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Mechanism of Psychological Effect on Unsafe Behaviour during the Storage and Transportation of Dangerous Chemicals

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The occurrence of accidents during the storage and transportation of dangerous chemical is catastrophic, which brings about a devastating blow to people's loss of life and property. There are multiple factors causing the accident, and the unsafe behaviour caused by psychological effect of people in the process of storage and transportation is the main cause. Thus, it is necessary to study the mechanism of psychological effect on human unsafe behaviour. To this end, based on the theory of psychological field, this paper identifies the factors of inducing unsafe behaviour under psychological effect, and analyses the interaction between various factors. Then, it combines the coupling theory to conduct vector analysis for the coupling between various factors, so as to reveal the mechanism of psychological effects on the unsafe behaviour during storage and transportation of dangerous chemicals. This has certain guiding significance for reducing the incidence of accidents in storage and transportation of dangerous chemicals.

1. Introduction

There are a wide variety of chemical hazards ranging from 5 million to 7 million, and more than 20,000 production enterprises of dangerous chemicals. During the storage and transportation of dangerous chemical (Yang and Fan, 2018), accidents are sudden, complicated and catastrophic, and the total number of accidents and deaths account for a large proportion. The human unsafe behaviour is the most important cause of accidents (Saat et al., 2014; Qiang and Hui, 2016). According to the Occupational Safety and Health Administration (OSHA) statistics in United States, fatal accidents during the storage and transportation of dangerous chemicals are directly related to human unsafe behaviour.

Based on the Heinrich's Domino theory, it is known that the accident is not an isolated event, but the result of a series of event interactions. Also, combined with the psychological field theory proposed by Kurt Lewin (1890-1947) in 1936 (Busemeyer and Townsend, 1993), the decision of human behaviour depends on the interaction between internal and quasi-environmental factors. Therefore, during the storage and transportation of dangerous chemical, unsafe behaviour is a complex system composed of many factors (Weinert and Agrawal, 1995). Changes in quasi-environmental factors can interfere with human psychological changes, thus changing people's behavioural decisions, and causing the decision-making orientation to change towards unsafe behaviour.

Due to various factors that cause accidents in the process of storage and transportation of dangerous chemical (Fine and Elsbach, 2000), it is difficult to comprehensively monitor all problems in real time. Therefore, in this paper, the failure analysis method of result-to-cause was adopted to create a relation chart between the risk factors during the storage and transportation process, and the topological relationship model between accident risk factors and the coupling theory were used to analyse the coupling relationship between various factors, revealing the mechanism of psychological effect on the unsafe behaviour during the storage and transportation of dangerous chemical.

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2. Theory of unsafe behaviour mechanism

2.1 Theoretical basis of the psychological field

The psychological field theory by Kurt Lewin indicates that human unsafe behaviour is determined by the individual's psychological location. Then mathematical models are used to describe the theory of psychological field in Formula 1:

$$\mathrm{Z} = f\left(X \cdot Y\right) \tag{1}$$

where, Z is the human behaviour, X is the internal factor of the individual, and Y is the environment in which the individual is located. Through the mathematical model in formula 1, the interaction between the individual and the environment determines the behaviour of an individual, and the factual factors that interact with the individual in the environment and affect the individual are called quasi-environmental factors (Y in formula 1).

2.2 Accident risk factors

The psychological effects of individual internal factors can affect the individual's physiological status and the level of individual ability, thus governing the individual's behavioural patterns. The adverse or negative psychological effects are influenced by external quasi-environmental factors and directly govern the individual's unsafe behaviour. Therefore, the failure analysis method was used to establish a relation chart of main risk factors for accidents in the storage and transportation process of dangerous chemical (Table 1).
The risk factors in the table are divided into three internal factors and 24 quasi-environmental factors. The internal factors include the degree of psychological effect, the degree of physiological perception, and the level of individual ability; the quasi-environmental factors include personnel operations (i.e., whether the operators are employed with certification Y_1, identification of hazard source Y_2, risk assessment Y_3, timely reporting of hazards Y_4, in-depth investigation of hazards Y_5, timely rectification of hazards Y_6, review by safety technical department Y_7, unauthorized departure of workers Y_8, violation of operating procedures Y_9), machinery equipment (storage and transportation containers rupture Y_{10}, complete installation of fire-fighting equipment Y_{11}, safety signs Y_{12}), external environment (reasonable planning of construction area Y_{13}, illegal construction Y_{14}, overall rational layout Y_{15}), management system (safety training Y_{16}, safety culture construction Y_{17}, regular inspection of fire-fighting equipment Y_{18}, regular annual inspection of business license Y_{19}, enterprise production operation qualification certificate Y_{20}, acceptance of safety facilities Y_{21}, perfection of management institutions Y_{22}, improvement of government supervision Y_{23}, and standardization of post responsibility system Y_{24}).

