A_{s4} = \Phi(q) + \Phi(q) + \Phi(q) + \Phi(q)$$

(50)

Setting (44) to (48) to zero as $q \to \infty$ in steady state, availability of subsystem D in (50) is now

$$A_{s4} = \frac{1 + \left(3\lambda_{s4} + 2\alpha_{s4}\right) \mu_s}{\left(3\lambda_{s4} + 2\alpha_{s4}\right) \mu_s} \frac{(3\lambda_{s4} + \alpha_{s4}) \mu_s}{\mu_s} \frac{3\lambda_{s4} + \alpha_{s4}}{2\mu_s} \frac{(3\lambda_{s4} + \alpha_{s4}) \mu_s}{\mu_s} \frac{3\lambda_{s4} + \alpha_{s4}}{2\mu_s}$$

(51)

The Corresponding reliability, maintainability, dependability and MTBF, MTTR for main and warm standby unit of subsystem D are

$$R_{s4}(q) = \exp^{-\lambda_{s4} q}$$

(52)

$$R_{s4}(q) = \exp^{-\alpha_{s4} q}$$

(53)

$$M_{s4} = 1 - \exp^{-\mu_{s4} q}$$

(54)

Mean time between failure (MTBF) = $\lambda_{s4}^{-1} = 28.5714h$

for main unit
Mean time between failure (MTBF) = $\alpha_1^{-1} = 58.8235 \text{h}$
for warm standby unit
Mean time to repair (MTTR) = $\mu_1^{-1} = 2.5 \text{h}$
Dependability ratio $d = \frac{\mu_3}{\lambda_3} = 11.4286$ for main unit

$$D_{\text{min}}(s_4) = 1 - \left( \frac{1}{d - 1} \right) \left( \exp \frac{\text{ind}}{d - 1} - \exp \frac{\text{ind}}{d - 1} \right) = 0.9307$$
for main unit
Dependability ratio $d = \frac{\mu_4}{\alpha_4} = 23.5294$ for warm standby unit

$$D_{\text{min}}(s_4) = 1 - \left( \frac{1}{d - 1} \right) \left( \exp \frac{\text{ind}}{d - 1} - \exp \frac{\text{ind}}{d - 1} \right) = 0.9630$$
for main and warm standby unit

**RAMD Analysis for Subsystem E (Cleaning)**

The cleaning section consists of four primary operation units, two warm standby unit and one cold standby unit. Using the method described in section 4.1 above, the Chapman-Kolmogrov differential difference equations (55)-(59) are derived using Markovian birth-death process from Table 8 below.

### Table 8. Transition rate table for Subsystem E

<table>
<thead>
<tr>
<th>$S_0$</th>
<th>$S_1$</th>
<th>$S_2$</th>
<th>$S_3$</th>
<th>$S_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_0$</td>
<td>0</td>
<td>$4\lambda_2 + 2\alpha_5$</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$S_1$</td>
<td>$\mu_5$</td>
<td>0</td>
<td>$4\lambda_2 + 2\alpha_5$</td>
<td>0</td>
</tr>
<tr>
<td>$S_2$</td>
<td>0</td>
<td>$2\mu_5$</td>
<td>0</td>
<td>$4\lambda_2 + \alpha_5$</td>
</tr>
<tr>
<td>$S_3$</td>
<td>0</td>
<td>0</td>
<td>$3\mu_5$</td>
<td>0</td>
</tr>
<tr>
<td>$S_4$</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>$4\mu_5$</td>
</tr>
</tbody>
</table>

Where $S_0$ is the perfect state, $S_1$, $S_2$, $S_3$ are partial failure states and $S_4$ is the complete failure state

$$\frac{d}{dq} \vartheta_1(q) = -(4\lambda_5 + 2\alpha_5) \vartheta_0(q) + \mu_5 \vartheta_1(q)$$

$$\frac{d}{dq} \vartheta_2(q) = -(4\lambda_5 + 2\alpha_5 + \mu_5) \vartheta_1(q) + (4\lambda_5 + 2\alpha_5) \vartheta_2(q) + 2\mu_5 \vartheta_3(q)$$

$$\frac{d}{dq} \vartheta_3(q) = -(4\lambda_5 + \alpha_5 + 2\mu_5) \vartheta_2(q) + (4\lambda_5 + \alpha_5) \vartheta_3(q) + 3\mu_5 \vartheta_4(q)$$

$$\frac{d}{dq} \vartheta_4(q) = -(4\lambda_5 + 3\mu_5) \vartheta_3(q) + (4\lambda_5 + \alpha_5) \vartheta_4(q) + 4\mu_5 \vartheta_5(q)$$

$$\frac{d}{dq} \vartheta_5(q) = -4\mu_5 \vartheta_4(q) + 4\lambda_5 \vartheta_5(q)$$

