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Performance Analysis of a Soap Plant using Machine learning

Shakuntla Singla, Shilpa Rani, Sonia, Diksha Mangla*, Savita Garg

ABSTRACT: This research presents the development of a reliability model for availability analysis of the soap operation, in which the main unit can function in a reduced condition following partial failure.The soap Plant essentially accommodates of 4 subsystems especially boiler, mixer, vacuum chamber and metal detector. Packaging has sub-units. The reliability model for soap industry availability is constructed, consisting of three non-identical units, and a main unit able to working in a diminished state with incomplete failure. The main unit can fail partially, resulting in an up-state, partially failed state, or completely failed state. In the event of a partial failure, the system can function at a reduced capacity. The repair of the unit and the treatment of the server are considered perfect. Machine learning is used to formulate and solve the exponential problem involving failure and repair rates. Tables and charts are likewise created to explain the system's practical trend using specific situations.

Key Words: Availability, RPGT, MTSF, Steady State, Linear Classifier(LC), Logistic Regression(LR).

Contents

1. Introduction

In this paper soap industry is developed in which four subsystem bolier, mixer, vacuum chamber and metal detector and packaging has sub units. A reduced state of function for the main unit in the case of a partial failure has been developed as part of a reliability model for the availability study of the soap industry. In soap industry, first process is boiling and in this model 'A' represents the boiler.

* Corresponding author.

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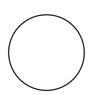
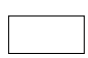
After boiling, the second process is mixing and refining and here 'B' represents the mixer and refiner. It is then extruded into a long log, divided into sufficient lengths, analyzed by a metal detector, and stamped into shape with refrigerated tools. The pressed bars are then packed in multiple ways. In this model 'D' represents the third process packaging. Priority in repair to the three units is in order A¿B¿D taking single repair facility is who is always available carries out all types of repair. System parameters are obtained using RPGT. Ahmadini et al.(2024) [1] has discussed optimization reliability of artificial bee colony to maximize to find busy period Expected number of visit repairman. John et al. (2023) [2] has discussed classified of failure of reliability multi hardware and software. Kumar et al.(2020) [3] has discussed with the help of mathematical modelling find out of reliability characterstic. Kim et al.(2011) [4] has discussed with a force sensing tactile sensor. Khan et al.(2022) [5] has discussed aim to transform a problem of bi-Level programming problem (BLPP) of reliability. Singla et al. (2011) [6] Comparison between availability pipe manufacturing with sub system are independent failure. Raghav et al. (2022) [7] with help of matlab cost maximized and availability also maximized in the interval for preventive maintance. Singla et al. (2022) [8] thresher plant has three sub system blower, concave, feeding depend upon the availability of system. Salvia et al. (1990) [9] has discussed k out of system of failure probability comparison of 1 dim. Mode. Singla et al. (2022) [10] has discussed availability investigated various availability of subsystem extruder computed. Singla et al.(2023) [11] has discussed with help of deep learning optimization of packing unit in series with repair and single never fails. Singla et al. (2024) [12] sensitive analysis of availability of working time understand of effective pararmeter. Singla et al.(2023) [13] with RPGT performance in all three unit in working state two or more state fail then system is reduce state. Singla et al. (2024) [14] with help of fuzzy linguistic approach analysis of two unit are repair system.To improve the working efficiency of the computer devices, an Artificail bee colony algorithm has been used to enhanced the work, studied by Anu et al. [15].

2. Assumption, and Notation

- There is only one repairman on call at all times.
- Failure and repair time distributions may be constant or variable.
- In the failed state of the system, nothing can further fail.
- The system is evaluated under steady-state conditions.
- Full Capacity Working State.



- Failed State



- A/a: Unit is either fully operational or failing; similar holds for other units.
- w_i/λ_i: Denote repair and failure rates of units.

