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A Mathematical Model of Urban Hazardous Chemicals Logistics Distribution Route Decision Based on Improved Genetic Algorithm

Ning Li

Rongzhi College of Chongqing Technology and Business University, Chongqing 401320, China
lining01123@126.com

The purpose of this study is to reduce the safety hazards and transportation costs of urban hazardous chemicals in the logistics distribution process. To this end, based on improved genetic algorithm, this paper conducts the time window processing and multi-objective processing to solve the model and then builds one multi-objective logistics distribution route optimization model of urban hazardous chemicals. The research shows that the established logistics distribution optimization system is beneficial to multi-objective optimization of logistics distribution process; the improved genetic algorithm promotes the computational efficiency of the optimization model and avoids the solving problem of traditional genetic algorithm approaching to local optimal solution; the logistics distribution route optimization model of urban hazardous chemicals based on improved genetic algorithm is conductive to achieving the optimization goal of minimum distribution cost and minimum distribution risk. In addition, this study also verifies the scientificity and rationality of the multi-objective optimization model for logistics distribution route through the specified example. The theoretical results have significant social application value and engineering significance, which help to guide the multi-objective optimization of urban hazardous chemicals distribution route.

1. Introduction

With the rapid development of the chemical production and industrial manufacturing industries, the demand for chemicals as one of the industrial raw materials has gradually increased. In addition, in recent years, the distribution mode and area of the logistics industry have gradually expanded, and more and more chemical enterprises have chosen to distribute hazardous chemicals in logistics (Jiang and Ying, 2014; Ravibabu, 2010). Research data shows that China's annual transportation of hazardous chemicals exceeds 200 million tons, and its transportation volume is about 1% of total road logistics (Wang and Wang, 2017; Zhang et al., 2015; He et al., 2013). According to incomplete statistics from the World Health Organization, there are more than 30,000 chemicals with potential threats or obvious dangers. The logistics transportation of these corrosive, oxidizing, flammable and explosive chemicals has become a dynamic hazard, and the occurrence of transportation accident will result in huge loss of life and property, and also the adverse social influence (Ma et al., 2012). The distribution of hazardous chemicals in cities has become one of the public safety issues that cannot be ignored (Ardjmand et al., 2016; Ma et al., 2018).

For China's logistics distribution of hazardous chemicals, there still exist lots of problems such as slack transportation supervision, inadequate professional literacy of managers and employees, and imperfect logistics and transportation infrastructure (Pan et al., 2017; Chai et al., 2017). At present, there are more problems about optimization decision-making in the logistics distribution of hazardous chemicals, which has a significant impact on logistics units to improve the transportation efficiency, reduce transportation costs and ensure transportation safety (Cantú et al., 2017; Pradhananga et al., 2010; Kokkinos et al., 2012). The optimization of the logistics distribution route can reduce the occurrence probability of the safety accidents for chemical dangerous goods in the transportation process. Some scholars have adopted genetic algorithms (GA) to optimize the logistics distribution scheme, but this kind of method cannot be applied to practical engineering due to the complicated calculation process (Keskinturk and Yildirim, 2011; Liu et al., 2011). In this

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paper, the factors affecting the logistics distribution of hazardous chemicals were firstly analysed. Then, based on the improved genetic algorithm, the optimization model of the multi-objective logistics distribution route for hazardous chemicals was established and solved, so as to achieve the distribution route of chemicals with the minimum potential risk, transportation and maintenance cost in the process of logistics transportation.

2. Optimization theory of logistics distribution route

Figure 1 shows that a variety of factors such as persons, roads, vehicles and facilities, and the external environment together constitute the logistics distribution system for hazardous chemicals. In the logistics distribution process of hazardous chemicals, the influence of external risk factors and the control effects of various factors in the distribution process determine the occurrence probability of safety accidents. Therefore, it is of great theoretical and social significance for optimizing multi-objectively the logistics distribution route for hazardous chemicals, and reducing the transportation distance and time of dynamic hazard sources.

