Risk Assessment of Human Error in Loading and Unloading Operations at Oil Terminal in Ports

Linlin LU[1], Lecai Liang[2,*], Yanhua HU[1]

Linlin LU, lulinlin@tk-aq.com

Lecai Liang, lianglecai@163.com, Corresponding author

Yanhua HU, huyanhua@tk-aq.com

[1] Tianjin Research Institute for Water Transportation Engineering, M.O.T. Tianjin, China

[2] Tianjin Port Petrochemical Terminal Co., Ltd. Tianjin, China

Abstract—A large number of manual auxiliary operations are needed in the loading and unloading operations at oil terminal, and most accidents of loading and unloading operations are caused by human error. In order to find out the human error modes that affect the safety of oil terminal and evaluate the risk level of human error, a method of CREAM combining with fuzzy probability was proposed in this paper. 18 human error modes are identified in total by using the CREAM method to identify the behaviors and human error modes of the loading and unloading operations. Aiming at the problem that it is difficult to obtain accurate statistical data for human error probability, the human error probabilities of 18 human error modes are calculated by using fuzzy probability method. Besides, the risk level of each human error mode and the quantitative evaluation results are obtained. Compared with the statistical data of enterprise accidents, the method proposed in this paper can get accurate evaluation results.

Keywords-component; Ports, oil terminal, human errors, CREAM

1 INTRODUCTION

Ports, as distribution centers for importing and exporting industrial and agricultural products, are important infrastructure for international trade and economics. Unlike highly automated production at chemical enterprises, port enterprises are less developed, for example, loading and unloading in many ports are not fully automated, which further requires a lot of human effort in operation and decision-making. Therefore, human error in loading and unloading operation is at a high level, and serious accidents occur from time to time. On July 16 2010, an oil pipeline at Port of Dalian China caught fire and exploded, causing at least 50 square kilometers of ocean polluted by crude oil. The direct cause of the accident was poor communication between operators. The tank enterprise was not informed when the tanker had stopped unloading oil, so and additives were still being added to the pipeline, which eventually led to explosion, fire and oil leakage. In recent years, a valuable study has been carried out to investigate human error in ports operation[1,2].

ICIDC 2022, June 17-19, Qingdao, People's Republic of China

DOI 10.4108/eai.17-6-2022.2322701

Human Error refers to the possibility that in a specific environment, a person will behave erroneously when operating the system and performing tasks, or the system function will be lost due to human behavior[3]. Human Error Analysis targets human unreliability. It originated around 1950s, and was mainly applied to the feasibility study of complex weapon systems. So far, there are multiple methods developed to identify human error. These methods can be roughly divided into three categories. The first category includes methods formed based on historical experience and mathematical statistics such as the Technology of Human Error Rate Prediction (THERP), Human Error Assessment and Reduction Technique (HEART), Human Cognitive Reliability Model (HCR), Success Likelihood Probability Method (SLIM), and etc. The second category includes Cognitive Reliability and Error Analysis Method (CREAM), Systematic Human Error Reduction & Prediction Approach (SHERPA), Human Error Analysis Techniques (A Technique for Human Error Analysis, ATHEANA), MERMOS, and etc. This type of analysis is based on the cognitive environment as the starting point for research. The third category is based on dynamic simulation including Nuclear Power Plant Operation Reliability Assessment (NARA), the Information, Decision, and Action in Crew context (IDAC) model, Integrated Decision Tree Human Factor Event Analysis System (IDHEAS), and etc. More details regarding the classification of the methods can be found in the literature[4], and all the mentioned three categories have been investigated in various studies as shown below.

For the first category, T. Deacon[5-6] used the HEART method to identify the risk of human error in the key steps of escape, evacuation and rescue process from offshore installations, and assessed the risk of the evacuation phase with historical accident data. Jian-Lan Zhou[7] used the same method to analyze human error in driving motor vehicles. Lijing Wang[3] analyzed the risk of human error during the emergency evacuation of coal mine accidents with the SLIM method.

