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Pre-location for temporary distribution station of urban emergency materials considering priority under COVID-19: A case study of Wuhan City, China

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ABSTRACT

In order to avoid the huge hidden dangers caused by emergencies, it is particularly vital to make a reasonable pre-location and layout of emergency logistics facilities. A multi-objective pre-location model of temporary distribution station for emergency materials was built, which considered the problems of information shortage and uncertain demand after the incident with minimum time, maximum time satisfaction, minimum delivery cost and psychological trauma to the masses. The priority of candidate points was solved by comprehensive evaluation methods, the nominal demand of served points was estimated by triangular fuzzy number theory (TFN), and the location model was solved by non-dominated sorting genetic algorithm. In addition, the optimal schemes without priority and considering it were compared and analyzed, the practicability of the model is verified by concrete examples. The results show the time and cost reduction of 7.754% and 25.651%, an increment of total satisfaction value of the scheme considering location priority. Therefore, the model and algorithm provide theoretical support and practical ideas for solving the location problem, which can better complete the task of the location problem for temporary distribution stations of urban emergency materials.

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For the sake of reducing unnecessary casualties and economic losses caused by sudden public events such as natural disasters and infectious diseases, it is indispensable to establish a scientific and accurate distribution system of emergency materials and an optimized pre-location system for the distribution centers in the logistics system network, which can not only accomplish the material distribution efficiently and timely, but also minimize the distribution cost and maximize the time satisfaction, furthermore, it can significantly improve the validity and ability of logistics management. For major emergencies, poor location of material supply center, uneven distribution of emergency resources, limited capacity of existing service facilities, delay of first aid time, inconvenient transportation and so on directly affect the successful completion of rescue work. Therefore, it is of great practical significance to research the pre-location of emergency medical facilities.

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1. Literature review

1.1. Location of general logistics facilities

The location theory of distribution center (DC) was first put forward by Alfred Weber in 1929. In the logistics system, the DC is in a crucial hub position, and the location for DC can optimize the whole logistics system. Actually, the location of logistics facilities aims to improve the efficiency of the logistics system by means of determining the geographical locations of distribution centers, warehouses and production facilities.

At present, a great deal of research has been done on the location of logistics facilities and fruitful results have been achieved, they mainly focusing on: Liu et al. studied the three-level optimal location allocation of transportation centers, processing plants and distribution centers in the supply chain network, and established a robust 0–1 mixed integer optimization model based on uncertain transportation costs and customer demands [1]. The optimal layout of transportation network hubs was of great practical significance for improving transportation efficiency. Therefore, Wang et al. established a location model with the objective of minimizing transportation network cost and solved it by genetic algorithm, the experiment showed that this model can effectively enhance the transportation efficiency of agricultural products [2]. And also, Wu and Yang put forward a bi-level programming model which combined the location optimization with the traffic distribution to realize the pre-location of manufacturing industry under the economic globalization [3]. Wang et al. proposed a method based on generalized cell mapping to solve the distribution of the exit position of weak noise excitation system on the basis of probability evolution analysis [4]. Wang et al. proposed an extended evacuation field model to determine the best location [5]. WALTER and GUTJahr developed a location model of relief allocation in a bi-objective optimization model and innovated a new algorithm to solve it [6]. Only a few papers considered quantitative and qualitative factors, thus, Ozgen and Gulsun combined the possibility linear programming and fuzzy analytic hierarchy process to study the multi-objective multi-facility location problem with limited capacity [7]. Elevli deeply discussed the location decision of logistics freight center based on fuzzy PROMETHEE method [8]. Besides, Shishebori and Babadi proposed a mixed integer linear programming model for the network design of medical service (MS) center location considering uncertain parameters [9]. Also, Liu et al. improved the design of genetic algorithm and applied it to the location of medical center, Abounacer et al. explored and innovated the solution method of location–transportation problem [10,11]. Rastaghi et al. considered the referral system and established a multi-objective hierarchical location allocation model for the design of medical network. Bashiire et al. believed that in a dynamic environment, there were mobile facilities in the central node, which can be transferred to other nodes in the next period. Using such facilities will save additional costs, and this method can be used in some practical applications with rapidly changing requirements. Karamyar et al. (2018) established a multi-dimensional objective hybrid localization model considering the minimization of cost and time and analyzed its sensitivity [12–14]. Murat and Novruz developed a new mutation operator to heighten the performance of genetic algorithm [15]. Ortiz-Astorquiza et al. conducted a comprehensive review of multi-level facility location issues and expanded several classic facility location issues. Different from other facility location, in order to minimize the number of residents who were not serviced, Chen et al. considered limited rational choice behavior of residents and established a location model based on limited rational choice behavior, they also designed simulated annealing algorithm and genetic algorithm [16,17].