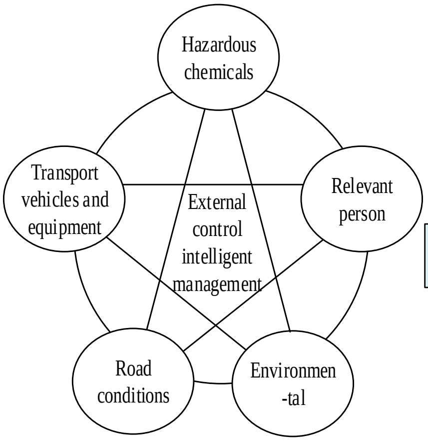

Figure 1: Logistics distribution system of dangerous chemicals

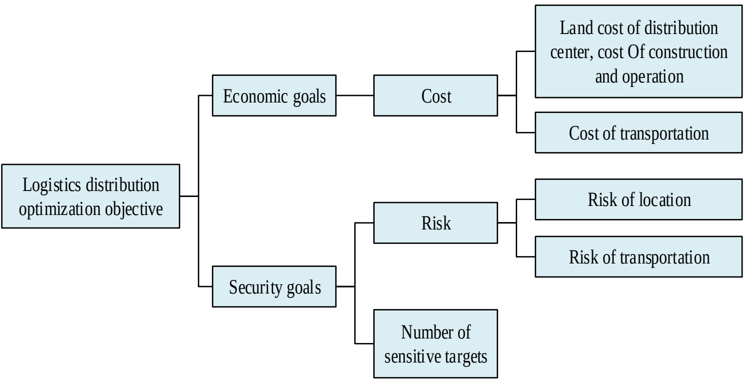

Figure 2: Target system for optimizing logistics distribution of dangerous chemicals

For hazardous chemical logistics, the maximum safety and the minimum delivery time for dynamic hazard sources is the most important optimization objective. In Figure 2, for the established optimization target system for the hazardous chemicals distribution, the optimization objectives are divided into two categories: economic goals and safety goals. It aims to achieve the minimization of cost, risk minimization, sensitive target number of people or sensitive road segments.

3. Optimization model design

3.1 Construction of the optimization model

In this paper, the optimization problem of logistics distribution route for urban hazardous chemicals can be described as follows: the distribution vehicle starts from the logistics distribution centre and delivers the dangerous chemicals of each customer to the designated place through the distribution route, and then returns to the distribution centre. The location of each customer and the quantity of hazardous chemicals are known. The distribution centre needs to arrange the distribution route according to the customer's constraints and its own conditions, so as to ensure that the objective function of logistics distribution is optimal. For the optimization model to be established, it is assumed that there is only one distribution route between the two demand points in the distribution system and no loop can be formed between the demand points, and there is only one distribution centre. Based on the above conditions, one optimization model for hazardous chemicals logistics distribution was established as follows: Formula 1 and 2 respectively indicate the lowest distribution cost and the smallest possibility of danger; Formula 3 and 4 respectively indicate that one customer has only one vehicle for distributing chemicals, and the total amount of hazardous chemicals in distribution vehicle *k* is not greater than the load capacity of the vehicle; Formula 5 represents that the vehicle entering a certain route node must leave there; Formula 6 is the time window constraint; Formulas 7-9 are variable constraints.

$$Z_1 = \min \underbrace{\sum_{i\in C}\sum_{j\in C}\sum_{k\in K} d_{ij}\cdot c_{ijk}\cdot x_{ijk}}_{1} + \underbrace{\sum_{i\in C}\sum_{k\in K} K_c \cdot x_{0ik}}_{2} + \underbrace{\sum_{i\in N}\sum_{j\in N}\sum_{k\in K}\sum_{l=1}^{\left|V_{(i,j)}\right|} G_{(i,j)}^{l}\cdot p_{ijk}^{l}\cdot x_{ijk}}_{3} \tag{1}$$

$$Z_2 = \min \sum_{i \in N} \sum_{j \in N} \sum_{k \in K} \sum_{l=1}^{\left|V_{(i,j)}\right|} v_{ijk}^{l} \cdot x_{ijk} \tag{2}$$

$$\sum_{i \in N} \sum_{k \in K} x_{ijk} = 1, \quad \forall j \in C \tag{3}$$

$$\sum_{j \in C} q_j \cdot \sum_{i \in C} x_{ijk} \le CAP, \quad \forall k \in K \tag{4}$$

$$\sum_{j \in N} x_{ijk} - \sum_{j \in N} x_{jik} = 0, \quad \forall i \in N, \quad \forall k \in K \tag{5}$$

$$ET_i \le T_{ik} \le LT_i, T_{ik} = T_{ik} + t_{ij} \cdot x_{ijk}, \forall i \in C, \forall k \in K \tag{6}$$

$$x_{ijk} = \{0,1\}, \forall i, j \in N, \forall k \in K \tag{7}$$

$$p_{ijk}^{l} = \{0,1\}, \forall i, j \in N, \forall k \in K, \forall l \in P_{(i,j)} \tag{8}$$

$$v_{ijk}^{l} = \{0,1\}, \forall i, j \in N, \forall k \in K, \forall l \in V_{(i,j)} \tag{9}$$

where: θ is the logistics distribution centre, and *i* is 0 at this time; N is the collection of each route node, $N = \{\theta\} \cup C$; *CAP* is the capacity of the distribution vehicle; K is the collection of distribution vehicles of hazardous chemicals, *k*=1, 2, …, $|K|$; K_c is the fixed cost of hazardous chemicals logistics distribution; q_i is the item demand of the *i*-th customer, i∈C. [*ETi*, *LTi*] is the time constraint of the *i*-th customer (time window requirement), ET_i and LT_i are the earliest and latest delivery times of hazardous chemicals respectively; c_{ijk} is the unit distance distribution cost of distribution vehicle from route node *i* to *j*; d_{ij} and t_{ij} are the distance and time required at route node i and j respectively; T_{ik} is the time when the delivery vehicle *k* travels to *i*.

