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Sensitivity Analysis and RAMD Investigation of Ghee Producing Unit of Milk Plant

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Abstract: The main aim of present investigation is to perform sensitivity analysis and reliability, availability, maintainability, and dependability (RAMD) investigation of ghee producing entity of milk plant. The ghee producing unit comprises four components viz. melting vats, boilers, ghee clarifier and ghee settling tank. These components configured in series structure having various types of redundancies. All the components' failure and repair distribution are exponentially distributed. The switch devices, repairs are perfect and sufficient repair facilities available with system. Simple probabilistic arguments and Markov methodology is used to derive the reliability measures od system components. Various system effectiveness characteristics of ghee producing unit and its components are derived. The numerical behavior of system in transient state is discussed to explore the execution of organization under various failure and repair rates. It is revealed from numerical results that system availability is 0.75403 and ghee settling tank is most sensitive component. The results may be utilized by maintenance personnel and system designers of milk plants to improve the performance of the plants.

Keywords: Ghee Producing Unit; Milk Plant; Sensitivity Analysis; Reliability; Maintainability.

2010 Mathematics Subject Classification. 90B25; 60K10.

1 Introduction

In present age of science and technology, dairy industry is a fastest growing sector in rural areas of developing countries. The key objective of establishment of dairy business is to conserve the milk for future use by converting it into various looks like ghee, powder milk, paneer, and butter. Ghee is one of the most used commodities in kitchen and it is filled with high nutrition. In ancient era, human being converts the milk into ghee so that it's self-life increased and it is used for long duration. It is used in the age of pre technological developments when refrigeration and pasteurization are not known to humans. Now, in current age automation introduced in all most all industrial sectors and dairy sector also benefited by it. A lot of advanced automated complex machinery of dairy industry developed and produced at affordable rates. Though the complexity of these machinery influences the performance of the dairy industry. That's why, it becomes necessary to investigate these systems at micro level. And RAMD is a suggested approach to understand the execution of the dairy plant and its components with respect to time and at numerous failure and repair rates. The advanced equipment's designed in such a way that they perform their task accurately, but chances of failures cannot be eliminated completely. Reliability of the components and system helps in the design of the system while availability, maintainability and dependability helped in planning the maintenance strategies for the system. Several studies have been conducted on the reliability and performance evaluation of manufacturing industries including dairy plants using various approaches of reliability evaluation. Few well-known approaches used in process industries are Markovian approach, semi-Markovian approach, tie method and minimal cut set approach. Adel *et al.* [1] explored the applicability of fuzzy failure mode, effect and criticality analysis in ghee and shop industries. The stretched run of criticality ranking assessment is proposed in this analysis. Aggarwal *et al.* [3] performed the availability optimisation of butter oil production unit and suggested a mathematical model for the same. Gupta *et al.* [6] investigated the performance of

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generator unit of steam turbine power plants. The reliability and maintainability of components and power plant derived using Markov approach by considering constant failure and repair rates. Goyal *et al.* [5] executed the sensitivity analysis of reliability characteristics of the physical processing unit of sewage plant. All the components in physical processing unit were configured in series structure. Kumar *et al.* [10] built a Markov model for tube-wells combined with concealed channels and most susceptible section recognized using RAMD algorithm. It is explored that source of energy played the critical role in operation of TIUP systems. Kumari *et al.* [12] worked on the performance evaluation of a butter-oil industry using Markov approach and supplementary variable technique. All the breakdown levels of the parts are measured as exponentially distributed. Kumar *et al.* [11] suggested an efficient stochastic model for e-waste management plant and performed RAMD investigation for identification of most sensitive component. Kajal and Tewari [8] used Markov approach for availability analysis of dairy plant and optimized the availability by using genetic algorithm. Maihulla and Yusuf [15] utilized RAMD approach in performance evaluation of photovoltaic systems assembled in solar power plants. Saini *et al.* [18] suggested an efficient and intelligent system for irrigation through optimization of reliability measures. Saini *et al.* [17] utilized RAMD methodology in reliability evaluation of microprocessor systems and proposed the maintenance strategies. Talkit *et al.* [21] investigated the reliability of repairable equipment's of dairy industries. Usman and Yusuf [22] utilized RAMD technique in serial industry like rice plants by incorporating the concept of coverage factor. Loganathan *et al.* [14] semi-Markovian approach for the investigation of reliability measures of manufacturing system. Sharma and Vishwakarma [19] explored the applicability of Markovian approach in the reliability evaluation of feeding system of sugar plants. Afsharnia *et al.* [2] used Markov chain for availability evaluation of sugarcane harvesting system. Kumar [9] utilized Markov approach for availability evaluation of boiler air circulation system in thermal power plants. Sachdeva *et al.* [16] used generalized stochastic petri nets approach for availability modelling of a screening system of paper plant. Kushwaha *et al.* [13] developed an intuitionistic fuzzy modelling-based integrated system for performance evaluation of juice clarification unit. Sobhani and Shahrokhi [20] utilized Markov chain methodology for availability optimization of multistate industrial system. Aly *et al.* [4] conducted comprehensive investigation of an industrial system by evaluating RAM measures. Gupta [7] suggested a stochastic model for reliability evaluation of critical industrial systems. It is observed that Markovian approach is the best suited methodology for availability evaluation of process industries having constant failure and repair rates. So far dairy product manufacturing industries not investigated using Markov approach at component level. So, here an RAMD investigation is made at component level with the objectives:

