

## System Availability Modeling for Steel Industries in Hisar

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### Abstract:

This paper presents a system availability modeling study for the steel industry in Hisar. The analysis, which focuses on a stainless steel plant with four major subsystems (Grinding, Descaling, Hot Steckel Mill, and Cutter Machine) arranged in series, uses the Regenerative Point Graphical Technique (RPGT) to model system behavior. RPGT is used to generate analytical expressions for system availability, and numerical examples are provided to demonstrate the effects of various failure and repair rates. The findings, presented in tables and graphs, provide actionable insights for optimizing availability in steel manufacturing systems, allowing plant managers in Hisar to improve operational reliability and reduce downtime.

**Keywords:-** RPGT, Availability, Steel Manufacturing, Reliability Analysis

### 1. Introduction:

The steel industry, especially in Hisar, serves as the backbone of industrial progress and economic strength, supporting key sectors like infrastructure and manufacturing. Within the steel manufacturing process, several interdependent subsystems such as grinding, descaling, hot Steckel mill, and cutting machines must operate seamlessly to ensure stable production and high-quality output. Any unplanned failure or maintenance delay in these subsystems can significantly disrupt operations, increase costs, and reduce overall productivity. It emphasizes the importance of availability analysis in evaluating and optimizing the continuous functioning of each subsystem within the plant. High system availability not only reduces downtime but also improves throughput and supports sustainable profitability objectives that are essential for Hisar’s vibrant steel sector. This research applies the Regenerative Point Graphical Technique (RPGT), a powerful analytical method, to model the availability of a plant composed of four critical subsystems configured in series. By assuming constant failure and repair rates for each unit, the study develops a state transition diagram that captures all operational and failed states of the system. RPGT is then used to obtain analytical expressions specifically for system availability, enabling quantitative assessment and optimization. The results are presented through detailed tables and graphical representations, offering practical insights for plant

managers and decision-makers to enhance availability, reduce downtime, and ensure consistent performance in the steel manufacturing environment of Hisar. Ahmed, Bhatia, and Kumar (2014) examined how delays in repair impact system faults, underlining the necessity of prompt maintenance for maximizing effectiveness. Ahmad and Kumar (2015) contributed two studies: one analyzing the availability of a two-unit centrifuge system under various fault conditions, and the other investigating associated profit outcomes. Arya and Verma (2025) advanced the field by using environment modeling and simulation for reliability and availability predictions in embedded systems, emphasizing the role of environmental factors and model accuracy in predictive maintenance. Bansal and Tyagi (2024) utilized artificial neural networks to optimize both availability and profitability in the continuous casting segment of steel industries, demonstrating the value of machine learning in reliability optimization. Bastos and Fujiyama (2023) illustrated the impact of reliability-centered maintenance in a steel mill, showing that focused maintenance strategies can significantly enhance plant performance and minimize unplanned downtime.

In summary, this work provides a focused, data-driven approach to system availability modeling for steel industries in Hisar, equipping management with the analytical tools needed for effective maintenance planning and operational excellence.

## **2. System Description**

The Indian steel industry, a key global player and the world’s second-largest producer of crude steel, has experienced remarkable growth in both production and consumption, largely due to its commitment to expanding capacity for domestic and international markets. Central to the industry's operational efficiency and system availability are four main subsystems: Grinding, Descaling, Hot Steckel Mill, and Cutter Machine. Grinding machines are crucial for shaping and finishing steel components, with any failure potentially leading to significant disruptions in final product quality. Descaling machines continuously treat steel strips of varying widths to remove mill scale, ensuring surface quality for further processing. The Hot Steckel Mill facilitates multiple rolling passes, reducing slab thickness and maintaining optimal temperatures through reheating processes. The effectiveness and reliability of these subsystems directly influence the overall availability and productivity of steel manufacturing plants in India.

## **3. Assumptions and Notations**

- The framework comprises of three non-identical sub-units. Firstly, two units are active and another unit is kept in cold standby.
- A single repairman is available 24\*7.

- $\beta_1$ : Constant failure rate of the unit ‘A’ from full capacity to complete failure.
- $\beta_2$ : Constant failure rate of the standby ‘B’.
- $\beta_3$ : Constant failure rate of the unit ‘C’.
- $p$ : Probability of the switch working properly.
- $\alpha_1$ : Constant repair rate of main unit.
- $\alpha_2$ : Constant repair rate of standby.
- $\alpha_3$ : Constant repair rate of unit ‘C’.
- $\alpha_4$ : Constant repair rate of the switch.
- A/a: Unit ‘A’ in good / failed state.
- B/ (B)/b: Redundant unit in operative/ standby / failed state.

