International Journal of Research and Technology (IJRT)

International Open-Access, Peer-Reviewed, Refereed, Online Journal

ISSN (Print): 2321-7510 | ISSN (Online): 2321-7529

Conference "Innovation and Intelligence: A Multidisciplinary Research on Artificial Intelligence and its Contribution to Commerce and Beyond"-

Held at IQAC – KHMW College of Commerce-December 2025

Reliability Analysis Of Dal Milling Plants In Rajasthan Using Regenerative Point Graphical Technique

Vikas Kumar[1], Dr. Arun Kumar[2]

[1]Research Scholar, Department of Mathematics, Shri Khushal Das University, Hanumangarh

[2]Research Supervisor, Department of Mathematics, Shri Khushal Das University, Hanumangarh

ABSTRACT

This paper presents a comprehensive reliability analysis of dal (pulses) milling plants in Rajasthan, utilizing the Regenerative Point Graphical Technique (RPGT) to model and evaluate system performance. By considering the interconnected operations of cleaning and dehusking, splitting and grading, and polishing and packaging, the study captures the complexity of multi-unit agro-processing systems. The analysis incorporates probabilistic modeling of failure and repair dynamics, accounts for operational states ranging from full capacity to partial and complete failures, and integrates maintenance strategies within a rigorous quantitative framework. Results highlight the critical impact of repair and failure rates on mean time to system failure, availability, maintenance workload, and overall profitability. The findings provide actionable insights for plant managers and stakeholders, emphasizing the importance of preventive maintenance and reliability optimization in enhancing the efficiency and economic returns of Rajasthan's pulses milling sector.

Keywords: Dal milling, Regenerative Point Graphical Technique (RPGT), Mean time to system failure, Availability, Preventive maintenance, Rajasthan, System modeling, Profitability

1. INTRODUCTION

The pulses (dal) milling industry is a vital component of Rajasthan's agro-processing sector, underpinning the state's agricultural economy and food supply chain. Rajasthan, with its arid climatic conditions and extensive cultivation of pulses such as chickpeas, lentils, mung beans, and pigeon peas, has emerged as a significant hub for dal processing. The industry not only fulfills local and national dietary needs by supplying a primary protein source but also generates substantial employment and value addition in rural areas. Despite its strategic importance, the dal milling sector faces persistent challenges related to equipment reliability, process complexity, and maintenance demands. The multi-stage nature of milling spanning cleaning, dehusking, splitting, grading, polishing, and packaging means that disruptions at any stage can lead to cascading operational losses. Traditional reliability metrics and maintenance practices may fall short in capturing the dynamic, multi-state nature of plant operations and optimizing performance under varying conditions.

Review of Literature Recent years have seen significant advancements in the reliability analysis and optimization of complex industrial systems, with a particular emphasis on mathematical modeling and the application of the Regenerative Point Graphical Technique (RPGT). Kumar and Mimansha (2025) developed a dynamic method utilizing adaptive cuckoo optimization to enhance reliability optimization in systems with failure dependencies. Rani, Malik, and Kumar (2025) contributed a mathematical modeling and behavioral analysis of a rice plant using the RPGT technique. Purnima, Kumar, and Kumar (2024) conducted sensitivity analysis on a warm stand-by three-unit system using the RPGT framework. Several studies by Kumar (2023) expanded the application of RPGT to diverse domains: In the bread-making industry, profit analysis and mathematical modeling were performed to evaluate the impact of reliability metrics and preventive maintenance on operational outcomes. Sensitivity analyses in both the polytube and bread-making industries underscored the influence of system parameters on reliability and profitability. Agrawal et al. (2021) analyzed the performance of a water treatment reverse osmosis plant, applying reliability and performance metrics to identify critical factors affecting system efficiency. In earlier work, Kumar, Garg, and Goel (2019) applied mathematical modeling and behavioral analysis to a washing unit in a paper mill, again leveraging RPGT for in-depth system evaluation. Their research demonstrated that RPGT is a robust tool for capturing the dynamic behavior of multi-unit systems and for informing maintenance and operational strategies. The literature reveals a growing trend towards integrating quantitative reliability analysis with economic and operational decision-making, thereby enhancing both efficiency and profitability across sectors. This study addresses these challenges by applying the Regenerative Point Graphical Technique (RPGT), a powerful analytical approach well-suited for modeling complex, multi-unit industrial systems. RPGT enables a detailed examination of system transitions between operational, degraded, and failed states, facilitating the quantification of key performance indices such as mean time to system failure, availability, and repair workload. By integrating reliability engineering principles with practical operational data, this research delivers actionable strategies for enhancing uptime, reducing maintenance costs, and increasing profitability in Rajasthan's pulses milling industry.