3. Model (Transition Diagram) Description

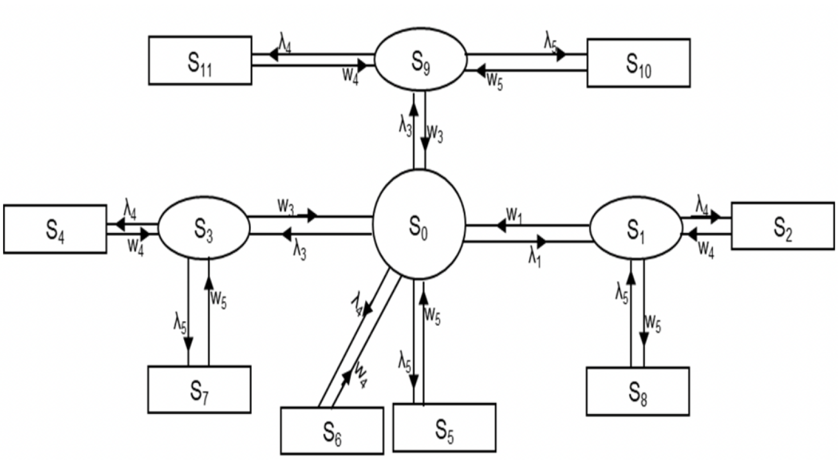


Figure 1: Transformation 523/Diagram

$$
\begin{aligned}
S_0 &= A_1A_2A_3BD(a),\\
S_1 &= AA_2A_3BD(a_0),\\
S_2 &= AA_2A_3bD,\\
S_3 &= A_1AA_3BD(a_2),\\
S_4 &= A_1AA_3bD(a_2),\\
S_5 &= A_1A_2A_3Bd,\\
S_6 &= A_1A_2A_3bD,\\
S_7 &= A_1AA_3Bd(a_2),\\
S_8 &= AA_2A_3Bd(a_1),\\
S_9 &= A_1A_2ABD(a_3),\\
S_{10} &= A_1A_2ABd(a_3),\\
S_{11} &= A_1A_2AbD(a_3).
\end{aligned}
$$

3.1. Probability Density function ($q_{i,j}(t)$)

$$q_{0,1} = \lambda_1 e^{-(\lambda_1+\lambda_5+\lambda_4+\lambda_2+\lambda_3)t}, \tag{3.1}$$

$$q_{0,5} = \lambda_5 e^{-(\lambda_1+\lambda_5+\lambda_4+\lambda_2+\lambda_3)t}, \tag{3.2}$$

$$q_{0,6} = \lambda_6 e^{-(\lambda_1+\lambda_5+\lambda_4+\lambda_2+\lambda_3)t}, \tag{3.3}$$

$$q_{0,3} = \lambda_2 e^{-(\lambda_1+\lambda_5+\lambda_4+\lambda_2+\lambda_3)t}, \tag{3.4}$$

$$q_{0,9} = \lambda_3 e^{-(\lambda_1+\lambda_5+\lambda_4+\lambda_2+\lambda_3)t}, \tag{3.5}$$

$$q_{1,2} = \lambda_4 e^{-(\lambda_4+\lambda_5+w_1)t}, \tag{3.6}$$

$$q_{1,8} = \lambda_5 e^{-(\lambda_4+\lambda_5+w_1)t}, \tag{3.7}$$

$$q_{1,0} = w_1 e^{-(\lambda_4+\lambda_5+w_1)t}, \tag{3.8}$$
$$q_{2,1} = w_4 e^{-w_4 t}, \tag{3.9}$$
$$q_{3,0} = w_2 e^{-(w_2+\lambda_5+\lambda_4)t}, \tag{3.10}$$
$$q_{3,7} = \lambda_5 e^{-(w_2+\lambda_5+\lambda_4)t}, \tag{3.11}$$
$$q_{3,4} = \lambda_4 e^{-(w_2+\lambda_5+\lambda_4)t}, \tag{3.12}$$
$$q_{4,3} = w_4 e^{-w_4 t}, \tag{3.13}$$
$$q_{5,0} = w_5 e^{-w_5 t}, \tag{3.14}$$
$$q_{6,0} = w_4 e^{-w_4 t}, \tag{3.15}$$
$$q_{7,3} = w_5 e^{-w_5 t}, \tag{3.16}$$
$$q_{8,1} = w_5 e^{-w_5 t}, \tag{3.17}$$
$$q_{9,0} = w_3 e^{-(w_3+\lambda_5+\lambda_4)t}, \tag{3.18}$$
$$q_{9,10} = \lambda_5 e^{-(w_3+\lambda_5+\lambda_4)t}, \tag{3.19}$$
$$q_{9,11} = \lambda_4 e^{-(w_3+\lambda_5+\lambda_4)t}, \tag{3.20}$$
$$q_{10,9} = w_5 e^{-w_4 t}, \tag{3.21}$$
$$q_{11,9} = w_4 e^{-w_4 t}. \tag{3.22}$$