The normalizing condition for this problem is

$$\vartheta_0(q) + \vartheta_1(q) + \vartheta_2(q) + \vartheta_3(q) + \vartheta_4(q) = 1$$

Availability of subsystem E is

$$A_{55} = \vartheta_0(q) + \vartheta_1(q) + \vartheta_2(q) + \vartheta_3(q)$$

Setting (55) to (59) to zero as $q \otimes \bigcup$ in steady state, availability of subsystem E in (61) is now

$$A_{55} = \frac{1 + \frac{m_5}{\mu_5} + \frac{m_2}{\mu_2} + \frac{(4\lambda_5 + \alpha_5)m_5^2}{6\mu_5^2}}{1 + \frac{m_5}{\mu_5} + \frac{m_2}{\mu_2} + \frac{(4\lambda_5 + \alpha_5)m_5^2}{6\mu_5^2} + \frac{\lambda_5(4\lambda_5 + \alpha_5)m_5^2}{24\mu_5^2}}$$

$$m_5 = (4\lambda_5 + 2\alpha_5)$$

The Corresponding reliability, maintainability, dependability and MTBF, MTTR for main and warm standby unit of subsystem D are

$$R_{54}(q) = \exp^{-\lambda_5 q}$$

$$R_{54}(q) = \exp^{-\mu_5 q}$$

$$M_{55} = 1 - \exp^{-\mu_5 q}$$

Mean time between failure (MTBF) = $\lambda_5^{-1} = 20 \text{h}$ for main unit
Mean time between failure (MTBF) = $\lambda_5^{-1} = 76.9230 \text{h}$
for warm standby unit
Mean time to repair (MTTR) = $\mu_5^{-1} = 1.81823 \text{h}$
Dependability ratio $d = \frac{\mu_5}{\lambda_5} = 10.9285$ for main unit

$$D_{\text{min}}(s_5) = 1 - \left( \frac{1}{d - 1} \right) \left( \exp \frac{\text{ind}}{d - 1} - \exp \frac{\text{ind}}{d - 1} \right) = 0.9285$$
for main unit
Dependability ratio $d = \frac{\mu_5}{\alpha_5} = 42.3072$ for warm standby unit

$$D_{\text{min}}(s_5) = 1 - \left( \frac{1}{d - 1} \right) \left( \exp \frac{\text{ind}}{d - 1} - \exp \frac{\text{ind}}{d - 1} \right) = 0.9784$$
for main and warm standby unit
NUMERICAL SIMULATIONS AND DISCUSSION

Numerical simulations of reliability, availability, maintainability, and dependability are discussed in this section.

Reliability Using Exponential Distribution

Reliability Using Lindley Distribution

Reliability Using Exponentiated Weibull Distribution

This section discusses the numerical simulations in order to obtain understanding of how the strength, efficacy, and performance of the model under review are evaluated at various levels. Here, we employ the exponential, Lindley, and exponentiated Weibull distributions as three alternative distributions to first choose the optimum distribution that will improve system reliability. On the basis of this, the performance of the model is evaluated.

Table 9 and Figure 1 displayed the results of availability of individual subsystems and the entire system with respect to failure rates. From the table and figure, it is noted that availability of individual subsystems and the entire system decreases with increase in failure rate. It is clear from the table and figure that the availability of the system is lower than the availability of the individual subsystems. This can

<table>
<thead>
<tr>
<th>Failure rate</th>
<th>Availability Subsystem A</th>
<th>Availability Subsystem B</th>
<th>Availability Subsystem C</th>
<th>Availability Subsystem D</th>
<th>Availability Subsystem E</th>
<th>System</th>
</tr>
</thead>
<tbody>
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<td>0.00</td>
<td>1.0000</td>
<td>1.0000</td>
<td>1.0000</td>
<td>1.0000</td>
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</tr>
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<td>1.0000</td>
<td>0.9998</td>
</tr>
<tr>
<td>0.04</td>
<td>0.9999</td>
<td>0.9999</td>
<td>0.9994</td>
<td>1.0000</td>
<td>0.9999</td>
<td>0.9991</td>
</tr>
<tr>
<td>0.06</td>
<td>0.9998</td>
<td>0.9998</td>
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<td>0.9999</td>
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</tr>
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<td>0.08</td>
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<td>0.9998</td>
<td>0.9972</td>
</tr>
</tbody>
</table>

Table 9. Variation in Availability of system due to with respect to availability of individual subsystem