3.2 Model solution

The time window constraints in the model were processed to punish the hazardous chemicals distribution scheme that failed to meet the time window requirements. The penalty values PF_1 and PF_2 (Formula 10) were calculated by the penalty functions Q_1 and Q_2, which together with the lowest objective function (Formula 8) of the distribution cost forms the total distribution cost. The revised model is as follows:

$$\begin{aligned} Z_3 = \min \sum_{i \in C} \sum_{j \in C} \sum_{k \in K} d_{ij} \cdot c_{ijk} \cdot x_{ijk} + \sum_{j \in C} \sum_{k \in K} K_c \cdot x_{0jk} + \sum_{i \in C} \sum_{j \in C} \sum_{k \in K} \sum_{i=j}^{\left|P_{(i,j)}\right|} G_{(i,j)}^{l} \cdot p_{ijk}^{l} \cdot x_{ijk} \\ + F_1 \cdot PF_1 + \left(1 - F_1\right) \cdot PF_2 \end{aligned} \tag{10}$$

$$F_1 = \begin{cases} 1 & T_{ik} < ET_i \\ 0 & T_{ik} < LT_i \end{cases}, \forall i \in C, \forall k \in K$$

$$\begin{aligned} PF_1 &= Q_1 \cdot \left(ET_i - T_{ik}\right), \quad T_{ik} < ET_i \\ PF_2 &= Q_2 \cdot \left(T_{ik} - LT_i\right), \quad T_{ik} > ET_i \end{aligned} \tag{11}$$

Based on the above analysis, the established model was multi-objectively processed, and the parameters in Formula 9 and 11 above were unified in dimension according to formula 12. Finally, the multi-objective optimization model was established (Formula 13).

$$Z_i^{'} = \frac{Z_i - Z_i^{\min}}{Z_i^{\max} - Z_i^{\min}}, \quad i=2, 3 \tag{12}$$

$$\text{Z} = \min \sum_{i} \omega_i \cdot Z_i^{'}, \quad i=2, 3 \tag{13}$$

3.3 Improved genetic algorithm

Genetic algorithm (GA) is a method for global search of the problem to be solved in the optimization combination. In the field of combinatorial optimization, the adaptive mutation mechanism (or adaptive function) is used to control the search results, gradually approaching to the global optimal solution. In this paper, the improved genetic algorithm was used to calculate the above optimization theory model. The content and basic flow of the improved genetic algorithm are shown in Figure 3.

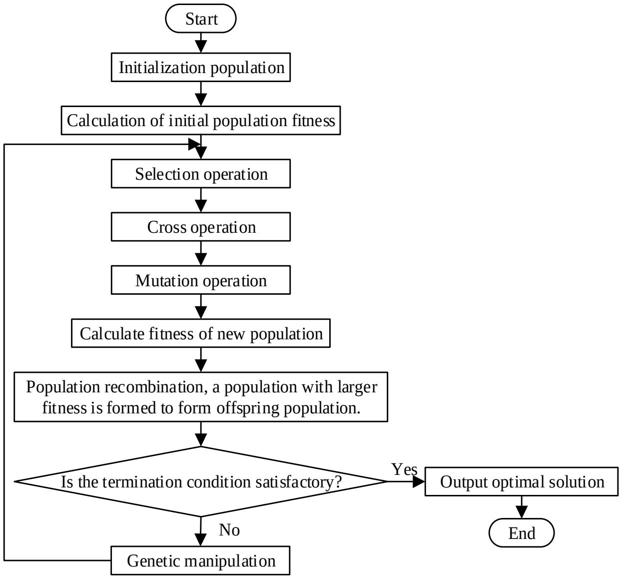

Figure 3: Steps of genetic algorithm

4. Case analysis

In this paper, an example of chemical material distribution was taken to verify the model established. Distribution Centre A can store 150 tons of chemical materials, at the location of (18,15), currently including 30 distribution vehicles with a load capacity of 20t. This centre needs to provide logistics distribution for 24 customers. Table 1 lists the geographical coordinate information of the designated location by each customer. According to the logistics distribution optimization model established above, the optimal distribution route and distribution plan were calculated, as shown in Figure 4 and Table 2, respectively. It can be seen that in the whole logistics distribution process, after the optimization based on the improved genetic algorithm, only 11 vehicles were used for the distribution of all items, and the distribution of hazardous chemicals only passed 52 dangerous areas, which has greatly reduces transportation costs and distribution risks.

