Research on location model of emergency material storage warehouse based on generalized maximum coverage

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Abstract. It is of practical significance to analyze the support requirements of each rescue team for the rationality of warehouse location. In order to solve the problem that the traditional emergency material storage warehouse does not consider the difference of material guarantee timeliness of rescue teams, a generalized covering location model is proposed. In this paper, the coverage is introduced to measure the quality of security services in each disaster area, and the maximum generalized coverage model is established to find the best location scheme of emergency material storage warehouse. Finally, the feasibility of the method is verified by an example, and the proposed method can better solve the location problem of emergency materials storage warehouse.

1. Introduction
When the rescue team supplies emergency materials, it is necessary to set up an emergency material storage warehouse to guarantee the emergency material supply in the disaster area. At present, the research methods of location problem are mainly divided into multi-attribute decision-making evaluation method [1] and four kinds of location optimization models (set coverage model, maximum coverage model, P median model, P center model) [2-5]. The above optimal location model is also widely used in fire stations, hospitals, military facilities and other emergency rescue location problems [6-8]. Based on the concept of "partial coverage" and "step-by-step coverage", the maximum generalized coverage model considers the influence of distance on the response degree of demand services, which can accurately reflect the degree of "coverage".

To sum up, a service satisfaction function of emergency material demand is constructed based on the location of emergency material reserve warehouse. The model considers the constraints of the maximum support delay time of each rescue area and the capacity constraints of the emergency material storage warehouse. Aiming at the problem of material supply in the rescue area which is not covered effectively, the penalty cost function of emergency material supply is constructed. The multi-objective maximum coverage location model is established, and the location of emergency material storage warehouse is solved. Finally, the feasibility of the model is verified by a case.

2. Problem Description
At the beginning of the disaster, the rescue team needs to arrange and select the location of the emergency material storage warehouse, so as to provide emergency material supply guarantee for each
disaster area. The emergency material storage warehouse must be located in combination with the requirements of the disaster affected areas for material supply support. In this paper, through the construction of emergency material service satisfaction function, the optimization model of emergency material supply is established to maximize the overall satisfaction of emergency material support. Due to the complex disaster environment, in order to facilitate the analysis and research on the location of emergency materials storage warehouse, the following reasonable assumptions are made:

1. Location information and material demand of each affected area are known;
2. The maximum delay time of material supply in each affected area is known;
3. According to the disaster situation, the number of emergency storage warehouse is known;
4. Each emergency material storage warehouse has a capacity limit, and the upper limit of its inventory is known;
5. To avoid using too many warehouse points, each disaster area is provided with an emergency material storage warehouse.

3. Modelling of Generalized Coverage Location

3.1. Satisfaction function of emergency material demand service

By constructing the service satisfaction function $F_i(t_{ij})$ of emergency material demand in each affected area, it reflects the satisfaction degree of emergency material demand response in the affected area $i (i = 1, 2, \ldots, I)$ effectively covered to alternative emergency material reserve warehouse $j (j = 1, 2, \ldots, J)$, $F_i(t_{ij}) \in [0, 1]$.

$$F_i(t_{ij}) = \begin{cases} (1 - \frac{t_{ij}}{T_i})^{\alpha_i} & 0 \leq t_{ij} \leq T_i \\ 0 & t_{ij} > T_i \end{cases} \quad (0 < \alpha_i < 1) \quad (1)$$

Where, $t_{ij}$ is the time required for alternative emergency material storage warehouse $j$ to reach disaster area $i$. $T_i$ is the maximum guarantee delay time in the affected area. When the supply time of emergency materials exceeds $T_i$, the service satisfaction of emergency materials demand is 0. $\alpha_i$ is the time sensitivity of the affected area $[9-10]$. According to the time limit requirements for emergency supplies in the disaster affected area, $0 < \alpha_i < 1$ is taken here.

To sum up, the overall satisfaction of emergency materials demand and service in the disaster affected areas is as follows:

$$Z_i = \sum_{i=1}^{I} \sum_{j=1}^{J} \omega_i d_i F_i(t_{ij}) x_{ij} \quad (2)$$

Where, $\omega_i$ is the importance weight of each affected area. $d_i$ is the emergency material demand of each affected area. $x_{ij}$ represents the decision variable that the emergency material storage warehouse can provide emergency material supply service to the disaster area, and meets the following requirements:

$$x_{ij} = \begin{cases} 1 & \text{Emergency warehouse alternative } i \text{ provides material support for disaster area } j \\ 0 & \text{other} \end{cases} \quad (3)$$

