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Research on Optimization of Location-Logistics of Hazardous Chemicals Waste Based on Uncertainty Conditions

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Based on the full study of the existing literature, in order to effectively solve the technical problems related to the location-transportation routing of hazardous chemicals waste, the multi-objective optimization model of risk, cost and risk equity of transportation and location is established in this paper with considerations of chemicals waste output and uncertainty of processing technologies. This model is verified using an example. Based on the triangular fuzzy membership function, the output of chemicals waste is described by fuzzy description and the measurement methods for location-routing risk equity is constructed. With considerations of the variable costs of the waste disposal center and the location risk, the computational model optimizes the single-objective calculation error. Multi-objective fuzzy model is transformed into multi-objective linear model by using inverse fuzzy algorithm. The results of the case study show that when the variable cost is not considered, the total risk increases by 110.68%; when the location risk is not considered, the total cost increases by 21.35%; when the risk equity is not considered, the total cost decreases by 8.71% and the risk increases by 48.32%. It is proved that the combination optimization of the established multi-objective function will lead to a slight increase in costs, but it will significantly reduce the related risks, so that the location-routing planning scheme can be more consistent with the actual situation and needs.

1. Introduction

Hazardous chemicals waste refers to dangerous substances that are inflammable, explosive, easily corrosive, easily infected and so on. If handled improperly, it will cause serious harm to the human body and the environment. The planning of the logistics location and transportation routing will also have a serious impact on the surrounding environment, economic and regional development. Therefore, establishing and improving the chemicals waste disposal center and planning the optimal transportation route can effectively reduce the risks and costs of chemicals waste (Erkut and Ingolfsson, 2005; Abkowitz et al., 2007; Sarsam, 2013; Lim and Desai, 2010).

Hazardous Chemicals Waste Location-routing Problem (HCWLRP) is a comprehensive problem of collaborative management of multiple optimization objectives. Many scientists have optimized two or more objectives. For example, Androutsopoulos studied the storage and transportation route planning of abandoned nuclear fuel; Leonelli took into account of environmental risks and transportation costs; Xie and Pradhananga designed a process-recovery system for hazardous chemicals that took into account the compatibility of different chemical processing technologies (Androutsopoulos and Zografos, 2012; Leonelli et al., 2000; Xie and Waller, 2012; Pradhananga et al., 2010). But none of the above studies have considered location changes in storage and processing centers (Faghih-Roohi et al., 2016; Weckman, 2015), and the parameters in the model are all fixed. However, in reality, the output, chemical characteristics and processing requirements of many hazardous chemicals wastes are incomplete or inaccurate, thus there is a big error in the calculation results obtained according to the traditional multi-objective optimization algorithm (Clark and Besterfield-Sacre, 2009; Kawprasert and Barkan, 2008; Giannikos, 2007; Toumazis and Kwon, 2013; Wyman and Kuby, 2015).

Based on the full study of the existing literature, in order to effectively solve the technical problems related to the location-transportation routing of hazardous chemicals waste, the multi-objective optimization model of risk, cost and risk equity of transportation and location is established in this paper with considerations of

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chemicals waste output and uncertainty of processing technologies. The research conclusions can provide a theoretical reference for the location -routing planning of related hazardous chemicals waste.

2. Description of Related Problems

Figure 1, the location planning structure of the hazardous chemicals waste disposal center, shows the coordination and unification in location between the planning of government sector and the profit of operating enterprises. The decision-making of government sector mainly considers the risks associated with the site selection of hazardous chemicals processing centers, including demographic factors, social factors, environmental factors, and others, while the operating enterprises should also think about reducing the overall construction cost besides the above risks (Alumur and Kara, 2007; Samanlioglu, 2013).

Figure 2 shows the abstract network of the logistics structure of hazardous chemicals waste. In general, there are p pending waste disposal centers and q enterprises that are in need of the disposed hazardous chemicals wastes in the entire logistics system. The location and routing optimization of hazardous chemicals wastes refers to the multi-objective optimization with comprehensive consideration of the environmental risk, social risk, cost and the demand of enterprises, so as to improve recovery efficiency and avoid waste of resources.

