Availability Analysis Of A System Performance With 3: 4:: G System Using Rpgt

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ABSTRACT

This study presents a comprehensive reliability and availability analysis of the 3:4::G system, as applied in an industrial setting at Metter Industry, Haryana. Employing the Regenerative Point Graphical Technique (RPGT), the research models the operational dynamics of a four-unit system where each unit's failure or repair impacts overall performance. The analysis incorporates Markov processes, sensitivity analysis, fuzzy logic, and machine learning to quantify key performance metrics such as Mean Time to System Failure (MTSF), system availability, and repairman workload. Results demonstrate how varying failure and repair rates influence system reliability and highlight the strategic importance of data-driven, preventive maintenance and targeted interventions.

Keywords: 3:4::G System, System Availability, Markov Process, Preventive Maintenance

1. INTRODUCTION:

Reliability engineering is fundamental to the efficient operation and sustained productivity of modern industrial systems. As technological complexity increases, so too does the challenge of ensuring uninterrupted performance and minimizing unexpected failures. This is especially evident in critical infrastructure, such as the 3:4::G system deployed at Metter Industry in Haryana, where system integrity directly affects competitiveness and operational safety. The 3:4::G system comprises four interdependent units—A, B, C, and D—each made up of series-arranged subunits. The system functions at full capacity only when all units are operational; failure of any single unit reduces capacity, while two or more failed units render the system non-functional. This configuration, common in process industries, highlights the importance of redundancy, modularity, and effective maintenance strategies. The analysis and optimization of complex system reliability have been extensively addressed in the field of industrial engineering, with particular focus on redundancy allocation, Markov modeling, and preventive maintenance strategies. Rajbala, Kumar, and Garg (2019) provided foundational insights into systems modeling and reliability analysis for manufacturing plants, demonstrating the value of structured mathematical approaches for predicting system behavior and guiding maintenance interventions. Furthering this foundation, redundancy allocation problems have been explored by Rajbala, Kumar, and Khurana (2022), who investigated optimal configurations to enhance system reliability in manufacturing settings. Kumar, Goel, and Garg (2018) applied Markovian analysis to a bread making system, revealing how state transition modeling can uncover bottlenecks and inform resource allocation. Kumar, Garg, Goel, and Ozer (2018) conducted a sensitivity analysis of the 3:4::G system, demonstrating that targeted improvements in repair efficiency or failure mitigation yield significant gains in system availability. Kumar, Garg, and Goel (2019) analyzed cold standby systems with preventive maintenance priorities, emphasizing that proactive interventions, especially when the system is fully operational, are most effective for sustaining high performance. Additional studies by Kumar and colleagues have extended these modeling frameworks to various industrial contexts, including edible oil refineries, paper mills, and fertilizer industries (Kumar, Garg, and Goel, 2017; 2019; Kumar, Goel, Garg, and Sahu, 2017), consistently affirming the value of Markov modeling, RPGT, and systematic sensitivity analysis for reliability optimization. This research addresses the dual challenges of anticipating failures and optimizing maintenance in such systems. By systematically collecting and analyzing operational data on failures, repairs, and preventive interventions, the study leverages advanced quantitative methods—including the Regenerative Point Graphical Technique (RPGT) and Markov processes—to model system behavior and transitions. The integration of sensitivity analysis, machine learning, and fuzzy logic further enhances the predictive and decision-making capabilities.

2. ASSUMPTIONS AND NOTATIONS

- The system is considered to be in the full capacity state only when all four units (A, B, C, D) are operational.
- Lowercase letters a, b, c, d: Indicate that the corresponding unit is in a failed (non-operational) state.
- β_i: Constant failure rate of the i-th unit (i = 2, 3, 4, 5, 6, 7).
- α_i: Constant repair rate of the i-th unit (i = 2, 3, 4, 5, 6, 7).

3. TRANSITION DIAGRAM

The system can be in any of the following states with respect to the above symbols.

