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System Impact Relation and Mechanism of Safety Capacity in Petrochemical Base

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Abstract: A study on the impact mechanism of safety capacity in petrochemical base is carried out, according to system structure modeling and system dynamics simulation. The hierarchical structure model of 14 factors that affect the safety capacity in petrochemical base is built up. Safety management and emergency management are included in the first hierarchy. In the next hierarchy, there are three factors: monitoring early warning, fire protection and medical safeguard. Traffic conditions, store layout, dock layout, channel water conditions are involved in the third hierarchy. All the rest factors including topographical conditions, meteorological conditions, population distribution, types and harm of hazardous chemical are classified as the base hierarchy. Digital variables are extracted from 14 factors on the basis of the mathematical simulation model of the feedback system. In addition, the mathematical relationship is established among these factors with the actual operating conditions. Then impact characteristics and mechanism of different factors on safety capacity in petrochemical base are summarized to propose the practical short-term portfolio to increase safety capacity in petrochemical base.

Keywords: Optimization, petrochemical base, safety capacity, simulation, system engineering.

1. INTRODUCTION

Petrochemical base has become a main form to develop petrochemical industry. It's an urgent problem to ensure production safety and environmental safety of petrochemical base. A large number of incidents indicate that the safety capacity in petrochemical base will directly affect the severity of the consequences of the accident [1-4]. Given intrinsic safety, we should study the inherent impact mechanism of safety capacity in petrochemical base, and then put forward some feasible safety measures to prevent accidents and decrease the accident loss [5]. This will bring great economic and social benefits to the country and social development.

At present, a lot of scholars conducted a preliminary exploration for safety capacity of large petrochemical base. Wang Shukun [6] defined the basic concept of safety capacity in petrochemical base from the perspective of risk. Li Chuangui [7] proposed and defined the maximum critical point for the ratio of danger quantity to safety capacity, and then determine the safety capacity of industrial park with it. Chen Xiaodong [8] carried out the study of safety inventory and transportation capacity study. Kyusang Han [9] reduced the risk of the existing capacity of the park by the reasonable design of petrochemical base. In short, scholars mainly studied the safety capacity concept and explored the practice of safety capacity factors. However, the research on the inner relationship and mechanism of factors that affect safety capacity in petrochemical base is still very lacking. According to the 14 main factors affecting safety capacity in petrochemical base, the paper deeply analyzed the inner relationship and mechanism of these relevant factors with the interpretative structural modeling (ISM) and system dynamics simulation.

2. ESTABLISHING INTERPRETATIVE STRUCTURAL MODEL

The basic idea of ISM is that it extracts composition elements of the problem, then processes these elements and their relationships using directed graph, matrix and computer technology, and explains it in words. The complex system is decomposed into several subsystems, and the system will eventually be constructed into a multilevel hierarchical structure model, a clear hierarchy and the overall structure of the problem, in order to clarify the hierarchy and overall structure of the problem and improve the understanding level of the problem [10-12]. The main steps of ISM methodology are as follows:

Step 1 The main influencing factors of safety capacity should be found, and then the relationship between each factor should be determined.

Step 2 Adjacency matrix is built based on the relationship in step 1, and reachability matrix is figured out according to the operation rules.

Step 3 The level of each element is allocated according to reachability matrix and the hierarchy structure is established finally.

Safety capacity of petrochemical base is hazardous chemicals quantity which the base can tolerate under the condition of maximum tolerable risk. The research team has been to a large petrochemical base in Zhoushan Archipelago

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New Area several times to conduct investigation and consult experts, and then determine 14 major factors that affect the safety capacity of petrochemical base. These 14 major factors are as follows: topographic condition, meteorological condition, population distribution, traffic condition, condition of water area, storage areas layout, port layout, the category and danger of hazardous chemicals, safety investment, monitoring early-warning, fire guarantee, medical security, safety management, emergency rescue. Taking these 14 factors as the analysis object and using the Delphi method consulted experts in companies and universities, the relationship between two elements is determined finally after several rounds of discussions. The details are showed in Table **1**. In the Table, "V" represents that row factors have a direct influence on column factors; "(V)" represents that the row factors have an indirect influence on column factor factors; "A" represents that column factors have a direct influence on row factors; "X" represents that row factors and column factors influence each other; Blank means that no influence on each other.

