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A Weighted Fuzzy CREAM for Assessing Human Error Probability in Risky Experiment Operation

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Laboratory safety accidents have recently been recognized as a new topic for safety research, and the existing research shows that human factor is a leading factor that causing laboratory accidents. However, at present, particular research • • on Human Error Probability (HEP) quantification of risky experiments in laboratory is limited. Therefore, it is necessary to implement Human reliability analysis (HRA) technique to quantify HEP during risky experiments in laboratory. Due to the above description, this study proposes a weighted fuzzy Cognitive Reliability and Error Analysis Methods (CREAM) to deal with HEP quantification for laboratory safety. The proposed method comprehensively considers each the weight of each Common Performance Conditions (CPC), each CPC's fuzzy membership degree, and the weight of each activated fuzzy If-Then rule to determine the final membership degree of each control mode. Afterwards, the wanted HEP value can be estimated by the centre of area defuzzification.
This study selects the 12•26 laboratory explosion accident in a university in Beijing, 2018, as the example, and through the proposed method, the HEP value and levels of the human reliability can be collected. Finally, some particular efforts can be reasonably made to avoid human errors.

Keywords: Human reliability, human error, fuzzy CREAM, laboratory safety..

1. Introduction

Some laboratories Laboratory safety has been widely concerned, but fire, explosion, poisoning and other accidents occur from time to time (Zhu et al., 2020). Particularly, there are 57 accidents in university laboratories in the past ten years, in which the improper operation is the main reason, takes 38 percents of the whole accident. Fortunately, some researchers have realized the importance of the safety issue in chemical-related experiment and have pointed out that more focuses should be given to laboratory safety (Olewski and Snakard, 2017; Ménard and Trant, 2020). There are something indispensable to do for not only we students, but also our school and the relevant departments. Thus, it is necessary to learn from those existing accidents, build the education and the management of laboratory safety up.

There are quantities of labs taking charge of varieties of experiments nowadays. These experiments differ from categories, instruments, and operations, but most of them are risky. Human factors are the direct factors result in accident. The 12•26 laboratory explosion accident is a representative accident that due to human factors, whose report puts forward 3 rectification opinions, include the all round safety management of the lab, the strict control of dangerous experimental materials, and the safety management of the overall operation process. The suggestions above are so sweeping that hardly to carry out accurately. What's worse, most accident reports give only qualitative analysis that seldom involve detailed data processing and quantitative analysis. So, bring the Human Reliability Analysis (HRA) Techniques in the safety analysis of laboratory is necessary.

Certainly, HRA Techniques are not anything new, we can say that since early eighties of the 20th century, a lot of methods and models have been developed (Orzáez et al., 2019). It started in 1950, developed and expanded in 1980s. As HRA upgrade and update, the rule: through quantifying the probability of human error and predicting human error, infer the performance ability of human, is reserved (Boring R.L, 2012). In the early years, we used to pay more attention to the economic benefits in the industrial production. The consciousness on safety production has enhanced recently. Same to the industrial engineering and experiments, human reliability determines the safety and success, while human reliability rest with the probability of human errors, depend on the various impact factors. HRA refers to a method for evaluating human errors and providing human error probabilities for application in probabilistic safety assessments. (Park et al, 2019). The well-known methods of the first generation HRA include SPAR-H and HEART. However, extensive researches on human performance factors show that the external environmental conditions are more important than the character of the task itself for carrying out tasks, Therefore, a number of scholars have doubts on the reliability of HEP, for what the second generation HRA methods like ATHEANA, MERMOS emerged (Yang et al., 2013). In view of defects of the first generation HRA methods, the new methods take problems into account such as probability methods of human performance hazards analysis, complexity of cognitive model, collection of PSF and model verification, etc.

