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Research on the Risk Assessment of Hazardous Chemical Supply Chain and the Application

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Hazardous chemical has the characteristics of easy explosion, toxicity, corrosiveness etc. These characteristics make dangerous chemical not only causing harm to the human body, but also polluting the environment. With the development of the global economy, the application of hazardous chemical is more and more widely. Compared with the traditional supply chain, the hazardous chemical supply chain has more potential factors and faces more risks. These potential risks threaten life and property safety. This is also a great challenge to the management of hazardous chemical, especially the management of the hazardous chemical supply chain. In order to assess the risk of hazardous chemical supply chain, we propose an improved AHP algorithm in this paper. This algorithm combines the PSO algorithm with AHP to improve the traditional AHP algorithm. After that, we apply the improved AHP algorithm to assess the risk of the hazardous chemical supply chain and get good results.

1. Introduction

The safety of hazardous chemical has become an international problem (Terwoert et al., 2016). Due to the continuous upgrading of the industrial chain, the trend of international industrial transfer is strengthening. In the process of production, transportation and storage, there are many risks in dangerous chemical supply chain due to the particularity of the goods. Using the thought of supply chain management to guide the hazardous chemical supply chain management brings a new opportunity for the hazardous chemical (Caroline, 2013). But we need to be aware that there are still many risks in the hazardous chemical supply chain. In order to ensure the safe operation of hazardous chemical supply chain, reduce the loss of personnel and cost, we must assess the risk of dangerous chemical supply chain.

In the links of production, storage, transportation, use and waste disposal, there is no negligence of the security risks. For the management of the hazardous chemical supply chain, we need not only the supervision of relevant departments, but also the cooperation among different disciplines. Compared with other supply chain, the risk management of hazardous chemical supply chain has the particularity of risk type, risk identification and so on (Börjeson et al., 2015; Fu et al., 2016; Jiang et al., 2016; Shi et al., 2016; Tan, 2016; Zheng et al., 2016; Ji and Lan, 2016; Wang and Hao, 2016; Tao, 2016.). In the present study, many scholars have studied the risk assessment of supply chain, but the risk assessment of hazardous chemical supply chain is less. However, the risk of dangerous chemical supply chain is more extensive and it results in more serious consequences. Because of the particularity of hazardous chemical, the risk identification and the control of the hazardous chemical supply chain is a common topic of the whole society.

AHP is a very practical method, which combines qualitative description and qualitative analysis. At present, AHP is widely applied in chain risk assessment (Dong et al., 2016), economy development level evaluation (Duan et al., 2016), supplier selection (Dweiri et al., 2016) and so on. PSO is proposed from the simulation of bird hunting behavior search strategy (Lin et al., 2015). In PSO, the solution of each optimization problem is called particle. Each particle has its own position, velocity and the fitness value. The particle swarm follows the current optimal particle to search in the solution space. At present, the PSO method has been applied in many fields (Dong et al., 2017; Kesavan et al., 2016; Tian et al., 2017).

In this paper, we propose an improved AHP method to assess the risk of hazardous chemical supply chain. This method combines AHP with PSO method so as to assess the risk of the hazardous chemical supply

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chain better. The first part of this paper is the introduction. The first part mainly introduces the research background of this paper. The second part is the risk assessment of hazardous chemical supply chain. In the second part, we set up the risk assessment indexes of dangerous chemical supply chain. The third part introduces the PSO algorithm. The fourth part is the improved AHP algorithm. In this part, we propose an improved AHP algorithm. The fifth part is the experiment and the sixth part is the conclusion.

2. The risk assessment index of dangerous chemical supply chain

Assessing the risk of hazardous chemical supply chain is a complex system assessment. The assessment involves more content and the factors will be considered more. Scientific and reasonable index of risk assessment of hazardous chemical supply chain not only related to the quality of the hazardous chemical supply chain evaluation work, but also the safety management of the operation of the hazardous chemical unit. The establishment of indicators must be reasonable and can fully reflect the impact of hazardous chemical supply chain of all factors. The risk assessment index of dangerous chemical supply chain is shown as the Table 1.