3.2. Penalty cost function of emergency supply

According to the requirements of emergency material supply guarantee, the alternative points of emergency material storage warehouse can’t effectively cover all the loading units. According to the principle of proximity, this paper provides emergency supplies to the affected areas that are not effectively covered by the emergency supplies storage warehouse with sufficient surplus stock and the closest distance. If the remaining inventory is not satisfied, it will be directly supplied by the general
emergency materials warehouse. Therefore, the penalty cost function of emergency supplies is introduced to measure the penalty cost of emergency supplies, as follows:

$$P_i(t_{ij}) = \begin{cases} \gamma \left( \frac{t_{ij} - T_{ir}}{\max(t_{ij}) - T_{ir}} \right)^{\beta_i} & \text{if } t_{ij} > T_{ir} \\ 0 & \text{if } 0 \leq t_{ij} \leq T_{ir} \end{cases}$$ \quad (4)

The penalty cost function $P_i(t_{ij})$ of emergency material supply reflects the penalty cost of alternative emergency material storage warehouse $j$ ($j = 1, 2, ..., J$) supplied by disaster area $i'$ ($i = 1, 2, ..., I'$) not effectively covered. $P_i(t_{ij}) \in [0, 1]$. $\beta_i$ is the time sensitivity of the affected area. Since the penalty function reflects the degree of penalty for delay, $1 < \beta_i$. $\gamma$ is the delay penalty factor, which is used to adjust the degree of delay penalty. $t_{ij}$ represents the time from the affected area not effectively covered to the alternative points of each warehouse and the rear warehouse.

To sum up, the total penalty cost of emergency supplies in the disaster area is:

$$Z_2 = \sum_{i \in I} \sum_{j \in J} \omega_i c_i d_i P_i(t_{ij}) x_{ij}^2$$ \quad (5)

Where, $c_i$ is the penalty cost of emergency supplies per unit time. $\omega_i$ is the importance weight of each affected area. $d_i$ is the emergency material demand of each affected area. $x_{ij}^2$ represents the emergency supplies storage warehouse that meets the supply requirements is selected from the remaining warehouses to provide emergency supplies to the affected areas that are not covered effectively, as follows:

$$x_{ij}^2 = \begin{cases} 1 & \text{Emergency warehouse alternative } i' \text{ provides material support for disaster area } j' \\ 0 & \text{other} \end{cases}$$ \quad (6)

3.3. The maximum generalized coverage location selection model based on multi-objective constraints

To sum up, the generalized maximum coverage location model $P_1$ with multi-objective constraints is established:

$$\max Z_1 = \sum_{i \in I} \sum_{j \in J} \omega_i d_i F_i(t_{ij}) x_{ij}^1$$ \quad (7)

$$\min Z_2 = \sum_{i \in I} \sum_{j \in J} \omega_i c_i d_i P_i(t_{ij}) x_{ij}^2$$ \quad (8)

Subject to:

$$\sum_{j \in J} y_{ij} = p$$ \quad (9)

$$\sum_{j \in J} x_{ij} = 1; \sum_{j \in J} x_{ij} = 1$$ \quad (10)

$$\sum_{i \in I} \sum_{j \in J} d_i x_{ij} \leq S_j$$ \quad (11)

$$t_{ij} = \frac{L_{ij}}{a}$$ \quad (12)

$$x_{ij}^1 \in \{0, 1\}, x_{ij}^2 \in \{0, 1\}, \forall i \in I, j \in J$$ \quad (13)

$$y_{ij} \in \{0, 1\}, j \in J$$ \quad (14)

The model has two objective functions and belongs to multi-objective optimization model. In this paper, the linear weighting method is used to standardize multiple decision-making objectives, and the
location model $P_1$ is transformed into a single objective location model $P_2$ by using the model solution idea of reference [11].

$$Z_3 = \max (k_1Z_1' - k_2Z_2')$$ \hfill (15)

Subject to: Formula (9) ~ Formula (13).

Where, $Z_1'$ and $Z_2'$ are the decision objectives after standardization.

4. Case Study and Analysis

According to the analysis of the situation of the disaster area, it is urgent to supply emergency materials to five disaster areas. According to the total disaster area, three warehouses from 20 warehouses should be selected as emergency supplies storage warehouses to provide emergency supplies to the disaster area. The initial values of the evaluation indicators of the 20 alternative points are shown in Table 1.