Regarding the second category, Shuen-Tai Ung[8] proposed to use the fault tree analysis (FTA) structure to evaluate the collision probability of tankers. Under this structure, combined with expert judgment method, a cognitive reliability and error analysis method (CREAM) based on improved fuzzy Bayesian network was developed to assess human errors. This method was subsequently used to assess the risk of tanker stranding[9]. Valentina DiPasquale[10] also proposed a new method for evaluating human error reliability, called Simulator for Human Error Probability Analysis (SHERPA), which uses the advantages of simulation tools and traditional HRA methods to simulate human behavior and predict the error probability for a given scenario in various industrial systems. Antonella Petrillo[11] proposed a hybrid model of emergency human error analysis targeting the probability of human error in emergency situations. This model is based on the SHERPA model, and was utilized to calculate the probability of human error from the central control room in the event of a fire accident at a waste oil reprocessing unit. Saptarshi Mandal[12] used the SHERPA method combing with a fuzzy VIKOR model to identify the risk of human error in the operation of an overhead crane. Peng-cheng Li et al.[13] proposed a method called Organization Oriented Technique of Human Error Analysis (OTHEA), which is used to study the root cause of human failure in modern nuclear control room at a digital nuclear power plants.

Regarding the application of the third category, Y.H.J. Chang[14] introduced the Information, Decision, and Action in Crew context (IDAC) model in five chapters. Yuandan Li[15] used the IDAC model to analyze the risk of human error in power plant operators.

The various methods mentioned in the above literature have their own advantages and disadvantages, and they are widely used in the field of human error identification and risk assessment. The research object of this article is loading and unloading operators at oil terminal. Based on the operating characteristics, the CREAM model is selected to identify human error patterns, and then the fuzzy probability method is used to give quantitative risk assessment results.

At present, there are only a few literature about the risk of human error in loading and unloading operations in ports. In this paper, the risk of human error in the process of loading and unloading operations at oil terminal in ports is studied. There are many operation processes involved in the loading and unloading process of oil terminal, but not all human errors will lead to serious consequences. The process of loading and unloading operations at oil terminal is analyzed in detail and 18 human error modes that may lead to serious accident consequences are identified in this paper. And in order to evaluate the quantitative risk of 18 kinds of human error modes, the fuzzy probability method is used to solve the problem that the probability of human error is lack of statistical data. At last the types and main causes of high frequency accidents in the operation at oil terminal are obtained.

The method of CREAM combining with fuzzy probability is used for the first time to evaluate the human error risk at oil terminal in ports in this paper.

2 METHOD

2.1Identification of human error by CREAM

Cognitive Reliability and Error Analysis Method (CREAM) divides all personnel's cognitive behavior into four parts: observation, explanation, plan, and execution. The meaning of each cognitive behavior is as follows:

Observation: Information is obtained by personnel through observation (such as changes in the status of systems, equipment, instruments, etc.);

Explanation: The observed information is interpreted, and the meaning it represents is understood;

Plan: An action plan is made based on understanding the system status;

Execution: The action plan is executed to adjust/restore system status.

The above four cognitive behaviors are integrated to an iterative process, for example, a personnel can modify the original behavioral intent based on the observed feedback. The CREAM method has two major functions such as tracing of the root cause of an accident and predicting the probability of human error. The CREAM method gives various failure modes corresponding to the four cognitive functions, shown in Table 1.

Table 1. COGNITIVE FUNCTIONS AND FAILURE MODES OF CREAM METHOD

NO.	Cognitive function	General failure mode
1	Observation	Observation errors
2		Identification errors

3		Observation not performed
4	Explanation	Diagnose failure
5		Error in decision making
6		Delayed explanation
7	Plan	Inappropriate priority
8		Inappropriate plan
9	Execution	Error in method
10		Runtime error
11		Wrong execution targets
12		Wrong sequence
13		Missing tasks

2.2Calculation of human error probability based on fuzzy mathematics

The basic error probability of the above 13 failure modes is calculated by the CREAM method, but in real world, the general error probability cannot reflect the real issues. In view of the difficulty of obtaining human error data, this paper proposes a method based on fuzzy mathematics combined with experts' judgment in order to convert words into fuzzy probability, thereby achieving quantitative calculation of human error probability.