Cognitive Reliability and Error Analysis Method is a representative second generation HRA method, put forward in 1998 by Hollnagel (Hollnagel, 1998; Fujita Y, 2004). It emphasizes the influence of the environment on operators and possible subsequent effects. CREAM is able to review and analyse flexible event process, and achieve a detailed and precise result, conducive to carry out following works. This method has been applied in aviation, traffic and many other fields.

Otherwise, a lot of modified methods show up. Shuen-Tai Ung proposed a risk assessment of human error contribution to oil tanker collision, evaluated the collision probability of oil tanker using a Fault Tree Analysis (FTA) structure under which a modified Fuzzy Bayesian Network based Cognitive Reliability Error Analysis Method is developed to conduct human error assessment (Ung, 2018). Renyou Zhang presented a modified fuzzy CREAM applied for HEP estimation in an oil offloading operation at the selected oil terminal that employs fuzzy degree of each common performance condition CPC, the weight of each CPC, and the compatibility degree of each activated fuzzy if-then rule together to calculate HEP and strengthen the quality of HEP estimation (Zhang et al., 2021). Xiao et al. (2020) developed a hybrid HRA model by integrating CREAM, the interval type-2 fuzzy sets, and analytic network process (ANP) to deal with the HRA problem that need to consider the interdependencies between the Common Performance Conditions and determine the weights of these CPCs, simultaneously. What's more, Qingji Zhou proposed a quantitative human reliability analysis model based on fuzzy logic theory, Bayesian network, and cognitive reliability &

error analysis method for the tanker shipping industry (Zhou et al., 2018). Ghasemi et al. (2022) developed a methodology in which, task analysis was performed using hierarchal task analysis and HEP was calculated using a hybrid technique of fuzzy set theory (FST), Bayesian network (BN) and cognitive reliability and error analysis method for predicting human error probabilities in various subtasks of this operation. Such improvements on CREAM mentioned above have strengthened the function and broaden the application fields of CREAM. More scholars are enthralled while the development get promote.

2. Methodology

The objective of this research is to propose an approach based on CREAM, which also introduces the fuzzy logic and cites data from a typical laboratory accident to study the issue of human factor in laboratory safety. CREAM was proposed by Professor Erik Hollnagel in 1998. As one of the most widely used second generation of HRA methods, even though there are drawbacks still, CREAM and the modified CREAM has been used successfully and extensively, while the use of CREAM interiorly is quite limited. Fuzzy CREAM is one of the most representative and successful modified CREAM methods. This study chooses the Fuzzy CREAM method to analyse the case, reckon the HEP value and predict the human errors. It combines the individual factors, the organization factors, the environmental and the technical factors, get the fuzzy membership degree of each control model, to provide proper HEP value. There are adequacy of organization, working condition, adequacy of man machine interface and operational Support, availability of procedure and plan, the number of simultaneous goals, available time, time of the day, adequacy of training and experience, and crew collaboration quality, 9 CPCs that determine 4 COCOMs, include strategic, tactical, opportunistic, and scramble, every COCOM corresponds to a specific HEP range showing in the Table 1 bellow.

Table 1. Control model and the corresponding HEP range

COCOM	HEP
Strategic	$5\times10^{-5}<P<1\times10^{-2}$
Tactical	$1\times10^{-3}<P<1\times10^{-1}$
Opportunistic	$1\times10^{-2}<P<5\times10^{-1}$
Scramble	$1\times10^{-1}<P<1$

CREAM is strict with the data of case, while it uses experts scoring mechanism as the data resource, therefore, this study brings in fuzzy function, because the CPCs are not all equal in the quantization process of CREAM (Marseguerra et al., 2007). Trapezoidal fuzzy function, a function used for solving problems in an uncertain environment, is chosen to describe the CPC and the level of each COCOM (Zhang et al., 2021), which helps weaken the subjectivity of the data. Besides, the IF-THEN rule does well in reflecting the relationship between premise and conclusion. In the end, the centre of gravity method is brought in defuzzification of the HEP value.

