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# A Framework for Systematic Assessment of Human Error in Construction Sites – A Sustainable Approach

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**Abstract** The construction industry is one of the most accident-susceptible sectors of the national economy and is characterized by a high rate of accidentality. The Human Error Assessment and Reduction Technique (HEART) is a generic method to identify human error. This technique uses generic task types and error producing conditions to calculate the probable human error. It is known that unsafe acts in the activity will also lead to unplanned events. Therefore, in this research, in addition to the existing factors, the probability of unsafe acts is also integrated. From the results, it is known that excavation (0.957), reinforcement erection for footing & column (0.631) and crane operation (0.269) are the tasks with a higher probability of human error. This can be minimized by frequent safety trainings to the workers and providing suitable personnel protective equipment (PPE) by the management. This proposed method may be applicable for all the workplaces, as it has a generic method to quantify human error with the task and error producing conditions. Knowledge of the circumstances of accidents will enable the formulation or modification of the labour law to be properly formulated, as well as the appropriate orientation of preventive measures and trainings in the field of occupational safety. All participants in the investment process: workers, construction site managers and supervisors, should be the recipients of these activities, who are also exposed to hazards and may suffer from accidents while performing their activities at a construction site. Parameters and the probable human error described by the authors allow for a comprehensive assessment of hazards and the probability of accident occurrences.

**Keywords** Construction Industry, Human Error, Unsafe act, HEART Method

## 1. Introduction

The idea of sustainable development in the construction industry is used at different levels. For example, sustainable design [1, 2], construction and use of a building as environmentally friendly in relation to the entire life cycle of buildings [3, 4], application of the possibility of substitution of construction products [5, 6] utilization of waste [7] or recycled material [8]. In addition, safety and sustainability are also connected. The development of safety at work is a multistep process in the management of an enterprise [9, 10]. There are both ways to engage employees to think about what they do every day, how they do it, and how they can prevent accidents at work. Reinforcing the importance of safety and sustainability ensures that employees think about it every day.

The construction industry is one of the most accident-susceptible sectors of the national economy and is characterized by a high rate of accidentality [11]. Construction sites have been overwhelmed by a large number amount of work-related accidents and injuries [12]. This is mainly due to the lack of safety and ignorance among the workers [13, 14]. Statistically, construction industries record a huge number of fatal & non-fatal injuries throughout the world and are considered to be one of the highly hazardous occupations [15]. Every occupational accident is caused by at least several causes. Each accident is the result of three types of causes: technical (T), organizational (O), and human (H) [16]. About 80% of the industrial accidents are caused due to human error (i.e., mistakes done by the workers, supervisors and also in different levels of the organization). This affects both quality and safety [17]. Human error is defined as the mismatch between an individual (i.e. worker, supervisor, and engineer) and the task [18], a lack of Safe Operating Procedures (SOP), and unwanted additional information gained by the worker to complete the task within the scheduled time [19]. Human errors are directly related to employees at workplaces on the job, who know the hazards, regulations and rules of occupational health and safety [20]. Most of the researchers found that 90% of the accidents can be prevented if the management adopts suitable control measures. Accidents are due to human error, and it is essential to study human factors and ensure the safety of workers [21]. The Human Error Assessment and Reduction Technique (HEART) is established by the generic principle that for each and every activity in our life there will be a failure probability. It is influenced by various error producing conditions. Therefore, to identify the human error and to solve the industrial problems, HEART is designed with different generic tasks and error producing conditions [22, 23]. This technique is identified as a highly effective and simple approach, while it is also applicable to various complex scenarios to determine the probability of human error [24]. Human factors play a significant role in the success of a project. This includes both the positive and negative characteristic of human nature, which includes ability, enthusiasm, competition, and loyalty [25]. Therefore, it is intended to study about the human factors in construction projects to make it a success.

### 1.1. Previous Research

Kurata et Al. [26] determined the probability of human error in the chicken processing company. The Generic Task Unreliability (GTU) and the Error Producing Conditions (EPC) were identified for each task, and the assessed effects were determined from expert opinions. The results showed that the “chopping area” has a higher probability of human error.

Kumar et al. [27] quantified the human error in the LPG refueling station. The HEART technique is adopted to quantify the human error, whereas fuzzy is incorporated to define the linguistic variables. Four tasks are identified and a panel of six experts is engaged as respondents.

Akyuz et al. [28] determined the probable human error in gas inerting operation on crude oil tankers. HEP is calculated using the Cognitive Reliability Error Analysis Method (CREAM) which is a second generation method. CREAM has two versions, basic and extended, in which the basic version is used to screen the human interactions and the extended version has a detailed analysis of the same. In order to know the failure probabilities CREAM has four control modes viz., opportunistic, scrambled, tactical, and strategic whereas the strategic control denotes lowest HEP and scrambled denotes highest HEP, using the Common Performance Conditions (CPC) human error is calculated.