The relationship between any two factors as follows:

(1) $S_iRS_j=1$, if S_i has a direct impact on S_j , the element "a_{ij}" in adjacency matrix is "1";

(2) $S_iRS_j=0$, if S_i has no impact on S_j , the element "a_{ij}" in adjacency matrix is "0".

The adjacency matrix can be built based on the relationship between each influencing factor.

$$A=\begin{pmatrix}
0&0&0&0&0&1&1&0&0&0&0&0&0&0\\
0&0&0&0&0&1&1&0&0&0&0&0&0&0\\
0&0&0&0&0&1&1&0&0&0&0&0&0&1\\
0&0&0&0&0&1&0&0&0&0&1&1&0&0\\
0&0&0&0&0&0&1&0&0&0&0&0&0&0\\
0&0&0&1&0&0&1&0&0&0&0&0&0&0\\
0&0&0&0&1&1&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&1&0&0&0&1&0\\
0&0&0&0&0&0&0&0&0&1&1&1&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&1&1\\
0&0&0&0&0&0&0&0&0&0&0&0&0&1\\
0&0&0&0&0&0&0&0&0&0&0&0&0&1\\
0&0&0&0&0&0&0&0&0&0&0&0&0&1\\
0&0&0&0&0&0&0&0&0&0&0&0&1&0
\end{pmatrix} \tag{1}$$

Then calculate as follow until the formula 2 is s workable.

$$M=(A+I)^{n+1}=(A+I)^{n}\neq\ldots\neq(A+I)^{2}\neq(A+I) \tag{2}$$

In formula 2, I is an unitary matrix; n is integer; the calculation is Boolean calculation [13, 14].

Matrix M=$(A+I)^{n}$ is called reachable matrix. "m_{ij}=1"means that factor S_i has a direct or indirect impact on factor S_i. Reachable matrix M is obtained by calculating the adjacency matrix in formula 1.

$$M=\begin{pmatrix}
1&0&0&1&1&1&1&0&0&0&1&1&1&1\\
0&1&0&1&1&1&1&0&0&0&1&1&1&1\\
0&0&1&1&1&1&1&0&0&0&1&1&1&1\\
0&0&0&1&1&1&1&0&0&0&1&1&1&1\\
0&0&0&1&1&1&1&0&0&0&1&1&1&1\\
0&0&0&1&1&1&1&0&0&0&1&1&1&1\\
0&0&0&1&1&1&1&0&0&0&1&1&1&1\\
0&0&0&0&0&0&0&1&1&1&1&1&1&1\\
0&0&0&0&0&0&0&0&1&1&1&1&1&1\\
0&0&0&0&0&0&0&0&0&1&0&0&1&1\\
0&0&0&0&0&0&0&0&0&0&1&0&1&1\\
0&0&0&0&0&0&0&0&0&0&0&1&1&1\\
0&0&0&0&0&0&0&0&0&0&0&0&1&1\\
0&0&0&0&0&0&0&0&0&0&0&0&1&1
\end{pmatrix} \tag{3}$$

$R(S_i)$ is a reachable set of the factor S_i , consisting of all the factors that can be reached from S_i in reachable matrix or directed graph. $A(S_i)$ is an advanced set of the factor S_i , consisting of all the factors that can reach S_i in reachable matrix or directed graph. $C(S_i)=R(S_i)\cap A(S_i)$, is a common part of the reachable set and advanced set. If $R(S_i)= C(S_i)$, $R(S_i)$ is the element set in the highest hierarchy. Then the row and column elements corresponding to S_i are crossed out successively, and the reachable set and advanced set in the second hierarchy can be obtained. Similarly, the element set in second, third,…, n hierarchy can be obtained. The results of hierarchy are as follows: S_{13} and S_{14} are in the first hierarchy; S_{10}, S_{11} and S_{12} are in the second hierarchy; S_4, S_5, S_6, S_7 and S_9 are in the third hierarchy; S_1、S_2、S_3、S_8 are in the fourth hierarchy. The interpretive structural model can be built, as shown in Fig. (**1**).

