APPLICATION OF HUMAN RELIABILITY ANALYSIS IN ASSESSING HIGH-RISK ACTIVITIES IN SRI LANKAN CONSTRUCTION SITES: A THERP-BASED APPROACH

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Abstract. The construction industry is recognised as one of the most hazardous sectors worldwide, with workers exposed to complex and high-risk tasks. Within this context, human error is a leading cause of accidents. To address this issue, the Technique for Human Error Rate Prediction (THERP) method of Human Reliability Analysis (HRA) applies to the construction industry. This study focuses on selected high-risk construction activities, including tower crane operation, excavation work, scaffolding erection, work at height, and electrical tasks. Semi-structured interviews were conducted with construction safety professionals to identify critical subtasks of construction activities, common human errors, and relevant Performance Shaping Factors (PSFs) associated with these activities. Then, nominal human error probabilities were adjusted using a weighted PSF model, and event tree analysis was conducted to evaluate the outcomes of sequential tasks. The study results indicate that tower crane operation, excavation work, and scaffolding erection are the most human error-prone activities. In addition, this study highlights areas where safety management can be strengthened by providing insights to improve human reliability in construction operations in Sri Lanka.

Keywords. *Construction Industry, Human Error, Human Reliability Analysis, Occupational Health and Safety, Performance Shaping Factors, THERP Methodology*

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1. Introduction

The construction industry is a vital contributor to a country's economic development. Yet, it is also considered one of the most hazardous industries due to the high-risk tasks performed in construction sites (Wijesekara et al., 2022). According to the International Labour Organisation, approximately 60,000 fatal accidents occur annually at construction sites around the world (Bussier & Chong, 2022). In addition, construction workers confront more fatal injuries compared to all other industries worldwide (Wijesekara et al., 2022). Reflecting this global trend, Sri Lanka has recorded 340 workplace accidents in 2020 and 337 in 2021. Fatal accidents accounted for 40.0% and 46.6% of total reported cases in 2020 and 2021. Among the reported fatalities, the construction sector contributed approximately 20% of total occupational deaths. (Department of Labour Sri Lanka, 2021). Among the various contributing factors, human errors have been identified as one of the leading causes of accidents. Reinforcing this point, approximately 80% of accidents resulted from human error (Ajith et al., 2022). Human errors in the construction industry can lead to accidents that can affect an organisation's reputation, cause property damage, and contribute to worker injuries and fatalities (Mollo & Emuze, 2022). Human Reliability Analysis (HRA) can be used as a structured approach to analyze and reduce human errors

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in the construction industry. According to Eisenberg (2001), "HRA is the method by which the probability of a system-required human action, task, or job will be completed successfully within the required time period, and that no extraneous human actions detrimental to system performance will be performed". HRA has been widely applied in high-risk industries where safety is a critical concern (Guglielmi et al., 2022). Studies on human reliability have shown that methods exist to analyse and reduce the risks caused by human error (Yalçın et al., 2024). HRA has evolved through three generations of methods. The purpose of the first-generation HRA methods is to detect human error and calculate the likelihood of human error by concentrating on the behavioural aspect of human performance (De Galizia et al., 2015). Second-generation HRA methods emphasise the cognitive aspects of human performance, focusing on the underlying causes of errors rather than their occurrence rate. Moreover, second-generation methods adopt a qualitative perspective, examining how human cognition and the interplay of performance-shaping factors influence errors (Di et al., 2013). Third-generation HRA methods have been developed to improve the limitations of earlier HRA methods by incorporating advances in cognitive science, causal modeling, and improved data collection techniques (Dsouza & Lu, 2016). Third generation HRA methods aim to provide a more realistic understanding of human behaviour and the decision-making process in a complex environment. Moaveni et al. (2019) argued that the application of HRA can help reduce the likelihood of human error in the construction industry. Previous studies have demonstrated the application of HRA methods such as Human Error Assessment and Reduction Technique (HEART) and Cognitive Reliability and Error Analysis Method (CREAM) within the global construction industry (Ramprasad & Kumar, 2019). Although several international studies have applied HRA methods such as HEART, CREAM, and Technique for Human Error Rate Prediction (THERP) within construction and other high-risk industries, there is no evidence of established HRA applications in the Sri Lankan construction context. In Sri Lanka, construction safety assessments continue to rely mainly on conventional risk assessment approaches, where likelihood values are largely based on expert judgement rather than systematic quantification of human error probabilities. Therefore, a significant knowledge gap exists regarding the application of HRA techniques in Sri Lankan construction operations. As an initial effort to introduce structured human reliability assessment into this context, this study applies the THERP, a first-generation HRA method, to quantify human error probabilities in selected high-risk construction activities. Accordingly, this study aims to apply THERP method to quantify human error probabilities in selected high-risk construction activities. To achieve the aim, the study pursues four objectives,

- To identify high-risk construction activities prone to human error
- To determine the Performance Shaping Factors (PSFs) influencing worker performance in the construction industry
- To calculate Human Error Probabilities using a THERP method
- To develop event tree models for selected construction tasks to systematically evaluate success and failure pathways.

The remainder of this paper is organized as follows: the paper begins with a literature review, and then it continues with the research method. Finally, it presents the research findings with a developed event tree model and conclusion.

2. Literature Review

2.1 HUMAN ERRORS IN THE CONSTRUCTION INDUSTRY

The Construction industry is highly risk-prone, with complex and dynamic project environments that create an atmosphere of high uncertainty and risk (Mhetre et al., 2016). Globally, more than 474 million people experience occupational illnesses and non-fatal injuries, and approximately 2.3 million workers lose their lives each year due to work-related accidents and diseases in the construction industry (Tripathi & Mittal, 2024). Furthermore, according to De Silva & Wimalaratne (2012), more than 30% of the total accidents occurred in the construction industry, which is about 13 times higher than in other industries. Every occupational accident typically has multiple contributing causes. However, 80% of industrial accidents are related to human error (Ajith et al., 2022). Sinabariba et al. (2020) defined human error as actions or decisions made by individuals that can negatively affect a system's safety, efficiency or overall performance. In order to prevent the occurrence of human errors, the root causes of human errors should be understood and addressed. Technological advancements in the construction industry have improved risk assessment and safety management. However, prevailing risk assessments generally focus on organisational factors; they often overlook personal factors that can contribute to human error (Bourahla et al., 2024). Furthermore, several important laws, regulations and standards have been established to ensure safety in construction and promote worker well-being. Including the Occupational Safety and Health Administration (OSHA), the Health and Safety Regulations Act, the Building and Other Construction Workers Act, 1996 (BOCW), International Organization for Standardization (ISO) 45000 standards, and the Workers' Compensation Act, which together help manage and protect workers' health and safety during construction projects (Tripathi & Mittal, 2024). Despite these regulations and initiatives, human errors continue occur. Hence, a more analytical approach is required that examines the reliability of human performance. This is where HRA becomes essential (Umair Khalid, 2022).

