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Location Optimization of Emergency Station for Dangerous Goods Accidents Considering Risk

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Abstract: Emergency station is very important for emergency rescue work in hazardous chemical accidents. In order to ensure the efficiency of emergency rescue work, the setting characteristics and objectives of the emergency station should be comprehensively considered. A bi-level programming model of emergency station location for hazardous chemical accidents is established in this paper. The optimization objectives of the model include the minimum risk of emergency station location, the minimum construction and operation cost, the minimum weighted path distance, and the highest coverage level. Based on the NSGA-II algorithm, the model solving technology is designed and applied to the case analysis. The obtained results showed that the efficiency of emergency rescue is continuously improving with the increase in the number of emergency stations.

Keywords: hazardous chemical accidents; emergency station location; risk assessment; bi-level programming; NSGA-II

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1. Introduction

Due to the sudden and disastrous nature of hazardous chemical accidents, there is a large demand for emergency resources in a short time. It is urgent for emergency decision-making departments to speed up the construction of an emergency management system, which is inseparable from the construction of an emergency station location model [1]. Emergency stations for hazardous chemical accidents refer to the rescue facilities, personnel, equipment, materials, and other hardware resources planned before the occurrence of hazardous chemical accidents and used in the emergency rescue activities after the occurrence of accidents [2]. It is of great practical significance and theoretical value to study the optimal location of an emergency station for hazardous chemicals to ensure the rational and scientific allocation of resources and effectively reduce the damage and loss caused by accidents. The site location of the hazardous chemical emergency station has its own characteristics. Although the probability of a hazardous chemical accident is low, once it happens, it requires a rapid response, and it requires rescue in a short time. After the accident, because the rescue resources of a single emergency station struggle to meet the needs of all the demand point, the emergency station should provide multilevel coverage. In addition, as hazardous chemical enterprises may pose risks to the emergency station, regional risks should be considered when selecting an emergency station. In a word, multiple objectives should be taken into account when determining the location model of the hazardous chemical emergency station.

The remainder of this paper is organized as follows: Section 2 presents an overview of the relevant literature. The multi-objective location model is presented in Section 3. Section 4 presents the solution procedure. In Section 5, we outline the application of the proposed analytical approach in studying a realistic case study. Finally, Section 6 concludes the paper.

2. Literature Review

Facility location is an important research field in location problems, which mainly uses operational research, topology, and other research methods, involving mathematical modeling and algorithm design. The emergency station location problem was first used in fire station and ambulance facilities. In solving the problem of P facility location, the goal is to minimize the maximum distance between P service points and service objects.

The traditional facility location problem can be divided into three categories: p-median problem, p-center problem, and coverage problem [3,4], among which the coverage problem is the most widely used model in facility location problems, especially suitable for the location of the emergency station. Sylvester [5] first proposed the p-center problem. The purpose of the p-center problem is to minimize the maximum distance between the resource demand point and service point. Hakimi [6] proposed the p-median problem, which aims to minimize the average distance between the service center and the resource demand point. Aly and White [7] built a set coverage model intending to minimize the number of emergency service facilities. Shier [8] proposed the absolute center model, which is used for a single facility location. The model minimizes the distance between emergency stations and network nodes. Toregas et al. [9] constructed a mathematical model based on the location set coverage problem, which enables the selected logistics to cover all demand points, and requires the minimum number of selected services. Daskin [10] proposed the maximum expected coverage model, which aims to maximize the expected coverage of resources and services. Revelle et al. [11] proposed the maximum available location problem under the given probability to maximize the coverage. The constructed model aims to ensure that at least one vehicle can reach the given probability. Marianov et al. [12] considered the state of service facilities and constructed a stochastic coverage model based on the deterministic set coverage model.

Jia et al. [13] proposed a maximum coverage model of quantity and quality for large-scale emergency resources with uncertain and insufficient demand. Ukkusuri et al. [14] established a pre-disaster logistics center location model, whose goal is to maximize the possibility of demand points covered by resource points.