3. ANALYSIS AND EXPLANATION FOR THE HIERARCHY STRUCTURE

As is shown in Fig. (**1**), the indexes that affect safety capacity in petrochemical base are a four layer hierarchical model. In this model structure, the potential of each factor of the safety capacity in petrochemical base are as follows:

(1) The first hierarchy includes two interacting factors of S_{13} safety management and S_{14} emergency rescue. Scientific and comprehensive safety management can effectively control human's unsafe behaviors and objects unsafe state, so as to prevent accidents; rapid and effective emergency rescue can prevent further spread of the disaster and the situation after the accident, to minimize casualties and economic losses. Safety management and emergency rescue reduce the risk of the base by reducing the probability and consequences of accidents, so that the safety capacity in the base can be increased. As the raw materials and products of petrochemical enterprises are mostly flammable, explosive and toxic hazardous chemicals, safety management and emergency management is put in the highest position, it conforms to the actual situation of the whole system, to ensure the safe operation of the whole system, safety management standard and emergency rescue capacity are essential. It also shows that safety management and emergency rescue are the most critical factors in the various influencing factors of safety capacity.

(2) The second hierarchy includes three factors of S_{10} monitoring early-warning, S_{11} fire guarantee and S_{12} medical security. By using high and new technology means to implement monitoring early-warning for all kinds of hazards, it can discover and eliminate hidden dangers timely, the accident nipped in the bud, change accident treatment into accident prevention, make the safety management work to a new level. Fire and medical are the guarantee of the emergency rescue work; they directly affect the situation development and personnel casualties, thus affecting the consequences of the accident. Therefore, monitoring early-warning, fire and medical guarantee are all can affect the base security level, thereby affecting the size of the base security capacity.

(3) The third hierarchy includes S_4 traffic condition, S_6 storage areas layout, S_7 port layout, S_5 condition of water

Table 1. The relationship between each impact factors of safety capacity in petrochemical base.

							V	V					S_1topographic condition
							V	V				S_2 meteorological condition	
V							V	V			S_3 population distribution		
		V	V					X		S_4 traffic condition			
							X		S_5 condition of water area				
	(V)					A	X	S_6 storage areas layout					
						A	S_7 port layout						
(V)	V				V	S_8 the category and danger of hazardous chemicals							
	(V)	V	V	V	S_9 safety investment								
V	V			S_{10} monitoring early-warning									
V			S_{11} fire guarantee										
V		S_{12} medical security											
X	S_{13} safety management												
S_{14} emergency rescue													

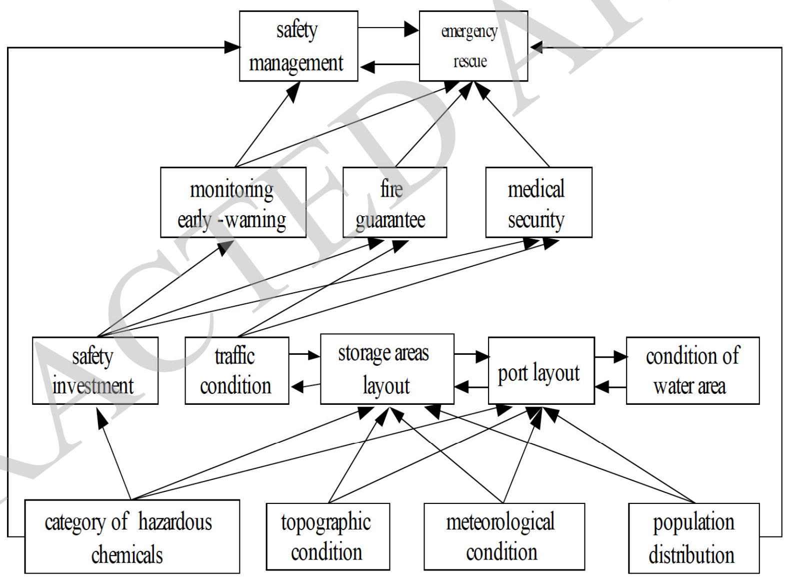

Fig. (1). ISM of impact factors of safety capacity in petrochemical base.