Castiglia et al. [29] assessed the probable human error in the hydrogen refueling station using the HEART method. Since in hydrogen refueling station, maintenance & testing phases are highly hazardous, human error involved in these tasks is identified. In addition to HEART, their proposed method also adopts fuzzy theory to improve the precision of expert opinions. The results are then compared with those of CREAM. It is established that fuzzy HEART has some improved criteria and is an effective method.

Jahangiri [30] et al. identified the human error in the Permit to Work System (PTW) in a chemical plant. The Standardized Plant Analysis Risk – Human (SPAR-H) reliability analysis method was adopted to estimate the probable human error. A total of 11 tasks are classified, and 4 operators such as two site men, one shift supervisor, and one safety officer are the respondents in the study. SPAR – H has eight Performance Shaping Factors (PSF) which are divided into several levels of PSF. Each PSF level has a multiplier, in which it is to be evaluated through the respondents. Finally, the Human Error Probability (HEP) is determined for each task.

Park et al. [31] estimated probable human error using the Analytical Hierarchy Process (AHP) and the Success Likelihood Index (SLIM) method. These two methods were combined because AHP checks the reliability of the collected data and SLIM follows the method of expert judgement. This method has the advantage that it is simple in estimating HEP by repetitive relative comparison of human error and PSF. This can also be used for different fields of application.

Grozdanovic [32] adopted the Absolute Probability Judgement (APJ) to calculate the human error. The steps involved in using APJ are selecting experts, defining the task statements, fixing the scale for judgement, estimating individual HEP, and calculating the geometric mean if the level of agreement varies. The HEP found by the expert is converted into logarithmic equivalent. As this method uses multiple judgements, this might enhance the method of estimation.

Abbassi et al. [33] integrated SLIM with the Technique of Human Error Rate Prediction (THERP) to assess the probability of human error in pump maintenance work. The steps involved in THERP are identifying the activities in the maintenance work, identifying the post maintenance activities, identifying the nominal human error values from THERP handbook, SLIM is used in the absence of HEP values in the handbook, dependency and PSF is identified, and event tree is formed to derive the final HEP values.

From the previous research work, it is identified that there are different techniques for determining human error, but HEART is found to be a generic method for quantifying probable human error. Although it is a first-generation technique, it plays a significant role in identifying human error. The existing HEART technique integrates task unreliability, EPC, and expert elicitation for determining probable error, but human error is also associated with unsafe acts of workers. Most studies are related only to chemical industries, chicken processing companies, and PTW but not to identifying human error at construction sites. Therefore, this research intends to quantify the probable human error in construction sites by integrating the probability of unsafe acts with the existing factors.

# 2. Methodology

The overall methodology to calculate human error involves 7 steps, as shown in Fig.1. The first four steps are based on experts' elicitation and the sixth step is based on workers participation in questionnaire survey.

