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Human Related Risk Assessment during Operating Dangerous Experiments in Laboratory

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Laboratory safety has become a key concern which attracts many attentions from governments and academic institutes. Besides, according to some published reports, about 70% of accidents are closely related to human-related risks. Therefore, to the laboratory safety, it is necessary to carry out some particular efforts to evaluate human-related risk during operation an experiment. However, there is limited research to analyse laboratory from the aspect of human-related risk. In order to assess human-related risk, this study provides an integrated method which contains Hierarchy Task Analysis (HTA), Human Error Assessment and Reduction Technique (HEART) and risk matrix. HTA method is used to decompose experiments into several steps for further analysis. Then widely used human reliability method HEART is used to calculate the human error probability in each decomposed step by evaluating the corresponding Error Produce Conditions (EPCs) for each step. Finally, a risk matrix is constructed to evaluated the risk level of human in each step. The proposed method is applied to a risky experiment (the effect of magnetic field on acetylene explosion rate and pressure), the human-related risk level and several risky steps are identified.

Keywords: Laboratory safety, human-related risk, HEART, risk matrix, HTA

1. Introduction

There have been many chemical-related laboratory accidents in the past few years, and many of the casualties have been caused by these serious accidents. Laboratory safety has become a key concern which attracts many attentions from governments and academic institutes. Besides, according to some published reports, about 70% of accidents are closely related to human-related risks. Therefore, to the laboratory safety, it is necessary to carry out some particular efforts to evaluate human-related risk during operation an experiment.

So far, A growing number of researchers are also making some efforts to keep experiments safe in the laboratory. Ayana et al. (2017) study investigated the status quo of chemical laboratory safety awareness, attitudes and practices among college students in Trinidad. It also seeks to determine whether there is any correlation between awareness and practice, and whether there are any useful predictors of the likelihood of accidents in the laboratory. The results show that although awareness is high, there are deficiencies in hazard identification and emergency response. The conclusion is that more education and training need to be implemented for improvement. Yliniemi et al. (2021) has done research on gamification lab simulations. Aiming at the defects of traditional laboratory safety evaluation, such as low accuracy, large influence of human factors, lack of unified evaluation system and so on. Tong et al. (2019) proposed a new machine learning-based laboratory safety management evaluation method, which gives a more accurate and reasonable laboratory safety risk level, verifies the rationality and feasibility of the established method, and realizes the possible loopholes in the process of laboratory management and operation of college students. Keckler et al. (2019) developed an evidence-based Continuous Quality Improvement (CQI) cycle for laboratory safety as a way to use survey data to improve safety in public health laboratory Settings. Shariff et al. (2011) used the Lab-ARBAIS project as a case study to show that students showed significant improvement in frequent high-risk behaviors. Lab-ARBAIS can easily be adopted in any academic laboratory to manage risky behaviors among students to ensure a safe working environment. With slight enhancement, Lab-ARBAIS can be easily scaled up for use in industrial laboratories. Olewski et al. (2017) believes that academic and research laboratories within universities contain a variety of hazards, and the risks associated with these hazards can be significant if not properly managed. The misconception that university LABS are "low-risk" and "inherently safer" persists both inside and outside academia, in part due to a lack of risk awareness. Selected challenges and suggested solutions are discussed. Oliver's findings demonstrate the importance of providing adequate and effective education and training to laboratory staff about the dangers and risks associated with their work (Oliver et al., 2020). Moreira et al. (2021) introduced the safety culture of our undergraduate students. It is found that the safety culture of female college students is better than that of male college students, and the safety culture of OHS undergraduates is better than that of other majors. Meanwhile, there is no significant difference in safety culture among students in different academic years. The findings point to the need for greater focus on boys in accident prevention programs and strategies to improve safety culture as the school year progresses (Salazar-Escoboza et al., 2020).

Therefore, to the laboratory safety, it is necessary to carry out some particular efforts to evaluate human-related risk during operation an experiment. However, there is limited research to analyse laboratory from the aspect of human-related risk. In order to assess human-related risk, this study provides an integrated method which contains Hierarchy Task Analysis (HTA), Human Error Assessment and Reduction Technique (HEART) and risk matrix.HTA method is used to decompose experiments into several steps for further analysis. Then widely used human reliability method HEART is used to calculate the human error probability in each decomposed step by evaluating the corresponding EPCs for each step. Finally, a risk matrix is constructed to evaluated the risk level of human in each step. The proposed method is applied to a risky experiment (the effect of magnetic field on acetylene explosion rate and pressure), the human-related risk level and several risky steps are identified.