Table 1: The risk assessment index of dangerous chemical supply chain

First grade index	Second grade index	Third grade index
Dangerous chemical supply chain risk	Contingency management	Hazard identification
		Monitoring and early warning
		Emergency plan
		Resource allocation
		Emergency rescue
		Emergency recovery capability
	Risk source index	Quantity of dangerous goods
		Hazardous substance toxicity
		Inflammable and explosive dangerous goods
		Dangerous goods operating pressure
	Vulnerability index	Distance from densely populated areas
		Population density
		Environmental sensitivity
	Logistics risk	Transportation risk
		Storage risk
		Delivery risk
	Enterprise risk	Enterprise safety level
		Comprehensive management evaluation
		Staff quality
		Working environment
		Outsourcing risk
		Strategic risk
		Supplier selection risk
	Other risks	Technical risk
		Natural disaster
		Policy risk
		Reputation risk

3. PSO

The space is n dimensions. The position of i(i=1, 2,…, n) is $x_i=(x_{i1}, x_{i2},\ldots, x_{iN})^T$ and the vector is $x_i=(x_{i1}, x_{i2},\ldots, x_{iN})^T$. The update formulas of the speed and the position are

$$v_{id}^{(k+1)} = v_{id}^{k} + c_1 r_1 (p_{id}^{(k)} - x_{id}^{k}) + c_2 r_2 (p_{gd}^{k} - x_{id}^{k}) \tag{1}$$

$$x_{id}^{(k+1)} = x_{id}^{k} + v_{id}^{(k+1)} \tag{2}$$

k is the iteration number. p_{id}^k is the individual extremum of the *i-th* particle at *k-th* iteration. p_{gd}^k is the global extremum of the *i-th* particle at *k-th* iteration. c_1 and c_2 are acceleration constant. The rang of r_1 and r_2 is (0, 1). They are the independent functions.

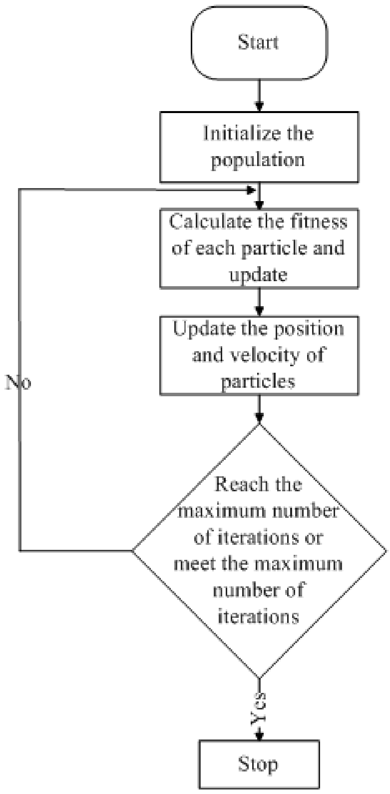

Figure 1: The flow chart of PSO

4. Improved AHP

We first establish the evaluation index structure model. This model includes destination layer, criterion layer and scheme layer. After establishing the evaluation index, we construct the judgment matrix $Ra=\{a_{ij}\}_{n\times m}$.

$$Ra=\{a_{ij}\}_{n\times m}=\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \tag{3}$$

The weights are w_i(i=1, 2,…, n). Where

$$w_i>0,\sum_{i=1}^{n} w_i=1 \tag{4}$$

According to the judgment matrix*Ra*, we know

$$a_{ik}=w_i/w_k\,,i=1,2,\cdots,n;k=1,2,\cdots,n \tag{5}$$

At the same time, the judgment matrix Ra meets

$$a_{ij}=w_i/w_j=1 \tag{6}$$

$$a_{ki}=1/a_{ik}=w_k/w_i \tag{7}$$

$$a_{ki}\cdot a_{kj}=(w_i/w_k)/(w_k/w_j)=w_i/w_j=a_{ij} \tag{8}$$

According to the judgment matrix*Ra*, we can get the weights of each evaluation index w_i(i=1, 2,…, n). If the judgment matrix satisfies the formula 5, the decision maker can measure it accurately. The judgment matrix Ra has complete consistency

$$\sum_{i=1}^{n}(a_{ik}w_k)=\sum_{i=1}^{n}(w_i/w_k)w_k=nw_i, i=1,2,\cdots,n \tag{9}$$

$$\sum_{k=1}^{n}[\sum_{k=1}^{n}(a_{ij}-w_k-nw_i)]=0 \tag{10}$$

In general, the judgment matrix*Ra* does not have complete consistency in real life. If the judgment matrix does not satisfy the consistency, we have to make some adjustments to the judgment matrix until it meets the consistency.
The left of formula 10 shows the consistency of the judgment matrix. If it is close to 0, the consistency of judgment matrix*Ra* has a high degree of the consistency. Therefore, the consistency of the judgment matrix is transformed into a linear optimization problem with constraints

$$\min CIF(n)=\sum_{k=1}^{n}\left|\sum_{k=1}^{n}(a_{ik}w_k-nw_i)\right|\Big/ n \tag{11}$$

$$s.t. w_k>0, k=1,2,\cdots,n, \sum_{k=1}^{n}w_k=1 \tag{12}$$

CIF(n) is the coherence function and the weights are w_i(i=1, 2,…, n). When the judgment matrix Ra is completely consistent, the formula 11 takes the global minimum *CIF*(n)=0. According to the constraint condition, the global minimum is unique.
Then, we use the improved PSO algorithm for consistency checking, that is, to optimize *CIF*(n). When *CIF*(n)is smallest, the judgment matrix has the highest degree of consistency. At the same time, *CIF*(n)is the fitness of the PSO.