#### 4. Transition Diagram of the System

Following the above assumptions and notations, the transition diagram of the system is as shown in Figure 1. The system can be in any of the following states with respect to the above symbol.  
 $S_2 = A(B)CD$ ;  $S_3 = a(B)Cd$ ;  $S_4 = a(B)CD$ ;  $S_5 = A(B)cD$ ;  $S_6 = A(B)Cd$ ;  $S_7 = a(B)cD$ ;  $S_8 = AbCd$ ;  
 $S_9 = abCD$ ;  $S_{10} = AbCD$ ;  $S_{11} = AbcD$

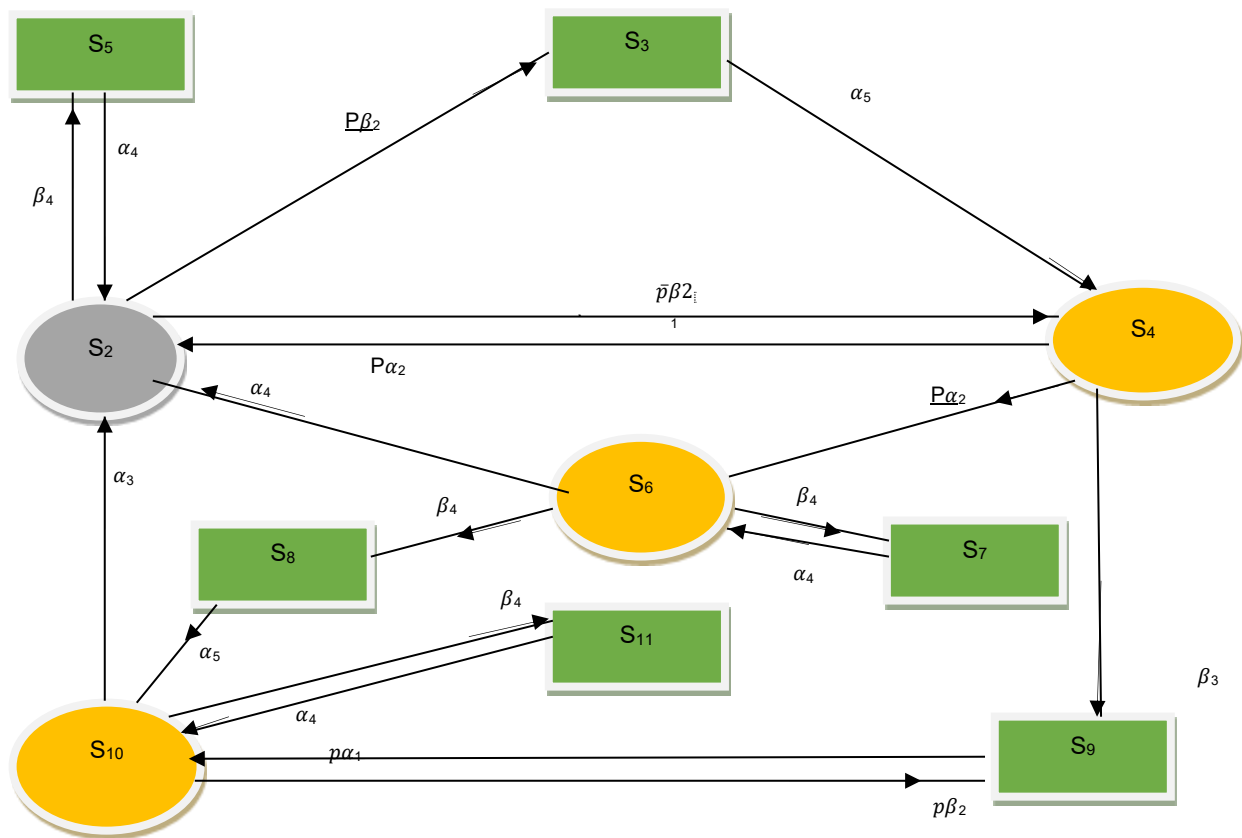


Figure 1: TRANSITION DIAGRAM OF THE SYSTEM

### 5. Transition Probability Factors:

The mean time to system failure and all the key parameters of the system (under steady state conditions) are evaluated by using Regenerative Point Graphical Technique (RPGT) and using ‘2’ as the base state of the system as under: -

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

$$V_{2,3} = \dots\dots\text{continue}$$

### 6. Evaluation of Parameters:

(a) **MTSF (T<sub>0</sub>):** The regenerative un-failed states to which the system can transit (Initial state ‘2’) before entering any failed state are: for ‘ξ’ = ‘2’, MTSF is given by