area and S_9 safety investment. Storage areas layout can be affected by traffic condition and the port layout, at the same time, the port layout can also be affected by the condition of the water area and storage areas layout. Storage areas can improve the traffic condition in the construction process after the completion of ports; the surrounding condition of water area can also be affected as a result. Judging from this, S4, S6, S7 and S5 are a whole which affects mutually. Once the intensive petrochemical enterprises suffer serious accidents such as fire, explosion or the leakage and diffusion of hazardous chemicals, it is likely to cause catastrophic "dominoes" chain. Many significant security incidents that have occurred currently are associated with unreasonable layout and the too small safety distance, therefore, reasonable storage areas layout and port layout are important approaches to risk control. Simultaneously, the traffic condition can directly affect the arrival time of emergency rescue fire fighting and medical institutions and whether rescue can be smoothly near the accident sites. Safety investment will affect monitoring early-warning, fire and medical guarantee and safety management, which in turn affect overall safety level and capacity of the base.

(4) The fourth hierarchy is composed of four factors of S_1 topographic condition, S_2 meteorological condition, S_3 population distribution, S_8 the category and danger of hazardous chemicals. The topographic condition, meteorological condition and population distribution can af-

fect the base location and the storage areas layout and port layout, when the entire petrochemical base had safety capacity planning in the beginning of the establishment, the first consideration was the site selection problem, generally, petrochemical base should be selected in the suitable meteorological and hydrological conditions, marine and corresponding terrestrial environment of stable geological conditions, avoiding the complicated sea which prone to typhoons, storm surges, lightning geological conditions, and avoiding the densely populated area at the same time. Therefore, topographic condition, meteorological condition, population distribution are the most basic factors of base security situation and security capacity. And the category and danger of hazardous chemicals can affect the safety investment and the size of the overall risk of the base, and then affect the size of the security capacity. Moreover, population distribution also can affect the emergency rescue and evacuation difficulty level to a certain extent.

4. DYNAMIC SIMULATION OF IMPACT FACTORS OF SYSTEM

The safety capacity in the petrochemical base depends on the 14 factors mentioned above, and changes with the change of every factor. The calculation of the safety capacity in the petrochemical base belongs to a overall planning problem that is how to find the maximum under the limiting risk conditions, so the basic conditions to solve the problem is risk assessment of hazardous chemicals in the petrochemical base [15-17]. We summarized some quantitative indicators according to the 14 factors, and built the model of the system dynamic simulation based on Vensim. Then we studied the change of the safety capacity under different conditions to explore the impact principle of factors, and put forward feasible measures to increase or decrease the hazardous chemicals in the base.

Recently the risk, as well as the impact model of safety capacity in the petrochemical base, has been studied from two aspects of the probability and loss of accidents. From the perspective of system dynamics, accidents are almost caused by people's unsafe behavior, unsafe state of objects and unsafe factors of the environment. The accident probability reflects the intrinsic impetus and depends on safety management, topographic and traffic condition, safety investment and storage areas layout. Considering from intrinsic safety, the total amount of hazardous chemicals has a direct impact on the accident loss [18-20]. In addition, the category and danger of hazardous chemicals, emergency rescue, population distribution and safety investment affect the accident loss.

We can build the system dynamic model of safety capacity in the petrochemical base to study the influence of every factor with the probability and loss of accidents, as shown in Fig. (**2**).