The traditional coverage problem has a basic assumption, that is, if the distance between the demand point and the facility point is less than a certain distance, it is considered complete coverage, otherwise, it will not be covered. This assumption can be called 0–1 coverage. Scholars recognize that this assumption is unreasonable in many cases, and put forward some ideas for improvement. Berman et al. [15] studied the maximum coverage location problem of “coverage gradually”. Another basic assumption of the coverage problem is that the demand point can only be served by one facility point. This assumption does not take into account the congestion or failure of facilities. Therefore, the coverage model considering uncertain factors has also attracted extensive attention from scholars. Daskin et al. [16] proposed a set-covering model with multiple covers. Hogan et al. [17] proposed a maximum coverage model considering spare coverage. Narasimhan et al. [18] proposed a multilevel coverage location model for emergency station considering capacity constraints, and solved it with the Lagrange relaxation algorithm. Revelle [19] studied the response of different emergency service facilities and proposed two backup coverage models. Pavankumar [20] studied the location of medical facilities after the terrorist attacks, and established the maximum coverage model under the condition of limited resources, taking into account the uncertainty of material demand and transportation time. Vatsa et al. [21] established a multistage maximum coverage site location mixed-integer programming model based on the minimum and maximum robustness optimization method, and designed a Benders decomposition method to realize the solution of the model. Ozbaygin et al. [22] considered the time constraint and demand uncertainty of emergency services, studied the location model of multilevel covering integer programming, and solved it by using a branch and bound algorithm.

The traditional facility location model is mostly single-objective decision making, but in the case of major emergencies, the location of the emergency station should consider many factors, and a multi-objective method is necessary to solve the location decision-making problem. Masood [23] took distance, time, and cost as objective functions, and took a fire station as an example to build a multi-objective mathematical location model. Brimberg [24] proposed a dual objective location model based on demand and cost. Wlodzimierz [25] constructed a dual objective model of emergency location, in which the center point and the median point were set as the two objectives. For solving the problem, the bi-objective model was transformed into a single-objective model of the center point. Matsutomi [26] studied the multi-objective site location of emergency station based on fuzzy mathematics theory. Bruni [27] applied the two-stage programming method to the stochastic programming model, constructed the probabilistic model of facility siting, and designed a heuristic algorithm for model solving.

Considering the demand characteristics of emergency supplies at demand points under chemical accidents, the idea of multilevel coverage and coverage attenuation, the maximum coverage demand, total operation cost, minimum risk value, highest emergency rescue efficiency, and other factors, we proposed a multitarget multilevel coverage attenuation siting model for determining the emergency station in chemical accidents.

3. Optimization Modeling of Emergency Station for Hazardous Chemical Accidents

3.1. A Risk Assessment Method for Hazard Source Area

Regional risk assessment is a comprehensive assessment problem accompanied by multiple risk sources within a region. Based on the assessment of multiple risk sources within a region, the comprehensive index of the regional risk is obtained. The unit of risk is "death/year" (P/a).

The method of regional risk assessment is divided into three steps [28]:

Step 1: Grid the area

The square elements of the same size are divided by the equal step size, and the two-dimensional space is represented by an $n \times m$ matrix. The element a_{ij} in the matrix represents the information of the corresponding square elements in the two-dimensional space.

$$A = (\mathrm{a}_{ij})_{n\times m} = \begin{pmatrix} a_{11} & \cdots & a_{1m} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nm} \end{pmatrix} \tag{1}$$

Step 2: Construct sub risk matrix

For each risk source, the sub risk matrix formed by gaseous and liquid diffusion is constructed according to its type, the diffusion model simplified by trapezoidal fuzzy relation can be obtained as follows:

$$\mathrm{r} = \begin{cases} r,\ (0 < x \le l') \\ \dfrac{r_0(l-x)}{l-l'},\ (l' \le x \le l) \\ 0,\ (x > l) \end{cases} \tag{2}$$

where r is the risk value of the calculation point, r_0 is the risk value of the calculation point, x is the distance between the calculation point and the risk source point, l' is the maximum influence radius of the serious injury area, and l is the maximum influence radius.

Step 3: Superimpose value at risk

By summing the risk values of each point in the matrix, the matrix formula can be obtained as follows:

$$A' = (a'_{ij})_{n\times m} = \begin{pmatrix} a'_{11} & \cdots & a'_{1m} \\ \vdots & \ddots & \vdots \\ a'_{n1} & \cdots & a'_{nm} \end{pmatrix} \tag{3}$$

For the convenience of displaying in the risk matrix, the risk value r in the form of an index is transformed into R in the form of a decimal.

$$R = 8 + \lg r \tag{4}$$

3.2. Problem Description

In the area with multiple hazardous chemical enterprises, to ensure the rapid implementation of emergency rescue after the accident, it is necessary to select several construction sites as emergency stations from the candidate sites. Emergency stations are required to cover hazardous chemical storage enterprises at multiple levels, and the number of materials transported at the emergency stations and demand points should be set in advance.

