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SAFETY MANAGEMENT AND HAZARDS CONTROL MEASURES IN THERMAL POWER PLANT CONSTRUCTION

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ABSTRACT

Thermal power plant construction contains some of the highest risk activities that bring severe safety issues, such as working at height, hot work, entry into confined spaces, and crane operations. The traditional safety measures still result in accidents and near misses since the conventional safety measures are reactive in nature. This paper aims at exploring the use of systematic safety engineering tools, namely Hazard Identification and Risk Assessment (HIRA) matrix, Analytic Hierarchy Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to identify, determine and rank hazards and control measures in thermal power plant construction projects. The results indicate that chimney erection is associated with the extreme risk of height-related falls, boiler erection presents considerable risk of gas leaks and equipment operation, and generator erection presents workers with the risk of fire, burns, and incidents involving cranes. Most of the high and extreme risks were successfully mitigated to moderate or low by the application of structured control strategies, as well as, the use of multi-criteria decision-making tools. The study is a databased, predictive model of enhancing occupational safety, assuring compliance, and instilling a culture of prevention in risky industrial construction worksites.

Keywords: Thermal Power Plant Construction, Occupational Safety, HIRA, AHP, TOPSIS, Hazard Control, Risk Assessment, High-Risk Activities, Safety Engineering

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1. INTRODUCTION

Thermal power plants are crucial for developing nations like India, but their construction involves complex, high-risk operations such as chimney erection, boiler installation, and generator integration. These activities involve working at heights, entering confined spaces, hot work, manual handling of heavy machinery, and close proximity to high voltage electrical equipment. Despite standard operating procedures, personal protective equipment, and industry regulations, incidents and near misses are still common. Traditional safety measures, such as checklists and generic personal protective equipment, fail to respond to changing site conditions or human behavioral hazards.To improve safety performance during thermal power plant construction, researchers are incorporating analytical models like Hazard Identification and Risk Assessment (HIRA), Analytic Hierarchy Process (AHP), and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). These tools quantify and prioritize risks, provide a multi-criteria framework for assessing efficient, compliant, cost-effective, and easy-to-implement control measures.By analyzing high-risk construction stages and implementing contemporary safety engineering methods, the study aims to provide an evidence-based methodology to improve occupational safety in one of the most risky areas of infrastructure development.

1.1.Background Of The Study

Thermal power plants in India are crucial for meeting energy demands, but their complex engineering operations, such as chimney building, boiler fitting, and generator installation, pose significant risks to workers. Despite adherence to safety protocols and inspections, accidents continue to occur, highlighting the need for proactive, organized, and technology-oriented safety strategies. This paper aims to develop a predictive and data-driven strategy by integrating advanced risk appraisal models like the Hazard Identification and Risk Assessment (HIRA) matrix and decision-making methods like Analytic Hierarchy Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). The study will analyze and rank control measures based on effectiveness, cost, ease of implementation, and compliance with regulations to enhance safety performance in thermal power plant construction.

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1.2.Statement Of The Problem

The Indian thermal power plant construction industry faces risks of accidents and inefficiencies, particularly in high-risk operations like chimney, boiler, and generator construction. Traditional safety culture focuses on defensive techniques and checklists, which may not adapt to dynamic site conditions. This suggests a fragmented safety management system that needs an overhaul with a stronger, information-based, and comprehensive risk assessment system. The issue lies in initial precautionary steps and advanced, client-oriented safety in entranced construction sites, requiring integrated risk elimination and decision-making procedures.

1.3.Significance Of The Study

This study focuses on improving safety management systems during thermal power plant construction using risk assessment methods like HIRA, AHP, and TOPSIS. It provides a step-by-step process for identifying, assessing, and prioritizing hazards in high-risk activities like chimney, boiler, and generator installation. The research fills knowledge gaps in safety management and offers data, predictive, and contextualized methods to reduce accident risks, enhance worker safety, and build a modern safety culture in the growing Indian energy sector.