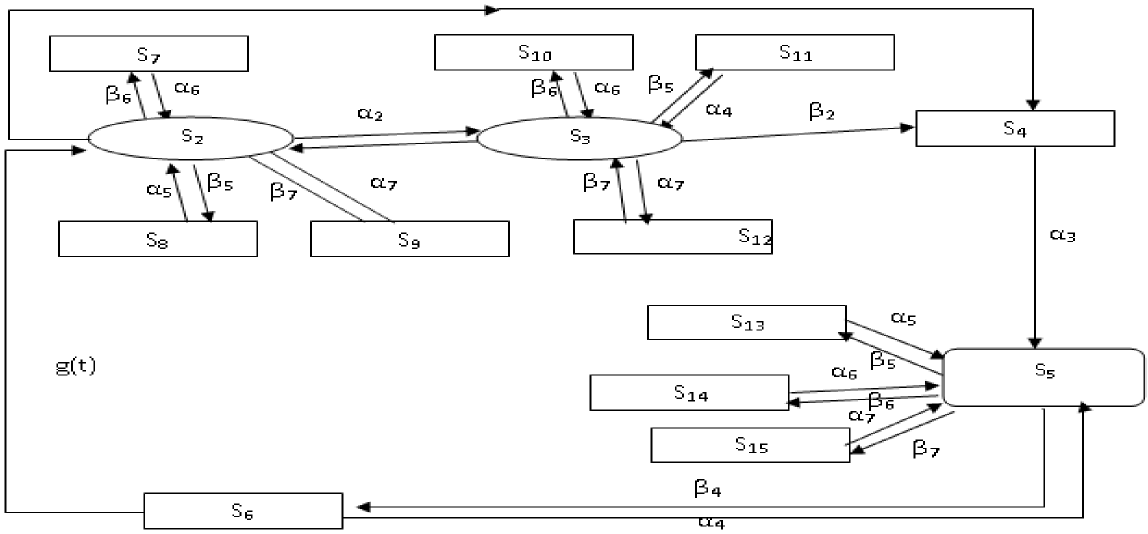

Figure 1: Transition Diagram

4. PATH PROBABILITY:

$V_{2,2}$ = = $\beta_2\alpha_2/(\beta+\beta_2+\beta_5+\beta_6+\beta_7)(\alpha_2+\beta_3+\beta_5+\beta_6+\beta_7)\div(\alpha_2+\beta_3+\beta_5+\beta_7)(\alpha_2+\beta_3+\beta_6+\beta_7)$ $(\alpha_2+\beta_3+\beta_5+\beta_6)(\alpha_2+\beta_3+\beta_5+\beta_6+\beta_7)^2+(\beta_5+\beta_6+\beta_7)/(\beta+\beta_2+\beta_5+\beta_6+\beta_7)+[\beta_2\beta_3/(\beta+\beta_2+\beta_5+\beta_6$ $+\beta_7)(\alpha_2+\beta_3+\beta_5+\beta_6+\beta_7)][\beta_4/(\beta_4+\beta_5+\beta_6+\beta_7)(g^*\alpha_4)]$

$V_{2,3} = \beta_2/(\beta_2+\beta_5+\beta_6+\beta_7+\beta)$

$V_{2,4}$ = …..Continuous

Path Probabilities from state '5' to different vertices are given as

$V_{5,2} = \beta_4 g^*(\alpha_4)/(\beta_4+\beta_5+\beta_6+\beta_7) \div 1-\beta_2\alpha_2/(\beta+\beta_2+\beta_5+\beta_6+\beta_7)(\alpha_2+\beta_3+\beta_5+\beta_6+\beta_7)(\beta+\beta_2+\beta_5+\beta_7)(\beta+\beta_2+\beta_6+\beta_7)(\beta+\beta_2+\beta_5+\beta_6)/(\beta+\beta_2+\beta_5+\beta_6+\beta_7)^2$

$V_{5,3}$ = …..Continuous

5. DATA ANALYSIS AND RESULTS

Availability of the System: In this context, the recreating states that contribute to system availability are defined as j = 2 to 6, while all possible degenerative (failed) states are denoted by i = 2 to 15. The availability is evaluated by taking the base state ξ = 2 and applying the Regenerative Point Graphical Technique (RPGT) to account for transitions and sojourn times across all relevant system states.

$$A_0 = \left[\sum_{j,sr}\left\{\frac{\{pr(\xi^{sr\to}j)\}fj,\mu j}{\Pi_{m_1\neq\xi}\{1-V_{\overline{m_1m_1}}\}}\right\}\right] \div \left[\sum_{i,s_r}\left\{\frac{\{pr(\xi^{sr\to}i)\}\mu_i^1}{\Pi_{m_2\neq\xi}\{1-V_{\overline{m_2m_2}}\}}\right\}\right]$$

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

$$A_0 = (V_{5,2}\mu_2+V_{5,3}\mu_3+V_{5,5}\mu_5) \div (V_{5,2}\mu_2+V_{5,3}\mu_3+V_{5,4}\mu_4+V_{5,5}\mu_5+V_{5,6}\mu_6+V_{5,7}\mu_7+V_{5,8}\mu_8+V_{5,9}\mu_9+V_{5,10}\mu_{10}+V_{5,11}\mu_{11}+V_{5,12}\mu_{12}+V_{5,13}\mu_{13}+V_{5,14}\mu_{14}+V_{5,15}\mu_{15})$$

6. SENSITIVITY ANALYSIS

Besides, the above after sections portray two sensitivity analysis scenarios and relating brings about plain and graphical structures broke down.

Scenario 1: In this scenario, the failure rates for all relevant units and subunits are assumed to be constant, set at $\beta_i = 0.10$ for $2 \leq i \leq 7$. The repair rates (α_i) are individually varied across a range of values: 0.50, 0.60, 0.70, 0.80, 0.90, and 1.00.

