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Qualitative and Quantitative Analysis on Human Factors under Emergency State

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Human factors under emergency state play a crucial role in evolution of accidents. Studying human factors under emergency states has theoretical and practical significance for prevention and reduction accidents. The study put forward an analysis framework about human factors under emergency states: "Human-System-Environment-Task-Organization" to qualitative and quantitative analysis accidents caused by human factors. Based on the framework, Human-HAZOP analysis and Bayesian network were adopted for the human factor analysis. Human-HAZOP relies on guidance words and attributive words, revealed consequences of human error and proposed preventive measures. Bayesian network graphically modeling accident caused by human error, quantitatively analysis interrelationship between human factors, finding the most contribution cause chain of accident. The framework was used to assess storage tank accidents and analyze the impact of the human factor under emergency states. The study proposed a systematic way to analyze the accident caused by human factor, which will contribute to preventing the accidents under emergency states.

1. Introduction

Many statistical data and research studies show that most of accidents are caused by human factors: psychologist Reason pointed that casualties are results of the accumulation of organizational and human's error(Reason, 1990); Pennsylvania conducted an analysis on the causes of 80,000 nuisance accidents show that accidents caused by human factors accounted for 98.2%(Hai Wu, 2008); The UK Health and Safety Executive Board (HSE) publication(HSE, 2005) referred that 90% of the accidents were caused to a certain extent by man-made reasons ; over 90% in nuclear accidents, over 80% in chemical process accidents, 75–96% in marine casualties, over 70% in aviation accidents in the European Union(Zuo *et al.*, 2006; Zarei *et al.*, 2019b). Emergency state is danger than normal state. In a complex industrial system, the abnormal state deviates seriously from the normal state, that is about to occur or has occurred accidents is called emergency state(Woodcock and Au, 2013). Human factor under emergency situation is more likely to induce accidents or increase accident severity. So it is significant to study human factors under emergency situations.

2. Reviews

Human factors have been more extensive researched in industrial accident. Human factors analysis method including qualitative analysis and quantitative analysis. Qualitative methods such as TRACEr; Root Cause Analysis (RCA); Liesson's "Swiss Cheese" model ; Human Factors Analysis and Classification System (HFACS) etc. And quantitative analysis including Technique for Human Error Rate Prediction method (THERP); Success Likelihood Index (SLIM), Human Cognitive Reliability (HCR), Human Error Assessment and Reduction Technique (HEART), A Technique for Human Event Analysis (ATHEANA) and Cognitive Reliability and Error Analysis Method (CREAM), Human Error Assessment and Reduction Methods (HEART),

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etc. In order to comprehensive qualitative and quantitative analysis for human factor under emergency situation. It is advisability to divide human factors into several relatively independent parts. Such as Kim et al. (Kim and Jung, 2003) suggested to divide the human factors into four categories, namely people, tasks, systems and the environment. Based on Kim's research, Sun et al. (Zhiqiang Sun, 2008) put forward a basic framework of human factor analysis form five aspects i.e. operator, system, environment, task and organizational factors. Chen and Zhang (Jinghua Chen, 2010) divided human error under the emergency state into six categories for analysis: system, physical environment, organizational management, work tasks, human status and human cognition, etc.

Human factors analysis based on the Bayesian network has been widely studied: Such as offshore platform blow out accident analysis (Cai *et al.*, 2013).;chemical process systems safety analysis(Zarei *et al.*, 2019a);Marine emergency evacuation analysis (Norazahar *et al.*, 2016), et. However, those method failed to comprehensively consider the human factors in a state of emergency at multiple levels.

By analyzing the characteristics of human factors in the emergency state, the proposed method put forward a human factor analysis framework i.e. human-environment-system-task-organization. Human-HAZOP method and BN is adopted, and the method explained based on fire and explosion accidents of tanks.

3. Qualitative and quantitative analysis of human factors under emergency state

3.1 Qualitative analysis of human factors under emergency state

The continuous storage tank accident poses a serious threat to the whole society. Therefore, the study take oil tank accidents as an example to analyze the impact of human factors under emergency state.

Qualitative analysis of human factor is based on the Human-HAZOP method proposed by HSE in 2005(HSE, 2005).But the analysis process is based on personnel safety activities and carry out analysis according to the task steps, and it's difficult to clearly distinguish between the activity phase and the steps involved emergency activities in emergency situation. Therefore, the proposed method revises the Human-HAZOP method proposed by HSE, and divides it from five aspects: "human-system-environment-task-organization", in order to more comprehensively and prudently analysis human factors in emergency situations. The Human factors analysis structure of storage tanks accidents under emergency situations is shown as figure 1 and Human-HAZOP analysis results is shown as Table 1 and due to layout reasons, only part of the content is displayed.