1.2. Location of emergency logistics facilities

For the sake of effectively dealing with all kinds of natural or social emergencies, it is particularly pivotal to strengthen the emergency management system. As an essential infrastructure of the emergency management system, the emergency materials reserve is of great significance in strengthening response efficiency and reducing disaster losses. Under the environment of risk, emergency multi-objective location is an NP-hard problem with high complexity of objectives and constraints. As soon as this kind of traffic problem is put forward, it has been widely concerned by scholars. Since then, the location and optimization of emergency logistics facilities have become more significant, also, more research results have been obtained in recent years.

Jia et al. discussed the modeling framework of the location for medical service facilities under large-scale emergencies, which provided theoretical ideas for future generations to study such problems. Guan et al. analyzed the model and algorithm of the center and spoke position of emergency service facilities for serious emergencies [18,19]. Khayal et al. proposed a mathematical model for the location planning of temporary distribution facilities for pre-location of emergency logistics facilities. Nickel et al. considered the total cost of installation and maintenance facilities, and discussed the location and quantity of ambulances and their bases in a certain area. Sudtachat et al. put forward a relocation strategy to elevate the performance of (Emergency Medical Service, EMS) system and verified it with an example [20–22]. There was once an earthquake in Turkey, Kilici et al. set up a positioning system model of temporary shelter area after the earthquake according to real cases, and Peker et al. also took Turkey as an example to analyze the location of logistics center based on ANP/BOCR. Ghasemi et al. proposed a multi-objective, multi-commodity, multi-cycle and multi-vehicle location–allocation model for emergency supplies based on the evacuation planning after the earthquake and considering uncertain factors. After sudden public events, limited transportation resources must be used to transport a large number of patients to medical facilities, the decisions about where to send patients are usually made by the on-site respondents.
in an ad hoc manner [23–25]. And, Mills et al. formulated two heuristic strategies on this issue [26]. Behnam et al. established a two-stage, multi-objective mixed integer, multi-period and multi-commodity location model of the three-level disaster relief chain, and they used NSGA-II and MOPSO to solve the given problem [27]. Mahdi et al. put forward a new mathematical model of temporary rescue center location, the objective function of which is to minimize the time to reach the last designated place. According to the complexity of the proposed problem, an improved mixed element heuristic algorithm based on the combination of decentralized search and variable neighborhood search is developed [28]. In addition, Li studied the related theories of multi-objective planning of emergency logistics under mixed uncertainties. Then, Liu considered uncertain factors and applied the robust optimization theory to the research of location model of emergency logistics center. Under the background of normalized epidemic prevention and control, for the sake of avoiding the shortage of materials caused by local cases in different regions, Song et al. built a model of location and distribution of the reserve pool to minimize the unmet demand rate and maximize the fairness of distribution, they solved it with multi-objective genetic algorithm [29–31]. In order to effectively deal with all kinds of natural or social emergencies, it is particularly important to strengthen the emergency management system. As an important infrastructure of the emergency management system, the emergency materials reserve is of great significance in improving response efficiency and reducing disaster losses. Wang joined the UAV system in the process of studying similar problems, which provided certain reference for the construction of emergency logistics service facilities for similar problems [32].

