

## **Mathematical Modeling And Expected Number Of Server’s Visits Of The Finishing Plant Haryana Using Rpgt**

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### **ABSTRACT**

This study develops a mathematical model for the reliability analysis and expected number of repairman visits in a textile dyeing and finishing plant in Haryana, employing the Regenerative Point Graphical Technique (RPGT). The plant’s operation, which involves Scouring, Bleaching, Dyeing, and Finishing units, is critically dependent on each subsystem’s reliability, particularly as the finishing stage incorporates a cold standby configuration. Analytical expressions are derived for mean time to system failure (MTSF), availability, server busy period, and the expected number of repairman visits under varying failure and repair rates. Sensitivity analysis reveals how these parameters influence maintenance demands and system resilience. The findings provide actionable insights for plant managers seeking to optimize preventive maintenance, minimize downtime, and enhance operational efficiency in textile finishing plants.

**Keywords:** Mathematical Modeling, RPGT, Reliability Analysis, Expected Server Visits, Cold Standby, Haryana

### **1. INTRODUCTION:**

The textile industry stands as a pillar of industrial and economic development in India, with dyeing and finishing plants forming a vital segment of the textile value chain. In today’s globally competitive and technology-driven era, manufacturers face mounting pressure to deliver high-quality products rapidly and cost-effectively—demands that hinge on the reliable performance of processing plants. Particularly in Haryana, the textile sector has grown into a major economic contributor, intensifying the focus on uninterrupted, high-throughput operations to meet domestic and international market expectations. In textile finishing plants, reliability is not just a technical metric—it is a strategic imperative that influences profitability, customer satisfaction, and competitive positioning. The failure of any key subsystem, such as scouring, bleaching, dyeing, or finishing, can halt production entirely, leading to financial losses and reputational risks. As a result, robust maintenance strategies and sophisticated reliability modeling have become essential tools for plant managers and engineers. One prevalent solution to enhance system reliability is the deployment of cold standby units, particularly in the finishing stage. These backup machines remain offline until the primary unit fails, at which point they are activated to maintain production continuity. While this configuration reduces downtime and helps manage wear, it also introduces complexity in terms of repair logistics and resource allocation. Reliability modeling and maintenance optimization have been extensively studied in the context of complex industrial systems. Agrawal et al.

(2021) analyzed water treatment plants, emphasizing the significance of reliability theory and advanced tools like RPGT for optimizing maintenance strategies and improving system availability. Zhang and Zeng (2016) developed optimal maintenance models for systems with multiple non-identical units, illustrating how mathematical modeling can handle real-world complexities and guide effective maintenance planning. Chang et al. (2020) investigated k-out-of-n systems using universal generating functions and linear programming, demonstrating that sophisticated analytical approaches can assess component reliability even in systems subject to brittle failures. Garg and Garg (2022) examined performance analysis in briquette machines, highlighting the impact of preventive maintenance and fault management on reliability and operational efficiency. The application of Markov processes to reliability analysis, as presented by Hua et al. (2018), simplifies the evaluation of phased-mission systems and supports the practical merging of system states to reduce computational complexity. Kumari et al. (2021) addressed constrained maintenance optimization problems using particle swarm optimization, a meta-heuristic that further broadens the toolkit for system reliability improvement. Ritikesh and Goel (2015) applied RPGT to single-unit systems undergoing degradation and post-repair, reinforcing the value of regenerative point techniques in predicting downtime and maintenance needs. Asi et al. (2021) compared various reliability methods for assessing probabilistic risks in civil engineering applications, underlining the importance of selecting appropriate analytical methods for different system types. Mathematical modeling, especially using Markov processes and advanced techniques like the Regenerative Point Graphical Technique (RPGT), enables a rigorous analysis of system behavior—including the prediction of system failures, server busy periods, and the expected number of maintenance interventions. Understanding these metrics is critical for planning preventive maintenance, allocating resources, and optimizing plant performance. This study leverages RPGT to model a four-stage textile dyeing and finishing plant, examining how different failure and repair rates affect key system parameters. Through sensitivity analysis, the research identifies which units exert the most influence on system reliability and maintenance demand. The insights generated provide a robust foundation for data-driven decision-making, enabling textile finishing plants to achieve higher efficiency, reliability, and profitability.

