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Methods to Classify, Forewarn and Pre-control Routine Operation in Hazardous Liquid Chemical Storage and Transportation Port

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In light of the actual operation and risk characteristics of hazardous liquid chemical storage and transportation port, we identified the division of eight types of routine operations in this paper. Based on the risk assessment theory, eight risk classification index systems were established according to the SMART principle and expert questionnaire survey, with their classification standards and quantization scores being determined. The AHP method was used to compute index weights, on whose basis the operation risk classification model was built up. Targeted at different risk classifications, we provided specific forewarning signals and measures for pre-control. The proposed scientific and highly-efficient risk forewarning and pre-control systems provide a scientific theory and devisal to classify, forewarn and pre-control routine operation in hazardous liquid chemical storage and transportation port.

1. Introduction

The demands for numerous chemical materials and the constant emergence of novel chemical products provide soil for the successive construction of chemical storage and transportation ports along coasts and inland rivers in China (Hu et al., 2009). However, the vast majority of chemicals are dangerous goods (Chen, 2008), especially for liquid hazardous chemicals whose destructive power to human kinds and the environment, once being accidentally released, will be immeasurable due to their ability to flow and diffuse.
Current researches into the safety of storage and waterway transport of hazardous chemicals focus on risk analysis and safety assessment with respect to cargo ships (Romer et al., 1993; Hu, 2016), operation equipment (Yan, 2001; Liu, 2003; Jiang, 2003; Jiang and Zhu; 2008; Shi et al., 2011; Wei and Bai, 2011), manual operations (Kao and Lu, 2011), on-site management (Vanem et al., 2008; Celik, 2010) and environment (Rigas and Sklavounos, 2002) and the like. Most of the starting points of these analyses are frequently-seen accidents such as leakage, fire and explosion whilst concluding with countermeasures against them. In addition, in consideration of the complexity and much hidden dangers of storage and waterway conveyance of hazardous chemicals, most studies on comprehensive safety assessment and emergency management are integrally conducted by spanning the horizontal dimension of the design phase, the construction phase and the operation phase and the vertical dimension of multiple units such as the cargo, the port, the pump house, pipelines, the warehouse and the transceiver station (Chow and Li, 2005; Zhang and Zhang, 2011; Zhang, 2011; Chow and Li, 2013). In terms of operation risk classification and management, there are national laws and regulations that stipulate 11 types of special operations (Wu, 1994; Gao and Wu, 1999; Luo et al., 2009).
Under the ideological guidance of the risk management theory, the paper designed corresponding methods to classify, forewarn and pre-control routine operation in hazardous liquid chemical storage and transportation port. They realize the referential and guiding functions in a pragmatic style.

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2. Analysis on routine operation of hazardous liquid chemical storage and transportation port

The routine operation of hazardous liquid chemical storage and transportation port refers to operations necessary for routine management of the port and its warehouse (district) with the direct involvement of hazardous liquid chemicals and the potential occurrence of chemical-related accidents. There are mainly 8 types of routine operations, including loading/unloading operation (The operation to load/unload goods to be stored/transported at the port.), delivery operation (The operation to deliver goods, which involves berthing/unbreathing, pipeline distribution, tank renewal, gauging and other operation units.), transfer operation (The port operation for goods to be transported to near-by warehouses or processing plants through pipelines.), tank cleaning operation (The operation to clean oil storage tanks, conducted generally according to examination/maintenance regulations or business demands for account settlement.), inverted tank operation (The situation-dependent operation to pour in-container oils into targeted apparatuses or containers by using devices and pipelines.), pipeline cleaning operation (Also known as pipeline rinsing, referring to the operation conducted generally before the debut of newly-built process pipelines or exchange of pipeline types.), pipeline pigging operation (The operation to check pipelines by ball test.), drainage operation (The operation to release residual water from oil tanks or those oil storage tanks that have been cleaned.).

3. The risk classification index system and classification methods

3.1 Construction of the risk classification index system

Based on the LEC method and the SMART principle, we referred to related documents and laws and preliminarily determined the risk assessment indexes of the said eight operation types in three dimensions: the probability that the loss will occur, the degree of personnel exposure, and the magnitude of the potential loss (Zhang and Zhang, 2011; Zhang, 2011). To ensure the rationality of indexes, the expert questionnaire investigation was conducted.

Objective indexes were quantified and graded by referring to related laws, regulations and industry standards, such as ship condition and material dangerousness. In terms of empirical indicators such as shift time system and the number of workers, due to the lack of objective quantitative tools, our quantification work was mainly done on the basis of expertise and actual situations. The four-layer quantification system was adopted in this section (part of the indicators are divided into two layers). Indexes were respectively endowed with 1 2 3 4 scores according to the classification results.