3.2. Total Density plays a role in applying Laplace to transition from state "i" to state "j". The following is the transform of the previous functions for infinite time intervals

$$P_{ij} = q^*_{i,j}(t)$$

$$p_{0,1} = \frac{\lambda_1}{\lambda_1+\lambda_3+\lambda_4+\lambda_2+\lambda_5},$$
$$p_{0,5} = \frac{\lambda_5}{\lambda_1+\lambda_3+\lambda_4+\lambda_2+\lambda_5},$$
$$p_{0,6} = \frac{\lambda_6}{\lambda_1+\lambda_3+\lambda_4+\lambda_2+\lambda_5},$$
$$p_{0,3} = \frac{\lambda_2}{\lambda_1+\lambda_3+\lambda_4+\lambda_2+\lambda_5},$$
$$p_{0,9} = \frac{\lambda_3}{\lambda_1+\lambda_3+\lambda_4+\lambda_2+\lambda_5},$$
$$p_{1,2} = \frac{\lambda_4}{\lambda_5+\lambda_2+w_1},$$
$$p_{1,8} = \frac{\lambda_5}{\lambda_5+\lambda_2+w_1},$$
$$p_{1,0} = \frac{w_1}{\lambda_5+\lambda_2+w_1},$$

$$
\begin{aligned}
p_{2,1} &= 1, \\
p_{3,0} &= \frac{w_2}{w_2 + \lambda_4 + \lambda_5}, \\
p_{3,7} &= \frac{\lambda_5}{w_2 + \lambda_4 + \lambda_5}, \\
p_{3,4} &= \frac{\lambda_4}{w_2 + \lambda_5 + \lambda_4}, \\
p_{4,3} &= 1, \\
p_{5,0} &= 1, \\
p_{9,0} &= \frac{w_3}{w_3 + \lambda_5 + \lambda_4}, \\
p_{9,10} &= \frac{\lambda_5}{w_3 + \lambda_5 + \lambda_4}, \\
p_{9,11} &= \frac{\lambda_4}{w_3 + \lambda_5 + \lambda_4}, \\
p_{10,9} &= 1, \\
p_{11,9} &= 1.
\end{aligned}
$$

3.3. Probability Density Functions for Mean Sojourn Times

$$
\begin{aligned}
R_0(t) &= e^{-(\lambda_1+\lambda_5+\lambda_4+\lambda_2+\lambda_3)t}, \\
R_1(t) &= e^{-(\lambda_4+\lambda_5+W_1)t}, \\
R_2(t) &= e^{-W_4 t}, \\
R_3(t) &= e^{-(W_2+\lambda_5+\lambda_4)t}, \\
R_4(t) &= e^{-W_4 t}, \\
R_5(t) &= e^{-W_5 t}, \\
R_6(t) &= e^{-W_4 t}, \\
R_7(t) &= e^{-W_5 t}, \\
R_8(t) &= e^{-W_5 t}, \\
R_9(t) &= e^{-(W_3+\lambda_5+\lambda_4)t}, \\
R_{10}(t) &= e^{-W_5 t}, \\
R_{11}(t) &= e^{-W_4 t}.
\end{aligned}
$$

3.4. Value of the parameter μ_i giving Mean Sojourn Times

$$\mu_i = R_i^*(0)$$

$$\mu_0 = \frac{1}{\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5}$$

$$\mu_1 = \frac{1}{\lambda_4 + \lambda_5 + w_1} \quad \text{or} \quad \mu_1 = \frac{1}{w_2 + \lambda_4 + \lambda_5}$$

$$\mu_2 = \frac{1}{w_4}$$

$$\mu_4 = \frac{1}{w_4}, \quad \mu_5 = \frac{1}{w_5}, \quad \mu_6 = \frac{1}{w_4}, \quad \mu_7 = \frac{1}{w_5} \quad , \mu_8 = \frac{1}{w_5}$$

$$\mu_9 = \frac{1}{w_3 + \lambda_4 + \lambda_5} \quad , \mu_{10} = \frac{1}{w_5} \quad , \mu_{11} = \frac{1}{w_4}$$

3.5. Probabilities (Transition) from the initial vertex '0' (Base State)

$$V_{0,0} = 1 \quad \text{(Verified)}$$

$$V_{0,1} = \frac{p_{0,1}}{(1 - p_{1,2}p_{2,1})(1 - p_{1,8}p_{8,1})}$$

$$V_{0,4} = \frac{p_{0,3} \cdot p_{3,4}}{1 - p_{3,7} \cdot p_{7,3}} = \frac{\left(\frac{\lambda_2}{\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5}\right)\left(\frac{\lambda_4}{w_2+\lambda_5+\lambda_4}\right)}{1 - \lambda_5\left(\frac{1}{w_2+\lambda_5+\lambda_4}\right)}$$

$$V_{0,6} = p_{0,6} = \frac{\lambda_4}{\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5}$$