2.2 HUMAN RELIABILITY ANALYSIS (HRA)

HRA is a methodological framework focused on assessing how human activities contribute to risk by examining the various factors that influence human performance (Johnson et al., 2023). According to Swain & Guttmann (1983), HRA refers to "the probability that a person correctly performs an action required by the system in a required time and that he does not perform any extraneous activity that can degrade the system". The primary HRA process comprises a sequence of steps, including problem definition, task analysis, human error identification, error representation, and error quantification (Forgac, 2018).

HRA has developed over three generations of methods. First-generation HRA methods break tasks into smaller parts and assess how specific performance factors influence human actions. However, these methods have been criticized for overlooking contextual and organisational influences (De Galizia et al., 2015). The main disadvantages of the first generation HRA methods are neglecting the environment, organisational and cognitive factors that contribute to human errors. Nevertheless, first-generation HRA methods are still applied in quantitative risk assessments (Bijelic et al., 2018). The second-generation.

HRA methods emerged based on the first generation (Li et al., 2022). These approaches emphasize both internal and external PSFs and place strong emphasis on cognitive processes (Yalçın et al., 2024). Third generation HRA methods are focused on the dynamic and evolving interrelationships among factors that influence human performance. Moreover, the third generation method expands by incorporating the changing nature of human behaviour over time within a complex system (Tabor, 2021). Yalçın et al. (2024) identified 33 different HRA methods over these three generations. Among them, HEART (Human Error Assessment and Reduction Technique), CREAM (Cognitive Reliability and Error Analysis Method), THERP (Technique for Human Error Rate Prediction), SHERPA (Systematic Human Error Reduction and Prediction Approach), SPAR-H (Simplified Plant Analysis Risk Human Reliability Assessment), ATHENA (A Technique for Human Event Analysis), NARA (Nuclear Action Reliability Assessment), and RARA (Railway Action Reliability Assessment) were recognised as most commonly implemented HRA techniques in different high-risk sectors.

2.3 APPLICATION OF HRA IN HIGH-RISK INDUSTRIES AND THE CONSTRUCTION INDUSTRY

HRA methods were initially developed for application in nuclear power plants and were subsequently adapted for use in other industrial sectors (Bijelić et al., 2018). Recently, the healthcare sector has applied HRA methods to improve the quality of patient care and prevent errors by identifying factors influencing the occurrence of human error (Sefidkouhi et al., 2024). In the chemical industry, the application of HRA plays a critical role in preventing accidents and maintaining operational safety (Bastos, 2023). According to Lam and Chan (2023), HRA has evolved as a method to assess human performance and manage associated risks that occur during aircraft operational procedures. However, the application of human reliability has received relatively low priority within the construction industry compared to the nuclear, aviation, oil, healthcare, chemical plants and gas sectors. Ramprasad and Kumar (2019) investigated six large-scale projects and identified the PSFs, such as workforce skills, communication barriers, and organisational influences, emphasising their impact on safety performance and human reliability. Umair Khalid (2022) focused on using the HRA framework to study human factors and revealed that approximately 80% accidents were attributable to human factors such as behaviour, attitude, and hazard perception. Furthermore, a study applied the CREAM method to 176 construction workers in Indonesia by analysing work behaviour and quantifying HEPs to identify high risk control modes (Sinabariba et al., 2020). Li et al. (2022) employed the CREAM method to assess scaffolding operations in China, developing operational and cognitive subtasks to demonstrate reliable worker performance. Moreover, Chan et al. (2022) identified 35 human error related factors as significant contributors to site accidents. Ajith et al. (2022) used the HEART method integrated unsafe act modelling for construction sites, by highlighting excavation, reinforcement erection and crane operation as tasks with the highest error probability. Collectively, these studies illustrate the value of HRA methods in quantifying human error, identifying risk factors and informing safety management in the construction industry.

2.4 TECHNIQUE FOR HUMAN ERROR RATE PREDICTION (THERP)

The THERP is a first-generation HRA method that calculates the probability of successful task performance. Moreover, it evaluates human performance like how conventional reliability analysis models machines or mechanical components (De Galizia et al., 2015). The technique relies on an error probability database developed by safety analysts, which quantifies Human Error Probabilities (HEP) for specific tasks using PSFs (Kazmi et al., 2016). Furthermore, to analyse these probabilities, the method breaks down each task into smaller sub-tasks and identifies potential error data from the THERP HEP handbook (Abbassi et al., 2015). In the final step, HEP is calculated using the human reliability event tree (Calixto, 2016).

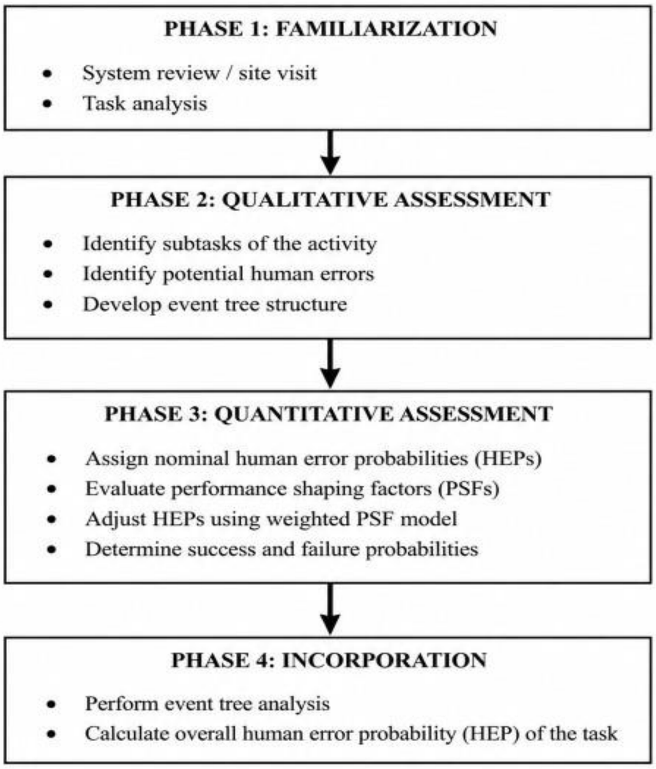


Figure 1, THERP Process adapted and redrawn based on THERP Handbook (Source: Swain and Guttmann, 1983).