The YAAHP 0.5.3 was used to calculate the judgment matrix constructed by the questionnaire results. After the consistency test, we obtained the index weights. The loading and unloading operation was taken as an example to display the risk classification index connotations, the classification standards and index weights, which is listed in Table 1.

Among them, the meteorological environment p_{16} is an important factor affecting the port production and operation. The paper analysed the possibility of various meteorological environment factors to affect safety operations at the port, and considered them as a whole with respect to their impact on the likelihood of accident occurrence. The factor level is in positive proportion to risks, i.e. the higher the level is, the greater the risk is. After related analysis and discussion, we determined that there are two types of meteorological environment factors: the disastrous meteorological environment which includes typhoon and cold waves; and the general meteorological environment which consists of high temperature, gale, heavy fog, lightning, precipitation, snowfall, frozen disaster and tide. A risk classification was conducted based on related regulations, and the typhoon risk classification standard was listed in Table 2 as an example. The risk classification criteria of the rest of meteorological environment factors is similar to that of typhoons, thus we will not discuss them in details in this paper.

Taking into account the above ten categories of meteorological environments that may have an impact on safety operation, the quantitative classification criteria for meteorological environmental factors were determined and derived from the following mathematical models:

$$N = [n] \cdot [\omega] \tag{1}$$

Where: N——the comprehensive meteorological environment risk index; [n]——the matrix for a single meteorological environment risk index, $[n] = [n_i]^T$, i = 1,2, ..., 10, if the port does not experience the ith weather, then n_i is equal to 0; [ω]——the weighed coefficient matrix of meteorological environment risk (as shown in Table 3, $[\omega] = [\omega_i]^T$.

Table 1: The score and weight of risk classification indexes for loading and unloading operations

Index	Connotation	Classification standard (Index score) 1	2	3	4	Weight
Shift work p_{11}	The quality of shift work each time during operation.	Shift work without anomalies	Shift work with anomalies settled	Shift work with anomalies unsettled	No shift work	0.135
Ship condition p_{12}	Judged by the age of ship.	< 12 years	[12,18)years	[18,30)years	≥30 years	0.091
Tank replacing p_{13}	Whether oil tanks need to be replaced during loading/unloading operation.	No	—	—	Yes	0.104
Material dangerousness p_{14}	The dangerousness of loaded and unloaded goods.	Flammable substances below Class C or substances of low hazards	Class C flammable substances or substances of medium hazards	Class B flammable substances or substances of high hazards	Class A flammable substances or substances of extra-high hazards	0.136
Operation time p_{15}	The time of operation.	06:00-12:00	12:00-18:00	18:00-24:00	00:00-06:00	0.091
Meteorological environment p_{16}	The variety of meteorological environmental factors that may affect safety operation at the port.	N < 10	N∈[10,40)	N∈[40,80)	N≥80	0.114
Berthing and unberthing conditions p_{17}	The necessity of berthing and unberthing operations according to specification requirements for ships at the targeted port.	Normal	—	—	Abnormal	0.111
Conditions of the previous operation p_{18}	Whether abnormities occur during the previous operation (equipment failure, leakage, etc.).	No anomaly	With an anomaly and anomalies settled	With an unsettled anomaly that harmless to production process	With an unsettled anomaly that affects the production process	0.073
Pre-operation security check p_{19}	Security check conditions prior to the operation.	No anomaly	With an anomaly and anomalies settled	With an unsettled anomaly that harmless to production process	With an unsettled anomaly that affects the production process	0.145
The number of workers l_{11}	The total number of staff at the loading and unloading site, including cable personnel and metrological personnel.	≤3	(3,6]	(6,10]	> 10	0.511
Carrying capacity l_{12}	Tonnage of the ship.	≤3000t	(3000,10000]t	(10000,30000]t	> 30000t	0.489
Loading/unloading time e_1	Duration of loading and unloading operations.	< 24h	[24,32)h	[32,48)h	≥48h	1.000

Table 2: Typhoon risk classification criteria

Disaster degree class	Description	Risk index n_1
1 blue typhoon warning	Likely to be subject to tropical depression within 24 hours, with average wind force scale 6-or-above or gust scale 7-or-above; or already subject to tropical depression, with average wind force scale 6-7 or gust scale 7-8, possibly continuable.	40
2 yellow typhoon warning and above	Likely to be subject to tropical storm within 24 hours, with average wind force scale 8-or-above or gust scale 9-or-above; or already subject to tropical storm, with average wind force scale 8-9 or gust scale 9-10, possibly continuable.	80

Table 3: Weighed coefficient matrix of meteorological environment risk

Meteorological environment type	Weighed risk coefficient ω_i
Disastrous meteorological environment	2.0
General meteorological environment	1.0