4. Methodology

4.1. MTSF (T_0)

The working (reformative) states to which the organization can join from original state '0', earlier going one down state are: 'i' = 0,1,3,9 attractive 'ξ' = 0

$$\text{MTSF}(T_0) = \left[\sum_{i,\text{sr}}\left\{\frac{\left\{\text{pr}\left(\xi \xrightarrow{\text{sr(sff)}} i\right)\mu_i\right\}}{\prod_{m_1 \neq \xi}(1 - V_{\overline{m_1 m_1}})}\right\}\right] \div \left[1 - \sum_{\text{sr}}\left\{\frac{\left\{\text{pr}\left(\xi \xrightarrow{\text{sr(sff)}} \xi\right)\right\}}{\prod_{m_2 \neq \xi}(1 - V_{\overline{m_2 m_2}})}\right\}\right]$$

$$= \mu_0 + \left\{\frac{p_{0,1}}{(1 - p_{1,2}p_{2,1})(1 - p_{1,8}p_{8,1})}\mu_1\right\}$$

$$+ \left\{\left[\frac{\lambda_2}{\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5}\right] \Big/ \left[(1 - \lambda_5(w_2 + \lambda_5 + \lambda_4))\,(1 - \lambda_4(w_2 + \lambda_5 + \lambda_4))\right]\mu_3\right\}$$

$$+ \left\{\left[\frac{\lambda_3}{\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5}\right] \Big/ \left[(1 - \lambda_5(w_3 + \lambda_5 + \lambda_4))\,(1 - \lambda_4(w_3 + \lambda_5 + \lambda_4))\right]\mu_9\right\}$$

4.2. Availability of the System

The states (regenerative) system is in partial / full working state are 'j' = 0,1,3,9 and all states are regenerative, taking 'ξ' = '0',

the total fractional availability using RPGT is given by

$$A_0 = \frac{\sum_{j,sr}\left\{\frac{\Pr(\xi^{sr\rightarrow} j) f_j \mu_j}{\prod_{m_1 \neq \xi}\left(1 - V_{\overline{m_1 m_1}}\right)}\right\}}{\sum_{i,sr}\left\{\frac{\Pr(\xi^{sr\rightarrow} i)\mu_i^1}{\prod_{m_2 \neq \xi}\left(1 - V_{\overline{m_2 m_2}}\right)}\right\}}$$

$$= \frac{\sum_j V_{\xi,j} f_j \mu_j}{\sum_i V_{\xi,i} f_i \mu_i^1}$$

4.3. Busy Period of the Server

The states in which server is busy for inspection/ repairing the units are 'j' = 1 to 11, taking ξ = '0',

the using RPGT is given by

$$B_0 = \frac{\sum_{j,sr}\left\{\frac{\Pr(\xi^{sr\rightarrow}j)n_j}{\prod_{m_1\neq\xi}\left(1-V_{\overline{m_1 m_1}}\right)}\right\}}{\sum_{i,sr}\left\{\frac{\Pr(\xi^{sr\rightarrow}i)\mu_i^1}{\prod_{m_2\neq\xi}\left(1-V_{\overline{m_2 m_2}}\right)}\right\}}$$

$$= \frac{\sum_j V_{\xi,j}\, n_j}{\sum_i V_{\xi,i}\, \mu_i^1}$$

4.4. Maximum number of inspections the repairman will perform(V_0)

The following states have been visited again by an overhaul man: j = 1, 3, 9 The reformative states are: Attractive 'ξ' = '0'; i = 0 to 11.,

$$V_0 = \frac{\sum_{j,sr}\left\{\frac{\Pr(\xi^{sr\rightarrow}j)}{\prod_{k_1\neq\xi}\left(1-V_{\overline{k_1 k_1}}\right)}\right\}}{\sum_{i,sr}\left\{\frac{\Pr(\xi^{sr\rightarrow}i)\mu_i^1}{\prod_{k_2\neq\xi}\left(1-V_{\overline{k_2 k_2}}\right)}\right\}}$$