THERP is described as a "decomposition" approach because it breaks tasks down into detailed and well-defined sub activities compared to many other techniques. Moreover, it follows a logical and systematic procedure and places greater emphasis on error detection and recovery than most other HRA methods (Bell & Holroyd, 2009). According to Kirwan (1994), THERP has several strengths and limitations. One of its main advantages is that the method is widely used in practice and has a strong, structured methodology that allows for auditing and review. According to Swain and Guttmann (1983), THERP is based on a comprehensive database provided in the THERP handbook, which enhances its credibility and consistency. However, the method can be resource-intensive and time consuming to apply and has limited guidance on modelling different scenarios and evaluating the impact of PSFs on human performance. Furthermore, the high level of detail required in THERP analyses may be excessive for certain types of assessments.

3. Methodology

To achieve the research aim, this study adopted a mixed-method approach, combining qualitative identification of human error factors through interviews with quantitative assessment using THERP to evaluate human error in high-risk construction activities. As highlighted in the research gap, HRA has not yet been systematically implemented within the Sri Lankan construction industry. Therefore, adopting a first-generation method such as THERP provides a feasible and practical entry point for introducing quantitative human reliability assessment into the local construction sector. Although the THERP method was originally developed for nuclear power plant safety assessment by Swain & Guttmann (1983), the effectiveness of the application of the method has been demonstrated across a wide range of high-risk industries. Table 1 presents the cross-industry application of the THERP method.

Table 1, Cross-Industry Application of the THERP Method

Author (Year)	**Industry**	**Application Area**
Swain and Guttmann (1983)	Nuclear Power	Nuclear power plant safety and operator reliability assessment
Abbassi et al. (2015)	Process / Chemical Engineering	Engineering process safety analysis
Nezamodini et al. (2018)	Manufacturing (Pipe Industry)	Industrial production and occupational safety evaluation
Ramezani et al. (2020)	Engineering Systems	Human reliability assessment in complex engineering systems
Yang et al. (2014)	Aviation	Aircraft take-off phase task reliability (A320)
Guo et al. (2020)	Aviation	Flight task analysis of aircraft

THERP has subsequently been adopted across multiple high-risk domains, including aviation, manufacturing, chemical process industries, and complex engineering systems. These applications demonstrate the methodological strength, structured task decomposition capability, and quantitative reliability modelling strength of THERP in diverse operational environments. The successful adoption of THERP across these sectors indicated that its applicability is not limited to static or highly controlled environments. Instead, the THERP task decomposition and probabilistic modelling approach are transferable to construction activities. Which can be represented as sequential operational tasks. Therefore, the cross-industry application of THERP supports its methodological validity for use in construction contexts. Moreover, THERP is a complementary starting point within a broader HRA framework. The structured outputs generated through THERP, such as task decomposition, identified error types, and quantified HEPs can stand as foundation steps for second- third-generation applications of HRA, such as HEART, CREAM, or SPAR-H. Therefore, THERP is not only a feasible choice but also a methodologically appropriate choice to meet the aim of this research.

Primary data of the research were collected through semi-structured interviews to systematically capture experiential knowledge from industry professionals regarding high-risk construction activities and associated human reliability issues. Twelve construction safety professionals were selected to interview based on predefined criteria to meet a minimum of three years of site-based experience, direct involvement in safety management or supervision, and practical exposure to high-risk construction activities. The sample included engineers, a safety officer, and a project manager to ensure representation of both operational and managerial perspectives. During the interviews, participants were requested to identify construction activities they consider most critical based on accident likelihood and consequence severity, and to justify their selections. For each identified activity, respondents were then asked to describe the sequence of subtasks, the common human errors observed in practice, and the key human, organisational, and environmental factors influencing performance. All interviews were conducted using a predefined interview guideline to ensure consistency while allowing flexibility for follow-up questions. The PSFs were further evaluated in terms of their relative impact on task reliability based on expert judgement. Participants were asked to indicate the severity of each factor using qualitative levels (low, moderate, high, or critical). These qualitative responses were then systematically mapped to a predefined proportional multiplier scale. To ensure consistency, responses were compared across participants, and the most frequently indicated severity level was selected for each factor. Each PSF was assigned a severity-based multiplier according to the following proportional scale. The details of the multiplier values are presented in Table 2.

Table 2, Proportionally Weighted Multiplier

Impact level	**Description**	**Multiplier**
Low	Minor influence on performance (10% increase)	1.1
Moderate	Noticeable influence on performance (30% increase)	1.3
High	Strong negative influence on performance (60% increase)	1.6
Critical	Severe impact on performance (100% increase)	2.0

The PSFs multiplier scale was presented in Table 2, proportionally representing performance degradation. This range ensures a realistic escalation of HEP values, preventing unrealistic probability inflation while still representing critical performance degradation. (Multiplier = 1.1) represents conditions where the influencing factor has only a minimal effect on task performance. Although the factor may be present, it does not significantly degrade the performance. However, the multiplier of 2.0 represents severe performance degradation. Such conditions may include extreme time pressure, complete lack of supervision, and fatigue. At this level, human reliability is considerably compromised, and immediate corrective or preventive interventions are necessary. Defining impact levels and their corresponding quantitative effects supports defensible estimation for the study.

Instead of directly multiplying PSFs multiplier by nominal HEP, a weighted PSF approach was applied. Each PSF multiplier was normalised by assigning a weight based on its relative contribution to the total PSF influence for the task. The weight of each PSF was calculated by dividing the individual PSF multiplier by the sum of all PSF multipliers associated with the subtask. The weighted PSF value was obtained by multiplying each PSF multiplier by its corresponding weight and summing the results. This aggregated weighted PSF was used to adjust the nominal HEP for each subtask using the following relationship. Formulae used,

$$\text{Weighted Multiplier} = 1 + \sum \left[w_i \left(PSF_i - 1 \right) \right]$$

$$\text{Adjusted HEP} = \text{Nominal HEP} \times \text{Weighted Multiplier}$$

This method ensures the credibility of the analysis by preventing the inflation of error probabilities and reflecting the relative impact of PSF conditions in a task.
This study adopted nominal HEPs reference to the Handbook of Human Reliability Analysis by Swain & Guttmann (1983). Nominal Human Error Probabilities are provided in the generic data tables, mainly in the tables of Chapter 20. The tables present derived probability ranges for different categories of human errors, such as omission, commission, sequence, time, and qualitative errors (Swain & Guttmann, 1982). To ensure consistency and transparency, each construction subtask was classified into standard THERP error categories. The Nominal HEP values were selected considering the nature of the tasks, level of skill required, degree of procedural guidance, time pressure, required cognitive effort and the task complexity of the construction activities.