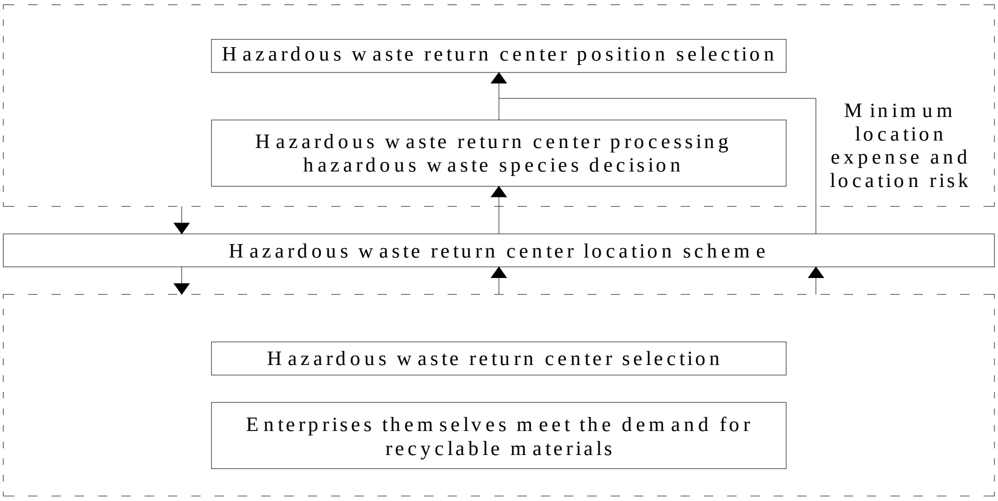

Figure 1: Location planning structure of the hazardous chemicals waste disposal center

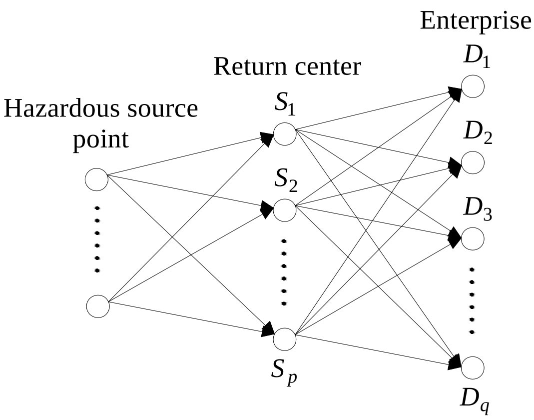

Figure 2: The abstract network of the logistics structure of hazardous chemicals waste

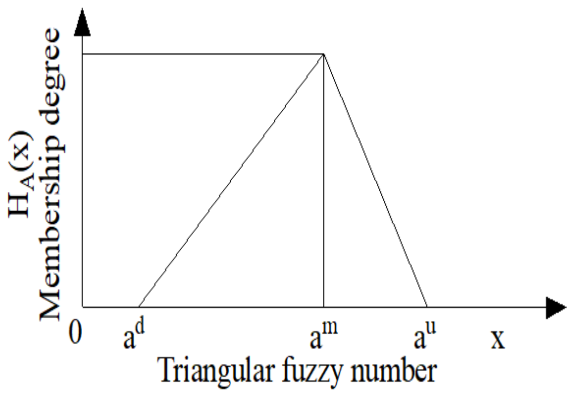

Figure 3: Triangular fuzzy membership function

The triangular fuzzy membership function can be expressed as: let X be a certain domain, A the triangular fuzzy number in X and A=(a^d, a^d, a^m, a^n), then the membership function of A, μ (x) is

$$\mu_A(x) = \begin{cases} 0, x \le a^d \\ \dfrac{x - a^d}{a^m - a^d}, a^d < x \le a^m \\ \dfrac{a^u - x}{a^u - a^m}, a^m \le x < a^u \\ 0, x \ge a^u \end{cases} \tag{1}$$

Figure 3 shows the relationship between the triangle fuzzy membership function μ(x) and the triangular fuzzy number x. This paper uses the triangle fuzzy membership function to express the uncertainty of hazardous chemicals waste.

