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Optimization of Hazardous Chemical Waste Location-Routing Logistics Based on Uncertain Conditions

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In order to effectively solve the hazardous chemical waste location-routing problem, based on the existing literatures, this paper considers chemical waste production and uncertainties in the processing technology, and establishes a multi-objective optimization calculation model involving transportation and location risks, costs and risk equity. It uses an example to verify the proposed model, and then establishes a measurement method with location-routing risk equity based on the fuzzy description of the chemical waste production by the triangular fuzzy membership function. The calculation model takes into account the variable cost and location risk of the waste disposal centre, reducing the error from single-objective calculation. Through the inverse fuzzy algorithm, the multi-objective fuzzy model is converted into a multi-objective linear model. The verification results of the example show that: if the variable cost is not considered, the total risk is increased by 110.68%; if the location risk is not considered, the cost is increased by 21.35%; if the risk equity is not considered, the total cost is decreased by 8.71%, while the risk is increased by 48.32%, which proves that the combinatorial optimization of multi-objective function model established will lead to a slight increase in cost, but a significant reduction of related risks, thus making the location-routing scheme more in line with the actual situation and needs.

1. Introduction

Hazardous chemical waste refers to hazardous substances that are flammable, explosive, corrosive and infectious. Improper handling of such waste can cause serious harm to human bodies and the environment, and improper planning of logistics location and transportation routes will also seriously affect the surrounding environment and local economic and regional development. Therefore, establishing a sound chemical waste disposal centre and planning the best transportation route can effectively reduce the risks and costs of chemical waste (Erkut and Ingolfsson, 2005; Abkowitz et al., 2007; Sarsam, 2013; Lim and Desai, 2010).

Hazardous Chemical Waste Location-routing Problem (HCWLRP) is a comprehensive problem about collaborative management of multiple optimization goals. Many scientists attempted to optimize two or more objectives. For example, Androutsopoulos studied the storage and transportation route planning of spent nuclear fuel; Leonelli took both environmental risks and transportation costs into account; Xie and Pradhananga designed a disposal-recovery system for hazardous chemicals that considers the compatibility of different chemical processing technologies (Androutsopoulos and Zografos, 2012; Leonelli, Bonvicini and Spadoni, 2000; Xie and Waller, 2012; Pradhananga, Taniguchi and Yamada, 2010). However, none of the above research methods considered the location changes of storage and disposal centres (Faghih-Roohi et al., 2016; Weckman, 2015), and the parameters in the models were all fixed values. In many cases in practice, the production, chemical characteristics and disposal requirements of hazardous chemicals are all incomplete or inaccurate, and as a result, the calculation results from the traditional multi-objective optimization algorithms have great errors (Clark and Besterfield-Sacre, 2009; Kawprasert and Barkan, 2008; Giannikos, 2007; Toumazis and Kwon, 2013; Wyman and Kuby, 2015).

In order to effectively solve the hazardous chemical waste location-routing problem, based on the existing literatures, this paper considers chemical waste production and uncertainties in the processing technology, and establishes a multi-objective optimization calculation model involving transportation and location risks,

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costs and risk equity. The research conclusions can serve as theoretical reference for the location-routing planning of hazardous chemical waste.

2. Problem description

Figure 1 shows the location planning map of a hazardous chemical waste treatment centre. It is the result of coordination and alignment between the government planning and the operating company's profitability. The government mainly considers the risks associated with the location of the hazardous chemicals processing centre, including demographic, social and environmental factors, while the operating company also considers minimizing the overall construction and operation costs besides the above risks (Alumur and Kara, 2007; Samanlioglu, 2013).

Figure 2 shows an abstract network diagram of the hazardous chemical waste logistics structure. In general, there are p waste disposal centres in the entire logistics system for selection and q companies that have demands for treated hazardous chemical waste. The location-routing optimization problem is to optimize multiple objectives by taking into account the environmental risk, social risk, cost, and type of wastes required by enterprises, so as to improve the recycling efficiency and avoid waste of resources.