Table1: Risk factors of accident

Classification		Factors	Mathematical set
Risk Factors Of accident	Individual factors	Psychological function	$\{X_1\}$
		Physiological perception	$\{X_2\}$
		Personal ability level	$\{X_3\}$
	Quasi-environmental	Personnel operation	$\{Y_1, Y_2, Y_3, \ldots, Y_9\}$
		Machinery equipment	$\{Y_{10}, Y_{11}, Y_{12}\}$
		External environment	$\{Y_{13}, Y_{14}, Y_{15}\}$
		Management system	$\{Y_{16}, Y_{17}, Y_{18}, \ldots, Y_{24}\}$

2.3 Evolution mechanism of unsafe behaviour

The psychological function of the individual, especially the unsafe psychological factors, directly affects the physiological perception changes, while the bad physiological experience counteracts the psychological state. At the same time, the two can also directly affect the individual's ability level, leading to unsafe behaviour. Besides, there exists the positive and negative interaction between quasi-environmental factors and internal factors, in which the quasi-environmental factors affect the internal factors of individuals, mainly the changes in individual psychological effects, directly affecting individual cognition and controlling individual behaviour (Xu et al., 2002), and the wrong or unsafe behaviour results in the accident. Fig.1 shows the comprehensive effects of psychological functions on the unsafe behaviour.

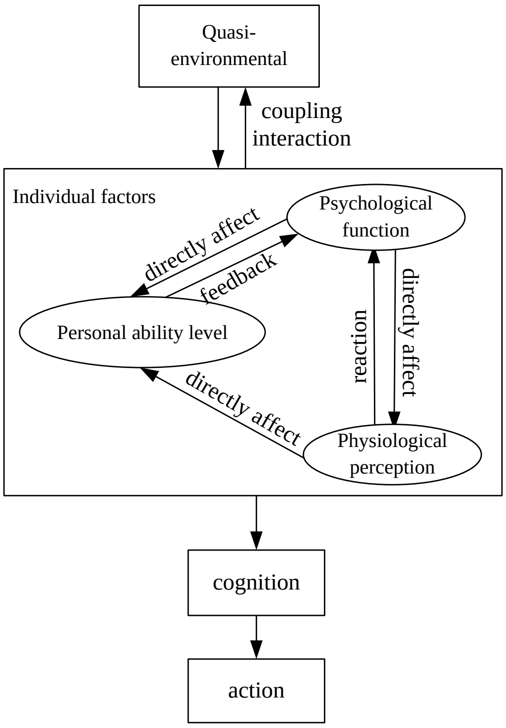

Figure 1: Interaction diagrams

3. Relations of accident risk factors

Human unsafe behaviour during the storage and transportation of dangerous chemical is the result of the interaction between various complicated factors (Oggero et al., 2006). For this, the topological structure model was used to reasonably analyse the risk factors of accidents, and also complex hierarchical relationships between the internal factors and quasi-environmental factors. Then, hierarchical processing was conducted to find their internal and hierarchical relationships (Welles et al., 2004), so as to establish a topological model of accident risk factors in the storage and transportation of dangerous chemical.