When determining the emergency station location for dangerous goods accidents, multiple optimization indexes need to be considered. Firstly, from the perspective of safety, the emergency station location should minimize the risk as the existence of dangerous goods will pose certain risks to the station within a certain range. Secondly, the construction and operation cost should be the smallest. Furthermore, the minimum weighted path distance from the rescue station to the demand point is required in terms of emergency efficiency. In addition, the highest level of coverage is required in terms of emergency support.

The assumptions of the emergency station location model are as follows:

(1) All emergency stations can provide rescue services for the demand point;
(2) The demand point requires a k-level demand coverage level, and each level of demand coverage level is provided by at most one emergency station, which is shown in Figure 1;
(3) The coverage satisfaction of the emergency station decreases with the distance to the demand point.

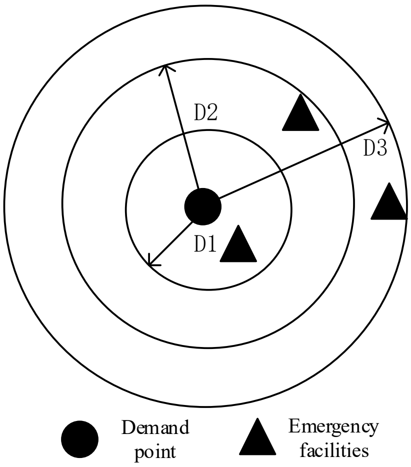

Figure 1. Schematic diagram of multilevel coverage of the emergency station (D1–D3 is the maximum distance of the 1-3-th coverage level).

When the distance between the facility point and the demand point is less than or equal to a certain distance, the coverage satisfaction is 1; otherwise, when the first distance is greater than the latter distance, the coverage satisfaction decreases with the increase of the distance.

The coverage satisfaction can be obtained as follows [19]:

$$f_j^k(d_{ij}) = \begin{cases} 1, d_{ij} \le D^k \\ 1 - \dfrac{d_{ij} - D^k}{\max(d_{ij}) - D^k}, d_{ij} > D^k \end{cases} \tag{5}$$

d_{ij} is the distance from any facility point to the demand point.
D^k is the maximum distance of the *k*-th coverage level.

The coverage radius of each coverage level can be obtained as follows:

$$D^k = D_{\min} + M^k(D_{\max} - D_{\min}) \tag{6}$$

M_k is the multiplier of the coverage radius of each level.

$D_{\min}$ and $D_{\max}$ are the minimum and maximum distances from the demand point to the alternative emergency station, respectively.

3.3. Notations

Sets, parameters, and decision variables of the model are described as follows:

Sets:

I is the set of demand points, indexed by i;
J is the emergency station, indexed by j.

Parameters:

p is the number of the emergency station to be set;
F_j is the construction cost of the emergency station j;
w_i is the weight of the demand point i;
d_{ij} is the distance from the emergency station j to demand point i;
r_j is the risk value of the emergency station j;
h_i is the emergency material demand of demand point I;
N_j is the total reserves of materials at emergency station j;
k is the coverage level of emergency station to demand points;
$f_i^k(d_{ij})$ is the coverage attenuation function of facility point j and demand point i providing k-level service.

Decision variables:

y_j is 1 if the emergency station is set, $j \in J$; 0, otherwise;
x_{ij}^k is 1 if the emergency station j provides k-level coverage for demand point i, $i \in I, j \in J$; 0, otherwise;
θ_{ij} is the quantity of emergency materials transported from emergency station j to demand point i; $i \in I, j \in J$.