3. Location - routing Model of Hazardous Chemicals Based on Fuzzy Multi-objective Constraint Function

The transportation network for the hazardous chemicals waste logistics system is set up and the nodes in the network include the waste source point, the candidate disposal center and the transportation node. The whole logistics system is divided into multiple regions, with different population, transportation risk and location risk in each region.

The assumptions are made as follows: hazardous chemicals waste transportation network is static; transportation route is unlimited; different kinds of chemical wastes are not transported in the same vehicle.

The fuzzy multi-objective constraint functions are set up as follows:

$$\min z_1 = \sum_{w\in W} \sum_{(i,j)\in E} a_{wij} x_{wij} + \left(\sum_{i\in T} \sum_{l\in L} b_{il} p_{il} + \sum_{w\in W} \sum_{i\in T} \sum_{l\in L} c_{wil} y_{wil} \right) \tag{2}$$

$$\min z_2 = \sum_{w\in W} \sum_{(i,j)\in E} D_{wij} x_{wij} + \sum_{w\in W} \sum_{i\in T} \sum_{l\in L} F_{il} y_{wil} \tag{3}$$

$$\min z_3 = \sum_{w\in W} \sum_{(i,j)\in E} \left(D_{wij} x_{wij} - R_E \right)^2 \tag{4}$$

$$\min z_4 = \sum_{w\in W} \sum_{i\in T} \sum_{l\in L} \left(F_{il} y_{wil} - R_V \right)^2 \tag{5}$$

$$\begin{cases} \sum_{(i,j)\in E} x_{wij} - \sum_{(j,i)\in E} x_{wji} = \hat{H}_{wi} \approx \left(h_{wi}^d, h_{wi}^m, h_{wi}^u \right), \forall w \in W, \forall i \in V \\ \alpha_{il} p_{il} \le \sum_{w\in W} y_{wil} \le \beta_{il} p_{il}, \forall w \in W, \forall i \in T, \forall l \in L \end{cases} \tag{6}$$

$$\begin{cases} y_{wil} \le \beta_{il} \Theta_{wl}, \forall w \in W, \forall i \in T, \forall l \in L \\ \sum_{w\in W} \sum_{l\in L} y_{wil} = 0, \forall i \in \left(V - T \right) \end{cases} \tag{7}$$

$$\begin{cases} p_{il} \in \{0,1\}, \forall i \in T, \forall l \in L \\ q_{wij} \in \{0,1\}, \forall w \in W, \forall (i,j) \in E \end{cases} \tag{8}$$

Formula 2 is objective function of the minimum cost, Formula 3 is objective function of the minimum risk, Formula 4 is the objective function of the minimum transportation risk difference, and Formula 5 is the objective function of the minimum location risk difference. Formula 6 is the chemical waste flow conservation constraint and maximum processing capacity constraint of equipment; Formula 7 is the compatibility constraint and location constraint; Formula 8 is the decision variable.

L is a variety of processing techniques; W is chemical waste; a_{wij} is the transportation cost of waste w on the arc(i, j); c_{wil} is the processing cost of waste w in the disposal center; D_{wij} is the total population of waste w on arc (i, j); β_{il} is the maximum processing capacity of the equipment; H_{wi} is the triangular fuzzy number; x_{wij} is the transportation volume of waste w on arc(i, j); y_{wil} is the processing amount of waste w in the disposal center.