The calculation of HEP value contains 5 steps in short: Step 1, define the fuzzy functions. According to the similar case and aiming at the quotative case, define the function matches to each CPC. Step 2, determine the fuzzy membership degree and weight of each CPC, get marks of each CPC from experienced experts, averaging and use functions got in the last step, construct an AHP matrix to collect the each weight. Step 3, through the fuzzy membership degree of each CPC to activate the IF-THEN rules, multiply the fuzzy membership degree of each CPC to get a IF-THEN rule weight. Step 4, compute the original weighted fuzzy degree of every COCOM. Step 5, defuzzification through the centre of gravity method and get the final HEP value.

The research step flow is showing in the Fig.1 bellow.

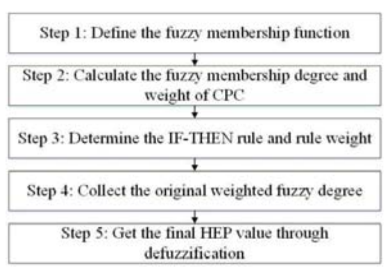

Fig. 1.Research step flow.

There are 2 problems to be solved: Firstly, due to the randomness and uncertainty of human error, the predict process rely too much on the previous history experience and may ignore some else human errors that would result in accident. As a result, the objective system data of human error is hard to obtain, while the fuzzy function is expected to deal with this problem. Secondly, there are a great variety of experiments proceeding in high schools, most of classifications are risky and the causes of accident are hardly to estimate, the simple qualitative analysis is far from enough to predict the hazards and prevent the accident, consequently, this study does quantitative analysis to reach a scientific HEP value that will do great help to carry out the accident prevention and safety education works.

3. Case Analyse

In this paper, the Hierarchical Task Analysis (HTA) method is referenced to sort out the 12•26 laboratory explosion accident in Beijing Jiaotong University.

3.1.*Case study*

This study extracts data from a representative accident caused by human error which resulted in enormous and profound social impact and received widespread concerns. It is an honor to have invited several excellent experts who has abundant experience of this field. The 12•26 laboratory explosion accident occurred at the second teaching building of the east campus in a university in Beijing, 2018. It is a sewage treatment of landfill leachate program that resulted in 3 deaths. The cause of the accident includes the violation operation, the illegal storage of hazardous chemical and the defect of the laboratory management. HTA is an implement used to describe the process of the task through the operation and the target of the task, the level of the plan, which helps to learn more about the cause of the accident and the existing safety hazard of laboratory.

3.2.*Application of CREAM*

Evaluate the 9 CPCs through experts scoring mechanism and get the average. The CPC 1 is showing in the Table 2 bellow:

Table 2. CPC 1 and the average.

CPC	Expert 1	Expert 2	Average
CPC1	60	65	62.5

Plot the fuzzy function and substitute the average into calculation (see Fig.2).

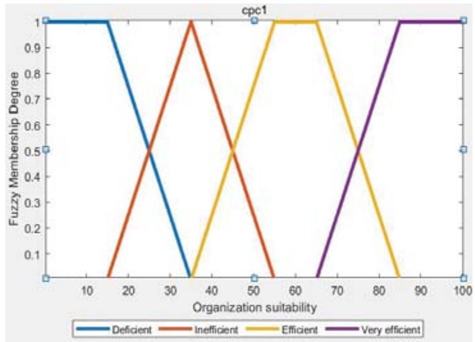

Fig. 2.The Fuzzy membership degree figure of CPC1.