3.4. Formulation

(1) Upper-level planning model:

$$Z_1 = \min \sum_{j \in J} r_j y_j \tag{7}$$

$$Z_2 = \min(c \sum_{i \in I} \sum_{j \in J} d_{ij} x_{ij}^k \theta_{ij} + \sum_{j \in J} F_j y_j) \tag{8}$$

s.t.

$$\sum_{j \in J} y_j = p \tag{9}$$

$$\sum_{i \in I} \sum_{j \in J} \theta_{ij} \geq h_i, \forall i \in I \tag{10}$$

$$x_{ij} \leq N_j, \forall i \in I, \forall j \in J \tag{11}$$

Objective (7) minimizes the total risk value of the selected emergency station. Objective (8) minimizes the overall operation cost of the emergency station. Constraint set (9) ensures that the number of the emergency station is p given in advance. Constraint set (10) requires that the total materials transported by each emergency station meet the demand of any demand point. Constraint set (11) requires that the materials delivered by any emergency station shall not exceed its total amount.

(2) Lower-level planning model

$$Z_3 = \min \sum_{i \in I} \sum_{j \in J} w_i d_{ij} x_{ij}^k y_j \tag{12}$$

$$Z_4 = \max \sum_{i \in I} \sum_{j \in J} \sum_{k \in K} f_i^k(d_{ij}) x_{ij}^k \tag{13}$$

s.t.

$$\sum_{i \in J} x_{ij}^k = 1, \forall i \in I, \forall k \in K \tag{14}$$

$$x_{ij}^k - y_j \leq 0, \forall i \in I, \forall j \in j \tag{15}$$

Objective (12) minimizes the total weighted distance from the demand point to the emergency station. Objective (13) minimizes the overall operation cost of the emergency station. Constraint set (14) requires that the demand point should be covered by only one emergency station at all levels of coverage. Constraint set (15) ensures that only when the emergency station is selected can it provide service for the demand point.

4. Solution Procedure

Firstly, we solve the emergency station scheme of emergency stations, then the emergency station in the scheme is allocated to each demand point, and finally, the material transportation volume from each emergency station to the demand point is allocated. The algorithm flow is as follows:

Step 1: Given *J* candidate sites, *p* of them were selected to set up the emergency station. All construction plans are recorded as $\mathbf{y}^1, \mathbf{y}^2, \cdots, \mathbf{y}^m$, of which

$$\mathbf{y}^u = (y_1^u, y_2^u, \cdots, y_J^u) \tag{16}$$

$$\sum_{j=1}^{J} y_j^u = p \tag{17}$$

$$y_j^i = \begin{cases} 1 & \text{the u construction plan selects the j candidate point} \\ 0 & \text{otherwise} \end{cases}, u = 1, 2, \cdots m \tag{18}$$

Calculate the fitness value of each construction scheme on objective Z_1.

Step 2: Under the given construction scheme, the optimization objectives Z_3 and Z_4 are obtained to derive the optimal facility allocation scheme. The optimization process is as follows:

Step 2.1: Initialize n emergency station allocation scheme as the initial population, and record as $X_0 = \{\mathbf{x}^1, \mathbf{x}^2, \cdots, \mathbf{x}^N\}$, in which $\mathbf{x}^v = (x_{ij}^v)_{I \times J} (v = 1, 2, \cdots, N)$,

x_{ij}^v represents that in the *V* allocation scheme, the *j*-th emergency rescue facility provides *k*-level demand coverage for the *i*-th demand point.

The fitness values of targets Z_3 and Z_4 were calculated.

Step 2.2: Hybrid variation produces offspring.

Firstly, the exchange allocation scheme of partial demand points is selected according to the hybrid probability, and then the partial demand point allocation scheme is selected according to the mutation probability.

The offspring is recorded as $O_t = \{\mathbf{o}^1, \mathbf{o}^2, \cdots, \mathbf{o}^N\}$. The fitness values of targets Z_3 and Z_4 were calculated.

Step 2.3: Non-dominated sorting strategy through NSGA-II.

N individuals were selected from $X_t \cup O_t$ as the next-generation individuals X_{t+1}.

Step 2.4: When the evolution algebra is less than the maximum evolution algebra Steps 2.2–2.3 are repeated:

When the evolution algebra is greater than the maximum evolution algebra, the output solution is the emergency station allocation scheme under construction scheme y^{τ}, which is recorded as $\overset{\sim}{\mathbf{x}}_{\tau}^{1}, \overset{\sim}{\mathbf{x}}_{\tau}^{2}, \cdots, \overset{\sim}{\mathbf{x}}_{\tau}^{N}$.