2. SYSTEM DESCRIPTION

A typical pulses (dal) milling plant in Rajasthan operates as an integrated system composed of three primary units: the Cleaning & Dehusking Unit (D), the Splitting & Grading Unit (G), and the Polishing & Packaging Unit (P). The Cleaning & Dehusking Unit initiates the process by removing impurities and outer husks from raw pulses, using specialized equipment such as vibratory screens, aspiration systems, and dehusking machines. Next, the Splitting & Grading Unit divides the cleaned pulses into halves and sorts them by size and quality, employing splitters and graders to ensure product uniformity and maximize yield. Finally, the Polishing & Packaging Unit enhances the appearance and shelf life of the dal through surface polishing and prepares the finished product for market with weighing, packaging, and sealing machines. Each unit plays a critical role in maintaining product quality, operational efficiency, and market competitiveness.

3. ASSUMPTION AND NOTATION: -

- There is one dedicated repairman available 24x7, and a secondary server can be called in as needed.
- All repairs are perfect; after repair, units are restored to "as good as new" condition.
- The order of repair priority is D > G > P (i.e., Cleaning & Dehusking first, then Splitting & Grading, then Polishing & Packaging).
- $\overline{D}$, $\overline{G}$, $\overline{P}$: Reduced capacity states of the respective units.
- d, g, p: Complete failure states of the respective units.
- β_i $(2 \leq i \leq 7)$: Failure rates of units and their subcomponents.
- α_i $(2 \leq i \leq 7)$: Repair rates for each unit and subcomponent.l

4. TRANSITION DIAGRAM:

In this reliability model, the system is represented as a multi-state network where each state corresponds to a unique combination of the operational, reduced, or failed status of the three units (D, G, P). The transitions between states are governed by the respective failure (β) and repair (α) rates, as well as the repair priority rules. Considering the various possibilities and following the assumptions and notations the transition diagram of the system is drawn as under in Figure 1.

International Journal of Research and Technology (IJRT)

International Open-Access, Peer-Reviewed, Refereed, Online Journal

ISSN (Print): 2321-7510 | ISSN (Online): 2321-7529

Conference "Innovation and Intelligence: A Multidisciplinary Research on Artificial Intelligence and its Contribution to Commerce and Beyond"-