The fuzzy membership degree is collected by Eq.(1)-(4)

$$\mu_{CPC1}^{imperfection}=\begin{cases}1 & (0\le x\le 15)\\ \frac{35-x}{20} & (15\le x\le 35)\end{cases} \quad (1)$$

$$\mu_{CPC1}^{insufficient}=\begin{cases}\frac{x-15}{20} & (15\le x\le 35)\\ 1 & (x=35)\\ \frac{55-x}{20} & (35\le x\le 55)\end{cases} \quad (2)$$

$$\mu_{CPC1}^{sufficient}=\begin{cases}\frac{x-35}{20} & (35\le x\le 55)\\ 1 & (55\le x\le 65)\\ \frac{85-x}{20} & (65\le x\le 85)\end{cases} \quad (3)$$

$$\mu_{CPC1}^{ample}=\begin{cases}\frac{x-65}{20} & (65\le x\le 85)\\ 1 & (85\le x\le 100)\end{cases} \quad (4)$$

where x is the expert scoring data, $\mu_{CPC1}^{imperfection}$, $\mu_{CPC1}^{insufficient}$, $\mu_{CPC1}^{sufficient}$ and μ_{CPC1}^{ample} represent the fuzzy membership degree. After the fuzzy membership function built, substitute the average score into the function and calculate.

Table 3. Fuzzy membership degree of the CPC.

CPC	Fuzzy membership degree

Adequacy of Organization	Sufficient (1)
Working conditions	Suitable (0.9)-superior (0.1)
Adequacy of man machine interface (MMI) and operational Support	Proper (0.75)-support (0.25)
Availability of procedures/plans	Acceptable (0.17)-Appropriate (0.83)
Number of simultaneous goals	Less than the actual dosage (1)
Available time	Adequate (1)
Time of the day/circadian rhythm	Daytime (1)
Adequacy of training and experience	Suitable experience (0.925)-Experienced (0.075)
Crew collaboration Quality	Effective (0.33)-Efficient (0.67)

3.3.*IF-THEN rule*

This part contains establishment and calculation of the rule.

3.3.1.*Rule establishment*

According to the last step, the CPC1, CPC5, CPC6, CPC7 belong to one fuzzy membership degree, the CPC2, CPC3, CPC4, CPC8, CPC9 have two fuzzy membership degree. Hence, there are 32(25) IF-THEN rules activated in total, few of them are showing in Table 4 bellow.

Table 4. Two IF-THEN rules.

CPC	Rule 1	Rule 2
CPC1	Sufficient	Sufficient
CPC2	Suitable	Suitable
CPC3	Proper	Proper
CPC4	Acceptable	Acceptable
CPC5	Fewer than actual capacity	Fewer than actual capacity
CPC6	Adequate	Adequate
CPC7	Daytime	Daytime
CPC8	Suitable experience	Suitable experience
CPC9	Effective	Efficient

3.3.2.*IF-THEN rule calculation*

The weight of IF-THEN rules is multiplied by the membership degree of each CPC. Take the CPC1 as an example, the first IF-THEN rule weight: $1\times0.9\times0.75\times0.17\times1\times1\times1\times0.925\times0.33=0.0350$. There are 32 rules totally, 8 of the IF-THEN rules are showing in the Table 5 bellow.

Table 5. The weight of 8 IF-THEN rules.

The rule	The weight	The rule	The weight
1	0.0350	5	0.1710
2	0.0711	6	0.3472
3	0.0028	7	0.0139
4	0.0058	8	0.0282

3.4.*The calculation of COCOM weighted ambiguity*

This section need to achieve the location, the final weighted fuzzy degree calculation and the original weighted fuzzy degree calculation of COCOM.

3.4.1.*The location of COCOM*

Each CPC has specific levels, every level corresponds to 3 reliability influences, "1" represents the positive effect, "0" is equivalent to no effect and "-1" matches to negative effect. The abstract judgement method refers to the Table 6 bellow.

Table 6. CPC level and the effect on reliability.