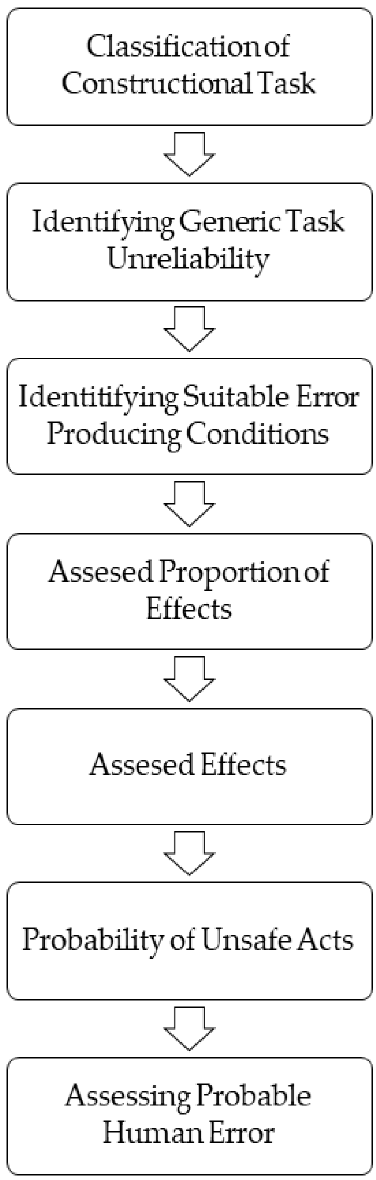


**Figure 1.** Research methodology

### 2.1. Classification of Construction Task

The probable human error associated with each activity is identified under all tasks on the construction site of the building. Ajith et al. [34] identified the list of tasks such as Excavation ($TK_1$), Reinforcement Erection for Footing & Column ($TK_2$), Shuttering and Formwork ($TK_3$), Concrete Mixer ($TK_4$), Manual Bar Bending ($TK_5$), Hot Work ($TK_6$), Concreting ($TK_7$), Material Handling ($TK_8$), Carpentry Work ($TK_9$), Vehicle Movement ($TK_{10}$), Crane Operation ($TK_{11}$), Hoist ($TK_{12}$), Drilling ($TK_{13}$), Scaffold/Ladder ($TK_{14}$), Painting ($TK_{15}$) to find the hazards and its associated risk in each and every task. But in this research the human error involved in these tasks are found. The HEART technique has four major steps in calculating the human error which are explained in the next sections.

### 2.2. Unreliability of Generic Tasks

There are 9 generic task types in the HEART, in which the assessor has to identify the suitable task and its corresponding nominal human unreliability value. This depends upon the type of task (i.e. how difficult or easier the task is, whether the task requires any specific skill to complete the task) in the site. The GTU's as shown in Table 1 are the identified excavation tasks. The assessor who identifies the GTU must have a good amount of experience in the field of construction safety.

### 2.3. Identifying Error Producing Conditions

The assessor identifies the Relevant Error Producing Conditions (EPC) and its multiplier for each activity. The identified EPC for excavating the land is shown in Table 2 which indicates that these EPCs influence the activity to fail.

### 2.4. Identifying the Major/Minor Activities in Each Task

The major/minor activities involved in each task are identified with the help of site engineers, as listed in Table 3. In order to know the GTU and EPCs for each activity, it is obtained from J.C. Williams HEART data base as mentioned in Table 1 and Table 2. The GTU and EPCs are identified by consulting with a team of engineers and safety officers. According to the HEART table, there are 38 EPC's, the first column of the identified EPC denotes the "serial number of the identified EPC" and the second column indicates the "maximum predicted nominal amount by which the unreliability could change going from good to bad" as mentioned in Table 3.

### 2.5. Assessed Proportion of Effects (APE)

The Assessed Proportion of Effects (APE) is based on expert opinion, and the values range from 0 to 1. It is defined as the impact of each identified EPC on the particular activity. A questionnaire survey is prepared with the identified EPC is prepared, and a panel of six experts is asked to assess the APE for each activity. Four various designated experts (viz. General Manager, HSE Engineer, Engineer and Safety Supervisor) are selected and the weighing factor for each expert is calculated as mentioned in Table 4. The results of determining the weighing score of each expert were mentioned in the last column of Table 4.

The weighting factor is determined from both the designation and the experience scores. The weighting score is calculated from the weighting factor to its sum. This score is used as an individual expert score.

### 2.6. Assessed Effects (AE)

The Assessed Effects (AE) for each Error Producing Conditions (EPC) are calculated using Equation 1.

$$AE = ((\text{Multiplier} - 1)\ APE) + 1 \quad (1)$$

The multiplier is the values from the HEART table. The impact and multiplication factor cannot be less than 1 because this would mean that EPC had improved things. Hence -1 and +1 is used [36].

### 2.7. Probability of an Unsafe Act (PUA)

The unsafe act is one of the major factors associated with human error. If unsafe act is considered in determining human error, then the majority of the human error that can occur in the particular task can be reduced. Human error can occur through workers' and supervisors' acts but as the workers' contribution is high in completing a specific task, this research analyses only the workers' unsafe acts. In order to determine the probability of unsafe acts in each task, a questionnaire survey is conducted with the 107 workers. The questionnaire is framed with 26 questions related to unsafe acts. The factors are adopted from the Indian Standard (IS) code of Practices as listed in Table 5. A four point Likert scale such as agree, strongly agree, disagree, and strongly disagree is adopted in the survey.

Then the Probability of Agreement [P (A)] is calculated using Equation 2 and combined with existing factors to determine the probable human error.

$$P(A) = \frac{\text{Total no.of agreement}}{\text{Total no.of samples}} \quad (2)$$

**Table 1.** Generic Task Unreliability (GTU)

| No. | Task | Nominal Human Unreliability |
|---|---|---|
| 1. | Shift or restore the system to a new or original state on a single attempt without procedures. | 0.26 |
| 2. | Complex task. | 0.16 |
| 3. | Fairly simple task. | 0.09 |
| 4. | Routine, highly practised, rapid task involving relatively low level of skill. | 0.02 |