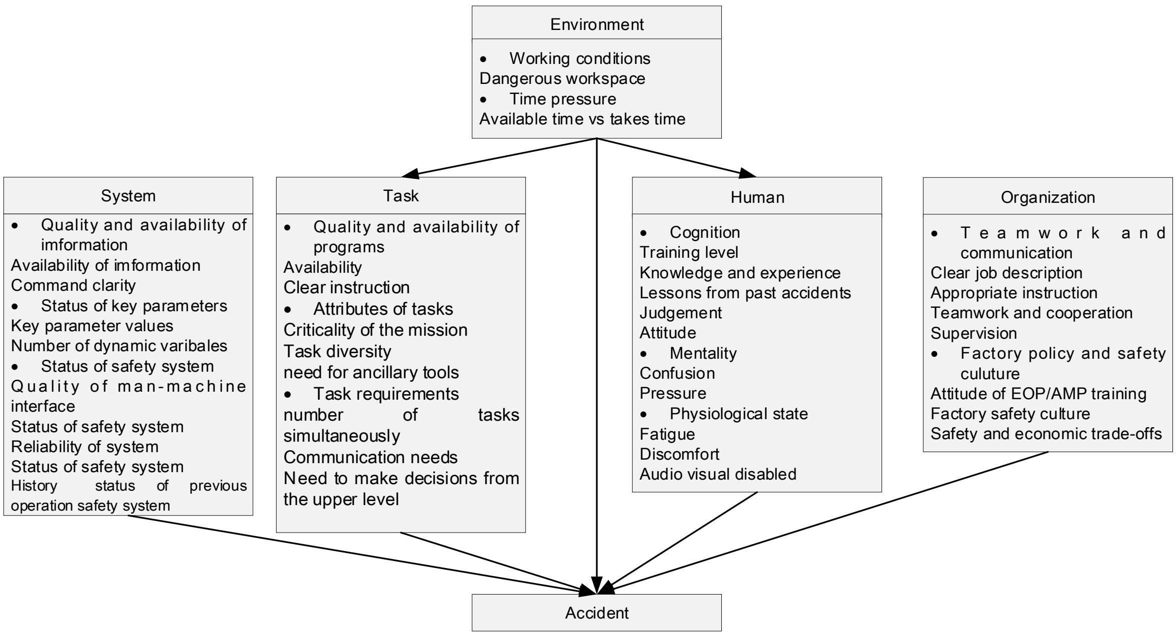

Figure 1 Human factors analysis structure of storage tanks accidents under emergency situations

Table 1: Human-HAZOP analysis of human factors about storage tank accidents (partly)

Attribute word		Guide word	Causes	Consequences	Measures
Human	Training	None	1）No professional training for the relevant personnel 2）Employees are not trained	Couldn't carry out the correct emergency operation	1）Strengthen professional training 2）Supervise the staff to receive professional training
		Less	1）The company has little professional training for the relevant personnel 2）Staff training is not enough	Couldn't fully cope with the emergency situation	1）Strengthen professional training 2）Supervise the staff to receive professional training
	Judgement	Poor	1）Lack of knowledge and experience 2）Past lessons are not enough 3）The degree of training is not enough	1）No judgment on emergency 2）Emergency measures couldn't be taken correctly	1）Strengthen professional training 2）Supervise the staff to receive professional training

3.2 Quantitative analysis of human factors under emergency state

3.2.1 Identifying nodes.

The main human factors based on the fire and explosion of the tank under emergency state are shown in Figure 1, and the state is classified according to reasonable situations.

3.2.2 Determination of conditional probability table

The determination of conditional probability table (CPT) is important in BN. Usually, CPT acquisition is obtained by statistical data and expert experience. Due to little statistical data about human error accident, the proposed method invites five safety experts from oil storage industry to score. According to the experience, the evaluation results is based on seven level language (very low; low, relative low, medium, relative high, high, very high) as shown in Table 4. Finally, the triangular fuzzy theory is used to convert the possibility.