$$\begin{aligned} v_{id}^{k+1}=wv_{id}^{k}&+[(c_{1f}-c_{1i})\frac{iter}{Iter-\max}+c_{1i}]r_1[\xi_l(p_{id}^{k}-x_{id}^{k})+\xi_{l-1}(p_{id}^{(k-1)}-x_{id}^{k-1})]\\ &+[(c_{2f}-c_{2i})\frac{iter}{Iter-\max}+c_{2i}]r_2[\xi_l(p_{gd}^{k}-x_{id}^{k})+\xi_{l-1}(p_{gd}^{k-1}-x_{id}^{k-1})]\end{aligned} \tag{13}$$

$$x_{id}^{k+1}=x_{id}^{k}+v_{id}^{k+1} \tag{14}$$

Where
c_{1i} and c_{1f} are the initial value and the final value of c_1 respectively. c_{2i} and c_{2f} are the initial value and the final value of c_2 respectively.
Improved AHP algorithm steps are as follows.
Step 1. Construct the index structure model.
Step 2. Construct the judgment matrix.
Step 3. Determinate the objective function $CIF(n)$.
Step 4. Weight values w_i(i=1, 2,…, n) are used as the optimization variable to encode the real value. The number of digits is determined by the dimension of the weights. Among them, each parameter value plus restrictions to ensure that the parameters are in the range of (0, 1). And they must meet the normalization conditions.
Step 5. Population is initialized. The population represents the sets which meet the judgment matrices. The real coded strings which are generated randomly represent a set of parameter values.
Step 6. The fitness is calculated according to the objective function to test the consistency of the judgment matrix.
Step 7. Iterative optimization is operated by improved PSO algorithm. If the precision requirement is met or the number of iterations is reached, the iteration is terminated.
Step 8. The evaluation results are obtained according to the index weight.

5. Experiment

In the experimental stage of this paper, we assess the hazardous chemical supply chain risk of four companies. Through the improved AHP algorithm, we first calculate the weights of each index which meet $CIF(n) < 0.001$. The weights of each index are shown in the following table.

Table 2: The weights of each index

Second grade index	Weights	Third grade index	Weights
Contingency management	0.21	Hazard identification	0.15
		Monitoring and early warning	0.19
		Emergency plan	0.13
		Resource allocation	0.11
		Emergency rescue	0.23
		Emergency recovery capability	0.19
Risk source index	0.26	Quantity of dangerous goods	0.21
		Hazardous substance toxicity	0.25
		Inflammable and explosive dangerous goods	0.31
		Dangerous goods operating pressure	0.23
Vulnerability index	0.19	Distance from densely populated areas	0.46
		Population density	0.27
		Environmental sensitivity	0.27
Logistics risk	0.14	Transportation risk	0.33
		Storage risk	0.34
		Delivery risk	0.33
Enterprise risk	0.12	Enterprise safety level	0.18
		Comprehensive management evaluation	0.16
		Staff quality	0.15
		Working environment	0.13
		Outsourcing risk	0.10
		Strategic risk	0.16
		Supplier selection risk	0.12
Other risks	0.08	Technical risk	0.38
		Natural disaster	0.27
		Policy risk	0.14
		Reputation risk	0.21

After that, we can get the hazardous chemical results supply chain risk assessment of four companies. The results are shown as the Table 3.

Table 3: The evaluation results of four companies

Company	A	B	C	D
evaluation results	0.7682	0.7053	0.7412	0.7829

Therefore, the ranking of the four companies is $D > A > C > B$

6. Conclusion

The emergence of chemical has brought a great help to the development of society. When people enjoy the convenience of chemical, the safety of hazardous chemical is in sight. The emergence of the supply chain management has promoted the development of supply chain. Apply the supply chain management to the chemical supply chain can bring great convenience. However, there is a huge security hidden in the hazardous chemical supply chain due to the special nature of chemical. Therefore, it is necessary and urgent to assess the risk of hazardous chemical supply chain. In this paper, we propose an improved AHP algorithm to assess the risk of hazardous chemical supply chain. The assessment results show that the method is correct and effective. The main contents of this paper includes (1) the research background of this paper is introduced (2) the evaluation index of is proposed (3) An improved AHP method is proposed and we use this method to assess the risk of dangerous chemical supply chain.

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