**Table 2.** Error Producing Conditions (EPC) and its multiplier adopted from J.C. Wiliams HEART table [36]

| No | Error Producing Conditions | Multiplier |
|---|---|---|
| 1. | A mismatch between an operator's model of the work and that imagined by the designer. | 8 |
| 2. | Operator inexperienced. | 3 |
| 3. | Unreliable instrumentation. | 1.6 |
| 4. | Unclear allocation of functions and responsibility. | 1.6 |
| 5. | Age of personnel performing perceptual task | 1.02 |

**Table 3.** Classification of activities and identification of GTU and EPC

| Task | Activities | GTU | Identified EPC | |
|---|---|---|---|---|
| $TK_1$ | 1. Setting out corner benchmarks | 0.16 | 6 | 8 |
| | | | 15 | 3 |
| | | | 25 | 1.6 |
| | 2. Excavation to the approved depth | 0.16 | 15 | 3 |
| | | | 23 | 1.6 |
| | | | 25 | 1.6 |
| | | | 38 | 1.02 |
| | 3. Dressing the loose soil | 0.16 | 15 | 3 |
| | | | 23 | 1.6 |
| | | | 25 | 1.6 |
| $TK_2$ | 1. Levelling and marking in ground | 0.16 | 6 | 8 |
| | | | 15 | 3 |
| | | | 23 | 1.6 |
| | | | 25 | 1.6 |
| | 2. Placing the reinforcement bars | 0.16 | 15 | 3 |
| | | | 25 | 1.6 |
| | 3. Welding at the joints of the bars | 0.16 | 15 | 3 |
| | | | 23 | 1.6 |
| | | | 25 | 1.6 |
| $TK_3$ | 1. Cutting of wooden blocks | 0.16 | 11 | 5 |
| | | | 15 | 3 |
| | | | 25 | 1.6 |
| | | | 38 | 1.02 |
| | 2. Aligning and fixing of beam bottom plate | 0.16 | 15 | 3 |
| | | | 25 | 1.6 |
| | 3. Adjusting props as per height to support beam bottom | 0.16 | 15 | 3 |
| | | | 25 | 1.6 |

**Table 3 Continued**

| | | | | |
|---|---|---|---|---|
| $TK_3$ | 1. Cutting of wooden blocks | 0.16 | 11 | 5 |
| | | | 15 | 3 |
| | | | 25 | 1.6 |
| | | | 38 | 1.02 |
| | 2. Aligning and fixing of beam bottom plate | 0.16 | 15 | 3 |
| | | | 25 | 1.6 |
| | 3. Adjusting props as per height to support beam bottom | 0.16 | 15 | 3 |
| | | | 25 | 1.6 |
| $TK_4$ | 1. Connect the concrete mixer to electricity | 0.09 | 32 | 1.2 |
| | | | 23 | 1.6 |
| | 2. Dumping the aggregates and water into the mixer | 0.02 | 32 | 1.2 |
| | | | 34 | 1.1 |
| | | | 36 | 1.06 |
| | 3. Transforming the fresh concrete into a portable pan | 0.16 | 32 | 1.2 |
| | | | 33 | 1.15 |
| | | | 3 | 10 |
| | | | 36<br>34 | 1.06<br>1.1 |
| $TK_5$ | 1. Fixing the bars at right position | 0.09 | 15 | 3 |
| | | | 32 | 1.2 |
| | | | 34 | 1.1 |
| | 2. Selecting the right tools for bar bending | 0.16 | 15 | 3 |
| | | | 32 | 1.2 |
| | | | 34 | 1.1 |
| | 3. Manually hammering the bars to bend | 0.16 | 32 | 1.2 |
| | | | 12 | 4 |
| | | | 34 | 1.1 |
| | | | 38 | 1.02 |
| | | | 36 | 1.06 |
| $TK_6$ | 1. Clamp the ground clamp to the table you're working on | 0.16 | 15 | 3 |
| | | | 25 | 1.6 |
| | 2. Hold the welding gun with both hands | 0.16 | 15 | 3 |
| | | | 23 | 1.6 |
| | | | 25 | 1.6 |
| | | | 34 | 1.1 |
| | 3. Position the tip of the welding gun on a 20-degree angle | 0.16 | 15 | 3 |
| | | | 23 | 1.6 |
| | | | 25 | 1.6 |
| | | | 32 | 1.2 |
| | 4. Turn the welding machine on and press the trigger | 0.16 | 15 | 3 |
| | | | 23 | 1.6 |
| | | | 25 | 1.6 |
| | | | 36 | 1.06 |
| | 5. Move the gun over the metal slowly to create the weld | 0.16 | 15 | 3 |
| | | | 23 | 1.6 |
| | | | 25 | 1.6 |
| | | | 33 | 1.15 |

