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Human Error Probability of Grinding Operation in Fabrication and Construction Company Using Fuzzy HEART Method

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Abstract. The accident record from the construction and fabrication company in 2015 until 2018 shows that the highest accident rate is in grinding operation with a percentage of 26%. The main accidents was caused by human error with a percentage 66.67%. This study aims to determine HEPs (Human Error Probabilities) to find out the highest cause of an error, to minimize human error potential, and to determine recommendations. This research determine the HEP values by using HEART (Human Error Assessment and Reduction Technique) method. Fuzzy linguistic approach was integrated on APOA (Assessed Proportion of Affect) determination in order to reduce the expert judgment subjectivity and inconsistency. The calculation result and analysis reveal that the highest Human Error Probabilities (HEP) value is 0.71324 which is shown by the task check the condition of safety guard or protector. Reducing the risk factor and focusing on the main cause of accident are determined by using Impact Assessment to get the risk rating of error and possible error. Some recommendations are given and prioritized based on high rating of error using Error Reduction Analysis.

Introduction

This research was conducted in Fabrication and Construction Company with a high accident rate for the past four years. 6 out of 24 accidents in total were in grinding operation. The main factor of those accidents were caused by human error. Thus, it needs to be evaluated by using Human Reliability Assessment (HRA) to assess human factor to risk that comprises the use of quantitative and qualitative methods [5].

According to [11], he has asserted the purpose of human reliability analysis are assessing the human error based on identification of possible errors, determining how likely the errors are to occur, increasing human reliability by reducing the likelihood of this error. Of 35 tools of HRA, 17 were considered to be of potential use to Health and Safety Engineer (HSE) [5]. Many researchers have used the HRA method to analyze human error potential [6, 14, 18]. For the purpose of this work, Human Error Assessment and Reduction Technique (HEART) has been adapted based on existing documentation for HEART [20]. Based on [10], he has emphasized that HEART is easy to understand, fast, and trustworthy. Because it is possible the capture of detailed human error data comprehensively which has been validated empirically in other areas of industry, In the other hand, HEART can be used for the retrospective review of incidents and as a probabilistic risk assessment which can be used to determine the predicted likelihood of human error termed human error probability (HEP). Thus, HEART has been selected as the proposed approach.

Previous research [7], HEART is strongly subjective and very dependent on the expert judgment assessment. Ambiguities and uncertainties in qualitative data can be handled by using

Fuzzy. [3]. Prior to that, fuzzy had been applied to industrial engineering [2, 8, 13, 15]. In order to overcome inherent weakness, [12] has proposed to modify using fuzzy linguistic expression concept in the representation of Assessed Proportion of Affect. However, Impact Assessment and Error Reduction Analysis hadn't been carried out in a previous research. In this research, reducing the risk level and focusing to the main factors of accident cause can be conducted using Impact Assessment. Then the Error Reduction Analysis step will be applied to give improvement recommendation [11].

The purpose of this research is to determine how much the probability of human error of grinding operation in Fabrication and Construction Company by using Fuzzy HEART method, and to determine the recommendation for reducing the probability of human error.

Method

Human Error Assessment and Reduction Technique (HEART). HEART, one of the technique used in the field of HRA, designed as a method which is easy to understand, fast and trustworthy [10]. It aims to analyze the probability of human error in a system or industry where human reliability becomes an important thing [5]. The basic of HEART consists of three parameters, those are: Generic Task Type (GTT) which suitable with the task, Error Producing Condition (EPC) which determine the cause of accident can be occurred, and the weight of each EPC based on its importance termed Assessed Proportion of Affect (APOA) [1]. Stages in applying HEART are as follows [19] :

1. Identification of problem and task involved
   This stage is to arrange a list of subtasks in accordance with the work instruction, the real condition, and brain storming session with expert judgments termed of Hierarchical Task Analysis (HTA) which are divided into several subtasks. [1, 4, 17]. Then, it will be discuss with experts to determine the possible error of those subtask
2. Deciding Nominal Human Unreliability to the subtasks which consist of range from 0.00002 - 0.55. Each GTTs can be seen in Table 1.