4. Research Findings, Analysis and Discussion

This section presents the findings derived from the semi-structured interviews and quantitative HRA. The collected qualitative data were analysed using manual content analysis to systematically categorise responses. The findings have been divided into three subsections: identification of high-risk construction activities, human error and PSF association, and quantitative HEP estimation and event tree evaluation.

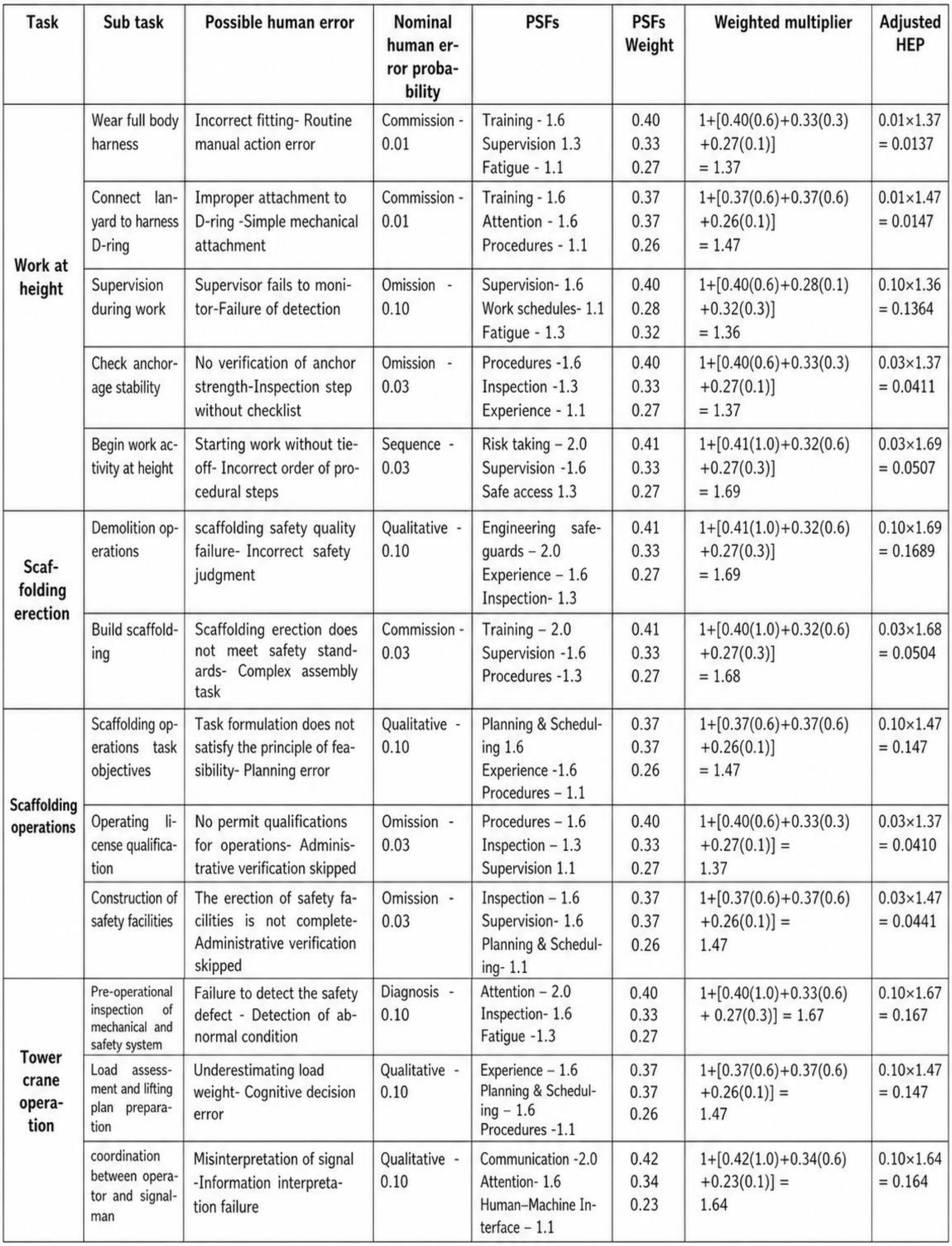
The identification of high-risk construction activities was conducted through manual content analysis of semi-structured interview responses. Participants were asked to identify construction activities they consider most critical in terms of accident likelihood and consequence severity. Their responses were categorised based on the mentioned frequency, justification provided and consistency across participants. All respondents repeatedly emphasised work at height, scaffolding erection, tower crane operation, excavation work, and electrical work. Using interview data and task-sequence clarification during participant conversations, each activity was further divided into operational sub-tasks. Respondents were asked to explain the detailed process that is usually followed while carrying out each task on a site. These narrative descriptions were manually coded to identify discrete sub-task stages. Once sub-tasks were established, participants were asked to identify common mistakes, unsafe behaviours, or procedural deviations they had observed in practice. These responses were categorised according to THERP error classifications, including omission, commission, sequence errors, diagnosis errors, and qualitative judgment errors. Furthermore, participants were asked to explain why specific errors occur and what conditions typically influence worker performance. The respondents provided PSFs relevant to construction activities, including training, supervision, fatigue, experience, attention, risk taking, procedural clarity, inspection, communication effectiveness and those grouped into standardised PSF categories.

Based on the identified error categories, nominal human error probabilities were assigned using THERP reference tables. PSFs extracted from interview data were evaluated using a proportional severity scale and integrated through a weighted multiplier model. The final adjusted HEP values were calculated by combining nominal probabilities with derived weighted PSF multipliers. The detailed results are presented in Table 3.

Table 3 presents a comprehensive application of the THERP method to high-risk construction activities, namely work at height, scaffolding erection, tower crane operation, excavation work, and electrical work. After integrating the weighted PSF model, the adjusted HEP values increased compared with the nominal values due to the influence of key human performance factors. However, the relative ranking of the activities remained consistent.