$$= \frac{\sum_j V_{\xi,j}}{\sum_i V_{\xi,i}\, \mu_i^1}$$

5. Machine Learning classification

5.1. Model Evaluation

We computed several execution evaluation confusion matrices (recall, accuracy, precision, and F1-measure) to evaluate the performance of our model's implementation. The objective of the model phase evaluation is to measure the design model's generalization precision and accuracy using a test dataset that is yet to be is bound. Here, we calculated this accuracy with the following formulas: Equation, which depends on the following metrics module available in the Scikit-learn Python library: precision (System Availability), accuracy (The Medium Term Strategic Framework (MTSF)), recall (Busy Period), when f score function (Maximum Number of Inspections by the repair man).1,2 ,3 and 4. In overall, the availability analysis is a useful method to evaluate all the factors that impact a soap plant's output and profitability [1, 2, 3]. Plant managers are able to improve production efficiency and profitability by investing properly in others, raw materials, and equipment by evaluating these variables [4,5,6,].

5.2. Dataset

Availability analysis of a soap plant can benefit from the use of machine learning for dataset analysis. Large datasets can include patterns and trends that are not immediately obvious to human analysts. Machine learning algorithms can help in identifying these trends. By performing this, the availability analysis's accuracy can be expressed, and plant managers will be more able to choose how to increase profitability and production efficiency. For example, recent plant data can be used to train algorithms for machine learning, and may be later used to forecast future plant product demand. By connecting production levels and raw material orders to the planned demand, managers can minimize waste and maximize profitability. In the same way, executives can maximize purchases and decrease costs by applying machine learning to find patterns in raw material availability and price variations [4,5,6,]. Predictive maintenance is another potential use case for machine learning in availability analysis. Machine learning algorithms may identify patterns among data from machine sensors and other sources which may indicate an eventual failure or maintenance demand.

Table 1: Tabular Form of Parameters

W $(w_1, w_2, \ldots, w_n)$	λ $(\lambda_1, \lambda_2, \ldots, \lambda_n)$	**S** $(s_1, s_2, \ldots, s_n)$	**p**
0–50, 51–100	0–0.100	0–50, 51–100	0–75

This can enable plant managers to schedule maintenance proactively, reducing downtime and improving overall equipment availability. In general, machine learning can be a very effective technique for raising the precision and effectiveness of a soap plant's availability analysis.By enabling more accurate predictions and insights, machine learning can help plant managers to optimize production, reduce costs, and improve profitability in Table 1.

6. Results and discussion

In general, availability analysis involves examining the factors that influence the availability of a particular product or service. For a soap plant, these factors might include the availability of raw materials, labor, equipment, and other resources required for production. According to Table 2, fig. 2, fig. 3, fig. 4 and fig. 5 show, comparison among model of Linear classifier is better than other model of machine learning.

Table 2: Table 2: Performance of Model

Model	**Accuracy** (MTSF)	**F1 Score** (Max inspections)	**Recall** (Busy Period)	**Precision** (Availability)
Linear Classifier	0.9412	0.9612	0.9412	0.9723
Logistic Regression	0.9312	0.9412	0.9423	0.9645
Decision Tree	0.9234	0.9323	0.9323	0.9467

Overall, identifying the factors of production and profitability through availability analysis is an important tool in the plant. Plant managers can increase production efficiency and profitability by investing effectively in others, raw materials, and equipment by being informed of these components.