The factors in the dashed box such as safety management, meteorological conditions result from the summary of 14 factors. They can reflect the influence mechanism of factors, and can be easily quantified. The capacity of hazardous chemicals can affect the probability and loss of accidents that can be affected by 14 factors, and then the capacity of hazardous chemicals in petrochemical base that can be adjusted by the comparison of calculated risk and risk tolerance will be equal to safety capacity.

Vensim is a multifunctional software that has graphics, documentation, simulation, analysis and other functions. It can be easily used to build cause-effect diagram and flow chart [21, 22]. The cause-effect diagram reflects the interaction mechanism among indicators that is helpful to build the flow chart and dynamics simulation. We use a well-known domestic petrochemical base as an example to calculate the safety capacity. This base covers an area of 2.8 square kilometers, consisting of three companies that take stockpiles of crude oil and refined products as the pillar industry. According to statistics, there are totally 8000000 tons hazardous chemicals in the base, in which refined oil accounts for 8%. There are also a small amount of liquid ammonia, methanol and other chemical raw materials. The simulation of safety capacity is shown as Fig. (**3**).

As an accumulation quantity, the capacity of hazardous chemicals in the base reflects the overall situation of simulation. And it can be adjusted by the proportion of hazardous chemicals, the loss of hazardous chemicals per ton, the accident loss impact factor and the potential loss of life. It will increase to the safety capacity by the comparison between the potential loss of life and the allowed loss of life. This is a negative feedback regulation and many factors above can affect its sensitivity. The accident probability depends on storage areas layout, safety investment and safety management. In Fig. (**3**), there are 11 variables including the proportion of hazardous chemicals, the potential allowed loss of life, population distribution, average number of personal conduct hidden danger, safety investment, emergency rescue, topographical and traffic conditions, safety management, the probability of high temperature and typhoon, storage areas layout and the loss of hazardous chemicals per ton. We use the very system to the factors that are difficult to quantify (6 is pass), and the rest of factors refer to actual data. The simulation takes the actual data and people's subjectivity into account which can guarantee the correctness of results.

Variables above are not arbitrary value given that the potential allowed loss of life, average number of personal conduct hidden danger, the probability of high temperature and typhoon and the loss of hazardous chemicals per ton change a little in a short term. We adjusted the rest of 7 variables to increase 10% (the proportion of hazardous chemicals changes as follows: fuel oil, gasoline and explosive materials increased by 10%, crude oil decreased by 5%, 5% reduction of toxic products). In addition, a combined program is executed as follows: all the factors increase by 10%. We set 8000000 tons as the initial value of hazardous chemical capacity in the base because there are totally 8000000 tons hazardous chemicals in the base. After a period of time, the capacity of hazardous chemicals in the base varies as Fig. (**4**).

The ninth line represents safety capacity under the current condition, and it is 1246.4 ten thousand tons. The forth line (1122.5 ten thousand tons) that represents the proportion of hazardous chemicals and the seventh line (981.1 ten thousand tons) that represents population distribution can decrease the capacity because different kinds of oil cause different accident loss and the increase of workers cause higher