Held at IQAC – KHMW College of Commerce-December 2025

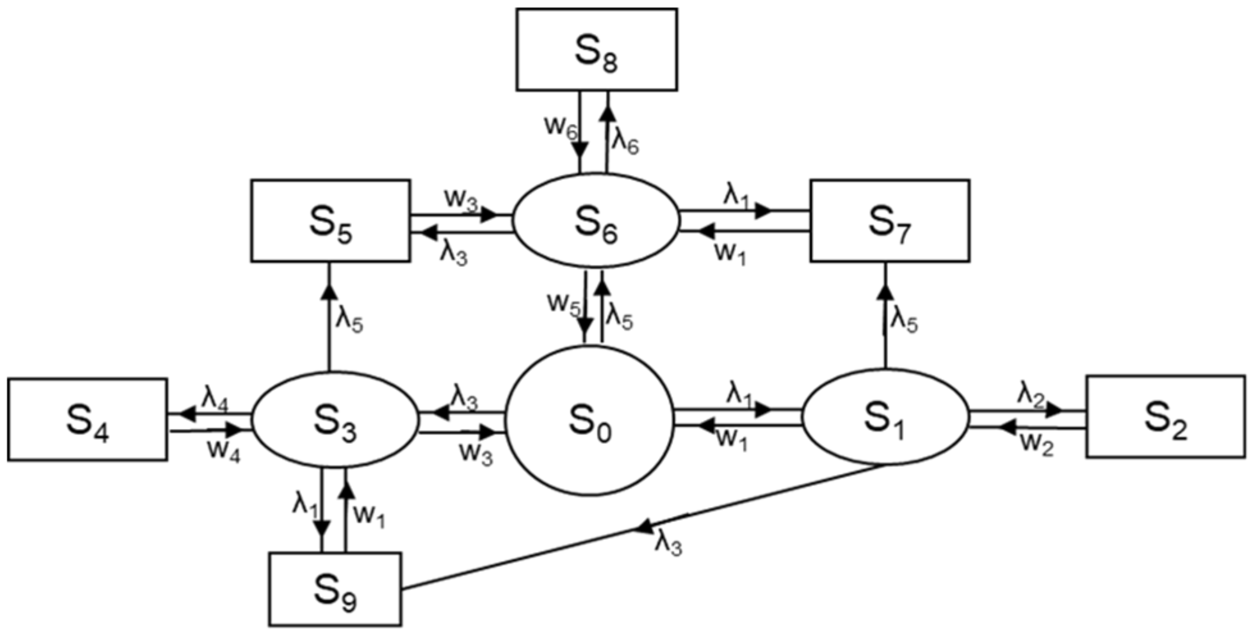

Figure 1: Transition Diagram

$S_2 = DGP$, $S_3 = \bar{D}GP$, $S_4 = dGP$, $S_5 = D\bar{G}P$, $S_6 = DgP$, $S_7 = D\overline{GP}$,
$S_8 = DG\bar{P}$, $S_9 = \bar{D}G\bar{P}$, $S_{10} = DGp$, $S_{11} = \overline{DG}P$

5. TRANSITION PROBABILITY

Transition probability quantifies the likelihood of the system moving from one state to another over a specified time interval. Assessing transition probabilities enables the prediction of system behavior under different operational and maintenance conditions.

$V_{2,2} = 1$ (Verified)

$V_{2,3} = (\beta_2/\beta_6+\beta_3+\beta_4+\alpha_2)/(\beta_2+\beta_6+\beta_4)(\beta_6+\beta_4+\alpha_2)$

$V_{2,4} = \beta_2\beta_3/(\beta_2+\beta_6+\beta_4)(\beta_6+\beta_4+\alpha_2)$

$V_{2,5} =$ ……Continuous

6. METHODOLOGY

By systematically combining these techniques, the methodology enables the evaluation of key reliability indices such as mean time to system failure (MTSF), system availability, server busy period, and expected maintenance interventions, supporting informed decision-making for plant optimization.

MTSF(T_0): The states to which the system can transit from initial state '2', before joining down state are: 'i' = 2,3,5,8 taking initial state 'ξ' = '2'.

$$\text{MTSF } (T_0) = \left[\sum_{i,sr}\left\{\frac{\left\{pr\left(\xi\xrightarrow{sr(sff)}i\right)\right\}\mu i}{\Pi_{m_{1}\neq\xi}\left\{1-V_{\overline{m_1m_1}}\right\}}\right\}\right] \div \left[1-\sum_{sr}\left\{\frac{\left\{pr\left(\xi\xrightarrow{sr(sff)}\xi\right)\right\}}{\Pi_{m_{2}\neq\xi}\left\{1-V_{\overline{m_2m_2}}\right\}}\right\}\right]$$