Table 2 Application example of triangular fuzzy number

Node	H3 experience of the accident	
Condition	1 (yes)	2 (no)
Expert 1	medium (0.3 , 0.5 , 0.7)	relative low (0.1 , 0.3 , 0.5)
Expert 2	relative high (0.5 , 0.7 , 0.9)	relative low (0.1 , 0.3 , 0.5)
Expert 3	medium (0.3 , 0.5 , 0.7)	relative low (0.1 , 0.3 , 0.5)
Expert 4	relative high (0.5 , 0.7 , 0.9)	medium (0.3 , 0.5 , 0.7)
Expert 5	relative high (0.5 , 0.7 , 0.9)	low (0 , 0.1 , 0.3)

Averaging: $\tilde{P}_{ij}^{'} = \frac{\tilde{P}_{ij}^{1} \oplus \tilde{P}_{ij}^{2} \oplus \ldots \oplus \tilde{P}_{ij}^{q}}{q} = (a_{ij}^{'}, m_{ij}^{'}, b_{ij}^{'})$ (1)

Defuzzification: $P_{ij}^{'} = \frac{a_{ij}^{'} + 2m_{ij}^{'} + b_{ij}^{'}}{4}$ (2)

Normalization: $P_{ij} = \frac{P_{ij}^{'}}{\sum_{j=0}^{r_i - 1} P_{ij}^{'}}$ (3)

The mean of the fuzzy probabilities of each node state in Table 3 is as follows:

$\bar{P}_{11}'$=(0.42 , 0.62 , 0.82) , $\bar{P}_{12}'$ =(0.12 , 0.3 , 0.5)

The fuzzy probability is solved and the fuzzy probability is transformed into the exact probability:

P_{11}'=0.62 , P_{12}'=0.305

The exact probability of each node's states is normalized: P11=0.67，P12=0.33 which is H3（yes, no）=（0.67，0.33）Similarly, for those who couldn't be found in historical data can use the expert scoring method.

3.2.3 Develop the Bayesian network.

A human error accident fault tree can be established based on figure 1. Then mapping from the fault tree into the BN based on Mapping algorithm(Bobbio *et al.*, 2001). The last step is to assign conditional probability tables. The developed the Bayesian network as shown in Figure 2.

3.2.4 Results and analysis

- Identify the most likely cause chain of human accidents

Based on the network established by Netica, the most likely cause chain by calculating the posterior probability of each node under the condition of human-induced accidents can be found. The accident node is set to the occurrence state, that is, P (c=yes) =100%, the most likely cause chain for human accidents.as shown in Figure 3,ie "Stress-Psychology-Human state-Accident". In addition, other causal chains can be found, but from a probability point of view, the rest are not the most likely causes of accidents, but does not rule out that some accidents will follow these causal chains.

- Sensitive analysis

Netica provided the sensitivity analysis function. From Figure 4-9, we can see that the most likely cause of "accident" is the "human state". In the "human state", "stress", "judgment" and "knowledge experience" have the greatest influence on "human state"; In the "environment", the available time has a significant effect on the environment; In the "task", "the need for ancillary tools", "availability" and " Task diversity" have the greatest influence on "task status"; In the "organization", "safety and economic trade-off", "factory safety culture" and "clear job description or role definition" have the greatest impact on "organizational state"; In the "system", "information availability" has the greatest influence on "system", and the other factors are relatively weak. From the point of view of accident prevention and rescue, the node with the highest contribution rate to the accident in each node is the main cause of the accident. In the accident emergency process. The most valid way is to deal with these factors effectively.