The steps of fuzzy based CREAM method are described as below. First, the operator's error probability is described in language by experienced experts, and then the description is converted into fuzzy numbers which is derived from fuzzy membership functions, and finally, fuzzy numbers are converted into fuzzy probability according to empirical formulas.

(1) Description of error probability in natural language

Generally, 3-5 experienced experts from different professional fields (operation, equipment management, site supervision, etc.) are invited to describe the error probability of operators in natural language, and classify the same for example, in five levels including Very Low, Low, Medium, High, Very High.

(2) Error probability represented by fuzzy numbers

The error probability described by natural language only accounts for semi-quantitative. Fuzzy numbers are used to further quantify the semi-quantity error probability. Commonly used fuzzy numbers are trapezoidal fuzzy numbers and triangular fuzzy numbers, and they can be represented by membership functions. The functional expressions of membership functions used in this paper are shown in **Equations 1-5** and Figure 1.

$$f_{VL}(x)=\begin{cases} 1 & 0<x\leq 0.1 \\ \dfrac{0.2-x}{0.1} & 0.1<x\leq 0.2 \\ 0 & otherwise \end{cases} \tag{Eqn.1}$$

$$f_L(x)=\begin{cases}\frac{x-0.1}{0.15} & 0.1<x\le 0.25\\ \frac{0.4-x}{0.15} & 0.25<x\le 0.4\\ 0 & otherwise\end{cases}$$ (Eqn.2)

$$f_M(x)=\begin{cases}\frac{x-0.3}{0.2} & 0.3<x\le 0.5\\ \frac{0.7-x}{0.2} & 0.5<x\le 0.7\\ 0 & otherwise\end{cases}$$ (Eqn.3)

$$f_H(x)=\begin{cases}\frac{x-0.6}{0.15} & 0.6<x\le 0.75\\ \frac{0.9-x}{0.15} & 0.75<x\le 0.9\\ 0 & otherwise\end{cases}$$ (Eqn.4)

$$f_{VH}(x)=\begin{cases}\frac{x-0.8}{0.1} & 0.8<x\le 0.9\\ 1 & 0.9<x\le 1\\ 0 & otherwise\end{cases}$$ (Eqn.5)

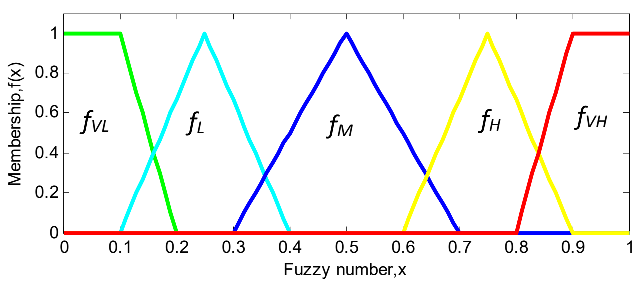

Figure 1. Membership functions.

VL, L, M, H, VH, represent the error probability description Very Low, Low, Medium, High, and Very High.

(3) Fuzzy Probability

In this paper, the maximum and minimum set method proposed by Chen[16] is used to transform fuzzy numbers into fuzzy probabilities, and empirical formulas in Equation 6-10 are applied.

$$F = \begin{cases} \frac{1}{10^k} & F_M \neq 0 \\ 0 & F_M = 0 \end{cases}$$ (Eqn.6)

$$k = \left(\frac{1 - F_M}{F_M} \right)^{1/3} \times 2.301$$ (Eqn.7)

$$F_M = \frac{F_{MR} + 1 - F_{ML}}{2}$$ (Eqn.8)

$$F_{MR} = \sup[f_M(x) \wedge f_{\max}(x)]$$ (Eqn.9)

$$F_{ML} = \sup[f_M(x) \wedge f_{\min}(x)]$$ (Eqn.10)

Where F is the fuzzy probability, k is a constant, FM is a mixed fuzzy number, FMR is a right fuzzy number, and FML is a left fuzzy number.