Availability of the System: The regenerative states at which the system is available are 'j' = 2,3,5,8 and the regenerative states are 'i' = 2 to 11 taking 'ξ' = '2' the availability for which the system is available is given by

$$A_0 = \left[\sum_{j,sr}\left\{\frac{\{pr(\xi^{sr\to}j)\}fj,\mu j}{\Pi_{m_{1}\neq\xi}\left\{1-V_{\overline{m_1m_1}}\right\}}\right\}\right] \div \left[\sum_{i,s_r}\left\{\frac{\{pr(\xi^{sr\to}i)\}\mu_i^1}{\Pi_{m_{2}\neq\xi}\left\{1-V_{\overline{m_2m_2}}\right\}}\right\}\right]$$

$$A_0 = \left[\sum_j V_{\xi,j}, f_j, \mu_j\right] \div \left[\sum_i V_{\xi,i}, f_j, \mu_i^1\right]$$

Busy Period of the Server: The states where the server is busy for doing some job are 'i' = 3 to 11, taking 'ξ' = '2', using RPGT busy period is given as

$$B_0 = \left[\sum_{j,sr}\left\{\frac{\{pr(\xi^{sr\to}j)\},nj}{\Pi_{m_{1}\neq\xi}\left\{1-V_{\overline{m_1m_1}}\right\}}\right\}\right] \div \left[\sum_{i,s_r}\left\{\frac{\{pr(\xi^{sr\to}i)\}\mu_i^1}{\Pi_{m_{2}\neq\xi}\left\{1-V_{\overline{m_2m_2}}\right\}}\right\}\right]$$

Expected fraction Number of Inspections by the repair man: The regenerative states where the repair man visits afresh are states 3, 5 and 8 to do this job the number of visit by the repair man is given by

$$V_0 = \left[\sum_{j,sr}\left\{\frac{\{pr(\xi^{sr\to}j)\}}{\Pi_{k_{1}\neq\xi}\left\{1-V_{\overline{k_1k_1}}\right\}}\right\}\right] \div \left[\sum_{i,s_r}\left\{\frac{\{pr(\xi^{sr\to}i)\}\mu_i^1}{\Pi_{k_{2}\neq\xi}\left\{1-V_{\overline{k_2k_2}}\right\}}\right\}\right]$$

6.1 PARTICULAR CASES:-

Specific Cases:- $\alpha_i\ (2 \le i \le 7) = \alpha$; $\beta_i\ (2 \le i \le 7) = \beta$

Profit Function (P_0): The system can be done by utilized PF

$P_0 = D_1A_0 - (D_2B_0 + D_3V_0) = D_1A_0 - D_2B_0 - D_3V_0,$

Taking $D_1 = 1500$; $D_2 = 300$; $D_3 = 500$,

Table 1: Profit Function (P_0)

P_0	α = 0.75	α = 0.85	α = 0.95
β = 0.25	25840	26010	26180
β = 0.35	23664	23969	24274
β = 0.45	22088	22408	22743

International Journal of Research and Technology (IJRT)
International Open-Access, Peer-Reviewed, Refereed, Online Journal
ISSN (Print): 2321-7510 | ISSN (Online): 2321-7529
Conference "Innovation and Intelligence: A Multidisciplinary Research on Artificial Intelligence and its Contribution to Commerce and Beyond"-
Held at IQAC – KHMW College of Commerce-December 2025