Step 3: Under the given AA and BB, the optimal objective 2 is to obtain the material delivery scheme from the emergency station to the demand point. The optimization process is as follows:

Step 3.1: Initialize m material transportation schemes as the initial population, which is recorded as $\Theta_0 = \left\{\boldsymbol{\theta}^1, \boldsymbol{\theta}^2, \cdots, \boldsymbol{\theta}^M\right\}$, in which $\boldsymbol{\theta}^v = (\theta_{ij}^v)_{I\times J}(u = 1, 2, \cdots, M)$, $\theta_{ij} \leq N_j, \forall j \in J$, $\sum\limits_{j\in J} \theta_{ij} \geq h_i, \forall i \in I$. θ_{ij}^v represents the number of materials required by the i-th demand point and transported by the j-th emergency rescue facility point in the v-th material transportation scheme. The fitness of target 2 was calculated.

Step 3.2: Hybrid variation produces offspring. For any $\mathbf{x}^u \in X$, random location $\mathbf{x}^v \in X_t$.

Firstly, the exchange allocation scheme of partial demand points is selected according to the hybrid probability, and then the partial demand point allocation scheme is selected according to the mutation probability.

For any $\boldsymbol{\theta}^u \in \Theta_t$, random location $\boldsymbol{\theta}^v \in \Theta_t$, the exchange allocation scheme of partial demand points is first selected according to the hybrid probability, and then the partial demand point allocation scheme is selected according to the mutation probability, which is recorded as $\Omega_t = \left\{\boldsymbol{\xi}^1, \boldsymbol{\xi}^2, \cdots, \boldsymbol{\xi}^M\right\}$. The fitness of target 2 was calculated.

Step 3.3: The $\Theta_t \cup \Omega_t$ is ranked according to objective Z_2, and the top m individuals were selected as the next generation.

Step 3.4: When the evolution algebra is less than the maximum evolution algebra Steps 3.2–3.3 are repeated:

When the evolution algebra is greater than the maximum evolution algebra, the output solution is the emergency station allocation scheme under y^{τ} and $\overset{\sim}{\mathbf{x}}_{\tau}^{\pi}$, which is recorded as $\overset{\sim}{\boldsymbol{\theta}}_{\tau}^{\pi}$.

Step 4: All $(y^{\tau}, \overset{\sim}{\mathbf{x}}_{\tau}^{\pi}, \overset{\sim}{\boldsymbol{\theta}}_{\tau}^{\pi})$ are ranked non-dominated by goals 1 and 2, and the output Pareto solution is the final solution of the model.

5. Numerical Example

There are 8 hazardous chemical enterprises in an area as emergency rescue demand points. The relevant data of enterprises are given in Table 1. In addition, the maximum impact radius of the serious injury area of hazard sources is taken as 500 m.

Table 1. Data list of hazardous chemical storage enterprises in a region.

Number	Central Point Coordinate	Category of Hazardous Substances	Maximum Influence Radius (m)	Risk Value (P/a)	Weight	Forecast Demand for Emergency Materials (t)
1	(3, 9)	Hydrocarbons and combustion volatiles	6280	0.000808	0.16	52.8
2	(2, 3)	Hydrogen sulfide and other poisons	6260	0.000932	0.17	55.8
3	(4, 14)	Hydrocarbons and combustion volatiles	6240	0.000808	0.15	48.6
4	(6, 7)	Strong corrosive liquid	6260	0.000932	0.13	43.8
5	(12, 10)	Fuel oil and combustion volatiles	6260	0.000932	0.11	47.8
6	(15, 13)	Hydrocarbons and combustion volatiles	5000	0.000048	0.09	48.8
7	(10, 2)	Strong corrosive liquid	5500	0.000044	0.08	46.4
8	(18, 4)	Hydrocarbons and combustion volatiles	6000	0.000068	0.12	44.8

It is required to select 4 out of 7 candidate sites to set up the emergency stations. The relative positions of demand points and emergency stations are shown in Figure 2. In the figure, ○ is the demand point and △ is the emergency station.