The following of this paper is arranged as: Section Two presents the methodology used in this study; Section Three illustrates the procedure of applying the adopted method to a real case; The last section concludes the findings and results of this study. The following arrangement of this paper is as follows: Section Two introduces the methods used in this study; Section Three describes the process of applying the method to real cases. The final section summarizes the findings and results of this study.

2. Methodology

The central idea of HEART method is to analyze the conditions of error and design corresponding measures to reduce the probability of human error, so as to improve human reliability. Risk matrix analysis method can classify risks and hazard factors according to the probability of accidents and the severity of consequences. The risk matrix approach classifies risks, sources of risks, or responses to risks by risk level to determine which risks should be analyzed in more detail or to be reminded of priorities. This method is convenient and easy to classify the importance level of risk quickly. HEART and risk matrix is selected as the main method for this study. The details of this method are presented in following parts.

HEART approach assumes that the reliability of any one task will change as a result of EPCs In the presence of EPCs, nine general accident types are defined and named as the benchmark human failure probability. In equations (1), used to predict the likelihood of human error for the task under consideration.

$$\begin{cases} WF_i = APOA_i \times (EPC_i - 1) + 1 \\ HEP = GEP_j \times \prod_{i}^{38} WF_i \end{cases} \quad (1)$$

WFi=The weight factor of the i-th EPC；

APOAi=Impact weight of the i-th EPC；

EPCi=The i-th digit；

GEPj=Reference human failure probability corresponding to the j-th general accident type；

HEP=Human error probability.

In practice, each subtask of HTA analysis is classified into a general category using a common task type table. Then, the error generation condition factors (EPCs) that may be involved are selected based on the common accident type of each subtask by referring to the error generation condition table. For a specific task, each EPC has a different degree of influence. In this paper, different weights are provided for its evaluation by analyzing the importance of the error generation condition factors (EPCs) in each subtask. Finally, the predicted human failure probability is calculated under the framework of HEART method formula 1-1. Reveal the key human error in the experimental steps, and analyze the relevant reasons.

Risk matrix method is used to evaluate the probability of the risk caused by human factors and the severity of the injury during the experiment. The basic steps are as follows:

(i) Hazard identification: Use HTA to analyze the sub-tasks and construct the structure chart;

(ii) Harshness judgment: According to the experimental steps, the harshness grade is formulated from the two aspects of property damage and the possible consequences of the accident, and each harshness grade is assigned a value;

(iii) Possibility judgment: Grade the probability calculated by HEART method, and assign a value to the divided probability interval;

(iv) Risk assessment: According to the results of steps 2 and 3, take the values of harshness and possibility of each subtask, find the corresponding intersection point on the matrix graph, and obtain the risk value and its corresponding risk level. The greater the risk value and risk level, the higher the risk level, indicating that the step is more dangerous and risky. Determine which risks need to be more closely analyzed or prioritized.

3. Case Study

In this case, the HEART method was used to combine the task modeling obtained by the HTA analysis experiment "Study the influence of magnetic field on the explosion rate and pressure of acetylene", which included the importance of error generation condition factors, and provided different weights for their evaluation. Under the framework of the HEART method, the probability of predicting human failure is calculated. It is of strong practical significance to reveal the key human errors in the experimental steps and analyze the relevant reasons, thereby improving the quality level of safety management and evaluation, and also providing effective support for laboratory safety management.

3.1.*HTA hierarchical task analysis*

Using hierarchical task analysis, each experimental step of the experiment "Study the effect of magnetic field on acetylene explosion rate and pressure" was divided into the subtasks shown below, as shown in Figure 1 of the table. Since this study was only evaluated for the course of the experiment, the operator's PPE wear was not counted.

Table1. Analysis of experimental HTA hierarchical tasks.