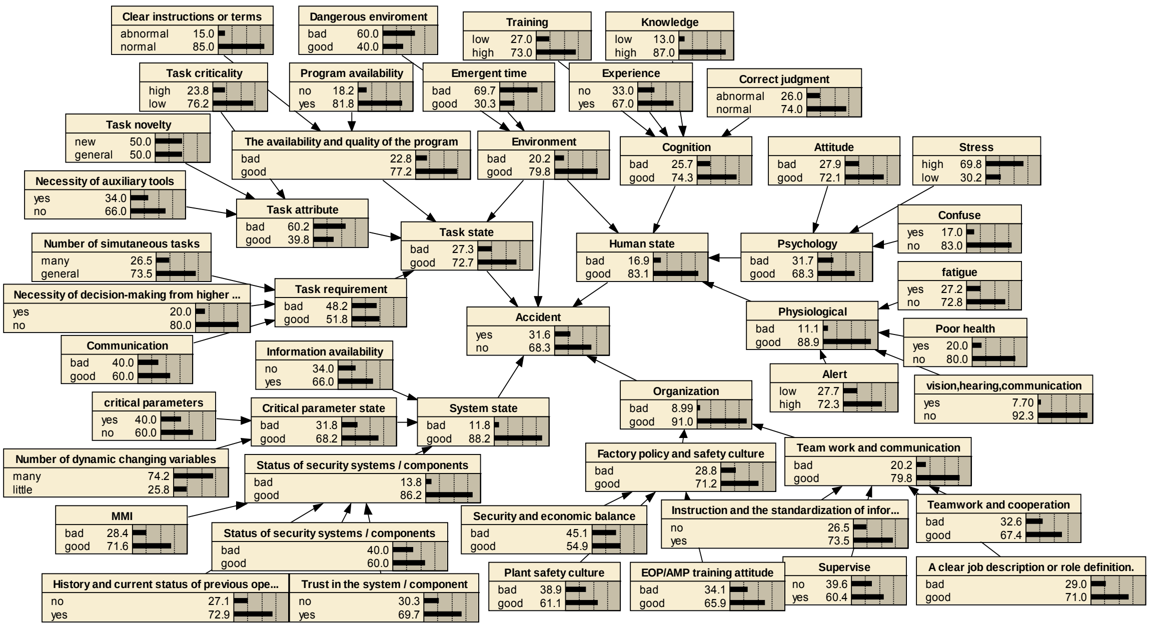

Figure 2 Prediction network for human factor accidents of storage tanks

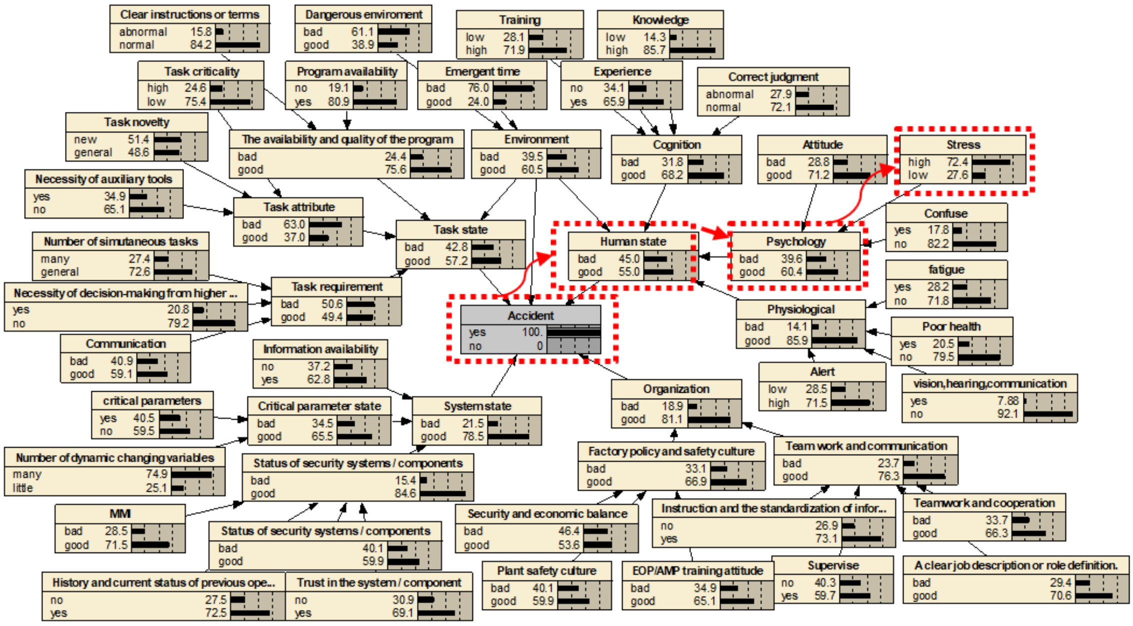

Figure 3 Diagnose network for human accidents of storage tanks

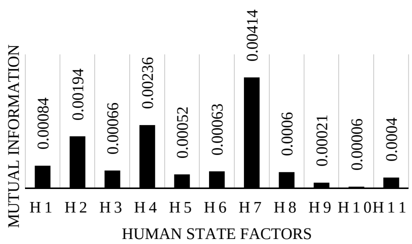

Figure 4 Mutual information of human state

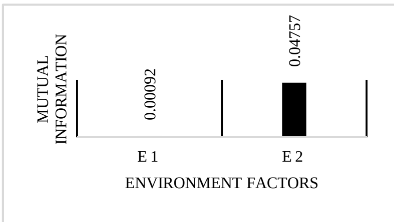

Figure 5 Mutual information of environment

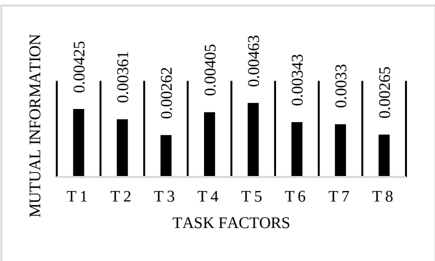

Figure 6 Mutual information of task

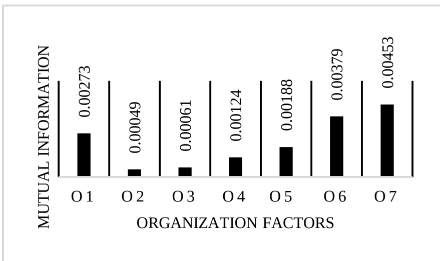

Figure 7 Mutual information of organization

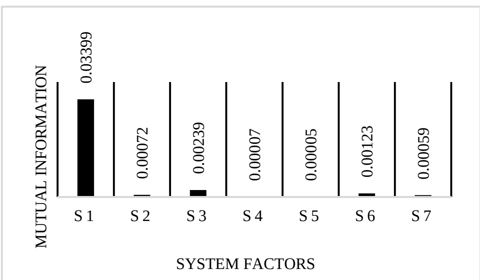

Figure 8 Mutual information of system

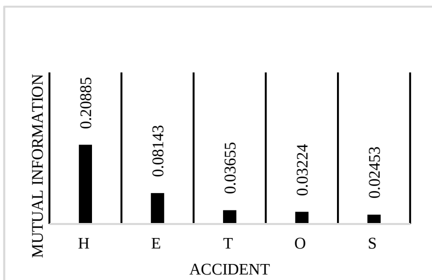

Figure 9 Mutual information of accident

4. Conclusions

The proposed method analyze the human factors under emergency states of oil storage tanks. The main results are as follows.

1) A new methods for qualitative and quantitative analysis of human factors under emergencies is proposed. Human factors under emergency state are divided into human-environment-system-task-organization five parts, and qualitative and quantitative analysis are separately based on Human-Hazop and Bayesian Network.

2) The analysis based on Human-HAZOP and Bayesian Network systematically and comprehensively analyses the possibility of human error induced accidents in emergencies. And Provide guidance for personnel in emergency situations.

3) Accident prevention measures: Human-HAZOP method is used to analyze the possible causes of tank fire and explosion accidents and consequences of human failure. As the same time the preventive measures are proposed. And a quantitative analysis based on Bayesian network suggest the most likely cause chain of human accidents, also the sensitive analysis give suggestions of the most valid way to deal with human factor accidents.

References

Bobbio, A., Portinale, L., Minichino, M., Ciancamerla, E., 2001. Improving the analysis of dependable systems by mapping fault trees into Bayesian networks. Reliability Engineering & System Safety 71, 249-260.