CPC	CPC level	Effect
Adequacy of Organization	Deficient	Reduced
	Inefficient	Reduced
	Efficient	Not significant
	Very efficient	Improved
Working conditions	Incompatible	Reduced
	Compatible	Not significant
	Advantageous	Improved
Adequacy of man machine interface (MMI) and operational Support	Inappropriate	Reduced
	Tolerable	Not significant
	Adequate	Not significant
	Supportive	Improved

Availability of procedures/plans	Inappropriate	Reduced
	Acceptable	Not significant
	Appropriate	Improved
Number of simultaneous goals	More than actual capacity	Reduced
	Matching current capacity	Not significant
	Fewer than actual capacity	Not significant
Available time	Continuously inadequate	Reduced
	Temporarily inadequate	Not significant
	Adequate	Improved
Time of the day/circadian rhythm	Night	Reduced
	Day	Not significant
	Evening	Reduced
Adequacy of training and experience	Inadequate	Reduced
	Adequate with limited experience	Not significant
	Adequate with high experience	Reduced
	Deficient	Improved
Crew collaboration Quality	Inefficient	Not significant
	Efficient	Not significant
	Very efficient	Improved

After the adjustment of reliability level of each CPC, decide the COCOM location of every IF-THEN rule referring to the Fig. 3. bellow.

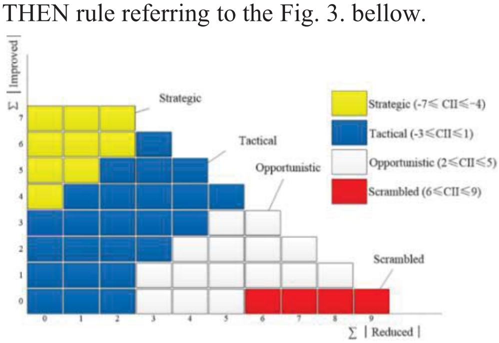

Fig. 3.The relationship of each CPC and COCOM.

The abscissa of the Fig. 3. represents the reduced number of CPC, while the ordinate means the increased number of CPC. The COCOM location of each IF-THEN rule is determined by judging each CPC level of every IF-THEN rule and adding the number of CPCs in the same level. The locations of 8 IF-THEN rule are showing in the Table 7 bellow.

Table 7. The locations of 8 IF-THEN rule

Rule	Location	Rule	Location
1	Tactical	5	Tactical
2	Tactical	6	Tactical
3	Tactical	7	Tactical
4	Tactical	8	Strategic

3.4.2.*The original weighted fuzzy degree calculation of COCOM*

Evaluate the 9 CPCs according to the 12•26 laboratory explosion accident in Beijing Jiaotong University. And the result is 0.04892 by the consistency check showing in the Fig.4 bellow.

$$A=\begin{pmatrix} 1 & 2 & 3 & 4 & 2 & 5 & 3 & 9 & 6 \\ \frac{1}{2} & 1 & 2 & 3 & 1 & 3 & 2 & 6 & 4 \\ \frac{1}{3} & \frac{1}{2} & 1 & 2 & \frac{1}{6} & 3 & 1 & 6 & 4 \\ \frac{1}{4} & \frac{1}{3} & \frac{1}{2} & 1 & \frac{1}{3} & 2 & \frac{1}{2} & 5 & 4 \\ \frac{1}{2} & 1 & 6 & 3 & 1 & 4 & 2 & 6 & 4 \\ \frac{1}{5} & \frac{1}{3} & \frac{1}{3} & \frac{1}{2} & \frac{1}{4} & 1 & \frac{1}{4} & 5 & 2 \\ \frac{1}{3} & \frac{1}{2} & 1 & 2 & \frac{1}{2} & 4 & 1 & 6 & 4 \\ \frac{1}{9} & \frac{1}{6} & \frac{1}{6} & \frac{1}{5} & \frac{1}{6} & \frac{1}{5} & \frac{1}{6} & 1 & \frac{1}{3} \\ \frac{1}{6} & \frac{1}{4} & \frac{1}{4} & \frac{1}{4} & \frac{1}{4} & \frac{1}{2} & \frac{1}{4} & 3 & 1 \end{pmatrix}$$