Process	Description
P1	1 Remove the gas required for the experiment (methane, ethane, propane, ethylene, hydrogen) from the cylinder and put it into the bag. 1.1 Check the cylinder pressure gauge 1.2 Connect the air bag to the hose 1.3 Open the valve 1.4 Close the valve 1.5 Remove the air bag from the hose port and the air extraction is complete
P2	2 The optical fiber sensor and pressure sensor are first installed on the test pipeline for air tightness inspection and pressure sensor debugging. 2.1 Install the fiber optic sensor and pressure sensor on the test pipe first 2.2 Conduct air tightness checks 2.2.1 Use vacuum pump to make the pipeline in a negative pressure state; Then observe the pressure gauge, if there is no change for 5 minutes, the pipeline air tightness is intact 2.2.2 If there is a leak, check its airtightness with sparkling water
P3	3 Install the experimental pipe and extract the vacuum. 3.1 Install the experimental pipeline 3.2 Turn on the vacuum pump and extract the vacuum 3 Install the experimental pipe and extract the vacuum.
P4	4 Use vacuum to inject the calculated volume of gas into the pipeline to supplement the atmospheric pressure of air 4.1 Remove the required gas from the air bag with a syringe; And connect the syringe to the tube 4.2 Slowly twist the pipe valve so that the gas slowly enters the pipeline
P5	5 The gas in the circulating pipeline is 2min, and it is allowed to stand for 5min to make the gas mix evenly 5.1 Connect the piping to the circulating pump 5.2 Turn on the circulating pump, circulate the gas for 2min, and let it stand for 5min; After the gas is evenly mixed, remove the circulation pump
P6	6 Connect the other end of the optical fiber sensor to the detonation speedometer, set the detonation speedometer measurement parameters, and set the detonation speedometer to the measurement state 6.1 Connect the other end of the fiber optic sensor to the speedometer 6.2 Set the measurement parameters of the detonation speedometer and set the detonation speedometer to the measurement state
P7	7 Set the pressure collection frequency and set the pressure collector to be measured 7.1 Set the pressure collection frequency and set the pressure collector to be measured
P8	8 Turn on the electromagnetic field device, first turn on the magnetic field switch and then immediately turn on the igniter, that is, add the magnetic field at the same time ignition explosion 8.1 Turn on the magnetic field switch first and then immediately turn on the igniter, so that the ignition explodes at the same time as the magnetic field is added
P9	9 Collect data on explosion pressure and flame propagation velocity 9.1 Record explosion pressure and flame propagation velocity data in a timely manner
P10	10 Exhaust gas treatment 10.1 Connect the stamping machine to the pipe 10.2 Turn on the stamping machine and evacuate the exhaust gas with CO and CO2 as the main components in the pipeline to the outside 10.3 After the exhaust gas is evacuated to the outside, turn off and remove the stamping machine, and the experiment is completed

3.2.*Subtasks: Common accident types and EPCs that may be involved*

For the subtask that has been split in the experiment "Study the influence of magnetic field on acetylene explosion rate and pressure" in 3.2.1, the general accident types are divided according to the table of the HEART method, and the EPCs that may be involved in each subtask are judged and summarized.

HEART provides nine common task types and their corresponding benchmark human failure probability. Next, it is time to consult the EPCs table, which represents the optimal conditions for inducing errors in the work area. These numbers represent the maximum amount that should be included in the HEART basic equation to reflect the impact of each EPCs.

A summary of the general accident types and EPC situations that may be involved in each subtask is shown in Table2:

Table 2. List of general accident types and EPCs that may be involved in each subtask.

number	Common accident types	EPCs that may be involved
1.1	G	EPC15
1.2	H	EPC32
1.3	G	EPC12；EPC32
1.4	G	EPC12；EPC32
1.5	H	EPC32
2.1	H	EPC15
2.2.1	H	EPC12；EPC15
2.2.2	H	EPC15
3.1	G	EPC15；EPC32
3.2	H	EPC15
4.1	G	EPC15
4.2	E	EPC12；EPC24；EPC28；EPC32
4.3	H	EPC15
5.1	H	EPC15；EPC32
5.2	G	EPC15；EPC32
6.1	H	EPC28；EPC32
6.2	G	EPC13；EPC32
7.1	G	EPC13；EPC32
8.1	G	EPC28
9.1	H	EPC13；EPC31
10.1	H	EPC15
10.2	G	EPC15；EPC32
10.3	H	EPC15

3.3.*HEART calculation*

According to the general accident type and EPCs that may be involved in each substep, by referring to the existing relevant literature and the degree of cognition of the model and experiment, different weight values of EPCs in each subtask are considered in various aspects, and the human error probability is calculated for each subtask according to the HEART formula