3.2 Establishment of risk classification methods

The establishment of the targeted mathematical classification model in this paper should take into consideration the multi-factor characteristic of the objective, and be based on risk assessment principles so that conforming to the operation risk features. The established model is:

$$R_i = f_i(p, l, e) = f_i(p) \times f_i(l) \times f_i(e) = (\sum_{a=1}^{k} p_{ia} \cdot \omega_{ia}) \times (\sum_{b=1}^{m} l_{ib} \cdot \omega_{ib}) \times (\sum_{c=1}^{n} e_{ic} \cdot \omega_{ic}) \quad (2)$$

Where: R_i——the risk value of the ith routine operation; p_{ia}——the index score of the ath risk possibility effect factor of the ith operation; ω_{ia}——the index weight of the ath risk possibility effect factor of the ith operation; a——the serial number of the risk possibility effect factors, a=1,2,……; l_{ib}——the index score of the bth risk consequence effect factor of the ith operation; ω_{ib}——the index weight of the bth risk consequence effect factor of the ith operation; b——the serial number of the risk consequence effect factors, b=1,2,……; e_{ic}——the index score of the cth risk exposure degree effect factor of the ith operation; ω_{ic}——the index weight of the cth risk exposure degree effect factor of the ith operation; c——the serial number of the risk exposure degree effect factors, c=1,2,…….

Operation risks can be classified according to the above model, which benefits classification, forewarning and pre-control of routine operation in hazardous liquid chemical storage and transportation port. Table 4 shows the operation risk classification criteria. The level of risk identified by analysis and evaluation reflects the risk level of the operation. The high level of risk indicates that the operation is of high potential to inflict accidents; the low level of risk indicates that the operation is of low potential to inflict accidents.

Table 4: Criteria and descriptions of routine operation risk classification

R	Risk level	Risk description
R≥24	I	High risk —unacceptable risk
12≤R < 24	II	Relatively high risk — undesirable risk
6≤R < 12	III	Medium risk — risks of conditional acceptance
1≤R < 6	IV	Low risk — acceptable risk

4. Approaches to risk classification forewarning and pre-control

Risk classification forewarning and pre-control is realized by monitoring the real-time risk statuses of all operations, delivering alerting signals (red, orange, yellow and green) that correspond to operation risks monitored before, and adopting targeted defensive measures (both technological and administrative) so that lowering the risk level down to acceptable ranges(Zhao, 2009; Salzano, 2009; Sun, 2010). There are 4 risk pre-control classes divided according to specific risk measures, as listed in Table 5.

According to the principle that risk classification pre-control measures should scientifically match risk classification forewarning, in addition to ensuring the timeliness and effectiveness of pre-control, the units that adopt our methods in practical cases are suggested to analyse the acceptance degree of risks of different forewarning classes and to implement corresponding risk pre-control measures which fit for the conditions and needs of the reality. If the risk forewarning level is high, high-level risk prevention and control measures should be adopted. If the risk forewarning level is low, low-level risk prevention and control measures should be adopted. Only when the defensive measures correspond to the classes of risk forewarning can resources invested be in the optimal proportion to safety performance and can they be reasonable and acceptable. The risk forewarning and pre-control matching system is shown in Table 6.

Table 5: Risk pre-control classes and specific measures

Risk pre-control class	Specific measures
High level	Suspending operation and turning to the implementation of all-pervasive countermeasures until the risk is eliminated or reduced to a certain extent.
Medium level	Roundly restricting operation and turning to local actions until the risk is reduced to a certain extent.
Moderately low level	Partially restricting operations and continuing some operations with selective countermeasures and control measures
Low level (normal)	Maintaining normal operations while remaining vigilant during the addition of on-site monitoring

Table 6: Risk forewarning and pre-control matching system

Risk class	Risk pre-control class			
	High level	Medium level	Moderately low level	Low level (normal)
Ⅰ	reasonable acceptable	unreasonable unacceptable	unreasonable unacceptable	unreasonable unacceptable
Ⅱ	unreasonable acceptable	reasonable acceptable	unreasonable unacceptable	unreasonable unacceptable
Ⅲ	unreasonable acceptable	unreasonable acceptable	reasonable acceptable	unreasonable unacceptable
Ⅳ	unreasonable acceptable	unreasonable acceptable	unreasonable acceptable	reasonable acceptable

5. Conclusion

Through the above research, the following conclusions can be drawn:
1) Through the analysis of the characteristics and risks of routine operation in hazardous liquid chemical storage and transportation port, we establish the risk classification index system for 8 types of daily operations such as loading and unloading operation as well as delivery operation; by quantifying indexes, the weight and score of each index are obtained. Accordingly, we build up 8 types of operation risk classification models.
2) The method of risk classification and forewarning for routine operations is determined. According to the principle of "scientific matching", the pre-control measures that match risks of different classes are proposed in a way that unifying safety and economy.

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