In Equation 9, the "sup" represents the y-axis coordinate value of the right intersection of f_M and $f_{\max}$, while in Equation 10, the "sup" represents the y-axis coordinate value of the left intersection of f_M and $f_{\min}$. The definition of $f_{\max}$, $f_{\min}$, and f_M are shown in Equation 11-13.

$$f_{\max}(x) = \begin{cases} x & 0 \leq x \leq 1 \\ 0 & otherwise \end{cases}$$ (Eqn.11)

$$f_{\min}(x) = \begin{cases} 1 - x & 0 \leq x \leq 1 \\ 0 & otherwise \end{cases}$$ (Eqn.12)

$$f_M(x) = \sum_{i=1}^{n} w_{ei} f_i, \qquad i = 1, 2, \ldots, n$$ (Eqn.13)

Where w_{ei} is the weight factor for expert i, f_i represents the fuzzy number transformed based on the expert i's opinion on an event, and n is the total number of experts ranging from 3 to 5 in general.

2.3Evaluation of Human Error Consequences

The consequences of human error can be considered from various aspects such as delayed production, property loss, casualties, and environmental pollution. Accidents often result in a combination of the consequences. Therefore, the actual situation should be evaluated comprehensively.

2.4Evaluation of Human Error Risks

Risk is a function of the probability of an accident and its consequences. In this article, a risk matrix is utilized to assess the risk of human error, in which the probability and consequences are divided into 5 levels according to the actual situation, as shown in Figure 2.

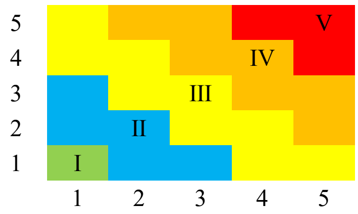

Figure 2. The Risks Matrix.

3 CASE STUDY

A liquid chemical terminal in north China belongs to a company specializing in handling liquid cargo in bulk. Currently, it has five berths for petrochemical industry, with a designed berthing capacity of 10,000 tons, 300,000 tons, 50,000 tons, 30,000 tons, 80,000 tons. The main function of the company is to provide a transfer platform for liquid cargo in ships and storage areas. The main equipment of the terminal is oil transfer arms, hoses, distribution stations, pipelines, valves, etc., and it has no power equipment (pumps). The flow of liquid cargo mainly depends on the pump on the ship or the pump in the reservoir area.

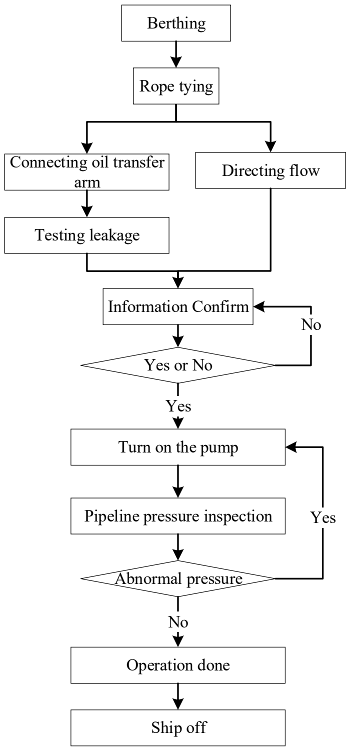

Figure 3. Diagram of loading and unloading operations of oil terminal

3.1Identification of human error at liquid error terminal

(1) Identification of liquid chemical terminal loading and unloading operation process

The liquid chemical terminal loading and unloading operation process can be divided into three stages, namely the preliminary preparation stage, the loading and unloading operation stage, and the late closing stage. The operations in each stage can be summarized as follows.

1) The preliminary preparation stage. The berthing of ship is arranged systematically. The dock company staff will drag the cable to the designated position and fix it, and connect the ship pipeline and the dock pipeline through the oil transfer arm or hose. To ensure that no leakage occurs during the transmission, a leak test is required. After the test is completed, the corresponding valve is opened or closed according to the operation instruction, thereby completing the preparation process for the flow from the cabin to the storage area.