In order to reduce the error of the solution, H_{wi} is defuzzified:

$$\hat{H}_{wi} \approx \left(h_{wi}^{d}, h_{wi}^{m}, h_{wi}^{u}\right) \approx \left[h_{wi}^{m} - \left(h_{wi}^{m} - h_{wi}^{d}\right), h_{wi}^{m}, h_{wi}^{m} + \left(h_{wi}^{u} - h_{wi}^{m}\right)\right] \tag{9}$$

$$d\left(\hat{H}_{wi}, o_1\right) = h_{wi}^{m} + \frac{\left(h_{wi}^{u} - h_{wi}^{m}\right) - \left(h_{wi}^{m} - h_{wi}^{d}\right)}{4} = \frac{2h_{wi}^{m} + h_{wi}^{d} + h_{wi}^{u}}{4} \tag{10}$$

$$\sum_{(i,j)\in E} x_{wij} - \sum_{(j,i)\in E} x_{wji} = \hat{H}_{wi} \approx \left(h_{wi}^{d}, h_{wi}^{m}, h_{wi}^{u}\right), \forall w \in W, \forall i \in V \tag{11}$$

The HCWLRP becomes a mixed linear optimization model after the conversion from Formula 9 to Formula 11, and the objective function is optimized for three sub-objectives of cost, transportation and location risk. Since the dimensions of these three sub-objectives are different, they must be transformed. Let Z (X) be the total objective function optimized for a multi-objective function, $z_i(x)$ be the three sub-objective functions and R be a feasible region, then it is known that when both Z (X) and $z_i(x)$ have the optimum solution, there must be Z (X) $>z_i(x)$, and then the fuzzy optimization algorithm is used to transform the multi-objective optimization problem of Z (X) into a single-objective optimization problem. The design optimization algorithm steps are as follows:
(a) Let X = {x, y, p, q} be the decision variable; input the corresponding parameters in the calculation model to calculate H_{wi}, R_E and other public information;
(b) Calculate the optimal solution of the three sub-objective functions respectively;
(c) Transform the multi-objective optimization problem into a single-objective optimization problem.

$$\max \lambda \,\text{s.t.} \begin{cases} z_i(X) + n_i^- - n_i^+ = z_i^* \\ \dfrac{n_i^-}{z_i^u - z_i^m} + \dfrac{n_i^+}{z_i^u - z_i^m} + \lambda \le 1 \\ \lambda, n_i^-, n_i^+ \ge 0 \\ X \in R, i = 1, \cdots, 4 \end{cases} \tag{12}$$

(d) Find the compromise of multi-objective function and output the optimization scheme.

4. Example Verification

A practical example is selected to verify the calculation model proposed in this paper. The example is as shown in Figure 4; there are 10 nodes and 20 transport channels in the network. Node 1-3 are the source points of hazardous chemicals waste, Node 4-Node 6 are the candidate construction sites for the hazardous waste disposal center, and Node 7-10 are the transport nodes.

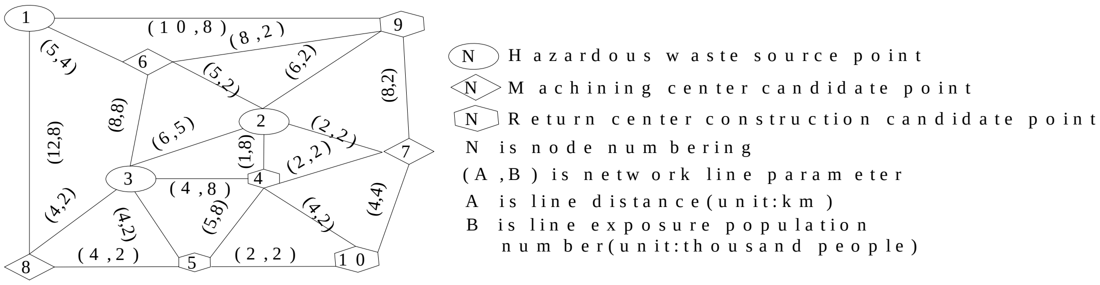

Figure 4: Hazardous chemicals waste storage - transportation network

Suppose there are 3 kinds of hazardous chemicals waste, and the triangular fuzzy number of the annual waste output at the three source points is as shown in Table 1.
Table 5 shows the solution for combinations of several single-objective optimization functions, from where it can be seen that when the variable cost is not considered, the total risk increases by 110.68%; when the location risk is not considered, the total cost increases by 21.35%; when the risk equity is not considered, the total cost decreases by 8.71% and the risk increases by 48.32%, indicating that The location-routing algorithm of hazardous chemicals wastes proposed in this paper can effectively optimize the single objective function,