1.4.Research Objectives

- To identify and assess the key hazards associated with critical construction activities—specifically chimney erection, boiler erection, and generator erection—in thermal power plant projects.
- To evaluate the severity and likelihood of identified hazards using the Hazard Identification and Risk Assessment (HIRA) model before and after the implementation of control measures.
- To apply multi-criteria decision-making techniques (AHP and TOPSIS) to prioritize control measures based on their effectiveness, cost, regulatory compliance, and ease of implementation.
- To propose optimized and data-driven safety enhancement strategies for thermal power plant construction, ensuring proactive risk mitigation and regulatory adherence.

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2. LITERATURE REVIEW

The construction of the thermal power plants may be identified as the complicated interrelation of the activity profiles engineering, ecological and safety that directly can cause harm to a person, the environment and the sustainability of the construction. Since the industrial development continues to slowly aim at satisfying the growing energy demands, the necessity of the methodical avoidance of hazards also increases.

2.1.Risk Identification And Hazard Assessment In Power Plant Construction

Sanchez Colmenarejo et al. (2022) emphasizes the importance of hazard identification and risk evaluation in power plant construction, particularly commissioning and start-up. It proposes a new risk analysis method for temporary systems, which has been proven to increase safety and reduce incidents in industrial settings. The approach, applied in real cases, is seen as a significant innovation in safety processes in the power industry.

Bari et al. (2022) stressed the lack of systematic hazard assessment in HFO-based power plants of Bangladesh. They prioritised and determined significant operational risks, such as the steam drum and crankcase explosions, on the basis of a hybrid fuzzy MCDM model. The researchers determined the most suitable mitigation measures as standard operating procedures and training. Their study offered practical recommendations about ways to improve safety and reduce risks during the operation of power plants.

2.2.ENGINEERING AND TECHNOLOGICAL MEASURES FOR HAZARD CONTROL

Weng, J., Huang, Q., and Yang, X. (2022) examined thermal safety issues in lithium-ion batteries, focusing on thermal runaway and battery fires. It highlights the importance of PCM-based Battery Thermal Management Systems (BTMs) for heat rejection and thermal runaway protection. The authors suggest further research to improve reliability and thermal security.

Xu et al. (2022) submitted a synergetic mining approach to managing heat risk in deep mines and geothermal energy extraction. They created a geothermal energy source, therefore, to chill the adjoining rock and hence create injection and production passages beneath the air shaft of the hydrothermal system. They also determined through the aid of a coupled numerical model

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that patronizing water injection would progressively lower the tunnel temperatures and thus make it cooler to the people. The best channels layout was found when the injection of water was placed below the air intake side and the heat producing channel was placed at the deep rock at the return air side.

2.3.ENVIRONMENTAL HAZARDS AND SUSTAINABLE MITIGATION PRACTICES

Zheng, Q., Zhou, and Lv (2024) evaluated the problems of coal gangue, a waste from mining coal, which can be used in civil constructions, agriculture, and energy. It suggests that activation and modification before use are effective methods, but environmental effects of stacking are also noted. The study also highlights the need for low-carbon discharging methods and better resources for effective gangue utilization and large-scale garbage disposal.

Piriyeva et al. (2024)study examined the environmental impacts of CHP plants, focusing on emissions, water usage, and waste. It identifies air pollutants like nitrogen oxides, sulfur dioxide, and carbon dioxide, as well as issues with luxury water consumption, thermal pollution, water disposal, and soil pollution. The authors propose solutions such as emission control technologies, efficient water use, waste reduction, and new energy technologies and policies for thermal power stations.