2) The loading and unloading stage. The valve status and the pipeline connection status will be confirmed before the ship / reservoir area is notified to start the pump. During the loading and unloading process, the operator must inspect the operating parameters (especially the pressure) frequently, and report and handle the abnormal pressure in time.

3) Late closing stage. After the operation is completed, the pump in the shipyard / reservoir area is stopped, and the operator purges the residual liquid in the pipeline. The cable then is released, and the ship is offshore.

The process is also described in Figure 3.

The research object in this article is dock operators, excluding ship crews and reservoir operators.

(2) Cognitive behavior and functions of loading and unloading operations at the liquid chemical terminal

The specific operation steps and operation intentions of each task behavior in Figure 3 is explained to identify the corresponding cognitive behavior and function.

(3) Human error identification of loading and unloading operations at the liquid chemical terminal.

The human error is identified based on the four cognitive functions and 13 general error modes proposed by the CREAM method. Since the modes are general descriptions, it should be noted that the error modes can be adjusted accordingly to each specific case.

Taking ship berthing operation as an example, the analysis of cognitive behavior, cognitive function, and human error identification is conducted as follows. This operation is mainly to fine-tune the position of the ship, to dock at the designated pier in accordance with the berthing requirements, and to tie the cable to the bollard, thereby fixing the ship. It mainly includes four cognitive behaviors, namely observing the current position and attitude of the ship (observation), maintaining communication with ship personnel to adjust the ship's position (execution), checking the quality of the cable (observation), and tying the cable (execution). The possible human error patterns are shown in Table 2. A total of 9 human error patterns were identified.

3.2Calculation of human error probability

As mentioned above, the probability of human error is difficult to quantify. Therefore, fuzzy mathematics is introduced here for the calculation. First, the operator's error probability is described by experienced experts in language, and description is converted into a fuzzy number. Fuzzy number can be expressed by fuzzy membership function and converted into fuzzy probability by empirical formula. Five front-line experts judged the probability of human error based on their daily work experience and provided their descriptions.

Let’s take the human error mode “The current status of the ship is not correctly identified.” as an example. In this case, the description of this error probability by the five experts is Low, Medium, Low, Low, and Medium. The corresponding mathematical expression and diagram can be referred to the discussion in Section II.A., Equation 2-3, and Figure 1.

To further simplify the analysis, lambda cuts is used to represent fuzzy numbers. The transformation method of each fuzzy number to its corresponding lambda cuts and the formula

Table 2. HUMAN ERROR IDENTIFICATION DURING SHIP BERTHING

Operation	Behavior recognition	Cognitive function	General failure mode	Human error mode
Berthing	observing the current position and attitude of the ship	Observation	Observation errors	/
			Identification errors	The current status of the ship is not correctly identified.
			Observation not performed	The current state of the ship is not observed.
	maintaining communication with ship personnel to adjust the ship's position	Execution	Wrong execution mode	Failure to communicate ship status with ship personnel
			Wrong execution time	Not timely communication with ship personnel
			Wrong execution target	/
			Wrong execution sequence	/
			Incomplete execution	/
	checking the quality of the cable	Observation	Observation errors	/
			Identification errors	Incorrect check of cable quality
			Observation not performed	No check on cable quality
	tying the cable	Execution	Wrong execution mode	Incorrect cable ties
			Wrong execution time	/
			Wrong execution target	Cables not tied at the designated locations
			Wrong execution sequence	/
			Incomplete execution	Missing ties

Table 3. CONSEQUENCES OF HUMAN ERRORS

economic loss	casualties	environmental pollution
Economic losses simply due to delayed workdays; Economic losses due to equipment damage, including equipment repair costs, new equipment purchases, installation costs, etc.	Casualties due to mechanical injuries, object strikes, toxic gas leaks, etc.	Environmental pollution caused by leakage of hydrocarbons such as petroleum