–Development of stochastic model for each subsystem of dairy plant
–Evaluation of reliability, availability, maintainability, and dependability of each subsystem
–Sensitivity analysis of the reliability of the dairy plant.

By keeping above facts and figure, the present study is performed with an objective of sensitivity analysis and RAMD investigation of ghee producing unit of milk plant. The ghee producing unit comprises four components viz. melting vats, boilers, ghee clarifier and ghee settling tank. All these components configured in series structure having various types of redundancies. All the components' breakdown and restoration distribution are exponentially distributed. The switch devices, repairs are perfect and adequate restoration capabilities accessible in plant. Various system effectiveness characteristics of ghee producing unit and its components are derived. The numerical behaviour of system in transient state is discussed to explore the execution of system under various breakdown and restoration rates. The results may be utilized by maintenance personnel and system designers of milk plants to improve the performance of the plants.

2 Material and Methods

2.1 System Description

Ghee is the traditional Indian name of butter-oil, and it is prominent product manufactured by dairy plant. In this system, raw material received as butter from the butter production unit. The system has four subsystems arranged in series structure. The subsystems description is as follows:

–*Melting Vats*: It is first subsystem of ghee production unit that comprises two non-identical components in cold standby redundancy. These components are used for melting the butter. The failure of both vats resulted the complete plant failure.
–*Boilers*: It is another important component of ghee production unit. It consists of three similar components, and it works in 2-out-of-3: *G* configuration. It boils the butter upto 180 degrees.
–*Clarifier*: Ghee clarifiers is an advance technology equipment that collect ghee from boilers. It is comprising with single component and failure resulted in complete ghee production plant.
–*Ghee Settling Tank*: The ghee is transferred from clarifiers to the settling tanks and after few hours' residuals are removed. It is comprising with single component and failure resulted in complete ghee production plant.

2.2 Notations

The mathematical model of ghee production plant is developed based on transition diagram using following notations:

(α_1, α_2) and (β_1, β_2)	:	Failure and repair rates of non-identical melting vats
γ and θ	:	Breakdown and restoration rates of boilers
τ and λ	:	Breakdown and restoration rates of clarifier
τ_1 and λ_1	:	Failure and repair rates of ghee settling tanks
$O/S/Fur/F$	:	Operating/standby/failed under repair /failed melting vats
$Z/Z1/z$	:	Operative/partially operative/failed boilers
Y/y	:	Operative/failed clarifier
X/x	:	Operative/failed ghee settling tank
$P_i(t)$	:	Probability that system is in the *i*th state at time *t*
$P_i'(t)$	:	Derivative of *i*th state probability at time *t*

2.3 Assumptions

The existing investigation is done beneath the subsequent set of beliefs:

–All the components worked with full capacity in the beginning.
–Sufficient repair facility always available.
–No simultaneous failures occurrence.
–Repairs, switches, and maintenance activities are perfect.
–All random variables are statistically independent.