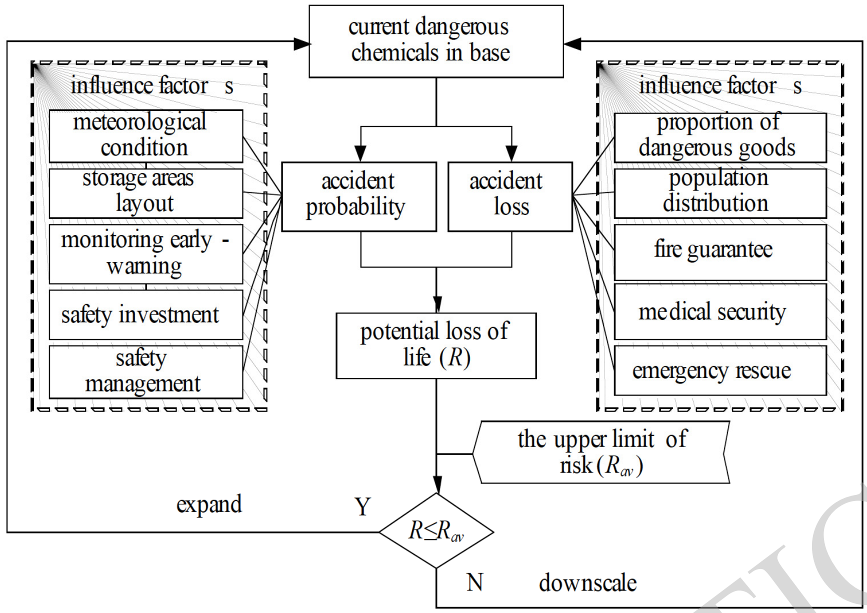

Fig. (2). Schematic diagram of model construction of factors influencing safety capacity in petrochemical base.

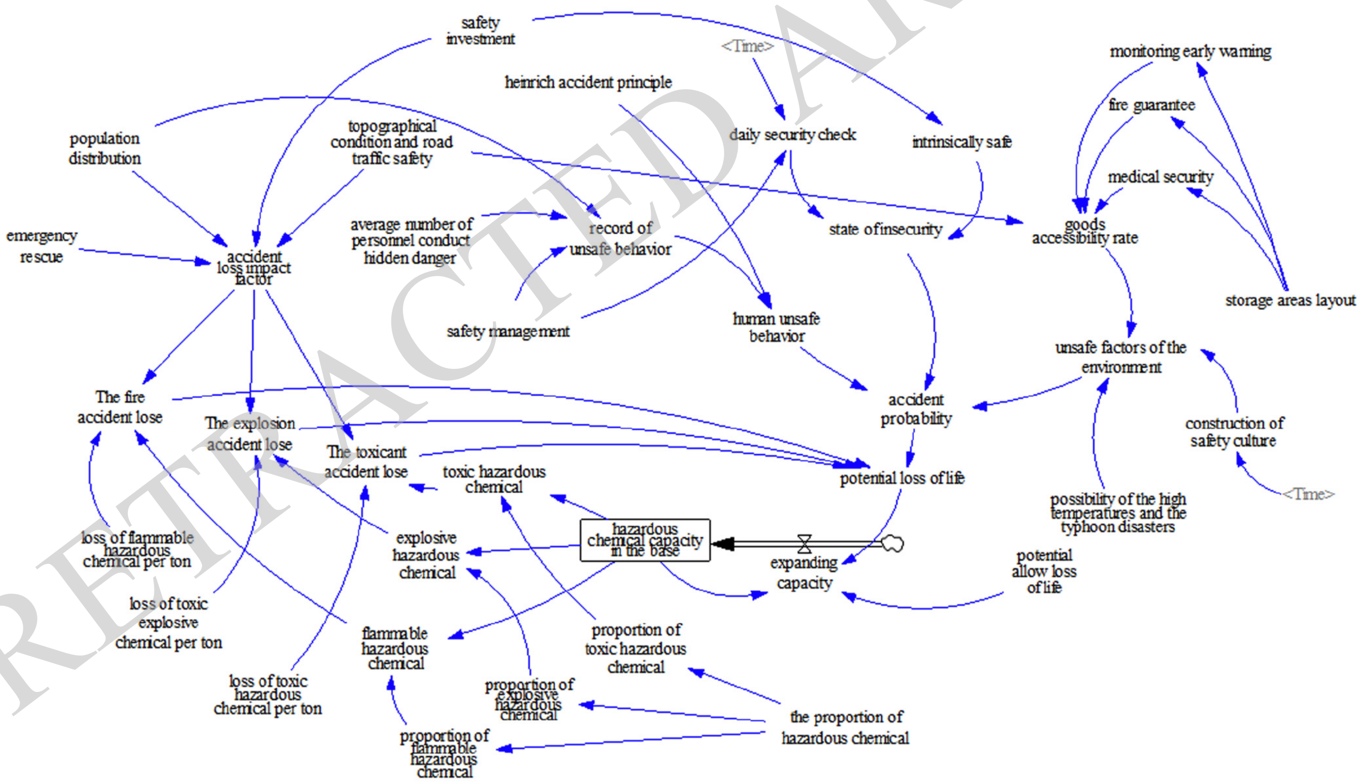

Fig. (3). The simulation diagram of system dynamic of safety capacity in petrochemical base.