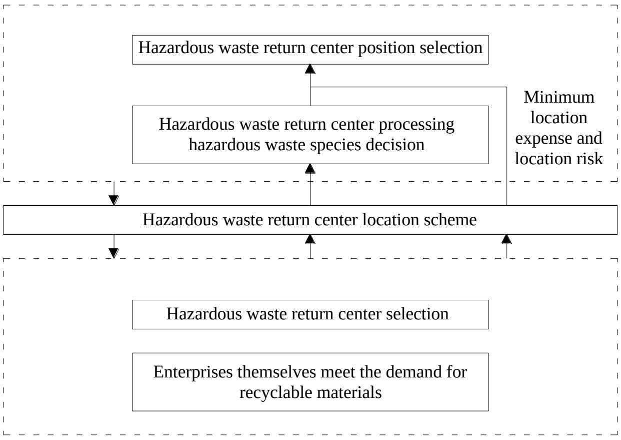

Figure 1: Location planning map of the hazardous chemical waste disposal centre

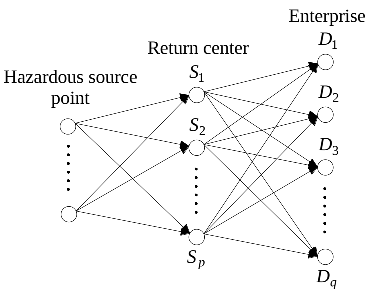

Figure 2: Abstract network diagram of the hazardous chemical waste logistics structure

The triangular fuzzy membership function can be expressed as: let X be a domain of definition, A be a triangular fuzzy number within X and A= (ad, ad, am, an), and then the membership function μ(x) of A is as follows:

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

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

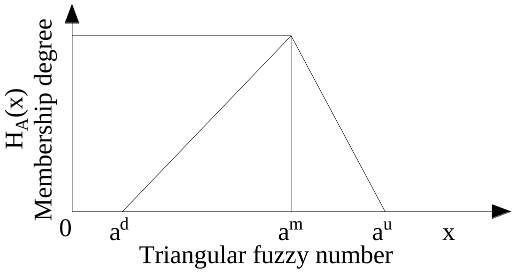

Figure 3: Triangular fuzzy membership function

3. Hazardous chemicals location-routing model based on fuzzy multi-objective constraint function

A transportation network is established for the hazardous chemical waste logistics system, which contains nodes like the waste sources, candidate disposal centres and transport nodes. The entire logistics system is divided into multiple regions, and all these regions have different populations, transportation risks and location risks.

Let us make the following assumptions: the hazardous chemical waste transport network is static; there are no restrictions on the transport route; and each vehicle does not carry more than one type of chemical waste.

The fuzzy multi-objective constraint function is established as follows:

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

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

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

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

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

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

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

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

L refers to all kinds of processing technologies; W is chemical waste; awij is the transportation cost of waste won the arc (i, j); cwil is the processing cost of waste w at the disposal centre; Dwij is the total population of waste won the arc (i, j); βil is the maximum processing capacity of the equipment; Hwi is the triangular fuzzy number; xwij is the transport amount of waste won the arc (i, j); and ywil is the processing amount of waste w at the disposal centre.
In order to reduce the solution error, Hwi is defuzzified:

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

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

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

After the transformations from Equation 9 to 11, the HCWLRP is changed into a hybrid linear optimization model. The optimization objective function has three sub-objectives - cost, transportation, and location risks. Due to their different dimensions, they must be transformed. Let Z(X) be the overall objective function for the multi-objective function optimization, zi(x) is the three sub-objective functions, and R is the feasible domain. Then we can see that when both Z(X) and zi(x) have the optimal solution, there must be Z(X)>zi(x). So, the fuzzy optimization algorithm is used to transform the multi-objective optimization problem of Z(X) into a single-objective optimization problem. The steps to design the optimization algorithm are as follows:
(a) Let X = {x, y, p, q} be the decision variable; input corresponding parameters into the calculation model, and calculate Hwi and RE, etc.;
(b) Calculate the optimal solution to each of the three sub-objective functions, respectively;
(c) Transform the multi-objective optimization problem into a single-objective optimization problem

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

(d) Obtain the compromise solution to the multi-objective function and output the optimization scheme.