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

(b) **Availability of the System (A<sub>0</sub>):** The regenerative states at which the system is available are j = 2, 4, 6, 10 and the regenerative states are i = 2 to 11 for ‘ξ’ = ‘2’, the total fraction of time system is available is given by

$$A_0 = \left[ \sum_{j,s_r} \left\{ \frac{\left\{ \text{pr} \left( \xi \xrightarrow{s_r} j \right) \right\} f_j \mu_j}{\prod_{m_1 \neq \xi} \{1 - V_{m_1, m_1}\}} \right\} \right] \div \left[ \sum_{i,s_r} \left\{ \frac{\left\{ \text{pr} \left( \xi \xrightarrow{s_r} i \right) \right\}}{\prod_{m_2 \neq \xi} (1 - V_{m_2, m_2})} \right\} \right]$$

(c) **Busy Period of the Server (B<sub>0</sub>):** The regenerative states where the server is busy while doing repairs are j = 3 to 11

$$B_0 = \left[ \sum_{j,s_r} \left\{ \frac{\left\{ \text{pr} \left( \xi \xrightarrow{s_r} j \right) \right\} n_j}{\prod_{m_1 \neq \xi} \{1 - V_{m_1, m_1}\}} \right\} \right] \div \left[ \sum_{i,s_r} \left\{ \frac{\left\{ \text{pr} \left( \xi \xrightarrow{s_r} i \right) \right\} \mu_i^1}{\prod_{m_2 \neq \xi} (1 - V_{m_2, m_2})} \right\} \right]$$

(d) **Expected number of server’s visits (V<sub>0</sub>):** The regenerative state to which server visits a fresh are j = 3, 4, 5 and the regenerative states are j = 2 to 11. Therefore no expected no. of server’s visit for ‘ξ’ = ‘2’ is given by

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

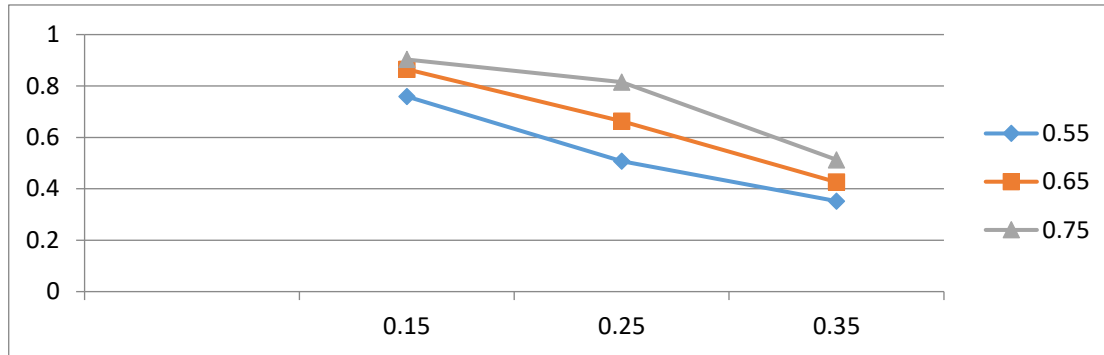
### 7. Particular Cases: -

For  $\beta_i = \beta ; 2 \leq i \leq 4 ; \alpha_i = \alpha ; 2 \leq i \leq 5 ; p = 1, p = 0,$

**Analytical Discussion: Behavior Analysis:** Fix;  $\alpha = \alpha_i ; \beta = \beta_i$

**Table 1: Availability of System (A<sub>0</sub>)**

$\beta \backslash \alpha$	0.55	0.65	0.75
0.15	0.759	0.865	0.903
0.25	0.508	0.663	0.815
0.35	0.352	0.426	0.513