Tower crane operation demonstrated the highest human error probabilities, particularly during pre-operational inspection (HEP = 0.168) and operator–signalman coordination (HEP = 0.165). These tasks require continuous monitoring, precise communication, and accurate interpretation of operational signals. Any misinterpretation or failure in inspection may directly affect lifting safety and increase the likelihood of accidents during lifting operations. Similarly, excavation work showed high error probabilities, especially in soil stability monitoring (HEP = 0.168) and identification of underground utilities (HEP = 0.137), indicating that hazard recognition and risk judgement play a critical role in excavation safety. These activities involve hazard recognition and situational judgement, where human decision-making plays a critical role. Failure to recognise early warning signs can lead to serious incidents such as trench collapse or utility damage. Furthermore, moderate error probabilities were observed in scaffolding erection activities, where demolition operations (HEP = 0.168) and scaffolding assembly (HEP = 0.0507) contribute notably to the overall risk. These tasks require proper inspection, engineering safeguards, and supervision to maintain structural stability during operations. In contrast, work-at-height activities showed comparatively lower human error probabilities, with harness fitting (HEP = 0.0137) and lanyard connection (HEP = 0.0147) presenting the lowest values among the analysed tasks since these tasks are generally routine procedural actions with safety procedures. Electrical work tasks also demonstrated relatively lower probabilities, although critical safety steps such as electrical isolation and lockout (HEP = 0.0845) still present a considerable risk if procedures are not strictly followed. Overall, the findings indicate that improving supervision, communication practices, and worker training is essential to reduce the likelihood of human errors and enhance safety performance in construction operations.

Table 3, High risk activities and possible human errors with adjusted error values



Task	Sub task	Possible human error	Nominal human error probability	PSFs	PSFs Weight	Weighted multiplier	Adjusted HEP
Work at height	Wear full body harness	Incorrect fitting- Routine manual action error	Commission - 0.01	Training - 1.6 Supervision 1.3 Fatigue - 1.1	0.40 0.33 0.27	1+[0.40(0.6)+0.33(0.3) +0.27(0.1)] = 1.37	0.01×1.37 = 0.0137
	Connect lanyard to harness D-ring	Improper attachment to D-ring -Simple mechanical attachment	Commission - 0.01	Training - 1.6 Attention - 1.6 Procedures - 1.1	0.37 0.37 0.26	1+[0.37(0.6)+0.37(0.6) +0.26(0.1)] = 1.47	0.01×1.47 = 0.0147
	Supervision during work	Supervisor fails to monitor-Failure of detection	Omission - 0.10	Supervision- 1.6 Work schedules- 1.1 Fatigue - 1.3	0.40 0.28 0.32	1+[0.40(0.6)+0.28(0.1) +0.32(0.3)] = 1.36	0.10×1.36 = 0.1364
	Check anchorage stability	No verification of anchor strength-Inspection step without checklist	Omission - 0.03	Procedures -1.6 Inspection -1.3 Experience - 1.1	0.40 0.33 0.27	1+[0.40(0.6)+0.33(0.3) +0.27(0.1)] = 1.37	0.03×1.37 = 0.0411
	Begin work activity at height	Starting work without tie-off- Incorrect order of procedural steps	Sequence - 0.03	Risk taking – 2.0 Supervision -1.6 Safe access 1.3	0.41 0.33 0.27	1+[0.41(1.0)+0.32(0.6) +0.27(0.3)] = 1.69	0.03×1.69 = 0.0507
Scaffolding erection	Demolition operations	scaffolding safety quality failure- Incorrect safety judgment	Qualitative - 0.10	Engineering safeguards – 2.0 Experience – 1.6 Inspection- 1.3	0.41 0.33 0.27	1+[0.41(1.0)+0.32(0.6) +0.27(0.3)] = 1.69	0.10×1.69 = 0.1689
	Build scaffolding	Scaffolding erection does not meet safety standards- Complex assembly task	Commission - 0.03	Training – 2.0 Supervision -1.6 Procedures -1.3	0.41 0.33 0.27	1+[0.40(1.0)+0.32(0.6) +0.27(0.3)] = 1.68	0.03×1.68 = 0.0504
Scaffolding operations	Scaffolding operations task objectives	Task formulation does not satisfy the principle of feasibility- Planning error	Qualitative - 0.10	Planning & Scheduling 1.6 Experience -1.6 Procedures – 1.1	0.37 0.37 0.26	1+[0.37(0.6)+0.37(0.6) +0.26(0.1)] = 1.47	0.10×1.47 = 0.147
	Operating license qualification	No permit qualifications for operations- Administrative verification skipped	Omission - 0.03	Procedures – 1.6 Inspection – 1.3 Supervision 1.1	0.40 0.33 0.27	1+[0.40(0.6)+0.33(0.3) +0.27(0.1)] = 1.37	0.03×1.37 = 0.0410
	Construction of safety facilities	The erection of safety facilities is not complete-Administrative verification skipped	Omission - 0.03	Inspection – 1.6 Supervision- 1.6 Planning & Scheduling- 1.1	0.37 0.37 0.26	1+[0.37(0.6)+0.37(0.6) +0.26(0.1)] = 1.47	0.03×1.47 = 0.0441
Tower crane operation	Pre-operational inspection of mechanical and safety system	Failure to detect the safety defect - Detection of abnormal condition	Diagnosis - 0.10	Attention – 2.0 Inspection- 1.6 Fatigue -1.3	0.40 0.33 0.27	1+[0.40(1.0)+0.33(0.6) + 0.27(0.3)] = 1.67	0.10×1.67 = 0.167
	Load assessment and lifting plan preparation	Underestimating load weight- Cognitive decision error	Qualitative - 0.10	Experience – 1.6 Planning & Scheduling – 1.6 Procedures -1.1	0.37 0.37 0.26	1+[0.37(0.6)+0.37(0.6) +0.26(0.1)] = 1.47	0.10×1.47 = 0.147
	coordination between operator and signalman	Misinterpretation of signal -Information interpretation failure	Qualitative - 0.10	Communication -2.0 Attention- 1.6 Human–Machine Interface – 1.1	0.42 0.34 0.23	1+[0.42(1.0)+0.34(0.6) +0.23(0.1)] = 1.64	0.10×1.64 = 0.164