**Table 3 Continued**

| | | | | |
|---|---|---|---|---|
| $TK_7$ | 1. Carrying the concrete | 0.26 | 32 | 1.2 |
| | | | 34 | 1.1 |
| | | | 22 | 1.8 |
| | 2. Dumping the concrete | 0.02 | 32 | 1.2 |
| | | | 34 | 1.1 |
| | 3. Levelling the concrete | 0.16 | 15 | 3 |
| | | | 11 | 5 |
| | | | 32 | 1.2 |
| | | | 34 | 1.1 |
| $TK_8$ | 1. Carrying of aggregates and cement bags | 0.26 | 32 | 1.2 |
| | | | 34 | 1.1 |
| | | | 36 | 1.06 |
| | 2. Stacking the cement bags | 0.16 | 32 | 1.2 |
| | | | 34 | 1.1 |
| | 3. Carrying of constructional tools | 0.02 | 32 | 1.2 |
| | | | 22 | 1.8 |
| | | | 34 | 1.1 |
| $TK_9$ | 1. Placing the wood on a workbench | 0.09 | 15 | 3 |
| | | | 23 | 1.6 |
| | | | 25 | 1.6 |
| | 2. Mark the line to be cut | 0.16 | 15 | 3 |
| | | | 23 | 1.6 |
| | | | 32 | 1.2 |
| | 3. Place the handsaw on top of the wood, slightly away from where the cut line was drawn | 0.09 | 15 | 3 |
| | | | 23 | 1.6 |
| | | | 32 | 1.2 |
| | 4. Continue the sawing motion until the piece of wood is ready to break off | 0.16 | 15 | 3 |
| | | | 23 | 1.6 |
| | | | 25 | 1.6 |
| | | | 34 | 1.1 |
| $TK_{10}$ | 1. Driving the vehicle in the correct path way | 0.26 | 15 | 3 |
| | | | 38 | 1.02 |
| | | | 32 | 1.2 |
| | 2. Maintaining the speed of the vehicle as mentioned in the site | 0.16 | 15 | 3 |
| | | | 12 | 4 |
| | | | 36 | 1.06 |
| | | | 32 | 1.2 |
| | 3. Loading/unloading of vehicle in the reserved area | 0.09 | 32 | 1.2 |
| | | | 36 | 1.06 |
| $TK_{11}$ | 1. Barricade around counterweight swing area | 0.09 | 12 | 4 |
| | 2. Lifting the objects as per the signaller | 0.16 | 15 | 3 |
| | | | 3 | 10 |
| $TK_{12}$ | 1. Placing the materials on the hoist | 0.09 | 25 | 1.6 |
| | 2. Closing the doors of the hoist | 0.02 | 25 | 1.6 |
| | 3. Operating the hoist | 0.16 | 15 | 3 |
| | | | 3 | 10 |

**Table 3 Continued**

| | | | | |
|---|---|---|---|---|
| $TK_{13}$ | 1. Connect the drilling machine | 0.09 | 15 | 3 |
| | | | 23 | 1.6 |
| | | | 25 | 1.6 |
| | 2. Position the tip of the drilling gun on the object to be drilled | 0.16 | 15 | 3 |
| | | | 23 | 1.6 |
| | | | 32 | 1.2 |
| | 3. Continue drilling until it is drilled | 0.16 | 15 | 3 |
| | | | 12 | 4 |
| | | | 23 | 1.6 |
| $TK_{14}$ | 1. Receiving work permit to work on scaffold | 0.16 | 20 | 2 |
| | 2. Climbing the scaffold/ ladder | 0.09 | 15 | 3 |
| | | | 23 | 1.6 |
| | 3. Working at scaffold/ ladder | 0.16 | 15 | 3 |
| | | | 3 | 10 |
| | | | 25 | 1.6 |
| $TK_{15}$ | 1. Clean the walls | 0.02 | 12 | 4 |
| | 2. Mixing the paint with thinners | 0.16 | 20 | 2 |
| | | | 15 | 3 |
| | 3. Painting the walls with suitable brushes | 0.02 | 15 | 3 |
| | | | 34 | 1.1 |

**Table 4.** Weighting Scores of Experts

| Expert | Designation | Scores | Experience | Scores | Weighting Factor | Weighting Score |
|---|---|---|---|---|---|---|
| 1 | General Manager/Safety officer | 4 | 17 | 4 | 8 | 0.26 |
| 2 | HSE Engineer | 3 | 9 | 3 | 6 | 0.19 |
| 3 | HSE Engineer | 3 | 9 | 3 | 6 | 0.19 |
| 4 | Engineer | 2 | 10 | 3 | 5 | 0.16 |
| 5 | Engineer | 2 | 7 | 2 | 4 | 0.13 |
| 6 | Safety Supervisor | 1 | 2 | 1 | 2 | 0.07 |