Table 1. Generic Task Type

Generic Task		Nominal Human Unreliability	Range
A	Totally unfamiliar, performed at speed with no real idea of likely consequences	0.55	(0.35-0.97)
B	Shift or restore system to a new or original state on a single attempt without supervision or procedures	0.26	(0.14-0.42)
C	A complex task requiring high level of comprehension & skill	0.16	(0.12-0.28)
D	Fairly simple task performed rapidly or given scant attention	0.09	(0.06-0.13)
E	Routine, highly practiced, a rapid task involving relatively low level of skill	0.02	(0.00-0.045)
F	Restore or shift a system to original or new state following procedures, with some checking	0.003	(0.00008-0.007)
G	Completely familiar, well-designed, highly practiced, routine task occurring several times per hour, performed to the highest possible standards by highly motivated, highly-trained & experienced person, totally aware of implications of failure, with time to correct the potential error, but without the benefit of significant job aids.	0.0004	(0.35-0.97)
H	Respond correctly to system command even when there is an augmented or automated supervisory system providing accurate interpretation of system stage.	0.00002	(0.14-0.42)
M	Others	0.03	(0.12-0.28)

3. Identification of relevant Error Producing Condition (EPCs)
   In this stage, Expert judgments may select an EPC which relevant with 38 possible conditions.

4. Determination of Assessed Proportion of Effect (APOA)
5. Estimation of Assessed EPC effect for each EPC

$$EPC' = ((EPCn - 1) x APOAn) + 1 \quad (1)$$

6. Calculation the value of HEP

$$p(E) = GT \times EPC'1 \times EPC'2 \times EPC'3 \quad (2)$$

Fuzzy Linguistic. The concept of linguistics is very helpful in handling with too complex situation which described in conventional quantitative expression [21]. The weighted of assessment method of each expert and its algorithm are used to reach consensus during aggregation in order to handle the inequalities data presented by [9]. Stages in applying incorporation of fuzzy set theory are as follows [12]:

1. Expert team formation, expert evaluation and linguistic terms definition
   According to the Table 2, the weighted scores are classified by a heterogeneous group of expert judgments. It depends on their professional position, experiences, and educational or technical qualification. For example: Technician of grinding who has 18 years experiences with secondary school in educational, so his total score is 7.

Table 2. Weighting scores of different experts

Constitution	Classification	Score
Professional Position	Professor, GM/DGM, Chief Engineer, Director	5
	Asst. Prof., Manager, Factory Inspector	4
	Engineer, supervisors	3
	Foreman, Technician, Graduate apprentice	2
	Operator	1
Experience (in years)	Greater than 20	5
	15 to 20	4
	10 to 15	3
	5 to 10	2
	Less than 5	1
Educational/Technical Qualification	Ph.D./M.Tech	5
	M.Sc./B.Tech.	4
	Diploma/B.Sc.	3
	ITI	2
	Secondary school	1

2. Fuzzification
   The result of expert assessment in the form of linguistic variables will be processed and adjusted to the existing fuzzy number set. The linguistic variables of APOA are represented by a fuzzy number divided into five fuzzy sets. Fuzzy number for each set has three parameters {li, mi, ui} which is represented by triangular fuzzy number. It can be seen in figure 1 below.

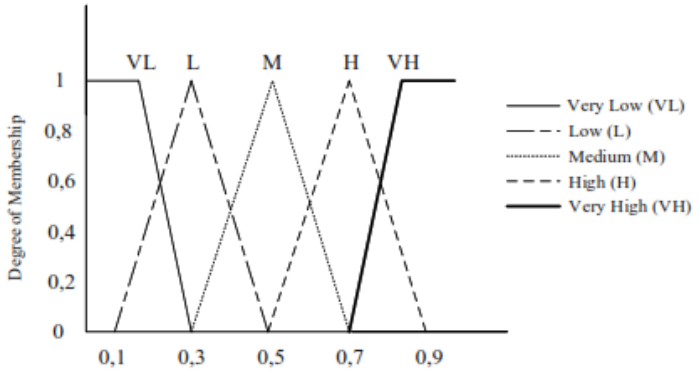

Figure 1. Representation of fuzzy linguistic variables of assessment factors

The following is the equation of membership function of APOA linguistic variable which refers to the following equation:

$$\mu_{VL} = \begin{cases} 0; & x < 0 \text{ or } x > 3 \\ \frac{(0{,}3-x)}{(0{,}15)}; & 0{,}15 < x \leq 0{,}3 \\ 1; & 0 < x \leq 0{,}15 \end{cases} \quad (3)$$

$$\mu_{L} = \begin{cases} 0; & x < 0{,}1 \text{ or } x > 0{,}5 \\ \frac{(x-0{,}1)}{(0{,}2)}; & 0{,}1 < x \leq 0{,}3 \\ \frac{(0{,}5-x)}{0{,}2}; & 0{,}3 < x \leq 0{,}5 \end{cases} \quad (4)$$