Task	Sub task	Possible human error	Nominal human error probability	PSFs	PSFs Weight	Weighted multiplier	Adjusted HEP
	Execution of lifting operations in accordance with load chart limits	Exceeding load chart limits- Failure to comply with required limit	Omission - 0.03	Risk taking – 2.0 Procedures – 1.6 Warning systems- 1.3	0.41 0.33 0.27	1+[0.41(1.0)+0.33(0.6) +0.27(0.3)] = 1.69	0.03×1.69 = 0.0507
	Post-operation inspection	Failure to secure crane properly - Required securing step omitted	Omission - 0.03	Fatigue – 1.6 Procedures – 1.3 Inspection – 1.1	0.40 0.33 0.27	1+[0.40(0.6)+0.33(0.3) +0.27(0.1)] = 1.37	0.03×1.37 = 0.0410
	Review excavation plan	Skipping plan review - Planning step omitted	Omission - 0.03	Planning & Scheduling- 1.6 Supervision – 1.6 Experience – 1.3	0.35 0.35 0.29	1+[0.35(0.6)+0.35(0.6) +0.29(0.3)] = 1.507	0.03×1.507 = 0.0452
	Identification and protection of underground utilities	Failure to detect underground services - Hidden hazard detection	Diagnosis - 0.10	Experience – 1.6 Engineering safeguards – 1.3 Procedures – 1.1	0.40 0.33 0.27	1+[0.40(0.6)+0.33(0.3) +0.27(0.1)] = 1.37	0.10×1.37 =0.137
Excavation work	Installation of excavation support systems	Support system not installed properly- Complex structural installation	Commission - 0.03	Training – 1.6 Supervision – 1.3 Engineering safeguard- 1.3	0.38 0.31 0.31	1+[0.38(0.6)+0.31(0.3) +0.31(0.3)] = 1.41	0.03×1.41 =0.0424
	Monitoring of soil stability and environmental conditions	Ignoring visible cracks or warning signs - Incorrect risk judgment	Qualitative - 0.10	Risk taking – 2.0 Attention – 1.6 Experience – 1.3	0.41 0.33 0.27	1 + [0.41(1.0) + 0.33(0.6) + 0.27(0.3)] = 1.69	0.10×1.69 =0.169
Electrical work	Access control and worker entry authorization	Allowing entry before safe condition- Premature action	Time - 0.05	Supervision – 2.0 Procedures – 1.6 Work schedules – 1.1	0.42 0.34 0.23	1+[0.42(1.0)+0.34(0.6) +0.23(0.1)] = 1.64	0.05×1.64 = 0.0824
	Verification of electrical licensing and competency	Unqualified worker performs electrical task- Required competency check skipped	Omission - 0.03	Procedures – 1.6 Supervision – 1.3 Training – 1.1	0.40 0.32 0.27	1+[0.40(0.6)+0.32(0.3) +0.27(0.1)] = 1.36	0.03×1.36 =0.0409
	Isolation and lockout of electrical power sources	Failure to isolate electrical source -Critical safety action omitted	Omission - 0.05	Procedures – 2.0 Attention – 1.6 Warning systems – 1.3	0.41 0.33 0.27	1+[0.41(1.0)+0.33(0.6) +0.27(0.3)] = 1.69	0.05×1.69 =0.0845
	Inspection of electrical tools and protective equipment	Not verifying zero energy state - Required verification step	Omission - 0.03	Attention – 1.6 Fatigue – 1.3 Procedures – 1.1	0.40 0.32 0.27	1+[0.40(0.6)+0.32(0.3) +0.27(0.1)] = 1.36	0.03×1.36 =0.0409
	Installation of temporary wiring and distribution boards	Incorrect cable connection -Routine wiring action	Commission - 0.01	training – 1.6 Experience – 1.6 Human–Machine Interface – 1.1	0.37 0.37 0.26	1+[0.37(0.6)+0.37(0.6) +0.26(0.1)] = 1.47	0.01×1.47 = 0.0147
	Testing and commissioning of electrical systems	Skipping functional testing- Required validation step omitted	Omission - 0.03	Risk taking – 2.0 Work schedules – 1.6 Inspection – 1.3	0.40 0.32 0.27	1+[0.40(1.0)+0.32(0.6) +0.27(0.3)] = 1.68	0.03×1.68 =0.0504

The HRA event tree was developed in accordance with the THERP methodology (see Figure 2). Each activity was decomposed into sequential sub-tasks and modelled using a binary success failure branch structure. All branches beyond the first were calculated as conditional probabilities. Since construction safety procedures require the successful completion of all sequential steps to prevent accidents, the activities were modelled as series systems. Accordingly, the overall activity success probability was calculated as the product of individual task success probabilities and the Human Error Probability (HEP) for each activity was determined using HEP=1−P(S). This approach ensures logical consistency and full representation of all failure paths within the event tree framework.