3 RAMD Investigation of Ghee Producing Unit

In this section, reliability, availability, maintainability, and dependability analysis of a ghee processing unit is performed. All random variables associated with failure and repair rates are exponentially distributed and Markov methodology is opted for development of stochastic models of subsystems. The state transition diagram of all subsystems is shown in Figures 1-4.

3.1 Analysis of Melting Vats

The melting vats is a prominent subsystem/component of ghee producing unit. In proposed system two non-identical melting vats configured in cold standby redundancy. The failure of both the melting vats resulted in the complete system failure. The mathematical model based on transition diagram given in Figure 1 is appended below:

$$\begin{aligned} & P_0(t+\Delta t) = (1-\alpha_1\Delta t)P_0(t) + \beta_1 P_1(t)\Delta t \\ \Rightarrow\ & P_0'(t) = -\alpha_1 P_0(t) + \beta_1 P_1(t) \\ & P_1'(t) = -(\beta_1+\alpha_2)P_1(t) + \alpha_1 P_0(t) + \beta_2 P_2(t) \\ & P_2'(t) = -\beta_2 P_2(t) + \alpha_2 P_1(t)\,. \end{aligned} \tag{1}$$

Taking $t \to \infty$ on equation (1), we get

$$\begin{aligned} & -\alpha_1 P_0 + \beta_1 P_1 = 0 \\ & -(\beta_1+\alpha_2)P_1 + \alpha_1 P_0 + \beta_2 P_2 = 0 \\ & -\beta_2 P_2 + \alpha_2 P_1 = 0 \end{aligned} \tag{2}$$

Using normalization $\sum P_i = 1$ and initial conditions, $P_k(0) = \begin{cases} 1, & \text{if } k = 0, \\ 0, & \text{if } k \neq 0 \end{cases}$ in equation (2), the availability of the system is derived as follows:

$$\text{availability} = \left[1+\frac{\alpha_1}{\beta_1}\right]\left[1+\frac{\alpha_1}{\beta_1}+\frac{\alpha_1\alpha_2}{\beta_1\beta_2}\right]^{-1}. \tag{3}$$

Other reliability measures of system effectiveness for melting vats are mentioned below:

MTTR $= \dfrac{1}{\beta_1+\beta_2}$; Reliability $= e^{-(\alpha_1+\alpha_2)t}$; MTBF $= \dfrac{1}{\alpha_1+\alpha_2}$; $M(t) = 1-e^{-(\beta_1+\beta_2)t}$;

$d = \dfrac{MTBF}{MTTR} = \dfrac{\beta_1+\beta_2}{\alpha_1+\alpha_2}$ and $D_{\min} = 1-\left(\dfrac{1}{d-1}\right)\left(e^{\frac{-\ln d}{d-1}} - e^{\frac{-d\ln d}{d-1}}\right)$.

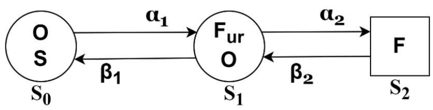

Fig. 1: State transition diagram of melting vats.

3.2 Analysis of Boilers

Boiler is a prominent component of ghee producing unit. In proposed system three boiler components are configured in 2-out-of-3: *G* arrangement. The breakdown of two or more components resulted as the complete system failure. The mathematical model based on transition diagram given in Figure 2 is appended below:

$$\begin{aligned} P_0'(t) &= -3\gamma P_0(t) + \theta P_1(t) \\ P_1'(t) &= -(\theta+2\gamma)P_1(t) + 3\gamma P_0(t) + \theta P_2(t) \\ P_2'(t) &= -\theta P_2(t) + 2\gamma P_1(t) \end{aligned} \tag{4}$$

Taking limit $t \to \infty$ on equation (4), we get

$$\begin{aligned} &-3\gamma P_0 + \theta P_1 = 0 \\ &-(\theta+2\gamma)P_1 + 3\gamma P_0 + \theta P_2 = 0 \\ &-\theta P_2 + 2\gamma P_1 = 0 \end{aligned} \tag{5}$$

Using normalization $\sum P_i = 1$ and initial conditions $P_k(t=0) = \begin{cases} 1, & \text{if } k=0, \\ 0, & \text{if } k \neq 0 \end{cases}$; the reliability measures are derived as:

$$\text{availability} = \left[1+\frac{3\gamma}{\theta}\right]\left[1+\frac{3\gamma}{\theta}+\frac{6\gamma^2}{\theta^2}\right]^{-1}. \tag{6}$$

Rest of measures are appended as:

Maintainability $= 1-e^{-2\theta t}$; Reliability $= e^{-5\gamma t}$; Dependability $= 1-\left(\dfrac{1}{d-1}\right)\left(e^{\frac{-\ln d}{d-1}} - e^{\frac{-d\ln d}{d-1}}\right)$.