4. Example verification

An actual example is used to verify the calculation model presented in this paper. The example is shown in Figure 4. There are 10 nodes and 20 transport channels in the network. Nodes 1 - 3 are the hazardous chemical waste source points; nodes 4 - 6 are the candidate construction points for hazardous waste disposal centre, and nodes 7 - 10 are the transport nodes.

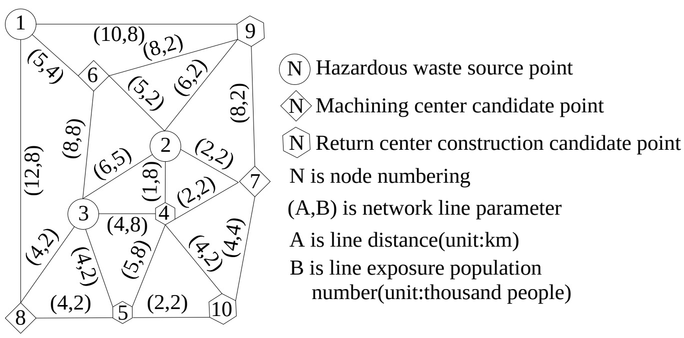

Figure 4: Hazardous chemical waste storage-transport network structure diagram

There is a total of 3 kinds of hazardous chemical wastes, and the triangular fuzzy numbers of the annual productions of the wastes at the three sources are shown in Table 1.

Table 1: Triangular fuzzy numbers of the annual productions of the three chemical wastes

Hazardous source Annual output/t 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)

The transportation costs of the three kinds of chemical wastes per kilometre are 26, 32 and 21 RMB per ton, respectively. Information on the candidate hazardous chemical waste disposal centres are listed in Table 2.

Table 2: Information on the candidate disposal centres for hazardous chemical 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/103
		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

With the calculation model proposed in Section 3, the optimized -calculation results of the 4 sub-objective functions involving cost, risk, location, and transportation are shown in Table 3.

Table 3: Optimized calculation results of 4 sub-objective functions

Target	The maximum value	The minimum value	Difference
Cost/million yuan	1.4812×106	271.4456	1480928.5544
Risk/million people•t	5.0048×107	2.7381×103	50045261.9
Location risk fairness	2.4672×1016	1.6173×1013	2.4656×1016
Transportation risk fairness	7.5833×1021	1.1191×1013	7.58329×1021

The results in Table 3 are transformed with the fuzzy optimization algorithm to form the corresponding compromise solution, as shown in Table 4.

Table 4: Optimized calculation result of the 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	2.7238×103	1.6012×1013	2.3584×1013	(7,2), (9,2)

Table 5 shows the problem combining several single-objective optimization functions. As seen from the table, if the variable cost is not considered, the total risk is increased by 110.68%; if the location risk is not considered, the cost is increased by 21.35%; if the risk equity is not considered, the total cost is decreased by 8.71%, while the risk is increased by 48.32%, which proves that the hazardous chemical waste location-routing algorithm proposed in this paper can effectively optimize single-objective functions. The combinatorial optimization of the multi-objective function will lead to a slight increase in cost, but a significant reduction of related risks, thus making the location-routing scheme more in line with the actual situation and needs.