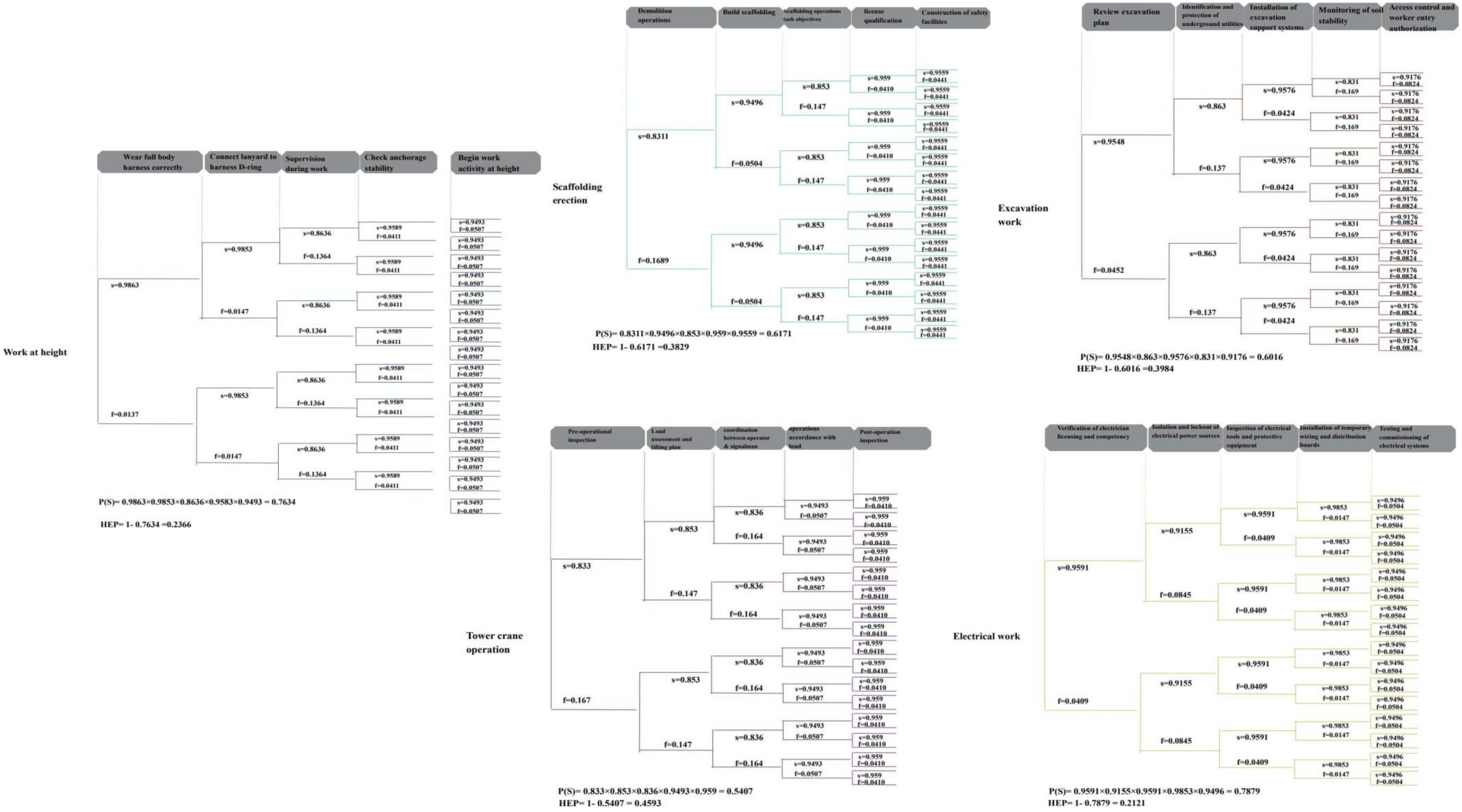


Figure 2, THERP-Based Event Tree for High-Risk Construction Activities

Table 4, Final values of event tree diagram

Construction Activity	**Probability of Success P(S)**	**Human Error Probability (HEP)**
Work at Height	0.7634	0.2366
Scaffolding Operations	0.6171	0.3829
Tower Crane Operation	0.5407	0.4593
Excavation Work	0.6016	0.3984
Electrical Work	0.7879	0.2121

Table 4 shows the summary of the event tree analysis results across the identified activities. Among these activities, tower crane operation recorded the highest human error probability (HEP = 0.4593), indicating its highest contribution to potential risk. This can be attributed to the complex nature of lifting operations, which require coordination between crane operators, signalmen, and ground workers. Errors in communication, load assessment, or operational procedures can significantly increase the likelihood of failure. Similarly, excavation work showed a relatively high HEP value (0.3984), reflecting the uncertainties associated with soil stability, underground utilities, and environmental conditions. These factors require continuous monitoring and strict adherence to safety procedures to minimise potential failures. Scaffolding operations demonstrated (HEP = 0.3829). The erection of scaffolding involves sub tasks. Errors during any of the stages can compromise structural stability and worker safety. In contrast, work-at-height activities exhibited a comparatively lower error probability (HEP = 0.2366). This result reflects the effectiveness of established safety practices during operations. The lowest human error probability was observed in electrical work (HEP= 0.2121). Electrical tasks typically follow well defined procedures and structured safety protocols that contribute to improved human reliability and reduced error likelihood during electrical operations.

According to the results, tower crane operation records the highest human error probability (HEP = 0.4593), followed by excavation work (HEP = 0.3984) and scaffolding operations (HEP = 0.3829). Similar results were identified by a previous study. Ajith et al. (2022) reported high error probabilities for several construction activities, particularly excavation work (HEP = 0.957), reinforcement erection (HEP = 0.631), and crane operation (HEP = 0.269) using the HEART method. Although the numerical values differ due to methodological variations, both studies identify lifting and excavation activities as high-risk operations. Furthermore, Li et al. (2022) reported low HEP for scaffolding operations (HEP = 4.3×10^{-3}) using the CREAM method. These comparisons suggest that the magnitude of HEP values depends on the analytical technique and contextual factors.

5. Conclusion

This study applied the THERP method to evaluate human reliability in five key high-risk construction activities, which are tower crane operation, excavation work, scaffolding erection, work at height, and electrical work. The results showed that tower crane operation had the highest human error probability, followed by excavation work and scaffolding operations. This indicates that tasks requiring complex coordination, hazard recognition, and changing work conditions are especially prone to human error. In contrast, work at height and electrical tasks had lower error probabilities, mainly because of established safety procedures and routine practices.

From an academic perspective, this research highlights how HRA can analyse human error in construction and provides a foundation for future studies on human reliability in construction safety management. For the industry, the findings offer useful insights to improve safety performance in construction projects by providing more credible likelihood values for OHS risk assessment, supporting safety personnel to avoid relying on overly subjective likelihood values. Further, it helps them focus on critical operations and implement targeted controls such as better supervision, clearer communication, and specialised worker training programs. These actions can enhance safety management, lower accident risks, and ultimately improve overall safety on construction sites. As future research directions driven through this research, it is recommended to conduct second and third generation HRA for construction activities, considering factors such as human cognitive processes, human–machine interaction, and time-dependent system behaviour, among others.

6. Reference

Abbassi, R., et al. (2015). An integrated method for human error probability assessment during the maintenance of offshore facilities. *Process Safety and Environmental Protection, 94*(C), 172–179. https://doi.org/10.1016/j.psep.2015.01.010

Ajith, S., Arumugaprabu, V., & Szóstak, M. (2022). A framework for systematic assessment of human error in construction sites: A sustainable approach. *Civil Engineering and Architecture, 10*(5), 1725–1737. https://doi.org/10.13189/cea.2022.100503

Bastos, B. M. (2023). Analysis of human reliability in accidents and incidents in a chemical industry. In *Seven Editora eBooks*. https://doi.org/10.56238/devopinterscie-002

Bell, J., & Holroyd, J. (2009). *Review of human reliability assessment methods* (RR679). Health and Safety Executive (HSE).