Table 1. Initial value of evaluation index for alternative warehouse point

| Alternative warehouse | Safety protection | Traffic convenience | Communication smoothness | Easy extensibility | geological conditions |
|-----------------------|------------------|---------------------|-------------------------|-------------------|--------------------|
| 1                     | 0.56             | 0.79                | 0.89                    | 0.82              | 0.68               |
| 2                     | 0.89             | 0.76                | 0.65                    | 0.79              | 0.68               |
| 3                     | 0.75             | 0.76                | 0.45                    | 0.79              | 0.89               |
| 4                     | 0.56             | 0.89                | 0.79                    | 0.59              | 0.75               |
| 5                     | 0.83             | 0.89                | 0.85                    | 0.89              | 0.89               |
| 6                     | 0.89             | 0.75                | 0.82                    | 0.56              | 0.46               |
| 7                     | 0.75             | 0.89                | 0.89                    | 0.75              | 0.46               |
| 8                     | 0.56             | 0.68                | 0.59                    | 0.75              | 0.75               |
| 9                     | 0.87             | 0.89                | 0.85                    | 0.86              | 0.86               |
| 10                    | 0.83             | 0.86                | 0.89                    | 0.82              | 0.85               |
| 11                    | 0.46             | 0.79                | 0.45                    | 0.82              | 0.75               |
| 12                    | 0.89             | 0.82                | 0.84                    | 0.82              | 0.86               |
| 13                    | 0.86             | 0.86                | 0.89                    | 0.86              | 0.89               |
| 14                    | 0.68             | 0.56                | 0.79                    | 0.46              | 0.75               |
| 15                    | 0.87             | 0.88                | 0.82                    | 0.85              | 0.89               |
| 16                    | 0.89             | 0.89                | 0.85                    | 0.89              | 0.86               |
| 17                    | 0.25             | 0.45                | 0.68                    | 0.89              | 0.89               |
| 18                    | 0.58             | 0.59                | 0.76                    | 0.79              | 0.86               |
| 19                    | 0.76             | 0.39                | 0.76                    | 0.56              | 0.46               |
| 20                    | 0.92             | 0.59                | 0.25                    | 0.68              | 0.59               |

According to the analysis and decision-making of experts, the weight values of five evaluation indexes are calculated by AHP as follows: 0.1707, 0.2230, 0.1781, 0.2177, 0.2105. Using the TOPSIS method based on B-type Association in literature [12], the closeness of 20 alternative emergency material storage warehouses is calculated as follows:

$$u_i = (0.32, 0.41, 0.32, 0.28, 0.66, 0.43, 0.43, 0.42, 0.49, 0.49, 0.44, 0.49, 0.63, 0.64, 0.21, 0.58, 0.79, 0.47, 0.58, 0.65, 0.34, 0.48, 0.28, 0.41)$$

The screening standard is set to be no less than 0.4, then the initial alternative warehouse for emergency materials reserve is: alternative warehouse 5, alternative warehouse 9, alternative warehouse 10, alternative warehouse 12, alternative warehouse 13, alternative warehouse 15 and alternative warehouse 16. According to GIS, the location information of 7 initial alternative emergency material storage warehouses, disaster areas and rear material storage warehouses can be obtained, as shown in Table 2.
Table 2. Parameters of spare parts supply time for initial alternative field depot

| Alternative warehouse | Disaster area | | | | Rear material warehouse | Inventory capacity $S_i$ |
|-----------------------|---------------|---|---|---|-----------------|-----------------|
|                       | 1  | 2  | 3  | 4  | 5  | 8  | 40  |
| 5                     | 3  | 2.5| 3  | 3  | 2.5| 8  | 40  |
| 9                     | 4  | 5.5| 4  | 2.5| 2  | 20 | 45  |
| 10                    | 2  | 2.5| 3  | 5.5| 1.5| 10 | 50  |
| 12                    | 5  | 4  | 3.5| 2  | 6  | 18 | 40  |
| 13                    | 2.5| 3.5| 4  | 1.5| 4  | 8  | 50  |
| 15                    | 6.5| 3.5| 2  | 2.5| 2  | 12 | 50  |
| 16                    | 1.5| 1.5| 3.5| 2.5| 3.5| 10 | 40  |

Emergency material demand

|                       | 25 | 25 | 15 | 30 | 20 |

Maximum delay time

|                       | 4  | 3.5| 3.5| 3  | 3  |

Importance degree

|                       | 0.18| 0.25| 0.1| 0.15| 0.32|

Penalty cost per unit time $c_i$

|                       | 6  | 8  | 3  | 5  | 10 |

Parameter $\alpha_i$

|                       | 0.6| 0.75| 0.3| 0.5| 0.9 |

Parameter $\beta_i$

|                       | 1.2| 1.3| 1.05| 1.1| 1.5 |

Parameter $\gamma$

|                       | 1  | 1  | 1  | 1  | 1  |

According to formula (9) ~ (13), using the genetic algorithm simulation calculation, the optimal scheme of the maximum generalized coverage location model is: warehouse 10, warehouse 13, warehouse 16.

5. Conclusion

In this paper, considering the timeliness constraints and warehouse capacity constraints of emergency supplies in each disaster area, the satisfaction function of emergency supplies service and the penalty cost function of emergency supplies supply are constructed, and a multi-objective generalized maximum coverage location model is established. The optimal site selection scheme is calculated. The results show that the method proposed in this paper can solve the location problem of emergency material storage warehouse under the condition of multiple constraints in disaster area.

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