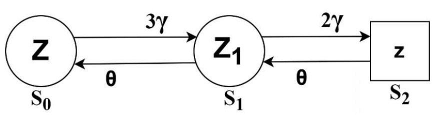

Fig. 2: State transition diagram of boilers.

3.3 Analysis of Clarifier

Clarifier is an important component of ghee producing unit. The proposed system comprises a single clarifier component and its failure resulted complete failure. The mathematical model based on transition diagram given in Figure 3 is appended below:

$$P_0'(t) = -\tau P_0(t) + \lambda P_1(t)$$
$$P_1'(t) = -\lambda P_1(t) + \tau P_0(t) \quad (7)$$

Taking $t \to \infty$ on equation (7), we get

$$-\tau P_0 + \lambda P_1 = 0$$
$$-\lambda P_1 + \tau P_0 = 0 \quad (8)$$

Using normalization $\sum P_i = 1$ and initial conditions $P_k(t=0) = \begin{cases} 1, & \text{if } k=0, \\ 0, & \text{if } k \neq 0 \end{cases}$; the reliability measures are derived as:

$$\text{Availability} = \left[1 + \frac{\tau}{\lambda}\right]^{-1}. \quad (9)$$

Rest of measures are appended as:

Maintainability $= 1 - e^{-\lambda t}$; Reliability $= e^{-\tau t}$; MTBF $= \frac{1}{\tau}$; MTTR $= \frac{1}{\lambda}$; Dependability $= 1 - \left(\frac{1}{d-1}\right)\left(e^{\frac{-\ln d}{d-1}} - e^{\frac{-d\ln d}{d-1}}\right)$.

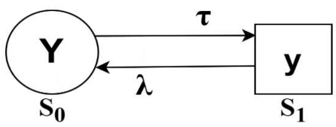

Fig. 3: State transition diagram of clarifier.

3.4 Analysis of Ghee Settling Tank

Ghee settling tank is an important component of ghee producing unit. In the proposed system a single ghee settling component is available whose failure causes complete system failure. The mathematical model based on transition diagram given in Figure 4 is appended below:

$$P_0'(t) = -\tau_1 P_0(t) + \lambda_1 P_1(t)$$
$$P_1'(t) = -\lambda_1 P_1(t) + \tau_1 P_0(t) \quad (10)$$

Taking $t \to \infty$ on equation (10), we get

$$-\tau_1 P_0 + \lambda_1 P_1 = 0$$
$$-\lambda_1 P_1 + \tau_1 P_0 = 0 \quad (11)$$

Using normalization $\sum P_i = 1$ and initial conditions $P_k(t=0) = \begin{cases} 1, & \text{if } k=0, \\ 0, & \text{if } k \neq 0 \end{cases}$; the reliability measures are derived as:

$$\text{Availability} = \left[1 + \frac{\tau_1}{\lambda_1}\right]^{-1}. \quad (12)$$

Maintainability $= 1 - e^{-\lambda_1 t}$; Reliability $= e^{-\tau_1 t}$; MTBF $= \frac{1}{\tau_1}$; MTTR $= \frac{1}{\lambda_1}$;

Dependability $= 1 - \left(\frac{1}{d-1}\right)\left(e^{\frac{-\ln d}{d-1}} - e^{\frac{-d\ln d}{d-1}}\right)$

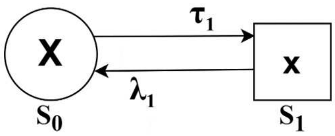

Fig. 4: State transition diagram of ghee settling tank.