## **2. SYSTEM DESCRIPTION**

The textile dyeing and finishing plant analyzed here consists of four main processing units: Scouring, Bleaching, Dyeing, and Finishing. These units are configured in a series, with the finishing stage employing a cold standby arrangement—one unit operates while two remain as backups. This architecture ensures that if the operating finishing unit fails, a standby is promptly activated, minimizing production interruptions. Each unit is critical; a failure in any stage halts the entire process, making reliability across all units paramount. Maintenance is performed by a centralized repairman, with rapid response protocols in place to restore failed units and maintain system uptime. This configuration reflects modern reliability engineering principles, emphasizing redundancy, preventive maintenance, and efficient resource deployment to sustain high throughput and product quality.

## **3. ASSUMPTION AND NOTATIONS: -**

- 1) Switching is perfect.

- 2) The repaired unit seems to be as good as new.
- 3) There is one repairman whose availability is 24x7 and another server is called on need basis.  
 $n_i / m_i (2 \leq i \leq 5)$  : Constant Failure/Repair rates of units S, B, D, F respectively.

A/a: Unit in full working/failed state, in the same way for other units.

$f_1$ : Active online component of unit F is in failed state.

$f_2$ : One stand by and online component of unit F is in failed state.

#### 4. TRANSITION DIAGRAM OF SYSTEM

Taking into reflection various suppositions & notations state transition diagram of structure is specified in Figure 1.

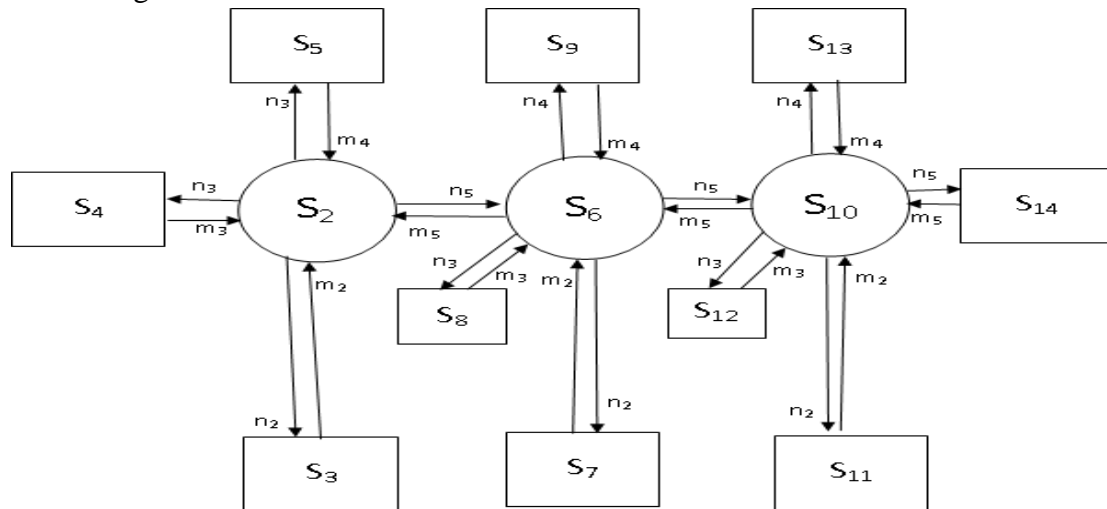


Figure 1: Transition Diagram of System

#### 5. EVALUATION OF PARAMETERS:-

The transition path probabilities from base state  $\xi = 10$  to reachable states are using RPGT are:

Probabilities in estate 10 to altered vertices and agreed for example

$$V_{10,2} = (10,6,2) / [\{1-(2,3,2)\} \{1-(2,4,2)\} \{1-(2,5,2)\} \{1-(6,8,6)\} \{1-(6,9,6)\} \{1-(6,7,6)\}]$$

$$= (p_{10,6} p_{6,2}) / [(1-p_{2,3} p_{3,2})(1-p_{2,4} p_{4,2})(1-p_{2,5} p_{5,2})(1-p_{6,8} p_{8,6})(1-p_{6,9} p_{9,6})(1-p_{6,7} p_{7,6})]$$

$$V_{10,3} = (10,6,2,3) / [\{1-(6,9,6)\} \{1-(6,7,6)\} \{1-(6,8,6)\} \{1-(2,4,2)\} \{1-(2,5,2)\}]$$

$$= (p_{10,6} p_{6,2} p_{2,3}) / [(1-p_{6,9} p_{9,6})(1-p_{6,7} p_{7,6})(1-p_{6,8} p_{8,6})(1-p_{2,4} p_{4,2})(1-p_{2,5} p_{5,2})]$$