(1).The human cause failure probabilities of all subtasks in the whole experiment were calculated, but the difference between each probability was large, which was inconvenient for subsequent evaluation. Therefore, all the probabilities of each subtask were logarithmic. Human failure probability of all subtasks in the experiment is shown in Figure 1:

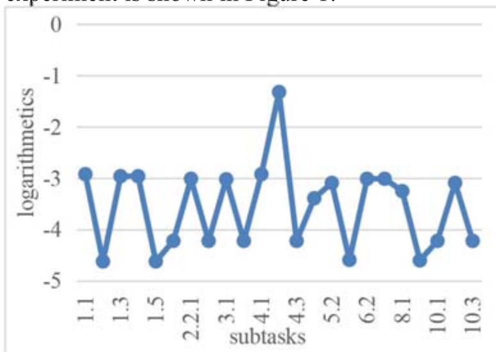

Fig.1Human failure probability line chart (probability logarithmization)

From the plot, it can be seen that subtasks 1.1, 1.3, 1.4, and 4.2 have a high probability of human factor failure.

3.4.Risk assessment

Establish a risk matrix, and conduct assessment and analysis according to the risk matrix diagram and risk grade diagram.

The risk matrix method is used to evaluate the probability of the risk caused by human factors and the severity of the injury during the experiment. The steps are as follows:

(1).Hazard identification: Use the HTA to analyze the sub-tasks and construct the structure chart;

(2).Harshness judgment: According to the experimental steps, the harshness grade is formulated from the two aspects of property damage and the possible consequences of the accident, and each harshness grade is assigned a value;

(3).Possibility judgment: Grade the probability calculated by HEART method, and assign a value to the divided probability interval;

(4).Risk assessment: Take the values of harshness and possibility of each subtask, find the corresponding intersection points on the matrix graph, and obtain the risk value and its corresponding risk level. The greater the risk value and the higher the risk level, the greater the risk level, indicating that the step is of great risk and risk.

3.4.1.Establish a risk matrix

Probability:The owner failure probability (log) calculated in 3.3 is divided into 5 grades, and the five grades are assigned different scores, respectively:

- correspond to X≤-4.5；
- correspond to -4.5＜X≤-3.5；
- correspond to -3.5＜X≤-2.5；
- correspond to -2.5＜X≤-1；
- correspond to X＞-1.

Severity: Because the laboratory involves the personnel and experimental equipment, so the severity will be from property damage and the possible consequences of accident to two classification and corresponding to the corresponding score, the greater the injury, the number of deaths or the more property loss of the corresponding severity level will increase, the score will be bigger. Specific divisions are shown in Table Table.3.

Table.3 Classification of severity

	Property loss: Y / ten thousand yuan	Y：The possible consequences of the accident	score
A	＜5	No casualties	1
B	5≤Y＜10	Minor injury	2
C	10≤Y＜50	Amputation, bone fracture, hearing loss, chronic disease (one person)	3
D	50≤Y＜100	Serious injury (one person)	4
E	100≤Y＜150	A number of people were seriously injured	5
F	150≤Y＜200	One person died	6
G	≥200	There were many deaths	7

Risk matrix diagram: The possibility of an accident is combined with the severity to build a risk matrix diagram, as shown in Table 4.

Table.4 Risk matrix diagram

		1	2	3	4	5
Accident severity level （From light to heavy）	1	1	2	3	4	5
	2	2	4	6	8	10
	3	3	6	9	12	15
	4	4	8	13	16	20
	5	5	10	15	20	25
	6	6	12	18	24	30
	7	7	14	21	28	35

Risk level map: All the intersection points on the matrix graph are calculated into the risk value, and the division is shown in Table 5.

Table.5 Figure Risk matrix plot

risk grade	risk grade	score	risk grade
I	Significant risk	1-4	
II	medium	5-9	
III	acceptability	10-16	
IV	Minor or negligible risk	18-35	

3.4.2.Risk assessment

The calculated probability of each subtask is divided into possibility division and severity classification, and the corresponding intersection point is found on the matrix graph to obtain the risk value and its corresponding risk level, and finally carry out evaluation and analysis. The risk levels of all subtasks are shown in Table 6.