3.1 The theoretical basis of the topology model

The basic binary relation matrix between system factors is expressed by the adjacency matrix $Q=(q_{ij})_{n\times n}$. By analysing the basic binary relation between individual internal factors and quasi-environmental factors, formula 2 is derived, in which R_1 indicates that there exists a binary relationship between Y_i and Y_j, and R_0 indicates that there is no binary relation between the two.

$$q_{ij}=\begin{cases}1 Y_i R_1 Y_j\\0 Y_i R_0 Y_j\end{cases} \tag{2}$$

The reachable matrix $D=(d_{ij})_{n\times n}$ describes the degree to which the nodes of the directed graph can reach after a certain length of path, and the maximum number of passes with no loop is defined as r, then the reachable matrix can be defined in detailed in Formula 3. R_1 indicates the path with the maximum i-j path length r (Van Hook, 1978; J.M et al., 2005), and R_0 indicates no path from i to j.

$$d_{ij}=\begin{cases}1 Y_i R Y_j\\0 Y_i R Y_j\end{cases} \tag{3}$$

Based on formula 2 and 3, the reachabile matrix of individual internal and quasi-environmental factors can be obtained (formula 4), and I is the unit matrix. At this time, $(Q+I)^{r+1}=(Q+I)^r\neq(Q+I)^{r-1}\neq\ldots\neq(Q+I)^2\neq(Q+I)$

$$D=(Q+I)^r \tag{4}$$

3.2 Creating a topological structure model of risk factors

According to the reachability matrix of all the elements in the system, different levels were divided, and the hierarchical relationship between accident risk factors was analysed. By removing the unit matrix in the hierarchical rank order, the topological structure model between individual factors and quasi-environmental factors was established (Fig. 2). Besides, the psychological field conceptual model proposed by topological psychology is transformed into a scalable mathematical model, including surface-layer direct relationship, middle-layer indirect relationship and deep-layer fundamental relationship.

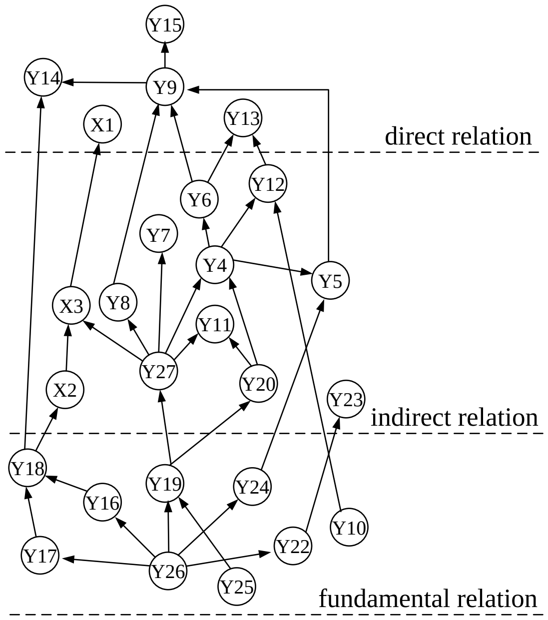

Figure 2: Topological relationship model of accident risk factors

3.3 Psychological field coupling vector analysis

The interaction between the internal factors and the quasi-environmental factors shows positive and negative coupling characteristics through different coupling paths. The positive coupling is represented by the symbol "+", i.e., the coupling characteristics between the coupling vectors are mutually enhanced; the negative coupling is by "-", i.e., the coupling characteristic between the coupling vectors that weakens or cancels each other.

Based on the coupling theory combined with the topological hierarchical structure model, the vector analysis was conducted for the coupling between the internal l factors and the quasi-environmental factors (Figure 3). According to the interaction *f* between the individual's internal factors X and the quasi-environmental factors Y, the quasi-environmental factor Y plays a positive role in guiding the internal factors X in a standardized, reasonable and perfect situation. In this case, the two are positively coupled, and the positive psychological effects are negatively coupled to the unsafe behaviour.