Table 4. CLASSIFICATION OF HUMAN ERROR CONSEQUENCES

Classification	Principles
1	**Economic loss**: Loss on working days (within 1 day)
2	**Economic loss**: Loss on working days (1~3 days); Losses due to equipment damage (within 2 million yuan) **Casualties**: Slight injury (1 person)
3	**Economic loss**: Loss on working days (4~5 days); Losses due to equipment damage (2~5 million yuan) **Casualties**: Slight injury (2~3 persons) **Environmental pollution**: Only fuel leakage within 2 tons (excluding toxic substances)
4	**Economic loss**: Losses due to equipment damage (5~10 million yuan) **Casualties**: Slight injury (4~5 persons) **Environmental pollution**: Only fuel leakage over 2 tons (excluding toxic substances)
5	**Economic loss**: Losses due to equipment damage (over 10 million yuan) **Casualties**: Death (over 1 person) **Environmental pollution**: Leakage of toxic, corrosive, or radioactive materials (over 0.5 ton)

of lambda cuts are described in the literature[17]. According to the method introduced in Section II.B., the mathematical expression of the fuzzy number $f_M(x)$ and its graphical expression are as follows based on the five experts' opinions.

$$f_M(x)=\begin{cases}\dfrac{x-0.17}{0.18} & 0.17<x\le 0.35\\ \dfrac{0.52-x}{0.17} & 0.35<x\le 0.52\\ 0 & otherwise\end{cases}$$ (Eqn.14)

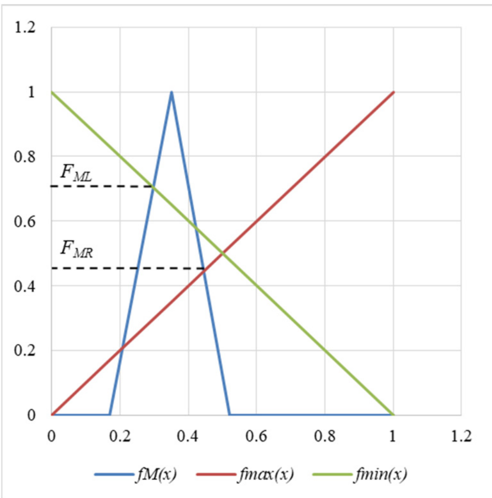

Figure 4. fuzzy membership

The left and right fuzzy numbers are calculated respectively according to equations (9) and (10). The results are shown below. The graphical expression is shown in Figure 4.

$$F_{MR} = \sup[f_M(x) \wedge f_{\max}(x)] = 0.44$$

$$F_{ML} = \sup[f_M(x) \wedge f_{\min}(x)] = 0.70$$

The mixed fuzzy number FM is calculated via Equation 8 as

$$F_M = \frac{F_{MR} + 1 - F_{ML}}{2} = 0.37$$

Finally, the fuzzy probability is quantified by Equation 6, 7.

$$k = \left(\frac{1 - F_M}{F_M}\right)^{1/3} \times 2.301 = \left(\frac{1 - 0.37}{0.37}\right)^{1/3} \times 2.301 = 2.74$$

$$F = \frac{1}{10^k} = \frac{1}{10^{2.74}} = 0.00182$$

It shows that the error probability of the error mode of "The current status of the ship is not correctly identified" is 0.00182.

3.3Identification and evaluation of the consequences of human error

Identification of the consequences of human error. According to the production status of liquid chemical terminals, the human error consequences are summarized into the following aspects, namely economic loss, casualties, and environmental pollution, as shown in Table 3. The classification of accident consequences refers to the internal accident management method of the company, which is subject to Table 4.

3.4Risk assessment of human error

According to the probabilistic calculation and consequence identification and evaluation methods proposed in Sections III.B. and III.C., and the risk evaluation according to the risk matrix given in Figure 2, the risk level of human error is obtained. The detailed evaluation results are shown in Table 5.