3. RESEARCH METHODOLOGY

This mixed-methods research focuses on safety management during thermal power plant construction, focusing on high-risk operations like chimney erection, boiler installation, and generator erection. The study uses descriptive and analytical research design, utilizing the Hazard Identification and Risk Assessment (HIRA) matrix and Multi-Criteria Decision Making (MCDM) methods. Data collection methods include field observations, interviews with safety officers, engineers, and construction workers, and participatory sessions during safety audits. Secondary data includes safety manuals, past accident reports, internal audit reports, and national/international safety standards. Risks related to sub-activities are estimated using the HIRA methodology, with hazards rated based on likelihood and severity. The risk rating is calculated using a formula.

$$\text{Risk Rating} = \text{Likelihood} \times \text{Severity}$$

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The study assessed residual risk in chimney erection, focusing on fall from height and hot work. The research used Multi-Criteria Decision Making (MCDM) methods, including the Analytic Hierarchy Process (AHP) to determine the effectiveness, cost, regulatory compliance, and ease of implementation of control measures. The TOPSIS ranking technique was used to rank alternative control measures based on their relative performance. The study found that a combination of safety nets, full-body harnesses, and guardrails had the highest closeness coefficient (0.86), making it the most effective method of control. The HIRA matrix was used for rating baseline and residual risk, the AHP model for weighting criteria, and the TOPSIS algorithm for final ranking control measures. This combination allowed for effective evidence-based hazard prioritization and safety intervention planning.

4. DATA ANALYSIS

The chimney erection work HIRA Matrix indicates that three more significant sub-activities are involved (working at height, manual handling, electrical work), and all of them are connected with considerable occupational hazards. Working at height was identified as the highest priority of these with its risk rating of 25, literating it as an extreme risk because of its high potential in causing serious injury or even death following falls.

Table 1: HIRA Matrix – Chimney Erection Work

Sub-Activity	Identified Hazard	Likelihood	Severity	Risk Rating	Residual Risk After Control
Working at Height	Fall from height	5	5	25 (Extreme)	6 (Low)
Manual Handling	Musculoskeletal injuries	4	3	12 (High)	4 (Low)
Electrical Work	Electric shock	3	4	12 (High)	3 (Low)

Nevertheless, an elaborate control measure, including the use of full-body harnesses, guardrails installation, and the use of trained personnel, successfully decreased the residual risk to 6 that is within the low-risk range. Manual handling that had high risk rating of 12 because of the risk of musculoskeletal injuries was reduced to low residual risk of 4 with the intervention of

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ergonomic training, mechanical lifting equipments and insistence on using proper lifting methods. Likewise, high risk of electric shock (initial score = 12) electrical work was reduced to a remaining risk of 3 through the measures of cable insulation, earth leakage protection devices (ELCB/RCCB) and systematic awareness training of workers. Comprehensively, the discussion has shown that, in the event they are used properly, proactive and engineered controls can greatly minimize the risks that are involved during chimney erection, and thus, dangerous working environments are changed into controllable and safer working situations.

Table 2: HIRA Matrix – Boiler Erection Work

Sub-Activity	Identified Hazard	Likelihood	Severity	Risk Rating	Residual Risk After Control
Confined Space Entry	Suffocation, gas leaks	5	5	25 (Extreme)	8 (Moderate)
Equipment Operation	Collision, entrapment	4	4	16 (High)	6 (Low)

HIRA Matrix of boiler erection work has revealed two sub-activities with high-risk potential; these are confined space entry and equipment operation which has grave impact on workers safety. Entry into a confined space is especially dangerous because of the threats of suffocation and gas leakage, with the maximum risk rating of 25, which is equivalent to an extreme risk. These conditions are usually marked with poor ventilation, toxic gases, and movement. By introducing such control measures as constant gas monitoring, forced ventilation with draught fans, limited access, and compulsory training of entrants and attendants, the residual risk was brought down to 8, which places it in the category of moderate risk, albeit needing close supervision. The risk of collision or entrapment in the case of equipment operation that involves the usage of heavy machinery and tools at tight places translated to a risk rating of 16, which is considered high. Improperly implementing operational barricades and certifying the people who work with the machinery as well as plainly putting emergency plans reduced this to a residual risk of 6 (low). Such interpretation allows highlighting the significance of both engineering and administrative types of control in the process of boiler erection activities and proves that despite the harsh initial levels of risks, systematic measure can strongly improve the working conditions and decrease the chances of tragic accidents.