$$\mu_{M} = \begin{cases} 0; & x < 0{,}3 \text{ or } x > 0{,}7 \\ \frac{(x-0{,}3)}{(0{,}2)}; & 0{,}3 < x \leq 0{,}5 \\ \frac{(0{,}7-x)}{0{,}2}; & 0{,}5 < x \leq 0{,}7 \end{cases} \quad (5)$$

$$\mu_{H} = \begin{cases} 0; & x < 0{,}5 \text{ or } x > 0{,}9 \\ \frac{(x-0{,}5)}{(0{,}2)}; & 0{,}5 < x \leq 0{,}7 \\ \frac{(0{,}9-x)}{0{,}2}; & 0{,}7 < x \leq 0{,}9 \end{cases} \quad (6)$$

$$\mu_{H} = \begin{cases} 0; & x < 0{,}7 \text{ or } x > 1 \\ \frac{(x-0{,}7)}{(0{,}2)}; & 0{,}7 < x \leq 0{,}85 \\ 1; & 0{,}85 < x \leq 1 \end{cases} \quad (7)$$

3. Aggregation of score

Step 1): Estimate degree of agreement (degree of similarity)

$$S(\tilde{A}1, \tilde{A}2) = 1 - \left(\frac{1}{3}\right) \sum_{i=1}^{3} |a_{1i} - a_{2i}| \quad (8)$$

Step 2): Similarly, Average Agreement (AA) degree

$$AA\ (Eu) of\ the\ experts, AA(Eu) = \frac{1}{M-1 \sum_{\substack{u \neq v \\ v=1}}^{M} S(\tilde{A}1, \tilde{A}2)} \quad (9)$$

Step 3): Similarly, Relative Agreement (RA) degree

$$RA\ (Eu) of\ M\ experts, RA(Eu) = \frac{A(Eu)}{\sum_{1}^{M} A(Eu)} \quad (10)$$

Step 4): Consensus Coefficient (CC) degree

$$\mathrm{CC(Eu)\ of\ expert,\ CC(Eu)} = \beta.\, \mathrm{w(Eu)} + (1 - \beta)\,.\,\mathrm{RA\ (Eu)} \quad (11)$$

Step 5): Expert judgments aggregated result

$$\hat{R}_{AB} = CC(E_1)\ x\ \hat{R}_1 + CC(E_2)\ x\ \hat{R}_2 + \cdots + CC(E_M)\ x\ \hat{R}_M \quad (12)$$

4. Defuzzification

$$X^* = \frac{\int_{a1}^{a2} \frac{x-a}{a_2-a_1} x dx + \int_{a2}^{a3} \frac{a_3-x}{a_3-a_2} x dx}{\int_{a1}^{a2} \frac{x-a_1}{a_2-a_1} x dx + \int_{a2}^{a3} \frac{a_3-x}{a_3-a_2} x dx} = \frac{1}{3}(a_1 + a_2 + a_3) \quad (13)$$

Data Analysis and Discussion

Human error identification. In this study, expert elicitation has been selected and interviewed according to several criteria in its determination [16]. They are from operator, foreman and Supt. HSE. According to the expert judgments opinion and literature study, Generic Task Types (GTTs) has been classified based on Table 1. The most frequent GTTs are C, and D with 84 % which indicates that the sub task is fairly routine and simple task.

Expert Weightage Assessment and Linguistic Term's Definition. Various expert judgments consists of level of experiences, educational background, and their position in the workplace. The weightage of each expert required need for heterogeneous experts. Conversion scale of five verbal terms are used for assessing subjective assessment of the APOA to each EPC. Those are Very Low (VL), Low (L), Medium (M), High (H) and Very High (VH). It can be seen in Table 4.

Table 4. Fuzzy number of conversion

Set of linguistic variable	(li, mi, ui)
VL (Very Low)	(0, 0.15, 0.3)
L (Low)	(0.1, 0.3, 0.5)
M (Medium)	(0.3, 0.5, 0.7)
H (High)	(0.5, 0.7, 0.9)
VH (Very High)	(0.7, 0.85, 1)

Fuzzification, Aggregation score, Deffuzification. After performing assessment, Aggregation by formula 8, 9, 10, 11, 12, and 13 on the 41 subtasks of grinding operation is carried out to those 41 subtask from 3 experts in order to attain for each EPC. The task which has the highest APOA value can be seen in Table 5.

Table 5. Aggregation calculation for EPC 8.3.