Table.6 List of human error probability and risk levels

step	I	II	III	IV	V
1.1	EPC15	-2.92	D	3	12
1.2	EPC32	-4.62	A	1	1
1.3	EPC12;EPC32	-2.96	B	3	6
1.4	EPC12;EPC32	-2.96	B	3	6
1.5	EPC32	-4.62	A	1	1
2.1	EPC15	-4.22	A	2	2
2.2.1	EPC12;EPC15	-3.01	D	3	12
2.2.2	EPC15	-4.22	D	2	8
3.1	EPC15;EPC32	-3.02	A	3	3
3.2	EPC15	-4.22	B	2	4
4.1	EPC15	-2.92	A	3	3
4.2	EPC12;EPC24 EPC28;EPC32	-1.32	D	4	16
4.3	EPC15	-4.22	B	2	4
5.1	EPC15;EPC32	-3.39	A	3	3
5.2	EPC15;EPC32	-3.09	C	3	3
6.1	EPC28;EPC32	-4.59	A	1	1
6.2	EPC13;EPC32	-3.01	A	3	3
7.1	EPC13;EPC32	-3.01	A	3	3
8.1	EPC28;	-3.25	A	3	3
9.1	EPC13;EPC31	-4.6	A	1	1
10.1	EPC15	-4.22	A	2	2

- “I” represent the possible EPC involved;
- “II” represent Human error probability(logialization);
- “III” represent Severity;
- “IV” represent Probability;
- “V” represent Risk value.

As can be seen from the above table, the probability and severity of subtasks 1.1, 2.2.1, and 4.2 are higher than those of other subtasks, so the corresponding risk level is medium risk. Subtasks 1.3, 1.4, 2.2.2, 10.2 have a high possibility, but their severity is average, so the corresponding risk level is acceptable. The other remaining subtasks are low in probability and harshness, so the corresponding risk level is mild or negligible.

During the experiment, the operator can refer to this risk level table for safer and more standardized operation experiments to reduce the possibility of accidents.

4. Conclusion

In this study, a human reliability analysis was performed on the experimental process "Studying the influence of magnetic field on the explosion rate and pressure of acetylene". In this experiment, because the experimenters may be experienced teachers and students, or may be inexperienced teachers and students, this makes the probability of human error in the experiment have great uncertainty. Therefore, for each subtask of this experiment, an application scheme is proposed based on the HEART evaluation form and risk matrix. The risk values of subtasks 1.1, 2.2.1, and 4.2 are 12, 12, and 16, respectively, which are higher than those of other subtasks. Experimenters can pay more attention to these three subtasks in the future experimental process to reduce the probability of human error and avoid accidents.

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References

Escoboza, M., J. Laborin-Alvarez and C. Alvarez-Chavez (2019) . Safety climate perceived by users of academic laboratories in higher education institutes[J]. Safety Science, 121:93-99.

Gong, Y (2019). Safety culture among Chinese undergraduates: A survey at a university[J]. Safety Science, 111:17-21.

Keckler, M., K. Anderson, S. Mcallister and J. Rasheed (2019). Development and implementation of evidence-based laboratory safety management tools for a public health laboratory[J]. Safety Science, 117:205-216.

Loughlin, W. and S, Cresswell (2020) . Online Safety Quiz for Interactive Revision Reveals Areas for Laboratory Safety Development in Second-Year Undergraduate Chemistry[J]. Journal of Chemical Education, 98,218-223.

Moreira, F., A. Ramos and K. Fonseca (2017) . Safety culture maturity in a civil engineering academic laboratory - ScienceDirect[J]. Safety Science, 134: 105076.

Olewski, T. and M. Snakard (2017). Challenges in applying process safety management at university laboratories. Journal of Loss Prevention in the Process Industries, 49, 209-214.

Shariff, A. and N. Norazahar (2012). At-risk behaviour analysis and improvement study in an academic laboratory[J]. Safety Science, 50(1):29-38.

Tong, P., C. Li, and X. Zhou (2019). Application of machine learning to laboratory safety management assessment[J]. *Safety Science*, 120: 263-267.

Viitaharju, P., K. Yliniemi, M. Nieminen and A. Karttunen (2018). Learning experiences from digital laboratory safety training[J]. Education for Chemical Engineers, 2021, 34(11):87-93.

Walters, A., W. Lawrence, and N. Jalsa (2017). Chemical laboratory safety awareness, attitudes and practices of tertiary students[J]. Safety Science, 96:161-171.

Wirth, O., A. Foreman and J Friedel (2020). Two discrete choice experiments on laboratory safety decisions and practices[J]. Journal of Safety Research,75,99-110.