Table 5. RISK IDENTIFICATION AND CONSEQUENCE EVALUATION OF HUMAN ERRORS IN LIQUID HANDLING TERMINALS

Operation	Purposes	Human error modes	Human error levels					Fuzzy Probability	Probability level	Consequence level	Risk Assessment
Berthing	Observe the status and position of the ship, communicate with ship personnel to adjust the position of the ship, check the quality of the cables, and tie the cables	The current status of the ship is not correctly identified (M1)	L	M	L	L	M	0.00182	3	1	II
		No observation of the current state of the ship (M2)	VL	VL	VL	VL	L	0.00005	2	2	III
		No communication with ship personnel about ship status (M3)	L	VL	VL	L	VL	0.00013	2	2	III
		Delay in communication with ship personnel (M4)	M	H	M	M	M	0.00668	4	1	III
		Incorrect check of cable quality (M5)	M	H	M	VH	H	0.01444	4	3	IV
		No checking of cable quality(M6)	H	M	VH	VH	H	0.02416	5	3	IV
		Incorrect cable ties(M7)	M	M	H	M	H	0.00885	4	2	III
		Incorrect cable tying position(M8)	VL	L	VL	M	M	0.00093	3	2	III
		Less tying cable(M9)	M	VL	L	VL	L	0.00053	2	1	II
Connecting oil transfer arm	Connect oil tanks and onshore pipelines via oil transfer arms	Incorrect connection of oil delivery arm(M10)	VL	L	VL	L	VL	0.00013	2	3	III
		Missing connection steps(M11)	M	M	VL	L	L	0.00133	3	4	IV
Testing leakage	Check for leaks at the connection between pipeline	incorrect testing leakage(M12)	L	VL	L	L	L	0.00046	2	4	III

Operation	Purposes	Human error modes	Human error levels					Fuzzy Probability	Probability level	Consequence level	Risk Assessment
	and oil transfer arm										
Directing flow	Adjust valve status and directing flow	Wrong tickets*(M13)	VL	L	L	VL	L	0.00027	2	3	III
		Incorrect valve operation(M14)	M	H	M	M	H	0.00885	4	3	IV
		Adjust wrong valve(M15)	M	M	H	H	M	0.00885	4	3	IV
		Adjust part of valves status(M16)	M	H	H	M	M	0.00885	4	3	IV
Pipeline pressure inspection	Inspect pipelines every two hours, and report any leaks or abnormal pressure timely	Incorrect time interval for pipeline inspection(M17)	VH	VH	H	VH	H	0.04332	5	2	IV
		Inspected part pipelines(M18)	VH	H	VH	H	M	0.02416	5	4	V

*Tickets, process change operation instructions prepared by process technicians, documenting changes in valve opening and closing conditions

4 RESULTS AND DISCUSSION

Judging by the possibility of human error, the three human error modes M6, M17, and M18 have the highest probability; the six human error modes M4, M5, M7, M14, M15, and M16 have the lowest probability. Judging by the severity of human error, the error mode M18, M11, and M12 trigger the most serious consequences. These three errors will cause a large number of dangerous goods to leak; the seven types of human errors M6, M5, M14, M15, M16, M10, M13 have the second most serious consequences. Considering the factors of both the possibility and corresponding consequences, M18 has the highest risk.

According to the summary of accidents at the liquid chemical terminal during 2013-2019, the company has a total of 85 accidents/incidents, including 47 pipeline overpressures and leakage accidents / incidents due to inadequate personnel inspections, accounting for 55.3 of the total. 20 incidents did not cause consequences, while the rest 27 led to leakage pollution and delay in construction period. Besides, a total of 15 cable breaking accidents occurred in this company, 12 of which were caused by unqualified cable and the failure of operators to conduct detailed inspection. Fortunately, the above 15 cable breaking accidents did not cause casualties or property losses.

The statistical results of the accidents are consistent with the human error analysis results by the fuzzy CREAM method.

According to the analysis of this paper and the statistical data, the types of accidents caused by human errors at oil terminal include ship collision terminal, cable rupture, pipeline overpressure, leakage, etc, among which cable rupture, pipeline overpressure and leakage are high frequency accidents. The causes of above accident are all related to the failure of operator to strictly implement the inspection and patrol requirements during the operation. Therefore, in order to avoid accidents caused by human errors, the quality level and safety awareness of operators should be improved through education and training. In addition, monitor-alarming devices and instruments, such as cable tension monitoring system, pipeline pressure alarm system, gas leakage monitor, etc, shall be added to realize abnormal state detection during loading and unloading operation so as to avoid serious consequences caused by human error.