Table 1: Geographic coordinates at the location of the customer's delivery

No	Demand for material (t)	Coordinates of customer (x,y)	Time window requirements of customer （ET，LT）	No	Demand for material (t)	Coordinates of customer (x,y)	Time window requirements of customer （ET，LT）
1	4.2	(12.1, 33)	(3, 14)	13	3.3	(23.9, 11)	(0, 16)
2	7.2	(7.2, 5.1)	(2, 8)	14	5.8	(40.5, 18.0)	(2, 7)
3	2.5	(2.5, 8)	(6, 11)	15	7.9	(25.6, 13)	(8, 11)
4	5.6	(5.6, 39)	(8, 19)	16	4.9	(36, 0)	(5, 13)
5	7.9	(7.9, 30)	(7, 22)	17	3.7	(41.7, 24)	(3, 18)
6	5	(5, 7.9)	(0, 8)	18	5.3	(40.8, 33.1)	(4, 16)
7	2	(2, 15)	(6, 14)	19	4.9	(52.6, 8.9)	(0, 18)
8	3.1	(3.1, 13)	(2, 20)	20	5	(2.1, 23.6)	(2, 22)
9	4.1	(4.1, 19.2)	(3, 17)	21	6.1	(2, 27.7)	(6, 17)
10	6	(6, 24.3)	(5, 9)	22	7.3	(8, 14)	(7, 12)
11	4	(15.5, 0)	(7, 16)	23	10.5	(39.2, 5)	(9, 16)
12	3	(32.8, 23.2)	(0, 23)	24	9.5	(12.4, 6.9)	(0, 17)

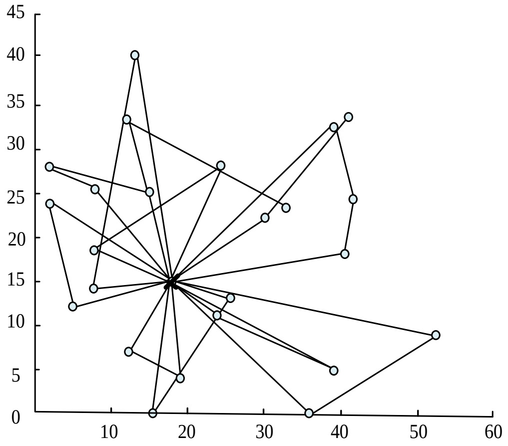

Figure 4: Distribution route map

Table 2: Distribution scheme

No	Distribution route	No	Distribution route
1	0-2-23-0	7	0-16-15-0
2	0-5-3-20-0	8	0-17-24-0
3	0-6-10-0	9	0-18-17-14-0
4	0-10-19-12-0	10	0-21-7-0
5	0-13-4-0	11	0-22-11-9-0
6	0-14-1-8-0		

5. Conclusions

With the rapid development of the logistics industry and the substantial increase in the urban hazardous chemicals distribution, it has become one necessary means to select the scientific and rational distribution route for reducing distribution costs and safety risks. In this paper, the factors affecting the logistics distribution of hazardous chemicals were firstly analysed. Then, based on the improved genetic algorithm, the optimization model for multi-objective logistics distribution route of hazardous chemicals was established and solved. Finally. the feasibility and validify of the model were verified through the case analysis. The main research results are as follows:

This paper establishes an optimization target system for hazardous chemicals logistics distribution. Based on this system, the optimization objectives are divided into two categories: economic goals and safety goals. Through optimization, it can achieve the minimization of cost, risk minimization, sensitive target number of people or sensitive road segments.

Based on the goals of minimum distribution cost and minimum distribution risk, the optimization model for the distribution route of hazardous chemicals was established (Formula 8 and 9); based on the improved genetic algorithm, the time window processing and multi-objective optimization processing were conducted to obtained the multi-objective optimization model for the distribution route of hazardous chemicals: $\mathrm{Z} = \min \sum_i w_i \, , Z_i', i = 2{,}3$.

The verification results for the established optimization model show that the optimization model of urban hazardous chemicals logistics distribution route based on improved genetic algorithm is reasonable and feasible. The logistics distribution route optimized by this model can achieve the goal of minimized distribution cost and the lowest risk.

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