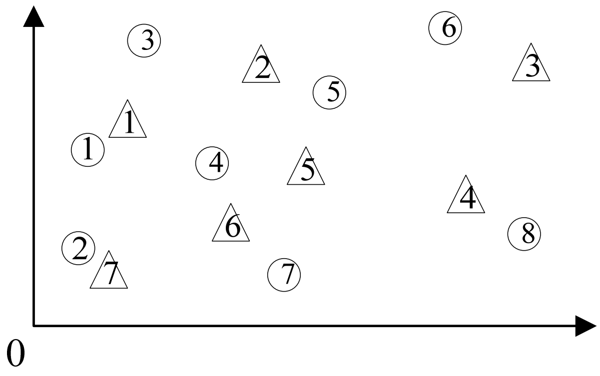

Figure 2. Location map of demand point and emergency station in an area.

The distance between the demand point and the emergency station is shown in Table 2.

Table 2. The distance between the demand points and the emergency stations (km).

Emergency Station Demand Point	1	2	3	4	5	6	7	8
1	3.2	9.2	2	5.3	8.2	11	11.7	16.1
2	7.2	12.2	5.1	6.7	4.2	6	11	12.7
3	15.3	18.3	14.1	13	6.3	3	12.9	8
4	13.3	14.3	14.4	10	5.6	7.1	7.2	2.8
5	8.2	9.8	9.8	5	3.1	7.2	5.1	7.6
6	5.6	5.4	9.4	2.2	7	11.3	4.2	11
7	6	2	11	4.4	10	14.9	6.1	14

The data in Tables 1 and 2 are substituted into Equation (2) to calculate the risk value of each demand point at the emergency station r_{ij}, which is shown in Table 3.

Table 3. Risk value of demand point to each emergency station.

	Emergency Station	1	2	3	4	5	6	7
Demand point	1	0.000431	0	0	0	0	0.000095	0.000039
	2	0	0 0	0	0	0	0.000139	0.000689
	3	0.000597	0.000160	0	0	0	0	0
	4	0.000155	0	0	0	0.000204	0.000657	0.000301
	5	0	0.000333	0	0.000107	0.000511	0	0
	6	0	0	0.000021	0	0	0	0
	7	0	0	0	0	0.000004	0.000011	0
	8	0	0	0	0.000040	0	0	0
Total risk value (P/a)		0.001183	0.000494	0.000021	0.000146	0.000719	0.000903	0.001029

Relevant data of emergency stations are shown in Table 4. In addition, the transportation cost in this area is CNY 2.3 per ton kilometer.

Table 4. Relevant data of emergency station.

Emergency Station	1	2	3	4	5	6	7
Construction cost (CNY 10,000)	3000	4900	2500	5530	5400	5900	2300
Risk value (10^{-3} P/a)	1.183	0.494	0.021	0.146	0.719	0.903	1.029
Reserves of emergency materials	21.12	20.32	19.44	17.52	15.12	21.52	20.56

Suppose the highest coverage level $K = 3$, $Mk = (0.05, 0.1, 0.15)$, we use Matlab 2018b software to program and solve the model. The results are shown in Tables 5–10.

Table 5. Performance analysis of hazardous chemical emergency station location model ($p = 4$).

Number of Emergency Station	Site Location Scheme	Total Risk Value	Total Cost (CNY 10,000)	Total Weighted Distance	Coverage Satisfaction
4	1, 2, 3, 7	2.727	12,700.6069	21.774	84.94%
	1, 3, 4, 7	2.379	13,330.6203	23.647	81.86%
	2, 3, 4, 6	1.564	18,830.6279	24.126	80.96%
	2, 3, 4, 7	1.69	15,230.6421	24.342	80.92%
	2, 3, 5, 7	1.263	15,100.6020	21.608	78.57%
Recommended scheme	2, 3, 5, 7	1.263	15,100.6020	21.608	78.57%

Table 6. Material supply scheme of the recommended scheme ($p = 4$).

Demand Point Number	Level 1 Emergency Station	Quantity of Supplies	Level 2 Emergency Station	Quantity of Supplies	Level 3 Emergency Station	Quantity of Supplies
1	5	12.7	2	19.6	7	20.5
2	7	20.6	5	15.1	2	20.1
3	5	15.0	2	19.6	7	14.0
4	2	8.6	5	14.8	7	20.5
5	5	14.9	2	18.9	3	14.3
6	3	19.3	5	14.3	2	15.3
7	2	10.9	7	20.4	5	15.1
8	2	10.3	5	15.1	3	19.4

Table 7. Performance analysis of hazardous chemical emergency station location model ($p = 5$).