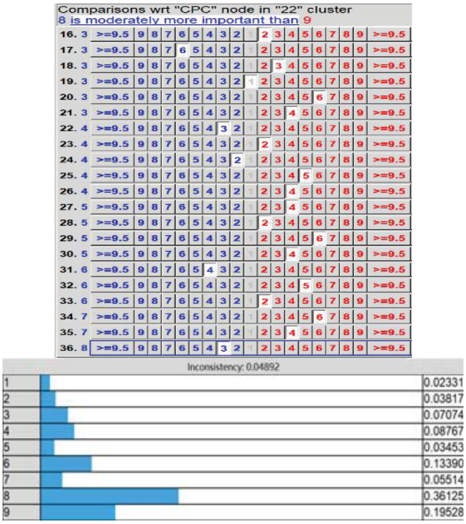

Fig.4.The result of consistency check.

The weight of each CPC is showing in the Table 8 bellow.

Table 8. The weight of each CPC.

CPC	Weight	CPC	Location
1	0.0233	6	0.1339
2	0.0382	7	0.0551
3	0.0707	8	0.3613
4	0.0877	9	0.1953
5	0.0345		

The original weighted fuzzy degree calculation method of COCOM is: multiply the fuzzy membership degree by the corresponding weight of each CPC. Table.9 shows the COCOM original weighted fuzzy degree of 8 IF-THEN rules bellow.

Table.9. The COCOM original weighted fuzzy degree of 8 IF-THEN rules.

Rule	Fuzzy degree	Rule	Fuzzy degree
1	0.7478	5	0.8057
2	0.8142	6	0.8721
3	0.4407	7	0.4986
4	0.5071	8	0.565

3.4.3.*The final weighted fuzzy degree calculation of COCOM*

Even though the original weighted fuzzy degree data for 32 IF-THEN rules are not much different, but what it presents are quite different due to the differences among COCOM locations. For this reason, it is hardly to do calculations directly, the hierarchical and systematic calculation is necessary. The final weighted fuzzy degree calculation method is: multiply the original weighted fuzzy degree by the weight of the corresponding IF-THEN rule. The final weighted fuzzy degree of Tactical and Strategic are 0.64114 and 0.168443 respectively.

3.5.*Defuzzification*

The center of gravity method can get the precise result by accurate control of the controlling quantity, which helps to achieve the final HEP value. The abstract formula is showing in Eq.(5)

$$y=\frac{\sum_{i=1}^{n}\left[\int_{x_L}^{x_U}\mu_i(x)xdx\right]}{\sum_{i=1}^{n}\left[\int_{x_L}^{x_U}\mu_i(x)dx\right]} \tag{5}$$

where y is the crisp value, $\mu_i(x)$ is the ith fuzzy membership function, in this study, x is ranging from -5.3 to 0. The upper and the lower limits of the integration for $\mu_i(x)$ is respectively expressed by x_U and x_L.
The logarithmic calculation of the formula based on 10:

$$Log_{10}\text{HEP}=\frac{\int_{-5.3}^{x_1}sxdx+\int_{x_1}^{-2}(-x-2)xdx+\int_{-3}^{x_2}(x+3)xdx+\int_{x_2}^{x_3}txdx+\int_{x_3}^{-1}(-x-1)\ldots}{\int_{-5.3}^{x_1}sdx+\int_{x_1}^{-2}(-x-2)dx+\int_{-3}^{x_2}(x+3)dx+\int_{x_2}^{x_3}tdx+\int_{x_3}^{-1}(-x-1)d\ldots}$$

And finally, the result goes to: $\log_{10}$ HEP=-2.6485, HEP=0.00225, which lies in the Tactical after substituting the result in the figure showing in the Fig.5 bellow.