Expert	Expert Opinion	EPC 8.3 (Clean the workplace)				
E1	H	0.5		0.7		0.9
E2	M	0.3		0.5		0.7
E3	M	0.3		0.5		0.7
S (1-2)	0.8	Wt of E1	0.36363636	CC (E1)	0.3531	
S (1-3)	1	Wt of E2	0.36363636	CC (E2)	0.3338	
S (2-3)	0.8	Wt of E3	0.27272727	CC (E3)	0.3081	
AA (E1)	0.9	RA (E1)	0.3462	Agregation (fuzzy value)		
AA (E2)	0.8	RA (E2)	0.3077	a1	a2	a3
AA (E3)	0.9	RA (E3)	0.3462	0.4311	0.63	0.829
Deffuzified Value						0.63

For example, the results of calculations in the APOA assessment in Table 5 show that the APOA value on EPC 8.3 is 0.63. First stage is determine the degree of similarity between every possible comparison of opinion which are calculated from equation 8. Equation 9 is used to calculate Average Agreement (AA) Degree from the average of similarity degree of every expert opinion are S (1-2), S (1-3), and S (2-3). Relative agreement degree (RA) is obtained as the

proportion of average agreement degree of every assessment to the sum total average agreement degree from equation 10. From equation 11 is used to calculate Consensus Coefficient (CC) with the relative agreement and relaxation factor (β =0.5). The aggregated opinion result for EPC 8.3 is obtained as product sum of CC and fuzzy opinion as equation 12. While the final value of APOA is obtained as equation 13.

Calculation HEP. In this step, it calculated HEP value on the tasks of grinding operation by formula 1, and 2. The task which has the highest HEP value shows in Table 6.

Table 6. Calculation of HEP

Task	Nominal Human Unreliability	EPC	APOA	Total Effect	Assessed Effect	HEP
Check the protector or safety guard	0.09	A mismatch between perceived & real risk	0.745891204	4	3.23767361	0.7132
		Operator inexperience	0.431057692	3	1.86211538	
		An incentive to use other more dangerous procedures	0.314485468	2	1.31448547	

Based on the calculation results, it shows that the HEP value describes the risk of accident on each task. The higher the HEP value, the higher the accident can be happened. From Table 6 shows that the highest HEPs value is 0.7132 on the subtask of checking the protector or safety guard. An error still occurred, although the task is a routine and simple task performed rapidly and already exist in work instruction procedurally. Lack of experience, doesn't know the real risk, and prefers to use other dangerous procedures which can affect an error.

Impact Assessment. Furthermore, Impact Assessment was carried out through identification of error, risk assessment and error reduction analysis.

Table 7. Impact Assessment

No.	Task	Possible error	Impact	HEP	*Likelihood*	*Severity*	*Risk Rating*
4.1.1	Check the protector or safety guard	No check the protector	Protector or safety guard isn't secure, workers injured by scratching machine	0.7231	3	3	H

From Table 8, the possible consequence of subtask 4.1.1 are protector or safety guard isn't secure, and workers injured by scratching machine. It's shown that the risk rating of this subtask is high based on ASNZ standard.
This is the following of determination of risk rating is as follows:

$$\text{Risk rating} = \text{Likelihood} \times \text{Severity}$$
$$= 3 \times 3$$
$$= 9$$

So, it's included in high category based on ASNZ standard.

Discussion. Based on the calculation results, it shows that the highest HEP value is on the subtask of checking the protector or safety guard with 0.7231. It means that the potential error on this sub task is high. And the result of an impact assessment of its subtask shows high in risk rating also. The task priority is based on consideration of the high HEP value and also the high risk rating on the task. One example, on sub task 4.1.1 has the highest HEP value of 0.713244 and risk rating

high. So, it needs to reduce the potential of an error by recovering point with ensure the competence of workers and the recommendation of the remedial action are increasing competent with conducting internal training to the grinding operation workers, enhancing detectability with conducting toolbox meeting and evaluation about the correct work instruction. In this study, Fuzzy logic approach implemented in this methodology enables accommodation to quantify expert judgment opinion which are non-crisp, imprecise, and vulnerable form operator performance. So, by using Fuzzy HEART method can minimalize the subjectivity of expert assessments.

Conclusions

A company should forecasting and assessing human factor in order to avoid accidents and consequences. Based on the overall result of Fuzzy HEART method, it is known that the highest HEP value in in task check the protector or safety guard with the HEP value is 0.7231. HEP's value indicates the task is the most error which happened in grinding operation. Then, priority recommendations are given based on error reduction analysis in task with the highest HEP and the highest risk rating, as follows:

a. Increasing competent with conducting internal training to the grinding operation workers
b. Enhancing detectability with conducting toolbox meeting and evaluation about the correct work instruction.

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