5 Conclusions

Port loading and unloading operations requires a large number of manual auxiliary operations, which leads to frequent human-computer interactions. The loading and unloading of liquid chemical in ports transports dangerous goods, and accidents such as ship collisions and cargo leakage due to human error during the operations can cause very serious consequences.

In this paper, the CREAM method is used to identify human error in the process loading and unloading operation of liquid chemical at ports, and the fuzzy comprehensive evaluation method is used to evaluate the risk of human factor error. Multiple human error modes were recognized, and their probability and consequences were analyzed, which provides a reference for improving the safe operation level of the port. The evaluation results are consistent with the statistics of the recorded accidents, which shows the effectiveness of the method.

Acknowledgment. This paper is supported and funded by programs with Fundamental Research Funds for the Central Public Welfare Research Institutes (Grant no. TKS 20200316, TKS 20200320).

Reference

[1] Corrigan S, Kay A, Ryan M, et al. Human factors & safety culture: Challenges & opportunities for the port environment[J]. Safety Science, 2018.

[2] Pallis, Petros L. Port Risk Management in Container Terminals[J]. Transportation Research Procedia, 2017, 25: 4411-4421.

[3] Zhao Yuku. Study on the safety behavior mode of the port railway operators[D]. Dalian Jiaotong University, 2014.

[4] Wang L, Wang Y, Cao Q, et al. A framework for human error risk analysis of coal mine emergency evacuation in China[J]. Journal of Loss Prevention in the Process Industries, 2014, 30: 113-123.

[5] Deacon T, Amyotte P R, Khan F I, et al. A framework for human error analysis of offshore evacuations[J]. Safety Science, 2013, 51(1): 319-327.

[6] T. Deacon, P. R. Amyotte, F. I. Khan. Human error risk analysis in offshore emergencies[J]. Safety Science, 2010(48): 803–818.

[7] Jian-Lan Zhou, Yi Lei, Yang Chen. A hybrid HEART method to estimate human error probabilities in locomotive driving process[J]. Safety Science, 2019(188): 80–89.

[8] Shuen-Tai Ung. Evaluation of human error contribution to oil tanker collision using fault tree analysis and modified fuzzy Bayesian Network based CREAM[J]. Ocean Engineering 179(2019) : 159–172.
[9] Shuen-Tai Ung. Human error assessment of oil tanker grounding[J]. Safety Science 104(2018) : 16–28.
[10] Valentina, Di, Pasquale, et al. A Simulator for Human Error Probability Analysis (SHERPA)[J]. Reliability Engineering & System Safety, 139(2015): 17–32.
[11] Antonella, Petrillo, Domenico, et al. Development of a risk analysis model to evaluate human error in industrial plants and in critical infrastructures[J]. International Journal of Disaster Risk Reduction, 23(2017): 15–24.
[12] Mandal S, Singh K, Behera R K, et al. Human error identification and risk prioritization in overhead crane operations using HTA, SHERPA and fuzzy VIKOR method[J]. Expert Systems with Applications, 2015, 42(20): 7195-7206.
[13] Peng-Cheng L, Li Z, Li-Cao D, et al. A new organization-oriented technique of human error analysis in digital NPPs: Model and classification framework[J]. Annals of Nuclear Energy, 2018, 120: 48-61.
[14] Cognitive modeling and dynamic probabilistic simulation of operating crew response to complex system accidents Part 1: Overview of the IDAC Model[J]. Reliability Engineering & System Safety, 92(2007): 997–1013.
[15] Li Y, Mosleh A . Modeling and Simulation of Crew to Crew Response Variability Due to Problem-Solving Styles[J]. Reliability Engineering & System Safety, 2017.
[16] Chen, Shanhuo, 1985. Ranking fuzzy numbers with maximizing set and minimizing set. Fuzzy Sets Syst. 17(2): 113-129.
[17] Lu L, Liang W, Zhang L, et al. A comprehensive risk evaluation method for natural gas pipelines by combining a risk matrix with a bow-tie model[J]. Journal of Natural Gas Science and Engineering, 2015, 25(Complete): 124-133.