<table>
<thead>
<tr>
<th>Time</th>
<th>Reliability of Subsystem A $\lambda_1 = 0.015$</th>
<th>Reliability of Subsystem B $\lambda_2 = 0.025$</th>
<th>Reliability of Subsystem C $\lambda_3 = 0.010$</th>
<th>Reliability of Subsystem D $\lambda_4 = 0.035$</th>
<th>Reliability of Subsystem E $\lambda_5 = 0.050$</th>
<th>System Reliability</th>
</tr>
</thead>
<tbody>
<tr>
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<td>1.0000000000</td>
<td>1.0000000000</td>
<td>1.0000000000</td>
<td>1.0000000000</td>
<td>1.0000000000</td>
<td>1.0000000000</td>
</tr>
<tr>
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<td>0.60653066</td>
<td>0.81873075</td>
<td>0.49658530</td>
<td>0.36787944</td>
<td>0.06720551</td>
</tr>
<tr>
<td>40</td>
<td>0.54881164</td>
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<td>0.67032005</td>
<td>0.24659696</td>
<td>0.13533528</td>
<td>0.00451658</td>
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</tr>
<tr>
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<td>0.00673794</td>
<td>0.00000137</td>
</tr>
</tbody>
</table>

Figure 1. Availability of the system and individual subsystems.
lead to decrease in production which will in turn culminated in less revenue mobilization. To avert this problem adequate preventive maintenance before such as regular inspection, oiling, greasing etc should be invoke to avoid system failure. From the table and figure, it is worthwhile to notice that subsystem C has the least availability. Therefore, maintenance priority should be set aside to subsystem C in order to improve its availability.

Table 10 and Figure 2 and table 11 and Figure 3 presents the results of reliability of the individual subsystems and the system when the failure rate of the main and warm standby unit follows exponential distribution. The table and figure show that reliability decreases drastically with passage of time.
time from 0 to 100. From the table and figure it can be seen that reliability of the system is less than the reliability of each subsystem. Subsystem E has the least reliability among the subsystems from the Table 10 and Figure 2 when the failure rate of the main unit obeys exponential distribution while subsystem D has the least reliability from Table 11 and Figure 3 when the failure rate of the warm standby unit obeys exponential distribution. From Table 12 and Figure 4 and Table 13 and Figure 5 for reliability analysis of the individual subsystems and the system when the failure rate of the main and warm standby unit obeys Lindley distribution. It is observed from the

<table>
<thead>
<tr>
<th>Time</th>
<th>Reliability of Subsystem A ( \lambda_1 = 0.015 )</th>
<th>Reliability of Subsystem B ( \lambda_2 = 0.025 )</th>
<th>Reliability of Subsystem C ( \lambda_3 = 0.010 )</th>
<th>Reliability of Subsystem D ( \lambda_4 = 0.035 )</th>
<th>Reliability of Subsystem E ( \lambda_5 = 0.050 )</th>
<th>System Reliability</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.03882340</td>
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</tr>
</tbody>
</table>

Figure 4. Variation in reliability of system due to changes in Lindley failure rate of subsystems for main unit.

<table>
<thead>
<tr>
<th>Time</th>
<th>Reliability of Subsystem A ( \alpha_1 = 0.015 )</th>
<th>Reliability of Subsystem B ( \alpha_2 = 0.016 )</th>
<th>Reliability of Subsystem C ( \beta_3 = 0.014 )</th>
<th>Reliability of Subsystem D ( \alpha_4 = 0.017 )</th>
<th>Reliability of Subsystem E ( \alpha_5 = 0.013 )</th>
<th>System Reliability</th>
</tr>
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<tbody>
<tr>
<td>0</td>
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</table>

Table 12. Variation in reliability of system due to changes in Lindley failure rate of subsystems for main unit

Table 13. Variation in reliability of system due to changes in Lindley failure rate of subsystems for Warm standby Unit
Table 14. Variation in reliability of system due to changes in Exponentiated Weibull failure rate of subsystems for main unit

<table>
<thead>
<tr>
<th>Time</th>
<th>Reliability of Subsystem A $\lambda_1 = 0.015$</th>
<th>Reliability of Subsystem B $\lambda_2 = 0.025$</th>
<th>Reliability of Subsystem C $\lambda_3 = 0.010$</th>
<th>Reliability of Subsystem D $\lambda_4 = 0.035$</th>
<th>Reliability of Subsystem E $\lambda_5 = 0.050$</th>
<th>System Reliability</th>
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Figure 5. Variation in reliability of system due to changes in Lindley failure rate of subsystems for warm standby unit.