and the combination optimization of the established multi-objective function will lead to a slight increase in costs, but it will significantly reduce the related risks, so that the location-routing planning scheme can be more consistent with the actual situation and needs.
The transport costs per kilometer for three kinds of chemical wastes are 26, 32 and 21 Yuan per ton, respectively. The information on hazardous chemicals waste disposal centers is shown in Table 2.
According to the calculation model in the third section, the optimization calculation results of functions of the 4 sub-objectives, including cost, risk, location and transportation, are as shown in Table 3.
The fuzzy optimization algorithm is used to transform the results in Table 3, and the corresponding compromise solution obtained is as shown in Table 4.

Table 1: Triangular fuzzy number of annual outputs of three kinds of chemical wastes

Hazarhous source	Annual output/t		
	Hazarhous 1	Hazarhous 2	Hazarhous 3
1	(550,650,750)	(200,300,600)	(180,450,700)
2	(280,550,640)	(240,600,850)	(600,750,800)
3	(230,350,600)	(900,950,1050)	(450,550,650)

Table 2: Information on the candidate disposal center for hazardous chemicals waste

Candidate point	Fixed cost/million yuan•a^{-1}	Variable cost/yuan•t^{-1}			Minimum processing capacity/t•a^{-1}	Maximum processing capacity/t•a^{-1}	Exposure population number/10^3
		Hazarhous 1	Hazarhous 2	Hazarhous 3			
3	60	300	400	500	1200	6500	4
4	40	300	400	500	1800	6500	5
5	70	300	400	500	1500	6500	3

Table 3: Optimization calculation results of the functions of the 4 sub-objectives

Target	The maximum value	The minimum value	Difference
Cost/million yuan	1.4812×10^{6}	271.4456	1480928.5544
Risk/million people•t	5.0048×10^{7}	2.7381×10^{3}	50045261.9
Location risk fairness	2.4672×10^{16}	1.6173×10^{13}	2.4656×10^{16}
Transportation risk fairness	7.5833×10^{21}	1.1191×10^{13}	7.58329×10^{21}

Table 4: Optimization calculation results of multi-objective constraint function

Single target	Cost/million yuan	Risk/million people•t	Location risk fairness	Transportation risk fairness	Machining center location
Target vaule	330.2617	2.7238×10^{3}	1.6012×10^{13}	2.3584×10^{13}	(7,2),(9,2)

Table 5: Comparison of optimization results of three kinds of multi-objective constraint functions

Project	Cost/million yuan	Change percentage/%	Risk/million people•t	Change percentage/%
Without onsidering variable cost	/	/	5.5645×10^{3}	+110.6795
Without considering location risk	3.4672×10^{2}	+21.3544	/	/
Without considering risk fairness	2.9519×10^{2}	-8.7088	3.8427×10^{3}	+48.3167

5. Conclusions

Based on the full study of the existing literature, in order to effectively solve the technical problems related to the location-transportation routing of hazardous chemicals waste, the multi-objective optimization model of risk, cost and risk equity of transportation and location is established in this paper with considerations of chemicals waste output and uncertainty of processing technologies. This proposed model is verified using an example, and the research conclusions are as follows:
Based on the triangular fuzzy membership function, the output of chemicals waste is described by fuzzy description and the measurement methods for location-routing risk equity is constructed. With considerations of the variable costs of the waste disposal center and the location risk, the computational model optimizes the single-objective calculation error.

(2) Multi-objective fuzzy model is transformed into multi-objective linear model by using inverse fuzzy algorithm. The results of the case study show that when the variable cost is not considered, the total risk increases by 110.68%; when the location risk is not considered, the total cost increases by 21.35%; when the risk equity is not considered, the total cost decreases by 8.71% and the risk increases by 48.32%. It is proved that the combination optimization of the established multi-objective function will lead to a slight increase in costs, but it will significantly reduce the related risks, so that the location-routing planning scheme can be more consistent with the actual situation and needs.

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