4 System RAMD Measures

As all the components configured in a series structure in ghee producing unit and the failure of anyone causes the complete system failure. So, the reliability measures of ghee producing unit is given as follows:

$$\text{Reliability of ghee producing unit} = \prod_{i=1}^{4} R_i(t) = e^{-(\alpha_1+\alpha_2+5\gamma+\tau+\tau_1)t}, \tag{13}$$

$$\text{Availability of ghee producing unit} = \prod_{i=1}^{5} A_i(t) = 0.75403, \tag{14}$$

$$\text{Maintainability of ghee producing unit } = \prod_{i=1}^{5} M_i(t) = 1 - e^{-(\beta_1+\beta_2+2\theta+\lambda+\lambda_1)t}, \tag{15}$$

$$\text{Dependability of ghee producing unit} = \prod_{i=1}^{5} D_i(t) = 0.61339. \tag{16}$$

5 Sensitivity Analysis

Sensitivity analysis is a very popular method to reveal the effect of predictors on the response variables as well as how much any model is sensitive about the structure and predictors under certain set of assumptions. In present study, sensitivity analysis of ghee producing unit's reliability is performed with respect to failure rates of various components is done. The reliability expression given in equation (13) is partially differentiated with respect to various failure rates and following mathematical expressions derived as:

$$\begin{aligned}
&\frac{\partial R(t)}{\partial \alpha_1} = -te^{-(\alpha_1+\alpha_2+5\gamma+\tau+\tau_1)t}; \quad \frac{\partial R(t)}{\partial \alpha_2} = -te^{-(\alpha_1+\alpha_2+5\gamma+\tau+\tau_1)t};\\
&\frac{\partial R(t)}{\partial \gamma} = -5te^{-(\alpha_1+\alpha_2+5\gamma+\tau+\tau_1)t}; \quad \frac{\partial R(t)}{\partial \tau} = -te^{-(\alpha_1+\alpha_2+5\gamma+\tau+\tau_1)t};\\
&\frac{\partial R(t)}{\partial \tau_1} = -te^{-(\alpha_1+\alpha_2+5\gamma+\tau+\tau_1)t}.
\end{aligned} \tag{17}$$

The numerical behavior of the sensitivity is shown for a particular case by considering failure rates as given in Table **??**.

6 Discussion and Conclusion

In this section, numerical results of system effectiveness measures of ghee producing units and its components viz. original melting vat, boilers, clarifier, and ghee settling tank by considering the failure and repair rates suggested by Kumari *et al.* [12] as given in Table 1. From Table 2, it is revealed that the availability of ghee producing unit is 0.75403 that is less than every component of the system. The ghee settling tank is the most sensitive having minimum availability.

Table 1: Failure and repair rates of ghee producing unit

Component Name	Failure rates	Repair rates
Original Melting Vat	$\alpha_1 = 0.01$	$\beta_1 = 0.2$
Duplicate Melting Vat	$\alpha_2 = 0.015$	$\beta_2 = 0.22$
Boilers	$\theta = 0.3$	$\gamma = 0.04$
Clarifier	$\lambda = 0.26$	$\tau = 0.035$
Ghee settling tank	$\lambda_1 = 0.28$	$\tau_1 = 0.045$

Table 2: Availability and other system effectiveness measures of ghee producing unit

Component Name	Availability	Dependability Ratio	MTBF (Hrs.)	MTTR (Hrs.)	Dependability
Melting Vats	0.999843	16.8	40	2.380952	0.95021
Boilers	0.99319	3	5	1.666667	0.80755
Clarifier	0.881356	7.428571	28.57143	3.846154	0.901458
Ghee settling tank	0.861538	6.222222	22.22222	3.571429	0.886754

The maximum mean time between failures of melting vats is 40 hours while minimum is 5 hours for boilers. The highest mean time to repair is 3.846154 hours for clarifier. The highest dependability is 0.95021 for melting vats having highest availability 0.999843.