$$V_{10,4} = \dots \dots \dots \text{Continue}$$

$$V_{2,2} = 1;$$

$$V_{2,3} = (2,3) = p_{2,3};$$

$$V_{2,4} = (2,4) = p_{2,4};$$

$$V_{2,5} = \dots \dots \dots \text{Continue}$$

#### 6. METHODOLOGY

**Expected Fractional Number of Assessments thru the repair man:** The states where repairman joins a fresh stand 3, 4, 5, 6, Taking  $\xi = 2$ , this value using RPGT is given by

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

$$V_0 = [\sum_j V_{\xi, j}] \div [\sum_i V_{\xi, i} \mu_i^1] = (V_{2,3} + V_{2,4} + V_{2,5} + V_{2,6}) / D$$

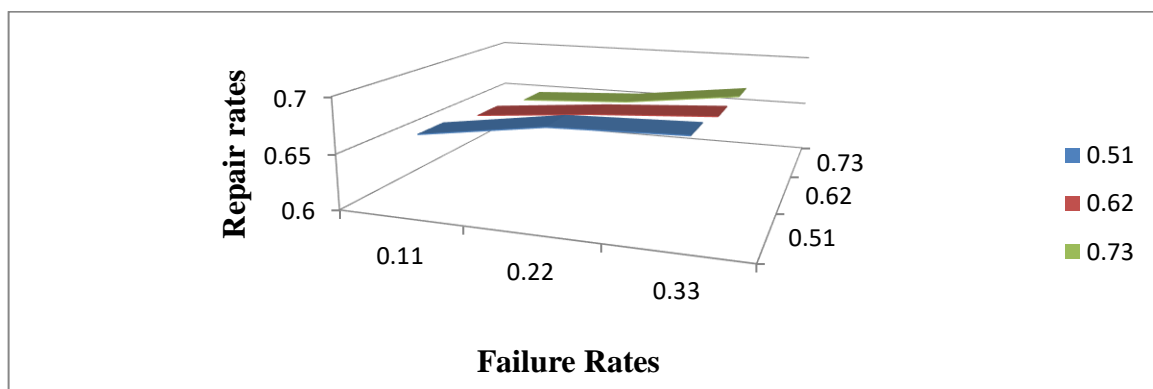
## 7. PARTICULAR CASES: RPGT AND DATA ANALYSIS RESULTS

Behavior Analysis: Fix;  $\alpha = n_i$ ;  $\beta = m_i$

Expected Number of server’s visits ( $V_0$ ):

**Table 1: Expected Number of server’s visits ( $V_0$ )**

n \ m	0.51	0.62	0.73
0.11	0.664	0.656	0.649
0.22	0.680	0.666	0.655
0.33	0.683	0.673	0.669



**Fig. 2: Expected Number of Server’s Visits**

Table 1 displays the expected number of server’s visits ( $V_0$ ) for various failure rates ( $n$ ) and repair rates ( $m$ ) in the system. As illustrated in Figure 2, the results demonstrate that the expected number of repairman interventions tends to increase with higher failure rates, reflecting the greater need for maintenance as system reliability declines. This analysis highlights the importance of managing both failure and repair rates to optimize maintenance activities and minimize disruptions in plant operations.

## 8. CONCLUSION:

This study has presented a robust mathematical modeling framework for analyzing the expected number of repairman visits in a textile dyeing and finishing plant in Haryana, employing the Regenerative Point Graphical Technique (RPGT). The results demonstrate that as subsystem failure rates increase, the expected number of maintenance interventions rises accordingly, stressing the need for effective reliability management and proactive maintenance. Conversely, higher repair rates marginally decrease the frequency of required visits, emphasizing the value of swift, efficient repairs in maintaining system uptime. By integrating sensitivity analysis, the research identifies critical units and parameters that most strongly influence maintenance demand and plant reliability. These insights empower plant managers to prioritize preventive maintenance, allocate resources efficiently, and formulate strategies that minimize downtime and operational disruptions. Ultimately, the application of RPGT and rigorous reliability modeling equips textile finishing plants with actionable tools to enhance productivity, profitability, and competitive advantage in a demanding industrial landscape.

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