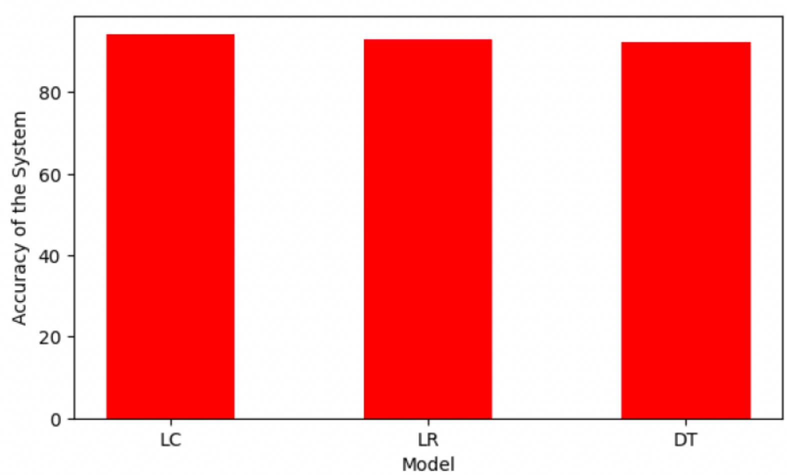


Figure 2: Comparison between Accuracy of models

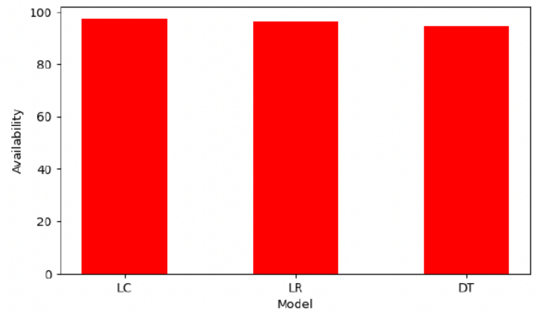


Figure 3: Comparison between Availability of models

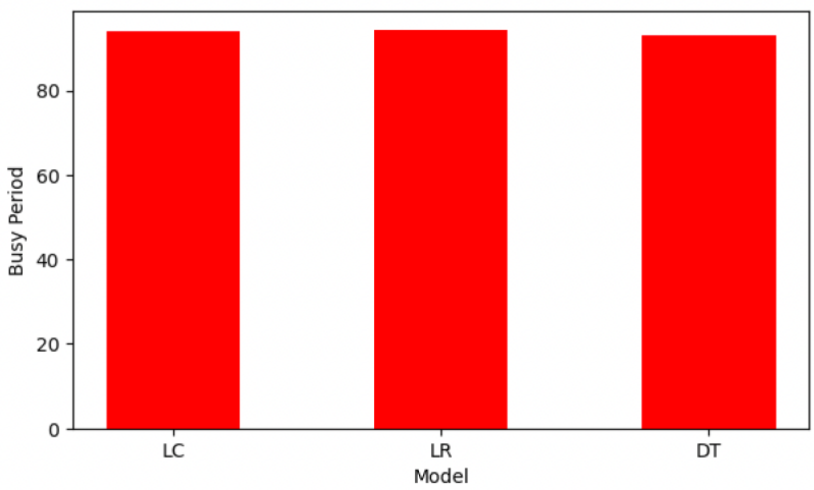


Figure 4: Comparison between Busy periods of models

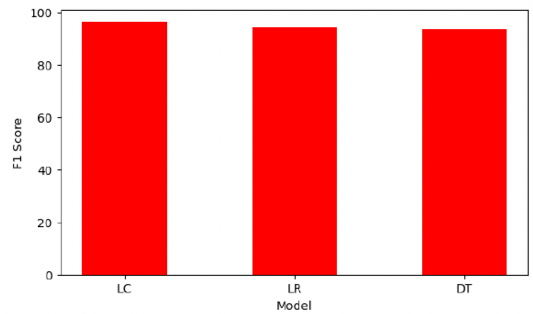


Figure 5: Comparison between F_1 score of models

7. Conclusion

The performance analysis's findings can be used to the soap plant's input variable optimization. As the system becomes more available, other system measures also exhibit expected behaviors. Decision-makers may choose which input variables to prioritize for optimization by analyzing which ones have the most impact on the output variable. This may improve the industry's profitability and efficiency as well as increasing the norm of the final product. By using these insights, processing parameters may be improved, raw material quality can be identified, and production efficiency and profitability can finally develop.

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Shakuntla Singla,

Department of Mathematics and Humainities, MMEC,

Maharishi Markandeshwar (Deemed to be University),

Mullana (Ambala), Haryana, India.

E-mail address: `shakus25@gmail.com, ORCID: 0000-0002-5713-2982`

and

Shilpa Rani,

Department of Mathematics,

D.A.V. College for Girls,

Yamuna Nagar, Haryana, India.

E-mail address: `gargshilpa46@gmail.com, ORCID: 0009-0008-8245-4036`

and

Sonia,
Department of Mathematics,
Dr. Bhim Rao Ambedkar Govt. College (Jagdishpura),
Kaithal, Haryana, India.
E-mail address: sonia_garg99@yahoo.com, ORCID: 0009-0006-9721-6116

and

Diksha Mangla,
Department of Computer Science & Engineering,
CGC College of Engineering, Chandigarh Group of College,
Landran, Mohali (Punjab), India.
E-mail address: dikshamangla1995@gmail.com, ORCID: 0009-0008-8921-449X

and

Savita Garg,
Department of Mathematics,
Mukand Lal National College,
Yamunanagar-135001, India.
E-mail address: savitarmn@gmail.com, ORCID: 0009-0002-1916-2491