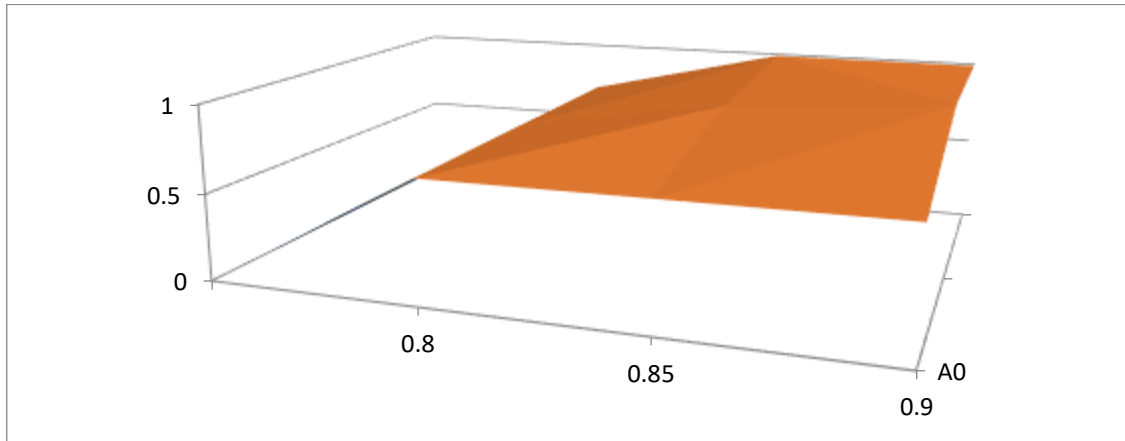
**Fig. 2: Availability of System**

Table 1 clearly shows that as the failure rate of steel plant subsystems increases, overall system availability declines sharply even with higher repair rates. While improving repair efficiency does boost availability, frequent equipment breakdowns still cause significant drops. Thus, minimizing failure rates is essential for maintaining optimal system availability in steel manufacturing.

**Scenario 1:** Sensitivity analysis w. r. t. amendment in repair rates, Varying repair rate  $\alpha_i = 0.8, 0.85, 0.9$  for different units and keeping the repair rate of other units at 0.8, we have the following table

**Table 2: Availability of the System ( $A_0$ )**

$\alpha_i$	$A_0$			
	$\alpha_2$	$\alpha_3$	$\alpha_4$	$\alpha_5$
0.80	0.69831	0.69831	0.69831	0.69831
0.85	0.70614	0.90559	0.98890	0.91907
0.90	0.71258	0.99155	0.98895	0.93587



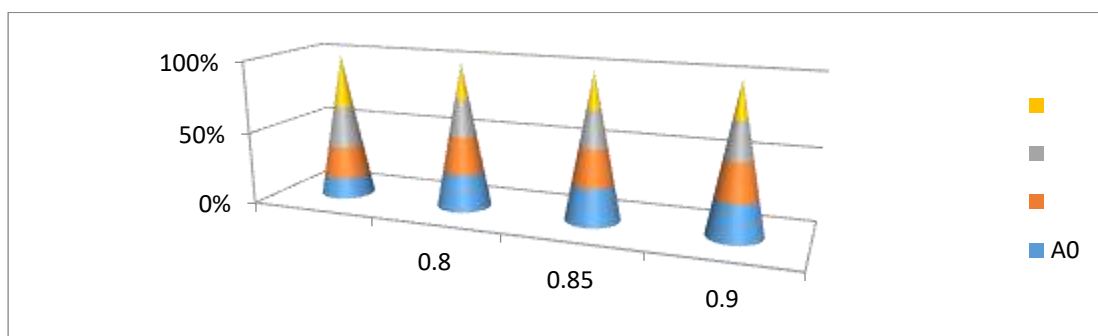
**Figure 3: Availability of System**

Table 2 and Figure 3 show that increasing the repair rate of individual subsystems, especially unit C, leads to a significant boost in overall system availability. While improvements in other units yield modest gains, focusing maintenance efforts and resources on the most critical subsystem maximizes uptime and operational efficiency in the Hisar steel plant.

**Scenario 2:** Sensitivity analysis w. r. t. amendment in Failure Rates, Varying failure rate  $\beta_i = 0.1, 0.15, 0.2$  for different units and keeping failure rate of other units at 0.1, we have the following table.

**Table 3: Availability of System ( $A_0$ )**

$\beta_i$	$A_0$			
	$\beta_2$	$\beta_3$	$\beta_4$	$\beta_5$
0.80	0.6145	0.6145	0.6145	0.6145
0.85	0.5247	0.5243	0.5237	0.5233
0.90	0.4358	0.4347	0.4341	0.4338



**Figure 4: Availability of System Graph**

Table 3 and Figure 4 reveal that system availability in the Hisar steel plant is most sensitive to the reliability of early-stage subsystems, like units A and B. While increasing repair rates helps, minimizing failures especially in these foundational units is crucial for maintaining high overall availability and ensuring smooth, uninterrupted plant operations.

**8. Conclusion:**

The analysis shows that reducing failure rates—especially in the most critical production subsystems—significantly boosts overall plant performance and availability in the Hisar steel facility. While faster repairs help, their impact is maximized when paired with proactive failure prevention and targeted maintenance. Prioritizing high-quality equipment and preventive care in key areas ensures sustained operational efficiency and long-term competitiveness.

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