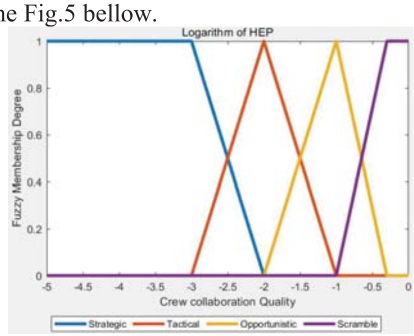

Fig.5. The logarithmic function figure of HEP.

4. Conclusion

This study evaluates the human errors in the laboratory of Beijing Jiaotong University. And finally achieves the result "Tactical" of human reliability. Although the result is in a acceptable range, the persistent safety control is indispensable. Moreover, this method has capable of using for similar human error analysis of laboratories. In addition, it provides reference for the similar laboratories of high schools. Those modified CREAM methods have the capacity to be applied to many other fields.

Meanwhile, there still a lot to improve in the following works. Firstly, for the numerical value of CPC, more expert data contribute to more accurate HEP value. Then, the deeper the researches on human error factors of laboratory conduce to the more scientific and more precise prediction result. In the end, our country needs to pay more attentions on researches of HRA, build a foundation for the quantitative safety prevention, provide practicable data for the construction of safety evaluation system. Furthermore, we would keep focusing on laboratory safety, stick to studying human factors in laboratory in the future.

Acknowledgement
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References

Chengyuan Zhu, Sen Tang, Zili Li, Xiuting Fang (2020). Dynamic study of critical factors of explosion accident in laboratory based on FTA. *Safety Science*,130.

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.

Ménard, A. and J. Trant (2019). A review and critique of academic lab safety research. *Nature Chemistry*, 12, 17-25.

F.L. Orzáez, Domingo R, M.M. Marín (2019). Considerations for the Development of a Human Reliability Analysis (HRA) Model Oriented to the Maintenance Work Safety. *Procedia Manufacturing*, 41:185-192.

Boring R.L (2012). Fifty years of THERP and human reliability analysis. *Probabilistic Safety Assessment and Management conference(PSAM 11)*. Helsinki,Finland; PSAM.

Park J, Arigi A M, Kim J (2019). Treatment of human and organizational factors for multi-unit HRA: Application of SPAR-H method. *Annals of Nuclear Energy*, 132:656-678.

Yang Z.L., Bonsall S., Wall A., Wang J (2013)., Usman M.A modified CREAM to human reliability quantification in marine engineering. *Ocean Engineering*, 58: 293-303.

Hollnagel E (1998). Cognitive Reliability and Error Analysis Method.Oxford (UK): *Elsevier Science Ltd.*

Fujita Y, Hollnagel E (2004). Failures without errors: quantification of context in HRA. *Reliability Engineering & System Safety*, 83 (2) :145-151.

Ung S T (2019). Evaluation of human error contribution to oil tanker collision using fault tree analysis and modified fuzzy Bayesian Network based CREAM. *Ocean Engineering*, 179(MAY 1):159-172.

Zhang R, Tan H, Afzal W (2021). A modified human reliability analysis method for the estimation of human error probability in the offloading operations at oil terminals. *Process Safety Progress*.

Xiaoqing Chen, Xinwang Liu, Yong Qin (2020). An extended CREAM model based on analytic network process under the type ‐ 2 fuzzy environment for human reliability analysis in the high ‐ speed train operation. *Quality and Reliability Engineering International*, 37(1).

Qingji Zhou, Yiik Diew Wong, Hui Shan Loh, Kum Fai Yuen (2018). A fuzzy and Bayesian network CREAM model for human reliability analysis – The case of tanker shipping. *Safety Science*, 105.

Ghasemi F, Ghasemi A, Kalatpour O (2022). Prediction of human error probability during the hydrocarbon road tanker loading operation using a hybrid technique of fuzzy sets, Bayesian network and CREAM. *International Journal of Occupational Safety and Ergonomics*, (3):28.

Marseguerra M., Zio E., Librizzi M (2007). Human reliability analysis by fuzzy CREAM. *Risk Analysis*, 27(1): 137-154.