Figure 6. Variation in reliability of system due to changes in Exponentiated Weibull failure rate of subsystems for main unit.
Table 15. Variation in reliability of system due to changes in Exponentiated Weibull failure rate of subsystems for warm standby unit

<table>
<thead>
<tr>
<th>Time</th>
<th>Reliability of Subsystem A $\alpha_1 = 0.015$</th>
<th>Reliability of Subsystem B $\alpha_2 = 0.016$</th>
<th>Reliability of Subsystem C $\alpha_3 = 0.014$</th>
<th>Reliability of Subsystem D $\alpha_4 = 0.017$</th>
<th>Reliability of Subsystem E $\alpha_5 = 0.013$</th>
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<td>0.91692365</td>
<td>0.94758262</td>
<td>0.70499843</td>
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</table>

Figure 7. Variation in reliability of system due to changes in Exponentiated Weibull failure rate of subsystems for warm standby unit.

Figure 8. Reliability for main unit failure against time for different distributions.
tables and figures that reliability decreases slightly with passage of time from 0 to 100 in which reliability of the system is less than the reliability of each subsystem. It is evident from the tables and figures that subsystem E has the least reliability among the subsystems when the failure rate of the main obeys Lindley distribution and subsystem D for warm standby unit obeys Lindley distribution.

On the other hand, when the failure follows exponentiated Weibull distribution for both main and warm standby unit. From Table 14 and Figure 6 and Table 15 and Figure 7 for reliability analysis of the individual subsystems and the system.
system it is clear that reliability decreases slightly with passage of time from 0 to 100 in which reliability of the system is less than the reliability of each subsystem. It is evident from the tables and figures that subsystem C for main unit has the least reliability among the subsystems and subsystem D is the least when the failure rate of warm standby unit obeys exponentiated Weibull distribution. Exponentiated Weibull distribution, in contrast, has a higher system reliability than the other two distributions for both main unit and warm standby units. This is seen in Figure 8 and 9, Table 14 and Figure 6 and Table 15 and Figure 7. The variation in system reliability caused by variations in the exponentiated Weibull failure rate of subsystems for main units is depicted in table 13 and figure 6. From this table 13 and its corresponding figure 6, we can see that the system reliability’s equivalent values for main unit at time $t = 40$ are $\text{Rel. subsystem A} = 0.99999916$, $\text{Rel. subsystem B} = 0.99966453$, $\text{Rel. subsystem C} = 0.99752124$, $\text{Rel. subsystem D} = 0.99999988$ and $\text{Rel. subsystem E} = 0.99999999$. The system is 0.33632241 times reliable at $t = 60$ due to a form decline. This is brought on by the low reliability value of subsystem C. This demonstrates that subsystem C is the main unit’s key subsystem. The value of availability is another indicator of how important subsystem C is to the main unit.

Table 9-15 and Figure 1-7 show the variation in system reliability caused by changes in the exponential, Lindley and exponentiated Weibull failure rate of the main and warm standby unit’s subsystems. Subsystems with the lowest reliability value among the other subsystems need adequate attention of the management for proper maintenance in order to avoid system breakdown and subsequent loss of production and revenue as the tables and figures make sufficient evident. This demonstrates that critical subsystems are the most important and delicate part of the system and needs careful consideration.

<table>
<thead>
<tr>
<th>Table 17. Ramd indices</th>
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<tr>
<td>Reliability Warm</td>
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<tr>
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<td>Dependability Main</td>
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<td>Dependability Warm</td>
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<tr>
<td>MTTR</td>
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<tr>
<td>MTBF Main</td>
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<tr>
<td>MTBF Warm</td>
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<tr>
<td>Dependability ratio Main</td>
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<tr>
<td>Dependability ratio Warm</td>
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</table>
CONCLUSION

In this study, the metrics of RAMD for both weaving, dry clean, cross cut, side seam and cleaning section of the textile are analyzed to assess the performance of the textile manufacturing system. Expressions associated with metrics for weaving, dry clean, cross cut, side seam and cleaning section have been derived and numerical experiments are performed. The assumed values for failure and repair rates for each subsystem are given in Table 1. Table 16 lists all RAMD measurements, while tables 3 and 4 capture the variation in reliability and maintainability over time, respectively. Tables 9, 10, 11, 13 and 14 indicate the impact of different failure rates on subsystems and system reliability and figures 2-7 that side seam is the most important and delicate component of the system. The models/results described in this work, if modified, will allow management to stop poor reliability assessments and decision-making, which will cause high expenditures. Moreover, the accepted framework for the model under considerations inspection and maintenance could be proposed and incorporated to satisfy the client and lower failure rates. These are the findings of the current investigation. This work can be enlarged to include both offline and online routine maintenance at both partial and total failure states. This study will be carried out in the future.

REFERENCES


[21] Yen TC, Wang KH. Cost benefit analysis of four
retrial systems with warm standby units and imperfect coverage. Reliab Eng Syst Saf 2020;202. [CrossRef]