Cai, B., Liu, Y., Zhang, Y., Qian, F., Liu, Z., Tian, X., 2013. A dynamic Bayesian networks modeling of human factors on offshore blowouts. Journal of Loss Prevention in the Process Industries 26, 639-649.

Hai Wu, G.P., Weijun Wang, 2008. "Group effect" and enterprise personnel accident defense [J]. China Safety Science Journal. China Safety Science Journal 18, 72-75.

HSE, 2005. Inspectors toolkit: human factors in the management of major accident hazards.

Jinghua Chen, L.Z., 2010. Analysis of Human Factors in Emergency State in Digital Industrial System. Management Observer, 121-123.

Kim, J.W., Jung, W., 2003. A taxonomy of performance influencing factors for human reliability analysis of emergency tasks. Journal of Loss Prevention in the Process Industries 16, 479-495.

Norazahar, N., Khan, F., Veitch, B., Mackinnon, S., 2016. Prioritizing safety critical human and organizational factors of EER systems of offshore installations in a harsh environment. Safety Science, S0925753516301680.

Reason, J., 1990. Human error. West J Med 12, 393-396.

Woodcock, B., Au, Z., 2013. Human factors issues in the management of emergency response at high hazard installations. Journal of Loss Prevention in the Process Industries 26, 547-557.

Zarei, E., Khakzad, N., Cozzani, V., Reniers, G., 2019a. Safety analysis of process systems using Fuzzy Bayesian Network (FBN). Journal of Loss Prevention in the Process Industries 57, 7-16.

Zarei, E., Yazdi, M., Abbassi, R., Khan, F., 2019b. A hybrid model for human factor analysis in process accidents: FBN-HFACS. Journal of Loss Prevention in the Process Industries 57, 142-155.

Zhiqiang Sun, X.S., Fengqiang Liu, 2008. Research on the cause analysis of human Error. China Safety Science Journal 18, 21-27.

Zuo, D., Yao, W., Wu, Y., 2006. Statistical analysis of major accidents in petrochemical industry notified to the major accident reporting system (MARS). Journal of Hazardous Materials 137, 1-7.