cost. As a result, the proportion of hazardous chemicals and population distribution cannot be adjusted alone. The second line (1139.3 ten thousand tons) represents storage areas layout, and it can be just adjusted at the beginning of reservoir construction. The fifth line (1239.0 ten thousand tons) that represents topographical and traffic conditions, the sixth line (1246.4 ten thousand tons) that represents emergency rescue, the eighth line(1246.4 ten thousand tons) that represents safety investment can be greatly adjusted. And they relate to the hard environment facilities and emergency resource allocation, so they are important factors for safety capacity. The third line (1167.5 ten thousand tons) that represents safety management can be easily improved, so it also an important factor. The first line (1270.4 ten thousand tons) represents the combined program. It can greatly change the capacity and is better than any other single factor.

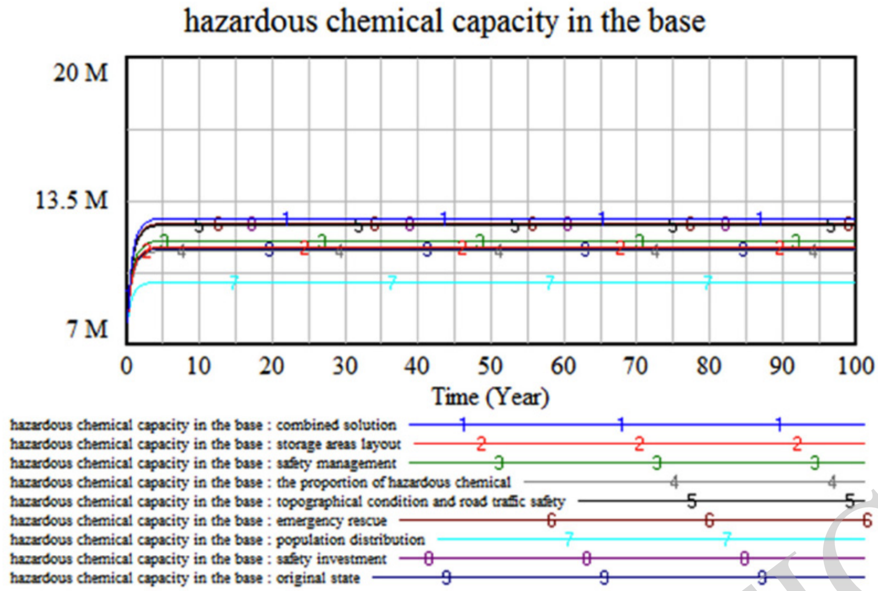

Fig. (4). The effect diagram of safety capacity under the conditions of different factors.

CONCLUISION

(1) The interpretive structural model of impact factors of safety capacity in petrochemical base was established. The hierarchical structure of each factor was obtained. The complex relationship among each factor and the importance of safety capacity were clarified, which can provide theoretical guidance for administrative authority to scientifically regulate and control safety capacity.

(2) Through the ISM analysis, it is found that safety management and emergency rescue are the key factors affecting safety capacity. The safety capacity of petrochemical base can be effectively increased by strengthening safety management and improve emergency rescue capabilities.

(3) The short and long term goals of enterprises will restrict factors that we can change. The impacts of different factors on the safety capacity are different from each other in the respect of time, manner and impact degree. The combination program is most appropriate.

(4) The factors that affect the safety capacity in the petrochemical base interact each other, the combination program can avoid disturbance to the system equilibrium from a single factor.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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