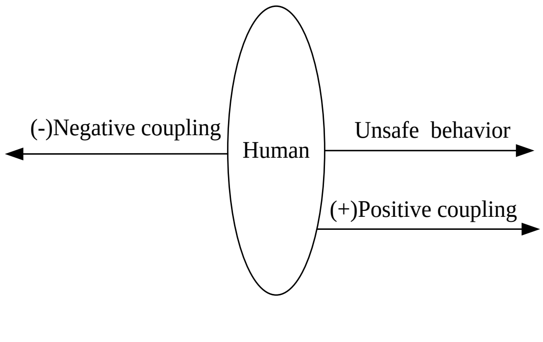

Figure 3: Coupling effect vector analysis diagram of Unsafe behaviour

It can be seen from Fig.4 that under the coupling of the internal factors and the quasi-environmental factors, the increment of human unsafe behaviour firstly rises sharply and then gradually decreases. The main reason is that in the initial stage of storage and transportation for dangerous chemical, people's safety awareness, psychology, physiology and personal ability level are all in the adaptive phase, and they are not familiar with external factors outside the internal factors of the individual, which easily lead to the unsafe behaviour of people under the action of interactive coupling; but, with the continuous improvement and perfection of quasi-environmental factors, further feedback is sent to individuals, and continuously improve individual ability level and psychological perception, which can effective reduce people's unsafe behaviour. Under the coupling effect of individual internal factors and quasi-environmental factors, the decrement of human unsafe behaviour firstly decreases slowly and then rises rapidly, indicating that the safety training education cannot significantly improve people's psychological cognition and individual ability level within a short time; however, with the continuous improvement and perfection of quasi-environmental factors, the positive internal interaction between the individual internal factors and the quasi-environment can fundamentally reduce the frequency of unsafe behaviours.

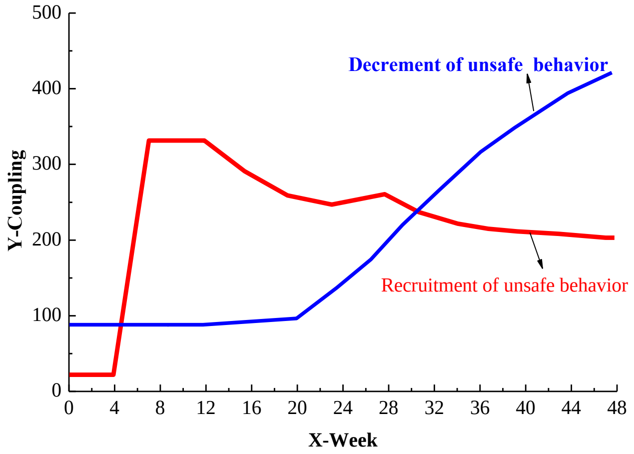

Figure 4: Coupling simulation of Unsafe behaviour

Positive psychological effects are positively coupled with human cognition. But it's negatively coupled with the negative factors in quasi-environmental factors, and then negative quasi-environmental factors can increase people's unsafe behaviour. Considering the negative coupling between quasi-environmental factors and unsafe behaviours, it is necessary to improve the management system, standardize the working environment, complete the operation of machinery equipment and safety supervision personnel from both objective and subjective aspects, which can enhance the individual's psychological positive feelings, and effectively reduce the occurrence probability of unsafe behaviour. Thus, the psychological effect of human self-safety plays an important role in reducing the occurrence of unsafe behaviour.

4. Conclusions

During the storage and transportation of dangerous chemical, unsafe behaviour is a complex system composed of multiple interacted factors. The change of quasi-environmental factors interferes with people's psychological changes, thus changing their behavioural decisions, and causing decision-making orientation towards unsafe behaviour. At present, psychological factors are basically used as the single-sided influencing factors of unsafe behaviours in most research. But, under the coupling interaction between individual internal factors and quasi-environmental factors, there have been few studies about the psychological effects on the unsafe behaviours. In this context, this paper carries out research on the mechanism of psychological effect on unsafe behaviour during storage and transportation. The main contents and conclusions are as follows:

(1) Based on the theory of psychological field, taking the risk factors of accidents in the storage and transportation of dangerous chemical as the research object, the fault analysis method was adopted to create one chart of key risk factors in the process of storage and transportation of dangerous chemical.

(2) Through analysis for the hierarchical relationship between accident risk factors, a topological structure

model between individual factors and quasi-environmental factors was established.
(3) Coupling relationship between various factors was analysed according to coupling theory, revealing the mechanism of psychological action on the unsafe behaviour of dangerous chemical storage and transportation. This has certain guiding significance for reducing the accident rate of dangerous chemical in the process of storage and transportation.

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