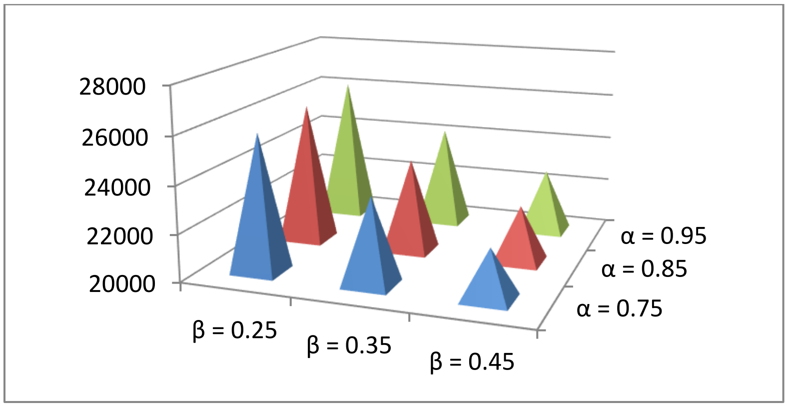

Figure 2: Profit Function (P_0)

Table 1 and figure 2 presents the calculated profit function (P_0) for the pulses (dal) milling plant, incorporating the effects of system availability, server busy period, and inspection frequency. The profit values are computed based on fixed cost and revenue parameters, showing that profitability increases with higher repair rates and decreases with higher failure rates. This table underscores the economic value of reliability optimization in dal milling operations.

7. CONCLUSIONS

This study provides a detailed and systematic reliability analysis of dal milling plants in Rajasthan using the Regenerative Point Graphical Technique (RPGT). By modeling the plant as an integrated, multi-unit system comprising cleaning & dehusking, splitting & grading, and polishing & packaging units, the research captures the operational complexities and interdependencies inherent in modern agro-processing facilities. The analysis demonstrates that both the mean time to system failure and overall system availability are highly sensitive to the repair and failure rates of critical units. These findings highlight the importance of prioritizing preventive maintenance, timely repairs, quality equipment, and regular inspections to mitigate breakdowns and optimize plant performance. In summary, the adoption of reliability engineering practices—supported by advanced modeling techniques like RPGT can significantly enhance operational resilience, product quality, and financial performance in Rajasthan's dal milling industry.

REFERENCES

1. Agrawal, A., Garg, D., Kumar, A., & Kumar, R. (2021). Performance analysis of the water treatment reverse osmosis plant. Reliability: Theory & Applications, 16(3), 16-25.
2. Kumar, A. (2023). Profit analysis of a bread making system using RPGT. International Journal of Engineering, Science and Mathematics, 12(6), 191-198.
3. Kumar, A. (2023). Sensitivity analysis of a polytube industry using RPGT technique. International Journal of Research in Engineering and Applied Sciences, 13(7), 30-44.

4. Kumar, A. (2023). Mathematical modeling and sensitivity analysis of a bread making system using RPGT. International Research Journal of Mathematics, Engineering and IT, 1-12.
5. Kumar, A. (2023). Profit analysis of 3:4:: Good system with preventive maintenance. ZENITH International Journal of Multidisciplinary Research, 13(9), 157-166.
6. Kumar, A. (2023). System modeling and behavior analysis of a cold standby system with waiting time for repair. In Proceedings of the National Conference on Research, Innovations & Practices in Mathematics, Computational & Physical Sciences (pp. 102-108).
7. Kumar, A., Garg, D., & Goel, P. (2019). Mathematical modeling and behavioral analysis of a washing unit in paper mill. International Journal of System Assurance Engineering and Management, 1(6), 1639-1645.
8. Kumar, A., & Mimansha. (2025). Reliability optimization of complex system under failure dependencies: A dynamic method in adaptive cuckoo optimization. International Journal of System Assurance Engineering and Management, 1-10.
9. Purnima, Kumar, A., & Kumar, N. (2024). Sensitivity analysis of warm stand-by three units system using RPGT technique. International Journal of Engineering, Science & Mathematics, 13(2), 46-60.
10. Rani, P., Malik, S., & Kumar, A. (2025). Mathematical modeling and behaviour analysis of a case study of rice plant using RPGT technique. International Journal of Statistics and Applied Mathematics, 10(3), 9-15.