Table 1: Availability of System (A_0)

α_i	α_2	α_3	α_4	α_5	α_6	α_7
0.50	0.667	0.648	0.635	0.620	0.605	0.590
0.60	0.679	0.667	0.648	0.635	0.620	0.605
0.70	0.697	0.679	0.667	0.648	0.635	0.620
0.80	0.714	0.697	0.679	0.667	0.648	0.635
0.90	0.728	0.714	0.697	0.679	0.667	0.648
1.00	0.748	0.728	0.714	0.697	0.679	0.667

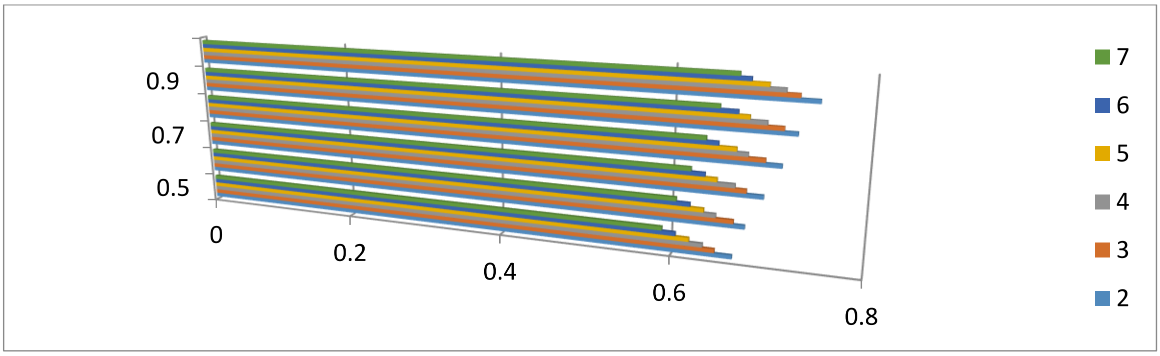

Figure 2: Availability of System

Table 1 illustrates how increasing the repair rate (α_i) of each unit individually leads to a steady rise in system availability (A_0). The greatest impact is observed when the repair rate of the first unit (α_2) is increased, indicating the criticality of this unit in maintaining system operational status. These results highlight the strategic value of prioritizing improvements in repair capabilities to maximize uptime.

Scenario 2: For the analysis, the repair rates for all relevant units and subunits are held constant at $\alpha_i = 0.70$ for $2 \leq i \leq 7$. The failure rates (β_i) are individually varied, one at a time, across the values 0.10, 0.20, 0.30, 0.40, 0.50, and 0.60.

Table 2: Availability of System (A_0)

β_i	β_2	β_3	β_4	β_5	β_6	β_7
0.10	0.534	0.554	0.568	0.580	0.593	0.606
0.20	0.512	0.534	0.554	0.568	0.580	0.593
0.30	0.498	0.512	0.534	0.554	0.568	0.580
0.40	0.482	0.498	0.512	0.534	0.554	0.568
0.50	0.473	0.482	0.498	0.512	0.534	0.554
0.60	0.461	0.473	0.482	0.498	0.512	0.534

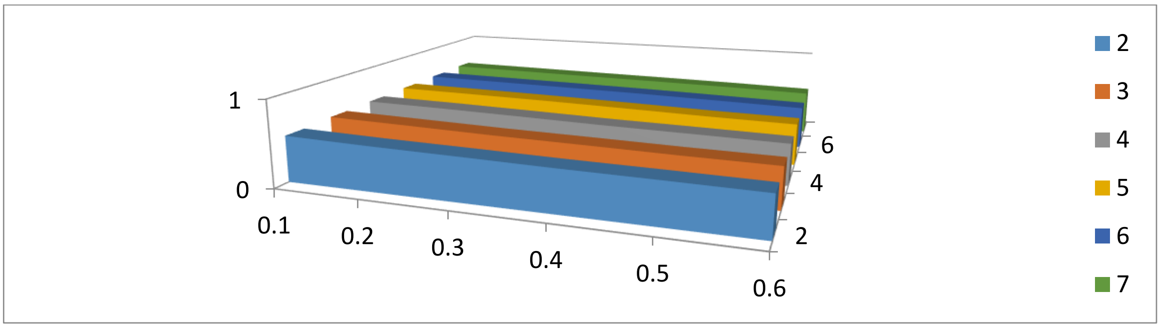

Figure 3: Availability of System

Table 2 demonstrates that as the failure rate (βi) of any unit increases, system availability (A_0) consistently decreases. The lowest availability (0.461) occurs at the highest failure rate, while the highest availability (0.606) is observed at the lowest failure rate. This underscores the importance of reducing failure rates for critical units to achieve higher system efficiency and reliability.

7. CONCLUSION:

The data-driven evaluation of the 3:4::G system using RPGT and sensitivity analysis reveals that enhancing repair rates and reducing failure rates are pivotal for maximizing system availability. Maintenance strategies that focus on critical units yield the greatest gains in reliability and operational efficiency. The findings support the adoption of targeted, data-supported preventive maintenance and repair programs, ensuring that industrial operations remain resilient, cost-effective, and competitive in demanding environments.

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