Table 3: Reliability of various components of ghee manufacturing unit with respect to time

Time (Hrs.)	Melting Vats	Boilers	Clarifier	Ghee settling tank
10	0.778801	0.135335	0.704688	0.637628
20	0.606531	0.018316	0.496585	0.40657
30	0.472367	0.002479	0.349938	0.25924
40	0.367879	0.000335	0.246597	0.165299
50	0.286505	4.54E-05	0.173774	0.105399
60	0.22313	6.14E-06	0.122456	0.067206
70	0.173774	8.32E-07	0.086294	0.042852
80	0.135335	1.13E-07	0.06081	0.027324
90	0.105399	1.52E-08	0.042852	0.017422
100	0.082085	2.06E-09	0.030197	0.011109
500	3.73E-06	3.72E-44	2.51E-08	1.69E-10
1000	1.39E-11	1.38E-87	6.31E-16	2.86E-20
10000	2.7E-109	0	9.9E-153	3.7E-196

It is revealed that boilers are the less reliable component while melting vats is the most reliable component of ghee producing system. It is observed that after 50 hours boilers reliability converges to zero while reliability of other components converges to zero after 100 hours. The maintainability results reflects that every failure can be repair with in 60 hours.

Table 4: Maintainability of various components of ghee manufacturing unit with respect to time

Time (Hrs.)	Melting Vats	Boilers	Clarifier	Ghee settling tank
10	0.985004	0.997521	0.925726	0.93919
20	0.999775	0.999994	0.994483	0.996302
30	0.999997	1	0.99959	0.999775
40	1	1	0.99997	0.999986
50	1	1	0.999998	0.999999
60	1	1	1	1
70	1	1	1	1
80	1	1	1	1
90	1	1	1	1
100	1	1	1	1
500	1	1	1	1
1000	1	1	1	1
10000	1	1	1	1

Table 5: Sensitivity analysis of the reliability of ghee producing unit

Time (Hrs.)	$\frac{\partial R(t)}{\partial \alpha_1}$	$\frac{\partial R(t)}{\partial \alpha_2}$	$\frac{\partial R(t)}{\partial \gamma}$	$\frac{\partial R(t)}{\partial \tau}$	$\frac{\partial R(t)}{\partial \tau_1}$
0	0	0	0	0	0
10	−788.53	−788.53	−3942.65	−788.53	−788.53
20	−3154.12	−3154.12	−15770.6	−3154.12	−3154.12
30	−7096.77	−7096.77	−35483.8	−7096.77	−7096.77
40	−12616.5	−12616.5	−63082.4	−12616.5	−12616.5
50	−19713.2	−19713.2	−98566.2	−19713.2	−19713.2
60	−28387.1	−28387.1	−141935	−28387.1	−28387.1
70	−38638	−38638	−193190	−38638	−38638
80	−50465.9	−50465.9	−252330	−50465.9	−50465.9
90	−63870.9	−63870.9	−319355	−63870.9	−63870.9
100	−78853	−78853	−394265	−78853	−78853

So, it is concluded from Table 3 that, the reliability of the boiler is minimum, and it effects the reliability of the ghee producing unit. Table 4 highlighted that 0.93919 percent changes that failed unit may be repaired within 10 hours. And it takes maximum 60hours in restoration. From sensitivity analysis results as shown in Table 5, it is revealed that boilers are the most sensitive component, and it influences the reliability of the ghee producing unit. Since the investigation is performed on a small-scale ghee producing unit, further it may be extended to large scale industries. So, it is recommended that system designers and maintenance engineers should take utmost care of boilers during operation of ghee manufacturing plants.

Declarations

Competing interests: Authors have no conflict of interest
Authors' contributions: MS: Original draft, software implementation; AK: Model development, Final draft of manuscript
Availability of data and materials: Data is available on request.
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References