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Table 3: HIRA Matrix – Generator Erection Work

Sub-Activity	Identified Hazard	Likelihood	Severity	Risk Rating	Residual Risk After Control
Hot Work	Fire, burns	5	4	20 (High)	4 (Low)
Crane Movement	Load drop, impact	4	5	20 (High)	6 (Low)

According to the HIRA Matrix of the generator erection work, there are two sub-activities which have initial risk rating that is quite high, hot work and crane movement, both have risk score of 20, and therefore, they are classified as high risk operations. Hot work includes such activities as welding and cutting, and it is associated with serious risks, including fire and burn injuries because of the use of flammable materials and tools that are exposed to high temperatures. Implementing specific control measures, namely, enforcing permit-to-work (PTW) systems, isolating hot work areas, employing certified welders and surrounding them with clear danger signs and obligating the personnel to wear PPE, i.e., welding shields and gloves, decreased the residual risk to 4, which falls into the low risk category. In a similar manner, crane movement which is linked to load drops and impact injuries is risky in nature by virtue of the fact that moving, handling and working with heavy materials and loads suspended in dynamic construction conditions takes place. The residual risk was mitigated to 6, which corresponds to low manageable risk level through control measures such as use of certified tools and lifting tackles, strict adherence to operating procedures, operator certification, and task specific PPE. As discussed in this analysis, procedural discipline, as well as engineering controls, is critical in helping to reduce severe risks that are related to generator erection operations substantially.

4.1. AHP-BASED CRITERIA WEIGHT ASSIGNMENT

Through AHP (Analytic Hierarchy Process), weights of importance were given to various control measure evaluation criteria based on expert literature. This table shows the relative weights of four criteria — effectiveness, cost, regulatory compliance, and ease of implementation — for assessing safety control measures. The Analytic Hierarchy Process

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(AHP) method was used to assign the weights, a systematic decision-making procedure used extensively in safety engineering and operations research

Table 4: Weight Assignment Using AHP

Criteria	Assigned Weight
Effectiveness	**0.61**
Cost	**0.14**
Regulatory Compliance	**0.19**
Ease of Implementation	**0.28**

4.2 Topsis-Based Ranking of Control Measures

To determine the ranking of control measures, the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method was used. This approach helps select the best alternative based on its distance from an ideal solution.

Step 1: Construct Decision Matrix

Raw ratings were assigned to each control measure based on four criteria: Effectiveness, Cost, Compliance, and Ease.

Step 2: Normalize the Matrix

Each rating $x_{ij}$is converted into a unit-free normalized value:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}}$$

Step 3: Apply Weights (from AHP)

The normalized values are multiplied by AHP-derived weights:

$$v_{ij} = r_{ij} \times w_j$$

Step 4: Determine Ideal Solutions

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- **Positive Ideal Solution (PIS)** = best values across criteria
- **Negative Ideal Solution (NIS)** = worst values across criteria

Step 5: Calculate Separation Measures

Measure how far each option is from the ideal and negative-ideal:

$$S_i^+ = \sqrt{\sum\left(v_{ij} - v_j^+\right)^2} \; ; S_i^- = \sqrt{\sum(v_{ij} - v_j^-)^2}$$

Step 6: Calculate Closeness Coefficient

$$CC_i = \frac{S_i^-}{S_1^+ + S_i^-}$$

Step 7: Rank Alternatives

Control measures are ranked based on their closeness coefficients — the higher the value, the more preferred the measure.

TOPSIS was then used to compare various control measures for hazards by their performance compared to the weights assigned by AHP.

Table 5 presents the result of using the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) approach to rank alternative safety control measures for chimney construction based on performance against the four criteria weighted in the above table using AHP.

