Two-stage optimization study on location and layout of emergency resources in chemical parks

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Abstract. This paper intends to study the layout of emergency centers in the chemical park in two stages. First, a multi-agent collaborative location model is established to find out the sites of emergency centers. Second, DEA method is adopted to evaluate the efficiency of the existing reserve structure of each center, along with the optimization suggestions for the inefficient center. Finally, the safety system of the chemical park is improved by the combination of the location model and the DEA.

Keywords: chemical park, emergency resources, location layout, DEA method.

1. Introduction

In the past thirty years, the construction scale of chemical industrial parks in China has been continually expanding. Hazardous chemicals are latent with huge risks in the process of production and storage. Once those dangerous chemicals leaked, it is easy to cause serious safety accidents such as fire, explosion and poisoning. For such accidents, whether the rescue force can arrive at the scene in the first time is an important standard to measure the management and control level of chemical accidents. A reasonable site selection and layout of the emergency center is the premise to ensure the efficient operation and rapid response of the emergency system. It plays an important role in minimizing human and property losses. Therefore, the study of this paper focuses on the optimal layout of emergency resources in the chemical industrial park to improve the rescue level.

In view of the special scenario of hazardous chemical accident, Berman [1] improved the traditional maximum coverage model on the basis of the high destruction of the accident. Wenyan [2] considered both risk and distance in the site selection model. However, these studies did not take the rescue time into consideration with the potential risk. Fiedrich [3] built a dynamic programming model to solve the allocation of emergency resources by stages. Panagiotis [4] studied the allocation efficiency of emergency resources based on Data Envelopment Analysis (DEA) to evaluate the allocation efficiency. Actually, these studies focus on the research of emergency supplies, lack of index analysis of rescue personnel, which is not in line with the actual rescue situation. Therefore, a two-stage optimization research method including all the rescue resource was proposed in this paper.
2. Problem description
There are no candidate sites in a chemical industrial park that meet the basic conditions. P should be selected from N as the sites of the emergency center. Each chemical plant should be covered by at least one emergency center in order to reduce potential losses. A simulation diagram of two-stage layout of the emergency center is shown below. The chemical plant is the potential accident point, and the emergency center is the supply point of emergency resources. In the first stage, P emergency centers are selected through the site selection model so as to deal with the potential hazardous chemical accidents. The second stage is to optimize the resource structure on the basis of previous stage. The DEA method is used to adjust resource reserves of each emergency center. As a result, the resource utilization and overall rescue timeliness would be optimized.

In order to improve the current situation of unreasonable emergency center location and resource reserve. The following hypotheses are put forward in this paper: (1) Consider only the impact of a chemical accident on the people around it; (2) All resources are dispatched at one time by land transportation; (3) Each chemical plant has different potential risk; (4) Input indexes of each emergency center are: firefighters, paramedics, firefighting supplies and medical supplies; (5) Output indexes of each emergency center are: rescue scope, personnel response rate and storage capacity utilization.

3. Mathematical model
3.1. Variable description
The description of symbols and variables is as follows: \( I = \{ i | i = 1, 2, 3, \ldots, N \} \) represents the set of candidates of the emergency center; \( J = \{ j | j = 1, 2, 3, \ldots, M \} \) represents the set of chemical plants; \( T \) represents the response time limit from emergency center to chemical plant; \( P \) represents the number of emergency centers; \( t_{ij} \) represents the transit time from candidate to chemical plant; \( x_i = 1 \) represents the candidate i is selected as the emergency center, otherwise, \( x_i = 0 \); \( y_j = 1 \) represents the emergency center i rescue the chemical plant j, otherwise, it is 0.
3.2. Model building

Based on above assumptions, the following site selection model can be established:

\[ F = \min \sum_{i=1}^{N} \sum_{j=1}^{M} t_{ij} y_{ij} r_j \]  
\[ y_{ij} \leq x_i, \forall i, j \]  
\[ \sum_{i=1}^{N} y_{ikj} \geq 1, \forall j \]  
\[ x_{ij} * t_{ij} \leq T, \forall i, j \]  
\[ \sum_{i=1}^{N} x_i = P \]  
\[ x_i \in \{0, 1\}, y_{ij} \in \{0, 1\}, \forall i, j \]

Equation (1) indicates the shortest total response time; Equation (2) indicates that candidates can only provide rescue services after being selected as emergency center; Equation (3) indicates that any chemical plant should be covered; Equation (4) indicates the response time limit; Equation (5) indicates that there are \( P \) emergency centers; Equation (6) indicates 0-1 variables.

After the location of emergency centers are completed according to the location model, DEA method is used to determine the reasonable amount of emergency resource reserves. In this stage, firefighters, paramedics, firefighting supplies and medical supplies, rescue scope, personnel response rate and storage capacity utilization are introduced as input or output evaluation index to reflect the conversion rate of emergency resources input. Specially, all the indexes are dimensionless processed in the Chemical accident emergency rescue efficiency index table. After the operation of DEA solver, scientific reserve structure of emergency resources would be obtained.