**Table 5.** Factors Considered for Determining Unsafe Acts of the Workers

| No. | Unsafe Acts | Reference |
|---|---|---|
| 1. | Placing the excavated soil away from working area. | [37] |
| 2. | Confirming that there are no electric lines and pipe lines before excavation. | [37] |
| 3. | Failing to wear safety shoes and helmets | [37] |
| 4. | Transporting steel bars in shoulders | [38] |
| 5. | Failing to wear safety gloves while handling steel bars | [38] |
| 6. | Failing to stack the construction materials | [38] |
| 7. | Failing to wear safety shoes and hand gloves while handling course aggregates | [38] |
| 8. | Failing to use heavy steel bars using slings and tackles | [38] |
| 9. | Failing to use respirators while working with cement and lime | [38] |
| 10. | Failing to use tag lines | [39] |
| 11. | Failing to attend tool box talks | [40] |
| 12. | Failing to check the insulations before starting the cement mixer | [41] |
| 13. | Failing to wear safety shoes and gloves while handling cement | [41] |
| 14. | Failing to use safety gloves and goggles while bending steel bars | [41] |
| 15. | Failing to attend safety trainings and programs | [41] |
| 16. | Failing to use respirators and gloves while painting | [41] |
| 17. | Failing to know the safe operating procedures | [41] |
| 18. | Failing to use safety mask and gloves while drilling | [41] |
| 19. | Failing to check the insulations of the drilling equipment's before the start of work | [41] |
| 20. | Failing to use hand gloves and coverall while transporting concrete | [41] |
| 21. | Failing to ensure fire extinguishers in welding workshop | [42] |
| 22. | Failing to use safety goggles, gloves and coverall while welding | [42] |
| 23. | Failing to maintain the floors in carpentry area | [42] |
| 24. | Failing to check the electric wires around the scaffolds | [43] |
| 25. | Failing to ensure scrap materials in the scaffolds | [43] |
| 26. | Failing to check the canopy provision in the scaffolds | [43] |

**Table 6.** Probability of Agreement

| No | Task | P(A) |
|---|---|---|
| 1. | $TK_1$ | 0.85285 |
| 2. | $TK_2$ | 0.56757 |
| 3. | $TK_3$ | 0.513 |
| 4. | $TK_4$ | 0.463 |
| 5. | $TK_5$ | 0.846 |
| 6. | $TK_6$ | 0.833 |
| 7. | $TK_7$ | 0.747 |
| 8. | $TK_8$ | 0.333 |
| 9. | $TK_9$ | 0.639 |
| 10. | $TK_{10}$ | 0.207 |
| 11. | $TK_{11}$ | 0.702 |
| 12. | $TK_{12}$ | 0.279 |
| 13. | $TK_{13}$ | 0.162 |
| 14. | $TK_{14}$ | 0.427 |
| 15. | $TK_{15}$ | 0.882 |

**2.8. Human Error Probability (HEP)**

The Human Error Probability (HEP) is calculated using Equation 3.

$$HEP = GTU * AE * PUA \quad (3)$$

where:

PUA is Probability of Unsafe Acts,

P(A) is the Probability of Agreement,

P(A) is calculated using PUA (i.e., the factors of unsafe acts using questionnaire survey).

The HEP cannot be greater than 1.0. In some cases if the value exceeds above 1.0, then the HEP should be assumed as one [36].

# 3. Results and Discussion

The probability of human error is calculated using the steps mentioned in Section 2.2 to 2.8. The HEP is calculated for each task on the building construction site, and it is found that excavation, reinforcement erection for footing & column and crane operation have a higher probability of error. Figure 2 represents the probable human error (in %) involved in each task.

The percentage of human error as indicated are the probability of errors that can occur on the particular construction site of the building. This can vary in each site according to the safety measures adopted in the site, as well as the cooperation of the workers with the supervisors. The percentage of human error as identified by integrating the unsafe acts is compared to the human error without integrating unsafe acts, as indicated in Figure 3. The P(A) obtained through the questionnaire survey as mentioned in Table 6 clearly shows that there is a higher percentage of unsafe acts exists in TK15, TK1 and TK5. When comparing the HEP without integrating the unsafe acts, TK1 and TK2 have a higher probability of error. Also, the final HEP is higher for TK1 and TK2 with integrating unsafe acts, but in such cases the HEP will only be merely equal. It is clearly seen that there is no much variation between the results. But since unsafe acts are a major and associated factor for human error, it has to be considered to enhance the HEP.