Number of Emergency Station	Site Location Scheme	Total Risk Value	Total Cost (CNY 10,000)	Total Weighted Distance	Coverage Satisfaction
5	1, 2, 3, 4, 7	1.873	18,230.5286	19.433	94.33%
	1, 2, 3, 5, 7	3.446	18,100.5207	18.766	88.72%
	2, 3, 4, 5, 6	2.283	24,230.5432	19.866	86.45%
	2, 3, 4, 5, 7	2.409	20,630.5577	20.03	87.41%
Recommended scheme	1, 2, 3, 4, 7	1.873	18,230.5286	19.433	94.33%

Table 8. Material supply scheme of the recommended scheme ($p = 5$).

Demand Point Number	Level 1 Emergency Station	Quantity of Supplies	Level 2 Emergency Station	Quantity of Supplies	Level 3 Emergency Station	Quantity of Supplies
1	1	21.1	2	13.1	7	18.6
2	7	20.6	5	14.3	1	21.0
3	5	7.5	2	20.2	1	20.9
4	5	15.0	1	8.7	7	20.3
5	2	19.1	5	15.0	3	13.8
6	3	19.1	5	11.3	2	18.5
7	2	11.1	5	14.8	7	20.5
8	2	10.3	5	15.1	3	19.4

Table 9. Performance analysis of hazardous chemical emergency station location model ($p = 6$).

Number of Emergency Station	Site Location Scheme	Total Risk Value	Total Cost (CNY 10,000)	Total Weighted Distance	Coverage Satisfaction
6	1, 2, 3, 4, 5, 7	2.592	23,630.4794	17.188	97.59%
	2, 3, 4, 5, 6, 7	3.312	26,530.4813	17.393	94.62%
Recommended scheme	1, 2, 3, 4, 5, 7	2.592	23,630.4794	17.188	97.59%

Table 10. Material supply scheme of the recommended scheme ($p = 6$).

Demand Point Number	Level 1 Emergency Station	Quantity of Supplies	Level 2 Emergency Station	Quantity of Supplies	Level 3 Emergency Station	Quantity of Supplies
1	1	20.8	2	11.5	7	20.6
2	5	14.9	7	20.6	1	20.3
3	5	8.7	1	19.9	2	20.1
4	1	8.3	5	15.0	7	20.5
5	2	19.3	5	14.7	4	13.9
6	3	18.9	4	12.6	2	17.4
7	4	11.9	7	20.4	5	14.1
8	4	17.5	5	15.1	3	12.4

Generally, the characteristics of dangerous goods accidents are that the accident probability is low, but the damage is huge. Therefore, the safety of the emergency station can be taken as an important consideration, and the scheme with the lowest total risk is selected as the recommended scheme.

The study results showed that with the increase in the number of emergency stations, the overall coverage satisfaction of hazardous chemical storage enterprises is becoming higher and higher. At the same time, the total weighted distance from the facility point to the demand point is becoming smaller and smaller, which means the efficiency of emergency rescue is continuously improving. However, with the increase in the number of emergency stations, the risk value and the cost of emergency stations will increase. In real emergency activities, a reasonable number of emergency stations should be set up according to the actual needs of emergency management, and the construction and operation costs should be reduced as far as possible, while ensuring the satisfaction and efficiency of emergency rescue.

6. Conclusions

This paper presents a risk assessment approach for hazard source areas, and optimization indexes of the emergency station location for dangerous goods accidents.

Unlike other works in the literature, we focus on the multilevel coverage problem of facility location and consider the risk value of emergency station location. The exhibited characteristic makes the model more suitable for emergency station location of hazardous chemical accidents. The multi-objective optimization model of hazardous chemical storage emergency station location was established with the minimum risk, minimum construction and operation cost, minimum weighted path, distance, and maximum coverage level as the optimization objectives. Using the idea of two-level programming and NSGAII genetic algorithm, the model-solving algorithm was designed, and an example was analyzed. The results showed that with the increase in the number of emergency stations, the overall coverage level of hazardous chemical enterprises is greater and greater, and the risk value and the total operating cost of emergency stations are increasing. It is hoped that our work can provide another perspective for scholars in various countries to study emergency stations for dangerous goods accidents.

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