4. The example application

There are 11 chemical plants located in the industrial park with different potential risks. Government needs to select 4 emergency centers from 11 candidate sites. The response time limit is 9 minutes. All the parameters are shown in table 1 and table 2, and the specific location structure as shown in figure 2.
Figure 2. Site selection structure diagram

Table 1. Risk factor of chemical plant

| Plants | B1, B2, B3, B4, B11 | B5, B9 | B6, B8 | B7 | B10 |
|--------|---------------------|--------|--------|----|-----|
| $r_j$  | 0.08                | 0.11   | 0.06   | 0.16| 0.09|

Table 2. The time required to arrive at the chemical plant from the alternative point

| $t_{ij}$ | B1 | B2 | B3 | B4 | B5 | B6 | B7 | B8 | B9 | B10 | B11 |
|----------|----|----|----|----|----|----|----|----|----|-----|-----|
| A1       | 1  | 6  | 4  | 5  | 6  | 6  | 3  | 8  | 4  | 5   | 2   |
| A2       | 7  | 4  | 6  | 3  | 4  | 2  | 8  | 8  | 7  | 5   | 4   |
| A3       | 2  | 7  | 6  | 3  | 6  | 7  | 4  | 5  | 6  | 7   | 6   |
| A4       | 6  | 4  | 2  | 6  | 5  | 3  | 7  | 8  | 4  | 5   | 6   |
| A5       | 6  | 6  | 7  | 3  | 8  | 6  | 7  | 6  | 5  | 7   | 4   |
| A6       | 4  | 8  | 7  | 6  | 4  | 6  | 5  | 3  | 7  | 6   | 8   |
| A7       | 5  | 6  | 4  | 3  | 7  | 9  | 9  | 8  | 2  | 6   | 7   |

According to the site selection layout model in 3.2, Matlab - Yalmip toolbox can be used to solve the site selection model on PC. The results are as following:

$$Y = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$x = \begin{bmatrix} 1 \\ 1 \\ 0 \\ 0 \\ 0 \\ 1 \\ 1 \\ 1 \end{bmatrix}$$

Figure 3. Location model solution results
It can be seen that each emergency center serves two or three chemical plants respectively in this stage, which is economical as well as highly responded. After the location of the four emergency centers are determined, the second stage of the layout will start. Combined with the DEA theory and example data, following optimal plan of emergency resource allocation can be obtained through solver.

Table 3. Data indicators of the emergency center

| object                  | B1 | B2 | B7 | B8 |
|-------------------------|----|----|----|----|
| Input index             |    |    |    |    |
| firefighters           | 9  | 9  | 4  | 5  |
| paramedics             | 8  | 9  | 4  | 6  |
| firefighting supplies  | 6  | 7  | 3  | 3  |
| medical supplies        | 5  | 5  | 3  | 4  |
| output index            |    |    |    |    |
| rescue scope           | 3  | 3  | 2  | 3  |
| personnel response rate| 0.94 | 0.89 | 0.62 | 0.73 |
| storage capacity utilization | 0.82 | 0.78 | 0.66 | 0.72 |
| DEA evaluation value    | 0.91 | 0.88 | 1  | 1  |
| sequence                | 3  | 4  | 1  | 1  |
| whether to adjust       | yes| yes| no | no |

Apparently, the DEA evaluation value of B3 and B4 are 1 and no need to be adjusted, while the input indexes of B1 and B2 need to be reduced appropriately. The specific results are shown in Table 4. After the improvement, the redundant emergency resources are greatly reduced, and the total rescue personnel can be reduced from 35.00 to 23.93. Similarly, total supplies can be reduced by 5.30 percent. In this way, the emergency centers of the chemical industry park can reduce unnecessary resource idleness and waste while ensuring the rescue effect, and effectively improve the utilization rate of emergency resources.

5. Conclusion

Based on the P-median value location model and DEA theory, this paper studies the location layout and resource optimal allocation of the emergency center in two stages, and the main conclusions are as follows: first, establish a multi-agent collaborative location model, introducing risk coefficients in the objective function, and determine the location of the emergency centers through Matlab - Yalmip toolbox, so as to achieve the best comprehensive rescue efficiency considering the potential accident risks of different chemical plants; Second, set input and output indicators conforming to the situation of chemical accident. Then the overall utilization of emergency resources can be evaluated by DEA methods, and the optimization scheme of resource allocation is proposed, which significantly improves the overall relative efficiency of the emergency system. Through the analysis of the example, it is shown that the model can better meet the actual allocation requirements. It is also conducive to more scientific and reasonable distribution and reserve of emergency resources, so that the rescue and safety system of the chemical park is more perfect and effective.

Acknowledgments

This paper is supported by National Key R&D Plan of China under Grant No. 2016YFC0803207 and China Postdoctoral Science Foundation No. 2019M650455.

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