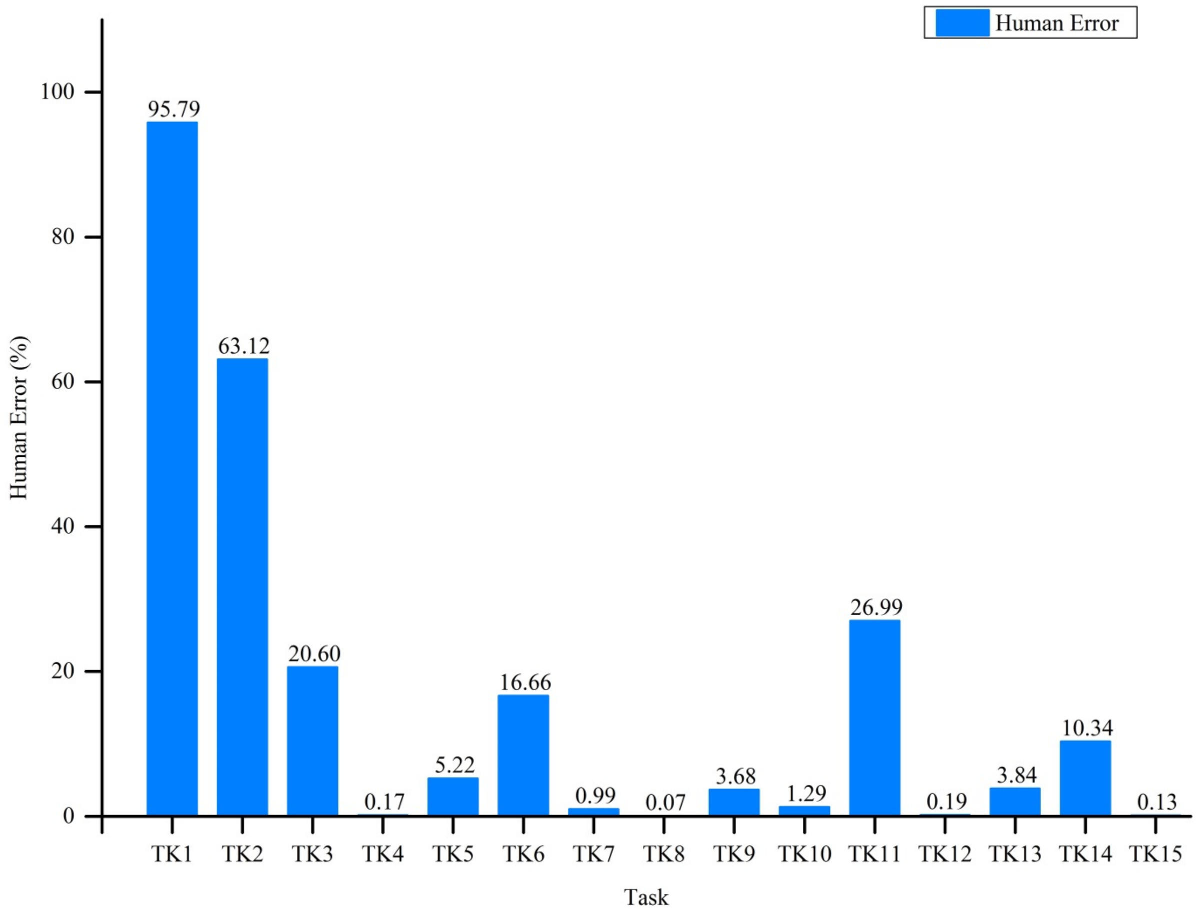


**Figure 2.** Percentage of Human Error in Each Task

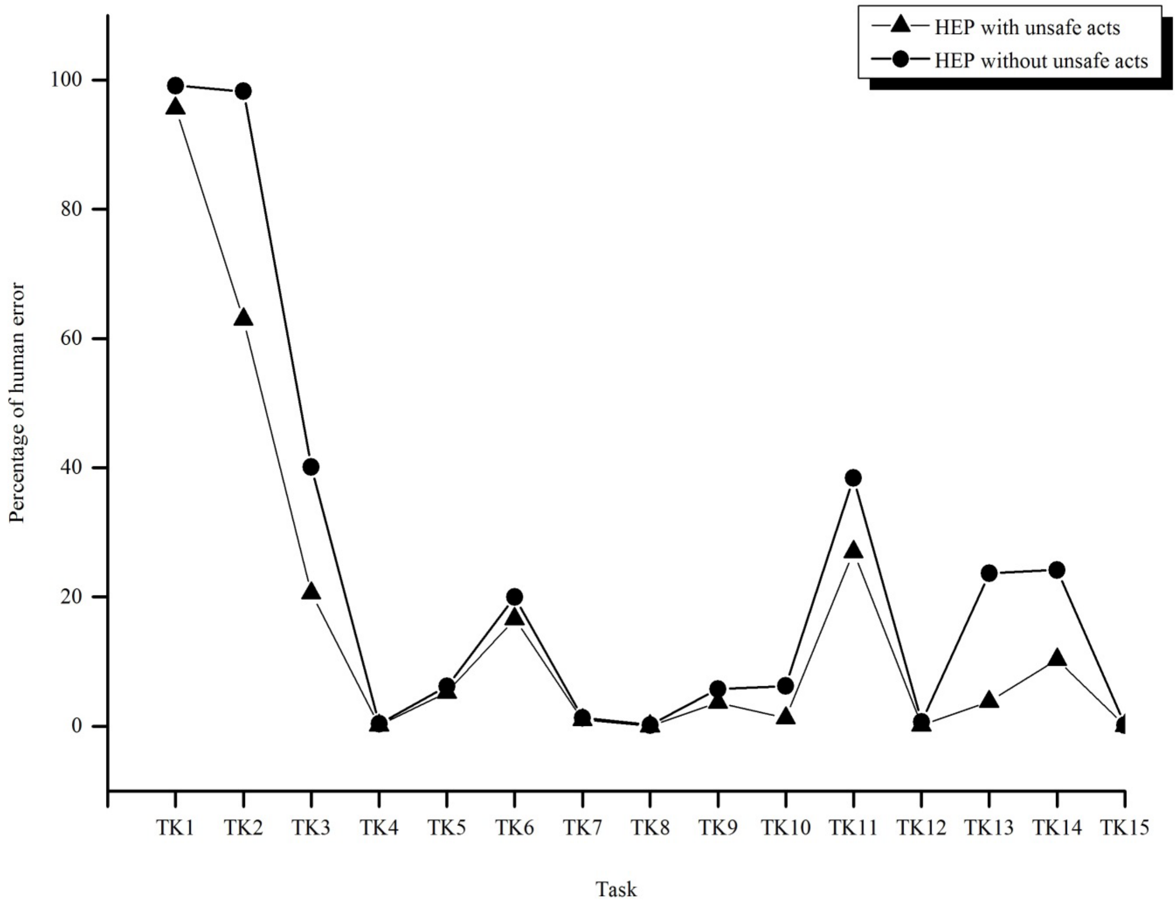


**Figure 3.** Comparison of HEP with and without unsafe acts

Task $TK_{11}$, $TK_{13}$ and $TK_{14}$ are found to be the second cluster task with higher HEP. This indicates that the workers involved in these tasks should receive safety training to handle high risk. In addition to this, behavior-based safety should be imparted to the workers to cultivate a positive attitude toward the work culture. Supervisors involved in these tasks should increase the frequency of inspection, as well as motivation, for workers. Tasks such as $TK_4$, $TK_7$, $TK_8$, $TK_{10}$ and $TK_{12}$ have lower HEP which indicates these task have suitable safety measures, but constant safety training should be given to the workers to make it error free zone.

Integrating the probability of unsafe acts with the existing factors does not mean that it increases or decreases the final HEP. Unsafe acts are the major factor in many industrial accidents. Therefore, identifying the probable human error through the suggested approach enhances the method of assessing human error. Therefore, it is the duty of the Safety Engineer to look not only at generic tasks and error producing conditions, but also at unsafe acts of the individual who are involved in the particular task.

# 4. Conclusions

Human error is identified in all the tasks of the construction site using the HEART technique. But in addition to the existing factors considered in HEART (i.e., generic task and error producing conditions), this research incorporated probability of unsafe acts for determining the human error. As human error is the combination of unsafe acts and unsafe conditions, this research highlighted that unsafe acts should also be a major concern in identifying human error. The results show that excavation (95.79%) has a higher probability of human error than other tasks. This can be minimized by frequent safety trainings to the workers and providing suitable Personnel Protective Equipment (PPE) by the management. This proposed method may be applicable for all the workplaces, as it has a generic method to quantify human error with the task and error producing conditions. Considering unsafe conditions, standard codes related to the country in which the workplace is located can be adopted to obtain effective results.

The results obtained will allow appropriate preventive actions, which aim to improve work safety, to be formulated. Knowledge of the circumstances of accidents will enable the formulation or modification of the labour law to be properly formulated, as well as the appropriate orientation of preventive measures and trainings in the field of occupational safety. All participants in the investment process: workers, but also construction site managers and supervisors, should be the recipients of these activities, who are also exposed to hazards and may suffer from accidents while performing their activities at a construction site. Parameters and the probable human error described by the authors allow for a comprehensive assessment of hazards and the probability of accident occurrences.

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