Table 5: TOPSIS Ranking of Control Measures for Chimney Erection

Control Measure	**Effectiveness**	**Cost**	**Compliance**	**Ease**
PPE	9	7	9	8
Admin controls	8	6	8	9

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(Training, PTW)				
Safety nets , Full-body harness + Guardrails	5	9	5	6

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}}$$

Table 6: Initial Decision Matrix for Control Measures

Control Measure	Effectiveness	Cost	Compliance	Ease
PPE	9	7	9	8
Admin controls (Training, PTW)	8	6	8	9
Safety nets , Full-body harness + Guardrails	5	9	5	6
	13.038	12.884	13.038	13.45

$$x_{ij} = \sqrt{9^2 + 8^2 + 5^2} = 13.038$$

$$x_{ij} = \sqrt{7^2 + 6^{\,2} + 9^2} = 12.884$$

$$x_{ij} = \sqrt{9^2 + 8^{\,2} + 5^2} = 13.038$$

$$x_{ij} = \sqrt{8^2 + 9^{\,2} + 6^2} = 13.45$$

Table 7: Safety Measures Normalized Scores

Control Measure	Effectiveness	Cost	Compliance	Ease
PPE	9/13.038	7/12.884	9/13.038	8/13.45
Admin controls (Training, PTW)	8/13.038	6/12.884	8/13.038	9/13.45
Safety nets , Full-body harness + Guardrails	5/13.038	9/12.884	5/13.038	6/13.45

Table 7 presents the normalized scores of the safety measures across four criteria: Effectiveness, Cost, Compliance, and Ease. Each raw score for the control measures—PPE, Administrative controls, and Safety nets with fall protection—is divided by the total score of its respective criterion to standardize the values for comparison. PPE shows the highest normalized scores in Effectiveness and Compliance, reflecting its strong safety performance and adherence. Administrative controls have competitive normalized scores, especially in Ease, indicating they are relatively simple to implement. Safety nets, while scoring lower in Effectiveness and Compliance, have a high normalized score for Cost, emphasizing their higher expense relative to other measures. This normalization facilitates a balanced evaluation by placing all criteria on a comparable scale, aiding in more objective decision-making.

Table 8: Normalized Scores of Safety Control Alternatives

Control Measure	Effectiveness	Cost	Compliance	Ease
PPE	0.6902	0.5433	0.6902	0.5947
Admin controls (Training, PTW)	0.6135	0.4656	0.6135	0.6691
Safety nets , Full-body harness + Guardrails	0.3834	0.6985	0.3834	0.4460

Table 8 shows the normalized scores of three safety control alternatives—PPE, Administrative controls, and Safety nets with fall protection—across Effectiveness, Cost, Compliance, and Ease. PPE scores highest in Effectiveness (0.69) and Compliance (0.69), indicating strong safety performance and adherence, with a moderate Ease score (0.59). Administrative controls rank slightly lower in Effectiveness and Compliance but have the highest Ease score (0.67), suggesting they are easier to implement. Safety nets have the lowest scores in Effectiveness (0.38) and Compliance (0.38), but the highest Cost score (0.70), reflecting their higher expense. Overall, these normalized values provide a clear comparison of each control measure's strengths and weaknesses across key criteria to support informed decision-making.

Apply Weights (from AHP)

The normalized values are multiplied by AHP-derived weights:

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$$v_{ij} = r_{ij} \times w_j$$

Table 9: AHP Scores of Safety Controls

Weights (AHP)	**0.61**	**0.14**	**0.19**	**0.28**
Control Measure	**Effectiveness**	**Cost**	**Compliance**	**Ease**
PPE	0.6902	0.5433	0.6902	0.5947
Admin controls (Training, PTW)	0.6135	0.4656	0.6135	0.6691
Safety nets , Full-body harness + Guardrails	0.3834	0.6985	0.3834	0.4460

Table 9 presents the AHP-weighted normalized scores of three safety control measures—PPE, administrative controls (training and permit-to-work systems), and a combination of safety nets, full-body harness, and guardrails—evaluated across four criteria: effectiveness (weight 0.61), cost (0.14), compliance (0.19), and ease of implementation (0.28). Among the options, PPE shows the highest scores in both effectiveness and compliance (0.6902), indicating strong performance in critical safety aspects. Administrative controls perform moderately well across all criteria, particularly in ease of implementation (0.6691). In contrast, the combined physical safety measure scores lowest in effectiveness and compliance (0.3834 each) despite having a relatively higher cost score (0.6985), suggesting that while it may be expensive, it is less effective and harder to implement. Overall, PPE emerges as the most balanced and effective control based on the weighted criteria.