[1] A. A. Adel, R. Ahmad, A. M. Badiea, S. A. Mustafa, Application of fuzzy failure mode, effect and criticality analysis (fuzzy FMECA) with extended rule of criticality ranking assessment: A case study in ghee and soap industry, *AIP Conference Proceedings* **2544(1)** (2023).
[2] F. Afsharnia, A. Marzban, M. A. Asoodar, A. Abdeshahi, Availability modeling of sugarcane harvesting system by using markov chain, *Journal of Biosystems Engineering* **45** (2020), 145–154.
[3] A. K. Aggarwal, V. Singh, S. Kumar, Availability analysis and performance optimization of a butter oil production system: a case study, *International Journal of System Assurance Engineering and Management* **8** (2017), 538–554.
[4] M. F. Aly, I. H. Afefy, R. K. Abdel-Magied, E. K. Elhalim, A comprehensive model of reliability, availability, and maintainability (RAM) for industrial systems evaluations, *JJMIE*, **12(1)** (2018), 59–67.
[5] D. Goyal, A. Kumar, M. Saini, H. Joshi, Reliability, maintainability and sensitivity analysis of physical processing unit of sewage treatment plant, *SN Applied Sciences*, **1** (2019), 1–10.
[6] N. Gupta, A. Kumar, M. Saini, Reliability and maintainability investigation of generator in steam turbine power plant using RAMD analysis, *Journal of Physics: Conference Series*, **1714(1)** (2021), 012009.
[7] S. Gupta, Stochastic modelling and availability analysis of a critical engineering system, *International Journal of Quality & Reliability Management*, **36(5)** (2019), 782–796.
[8] S. Kajal, P. C. Tewari, Performance optimization for skim milk powder unit of a dairy plant using genetic algorithm, *Int. J. Eng.*, **25(3)** (2012), 211–221.
[9] R. Kumar, Availability analysis of thermal power plant boiler air circulation system using Markov approach, *Decision Science Letters*, **3(1)** (2014), 65–72.

[10] A. Kumar, M. Saini, R. B. Patil, S. Al-Dahidi, M. A. Mellal, Reliability, availability, maintainability, and dependability analysis of tube-wells integrated with underground pipelines in agricultural fields for irrigation, *Advances in Mechanical Engineering*, **14(8)** (2022), 16878132221115931.

[11] N. Kumar, D. Sinwar, M. Saini, D. K. Saini, A. Kumar, M. Kaur, D. Singh, H.-N. Lee, Efficient computational stochastic framework for performance optimization of E-waste management plant, *Journal of King Saud University-Computer and Information Sciences* **34(8)** (2022), 4712–4728.

[12] P. Kumari, M. S. Kadyan, J. Kumar, Profit analysis of butter-oil (ghee) producing system of milk plant using supplementary variable technique, *International Journal of System Assurance Engineering and Management* **10** (2019), 1627–1638.

[13] D. K. Kushwaha, D. Panchal, A. Sachdeva, Intuitionistic fuzzy modelling-based integrated framework for performance analysis of juice clarification unit, *Applied Soft Computing*, **124** (2022), 109056.

[14] M. K. Loganathan, G. Kumar, O. P. Gandhi, Availability evaluation of manufacturing systems using Semi-Markov model, *International Journal of Computer Integrated Manufacturing*, **29(7)** (2016), 720–735.

[15] A. S. Maihulla, I. Yusuf, Performance analysis of photovoltaic systems using (RAMD) analysis, *Journal of the Nigerian Society of Physical Sciences*, (2021), 172–180.

[16] A. Sachdeva, D. Kumar, P. Kumar, Availability modeling of screening system of a paper plant using GSPN, *Journal of Modelling in Management*, **3(1)** (2008), 26–39.

[17] M. Saini, A. Kumar, V. G. Shankar, A study of microprocessor systems using RAMD approach, *Life Cycle Reliability and Safety Engineering*, **9** (2020), 181–194.

[18] M. Saini, A. Kumar, V. S. Maan, D. Sinwar, Efficient and intelligent decision support system for smart irrigation, *Journal of the Nigerian Society of Physical Sciences*, (2022), 945–945.

[19] S. P. Sharma, Y. Vishwakarma, Application of Markov process in performance analysis of feeding system of sugar industry, *Journal of Industrial Mathematics*, **2014** (2014).

[20] Z. Sobhani, M. Shahrokhi, Availability optimization of a multi-state industrial system with the Markov chain approach, *Industrial Management Journal*, **11(3)** (2019), 380–404.

[21] V. Talkit, R. Kininge, P. Kokate, D. Narkhede, A. Bewoor, R. B. Patil, Reliability analysis of repairable and replaceable system: Dairy product industry, *Materials Today: Proceedings*, **77** (2023), 573–578.

[22] N. M. Usman, I. Yusuf, Reliability, availability, maintainability, and dependability of a serial Rice Mill Plant (RMP) with the incorporation of coverage factor, In *Advances in Reliability, Failure and Risk Analysis*, pp. 377-409, Singapore: Springer Nature Singapore, (2023).