Table 5: Comparison of the optimized calculation results of the 3 multi-objective constraint functions

Project	Cost/million yuan	Change percentage/%	Risk/million people•t	Change percentage/%
Without considering variable cost	/	/	5.5645×103	+110.6795
Without considering location risk	3.4672×102	+21.3544	/	/
Without considering risk fairness	2.9519×102	-8.7088	3.8427×103	+48.3167

5. Conclusions

In order to effectively solve the hazardous chemical waste location-routing problem, based on the existing literatures, this paper considers chemical waste production and uncertainties in the processing technology, and establishes a multi-objective optimization calculation model involving transportation and location risks, costs and risk equity. It uses an example to verify the proposed model and obtains the following conclusions:
(1) This paper establishes a measurement method with location-routing risk equity based on the fuzzy description of the chemical waste production by the triangular fuzzy membership function. The calculation model takes into account the variable cost and location risk of the waste disposal centre, reducing the error from single-objective calculation.
(2) Through the inverse fuzzy algorithm, the multi-objective fuzzy model is converted into a multi-objective linear model. The verification results of the example show that: if the variable cost is not considered, the total risk is increased by 110.68%; if the location risk is not considered, the cost is increased by 21.35%; if the risk equity is not considered, the total cost is decreased by 8.71%, while the risk is increased by 48.32%, which proves that the combinatorial optimization of multi-objective function model established will lead to a slight increase in cost, but a significant reduction of related risks, thus making the location-routing scheme more in line with the actual situation and needs.

References

Abkowitz M., Allen J., Greenberg A., Lepofsky M., and Mcsweeney T., 2007, An evolving paradigm for managing hazardous materials transportation risk. International Journal of Critical Infrastructures, 3(3-4), 268-286.
Alumur S., and Kara, B.Y., 2007, A new model for the hazardous waste location-routing problem. Computers & Operations Research, 34(5), 1406-1423.
Androutsopoulos K.N., and Zografos K.G., 2012, A bi-objective time-dependent vehicle routing and scheduling problem for hazardous materials distribution. Euro Journal on Transportation & Logistics, 1(1-2), 157-183.
Clark R.M., and Besterfield-Sacre M.E., 2009, A new approach to hazardous materials transportation risk analysis: decision modeling to identify critical variables. Risk Analysis, 29(3), 344.
Erkut E., and Ingolfsson A., 2005, Transport risk models for hazardous materials: revisited. Operations Research Letters, 33(1), 81-89.
Faghih-Roohi S., Ong Y.S., Asian S., and Zhang A.N., 2016, Dynamic conditional value-at-risk model for routing and scheduling of hazardous material transportation networks. Annals of Operations Research, 247(2), 715-734.
Giannikos I., 2007, A multiobjective programming model for locating treatment sites and routing hazardous wastes. European Journal of Operational Research, 104(2), 333-342.
Kawprasert A., and Barkan C.P.L., 2008, Effects of route rationalization on hazardous materials transportation risk. Transportation Research Record Journal of the Transportation Research Board, 2043(2043), 65-72.
Leonelli P., Bonvicini S., and Spadoni G., 2000, Hazardous materials transportation: a risk-analysis-based routing methodology. Journal of Hazardous Materials, 71(1-3), 283.
Lim G.J., and Desai, S.S., 2010, Markov decision process approach for multiple objective hazardous material transportation route selection problem. International Journal of Operational Research, 7(4), 506-529.
Pradhananga R., Taniguchi E., and Yamada T., 2010, Ant colony system-based routing and scheduling for hazardous material transportation. Procedia - Social and Behavioral Sciences, 2(3), 6097-6108.
Samanlioglu F., 2013, A multi-objective mathematical model for the industrial hazardous waste location-routing problem. European Journal of Operational Research, 226(2), 332-340
Sarsam S.I., 2013, Analysis of risk attributed to hazardous material transportation through urban arterials. , 1(2), 49.
Toumazis I., and Kwon C., 2013, Routing hazardous materials on time-dependent networks using conditional value-at-risk. Tramsportation Research Part C Emerging Technologies, 37(3), 73-92.
Weckman G., 2015, Applying genetic algorithm to a new location and routing model of hazardous materials. International Journal of Production Research, 53(3), 916-928.
Wyman M.M., and Kuby M., 2015, Proactive optimization of toxic waste transportation, location and technology. Location Science, 3(3), 167-185.
Xie C., and Waller S.T., 2012, Optimal routing with multiple objectives: efficient algorithm and application to the hazardous materials transportation problem. Computer-Aided Civil and Infrastructure Engineering, 27(2), 77–94.