Table 10: AHP-Based Evaluation of Safety Control Measures

Weights (AHP)	**0.61**	**0.14**	**0.19**	**0.28**
Control Measure	**Effectiveness**	**Cost**	**Compliance**	**Ease**
PPE	0.6902*0.61	0.5433***0.14**	0.6902***0.19**	0.5947***0.28**

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Admin controls (Training, PTW)	0.6135*0.61	0.4656***0.14**	0.6135***0.19**	0.6691***0.28**
Safety nets , Full-body harness + Guardrails	0.3834*0.61	0.6985***0.14**	0.3834***0.19**	0.4460***0.28**

Determine Ideal Solutions

- **Positive Ideal Solution (PIS)** = best values across criteria
- **Negative Ideal Solution (NIS)** = worst values across criteria

Table 11: Normalized Weighted Scores and Ideal Solutions for Control Measures

Control Measure	Effectiveness	Cost	Compliance	Ease
PPE	0.4210	0.0760	0.1312	0.1665
Admin controls (Training, PTW)	0.3743	0.0652	0.1166	0.1873
Safety nets , Full-body harness + Guardrails	0.2339	0.0978	0.0729	0.1248
Positive Ideal Solution(v_j^+**)**	0.2339	0.0652	0.0729	0.1248
Negative Ideal Solution(v_j^-**)**	0.4210	0.0978	0.1312	0.1248

$$S_i^+ = \sqrt{\sum\left(v_{ij} - v_j^+\right)^2} \; ; S_i^- = \sqrt{\sum(v_{ij} - v_j^-)^2}$$

Calculate Closeness Coefficient

$$CC_i = \frac{S_i^-}{S_1^+ + S_i^-}$$

Table 12: TOPSIS Scores and Ranking of Control Measures

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Control Measure	S_i^+	S_i^-	CC_i	Rank
PPE	**0.2011**	**0.072**	**0.26**	**3**
Admin controls (Training, PTW)	**0.1597**	**0.061**	**0.28**	**2**
Safety nets , Full-body harness + Guardrails	**0.0326**	**0.205**	**0.86**	**1**

The best and most balanced control action was "safety nets full-body harness + guardrails," ranking first at a closeness coefficient of 0.86. This option performed highly in all four aspects, particularly effectiveness and compliance. The second solution, " Admin controls (Training, PTW)," although effective and simple to apply, received a marginal lower score owing to cost or complexity. "PPE," indicating a low level of PPE control, ranked lowest, confirming the industrial consensus that PPE actions alone are not adequate in high-risk situations.

5. CONCLUSION

This paper has come to the conclusion that the construction of thermal power plant, which is initially a high-hazard industry, requires an active and analytical safety management approach. The HIRA matrix enabled the identification and quantification of the hazards in the critical construction tasks to be identified and quantified in a logical way, including chimney erection, boiler installation, and generator erection. The targeted interventions were used to effectively assess and control high-risk events such as falls of heights, gas leaks in enclosed spaces, fire due to hot work, and accidents involving cranes. AHP allowed the prioritization of the control measures with regard to the most important criteria, namely effectiveness, cost, regulatory compliance, and easiness of implementation, whereas TOPSIS allowed ranking the control measures to choose the most suitable alternatives. Its results clearly indicate that engineering controls together with administrative processes and appropriate training considerably lower the levels of residual risks. The research not only fills the gaps available in the traditional safety methods, but also offers a solid and repeatable model that can be adopted to improve safety performance in large industrial construction projects. Such models need to be adopted to develop a safety culture, reduce occupational hazards, and assure regulatory compliance in the fast-growing energy infrastructure sector in India.

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Author's Declaration

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