Bijelic, B., Stankovic, M., & Grozdanovic, M. (2018, December 1). The importance of human reliability analysis in risk assessment process. https://doi.org/10.6722/tes.201812_2(2).0001

Bussier, M. J. P., & Chong, H. Y. (2022). Relationship between safety measures and human error in the construction industry: Working at heights. *International Journal of Occupational Safety and Ergonomics, 28*(1), 162–173. https://doi.org/10.1080/10803548.2020.1760559

Bourahla, A., Fernandes, G., & Ferreira, L. M. D. F. (2024). Managing occupational health and safety risks in construction projects to achieve social sustainability: A review of literature. *Procedia Computer Science, 239*, 1053–1061. https://doi.org/10.1016/j.procs.2024.06.269

Calixto, E. (2016). Human reliability analysis. In *Elsevier eBooks* (pp. 471–552). https://doi.org/10.1016/B978-0-12-805427-7.00005-1

Chan, D. W. M., Sarvari, H., & Baghbaderani, A. B. (2022). An empirical study of the human error-related factors leading to site accidents in the urban construction industry. *Buildings, 12*(11), 1858. https://doi.org/10.3390/buildings12111858

Department of Labour. (2021). *Annual labour statistics report*. https://labourdept.gov.lk/downloads/stat/7.pdf

De Galizia, A., Duval, C., Serdet, E., Weber, P., & Simon, C. (2015). Advanced investigation of HRA methods for probabilistic assessment of human barriers efficiency in complex systems for a given organizational and environmental context. https://hal.science/hal-01237119v1/document

De Silva, N., & Wimalaratne, P. (2012). OSH management framework for workers at construction sites in Sri Lanka. *Engineering, Construction and Architectural Management, 19*(4), 369–392.

De Silva, N., & Nawarathna, A. (2014). Reporting procedure of construction accidents in Sri Lanka. https://www.researchgate.net/publication/316911490

Dsouza, N., & Lu, L. (2016). A literature review on human reliability analysis techniques applied for probabilistic risk assessment in the nuclear industry. *Advances in Intelligent Systems and Computing*, 41–54. https://doi.org/10.1007/978-3-319-41950-3_4

Di Pasquale, V., Iannone, R., Miranda, S., & Riemma, S. (2013). An overview of human reliability analysis techniques in manufacturing operations. In *Operations Management* (pp. 221–240). InTechOpen. https://doi.org/10.5772/55065

Eisenberg, N. A. (2001). *Human reliability analysis and repository preclosure safety: An initial evaluation*.

Forgac, A. (2018). Methods of human reliability analysis. *Central European Researchers Journal, 4*(2).

George Mollo, L., & Emuze, F. (2022). Management's impact on human errors on construction sites. https://www.researchgate.net/publication/377665160

Guglielmi, D., Paolucci, A., Cozzani, V., Mariani, M. G., Pietrantoni, L., & Fraboni, F. (2022). Integrating human barriers in human reliability analysis: A new model for the energy sector. *International Journal of Environmental Research and Public Health, 19*(5). https://doi.org/10.3390/ijerph19052797

Johnson, K., Morais, C., & Patelli, E. (2023). AI tools for human reliability analysis. *UNCECOMP Proceedings*, 437–452. https://doi.org/10.7712/120223.10348.20039

Kazmi, D., et al. (2016). An extensive study on the quantification of human errors that hampers the performance and construction of structure particularly in geotechnical ambit. https://doi.org/10.9790/1684-1304053343

Kirwan, B. (1994). *A guide to practical human reliability assessment*. Taylor & Francis.

Lam, S. T. F., & Chan, A. H. (2023). Human reliability analysis in aviation accidents: A review. *AHFE International*. https://doi.org/10.54941/ahfe1003550

Li, X., Guo, Y., Ge, F., & Yang, F. (2022). Human reliability assessment on building construction work at height: The case of scaffolding work. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.4112851

Mhetre, K., Konnur, B. A., & Landage, A. B. (2016). Risk management in construction industry. *International Journal of Engineering Research, 5*(Special Issue 1), 153–155.

Moaveni, S., Banihashemi, S. Y., & Mojtahedi, M. (2019). A conceptual model for a safety-based theory of lean construction. *Buildings, 9*(1), 23. https://doi.org/10.3390/buildings9010023

Nezamodini, Z. S., Movahedi, Z., Kouhnavard, B., & Mosavianasl, Z. (n.d.). Investigation of human error by using THERP method in control room of incoiler department in a pipe manufacturing company. *Archives of Hygiene Sciences*.

Ramprasad, S. K., Kumar, P., & Prabhat Kumar, S. R. K. (2019). Study of human reliability in construction of infrastructure projects. *International Journal of Civil Engineering and Technology, 10*(5).

Ramezani, A., Nazari, T., Rabiee, A., Hadad, K., & Faridafshin, M. (n.d.). Human error probability quantification for NPP post-accident analysis using cognitive-based THERP method. *Progress in Nuclear Energy*.

Sinabariba, M. A. P., Ghifari, M. R., Muslim, E., & Moch, B. N. (2020). Analysis of human error risk with human reliability methods in construction projects. *IOP Conference Series: Materials Science and Engineering, 1003*(1), 012079. https://doi.org/10.1088/1757-899X/1003/1/012079

Sefidkouhi, H. M., Najafi, E., Haji, A., & Arasteh, A. (2024). Investigating human reliability in the healthcare sector using the fuzzy analytic network process and the success likelihood index method. *Iranian Journal of Public Health, 53*(3). http://ijph.tums.ac.ir

Swain, A. D., & Guttmann, H. E. (1983). *Handbook of human reliability analysis with emphasis on nuclear power plant applications* (NUREG/CR-1278). Sandia National Laboratories.

Tabor, J. (2021). Improving occupational safety management with the use of human reliability analysis methods. *Quality Production Improvement, 3*, 120–131. https://doi.org/10.2478/cqpi-2021-0012

Tripathi, P., & Mittal, Y. K. (2024). Current safety practices in the construction industry: A case study approach. *IOP Conference Series: Earth and Environmental Science, 1326*(1), 012156. https://doi.org/10.1088/1755-1315/1326/1/012156

Khalid, U. (2022). *Investigation into the development of a human reliability analysis framework for the safety management of construction*.

Wijesekara, M., Fernando, P., & Gunarathna, N. (2022). Causes for death and injuries in construction industry in Sri Lanka. *Proceedings of the SLIIT International Conference on Engineering and Technology*, 453–464. https://doi.org/10.54389/XGMP5935

Yang, X., et al. (2014). Human reliability analysis in aviation operations: A case study of aircraft take-off. *Safety Science, 62*, 51–60.

Yalçin, E., Çiftçioğlu, G. A., & Güzel, B. (2024). Human reliability analysis methods. *Pamukkale University Journal of Engineering Sciences, 30*(2), 282–292. https://doi.org/10.5505/pajes.2023.33958