1.3. Research gap

Based on the above research results, it can be found that the priority of logistics distribution center is neglected in most existing studies, only the location factor is considered in the study of site-path optimization. In fact, there are many factors influencing the location of emergency logistics distribution center, such as the environment of demand point, road condition, society and history, among which social factors include population density, economic development level and medical condition. In view of these, this paper will use the comprehensive evaluation methods to evaluate the priority of alternative logistics distribution sites considering the influence of various factors. The essence of the research is a multi-objective optimization problem of pre-location for urban emergency logistics facilities. The non-dominant sorting genetic algorithm is adopted to solve the mathematical model of this problem, and an example is given to verify model. At the same time, the optimal location scheme considering the priority is compared with the scheme without considering the priority.

The content structure of this paper is as follows: Section 1 studies the research of previous scholars on the modeling method and solution algorithm concerning logistics facilities pre-location; Section 2 establishes a mathematical model to describe the problem; Sections 3–4 give the solution of the model, which test the proposed method framework through case analysis, including scheme comparison of the solutions considering the location priority or not. The conclusion and future research work are discussed in Section 5.

2. Pre-location model of temporary distribution station under emergencies

2.1. Problem statement

With the recent sudden outbreak of COVID-19, Wuhan, Hubei Province was one of the high-risk areas. The research content of this paper is the pre-location problem of emergency logistics facilities considering priority or not under emergencies, a multi-objective optimization model of pre-location is established, the superior location scheme of emergency material distribution station under the condition of full-service coverage to all demand points is determined, and the comparative analysis on the results based on the optimal scheme before & after considering the location priority are carried out. Fig. 1 is a flow chart of the pre-site selection problem.

In addition, the following assumptions are made in the location model. (1) Concentrate scattered demand at one point. (2) A certain emergency scenario is assumed in this model since there are many emergency situations under realistic conditions. (3) The distribution capacity carried by the distribution center can meet the total nominal demands of the demand points. (4) The total delivery cost only considers the fixed expense of the open facilities, the transportation cost, the penalty cost for violating the time constraint and the psychological trauma caused by the incident to the masses. (5) Euclidean distance is used as the distance in this paper. (6) Every demand point must be completely covered. (7) The position coordinates of candidate points are known (see Table 1).

2.2. Mathematical model of pre-location

\[
\begin{align*}
(1) \text{Minimize delivery time} \\
\text{Quote decision variable } x_{ij} = \begin{cases} 
1 & j \text{ transport materials for demand point } i \\
0 & \text{Else} \end{cases} . \\
\min f_{TIME} = \min \sum_{i \neq j; i \in N} \sum_{j \in M} x_{ij} \cdot Z_j \cdot [t^{ij} + (s_j^f + s_i^f)] 
\end{align*}
\]
Table 1
Symbol definition of model.

\[
\begin{array}{ll}
s_j^\text{L} & \text{Loading time at emergency materials temporary distribution station } j \\
s_j^\text{U}, s_i^\text{R} & \text{Unloading time and rest time at closed community demand point } i \\
[\text{RE}, \text{RE}^\text{L}] & \text{The time window when demand point } i \text{ is pretty satisfied and pretty dissatisfied for the arrival of materials, i.e., the longest acceptable waiting time when demand point } i \text{ is very satisfied and the shortest waiting time when } i \text{ is very dissatisfied.} \\
d_{ji} & \text{Quantity of emergency supplies delivered from candidate point } j \text{ to demand point } i \\
d_i^\text{max} & \text{Nominal demand of demand point } i \\
\zeta_j, \zeta_j^\text{U} & \text{Variation coefficient of psychological trauma} \\
k_j & \text{Fixed cost after selecting candidate point } j \\
k_{ji}^\text{d} & \text{Unit cost of transporting materials from point } j \text{ to point } i \\
\lambda_{\text{PFUN}}, \delta, \omega_{\text{PSY}} & \text{Penalty coefficient for violation of time window constraint} \\
\pi & \text{Sensitivity coefficient of positive time} \\
\end{array}
\]

\[
\begin{align*}
\pi > 1 & \Rightarrow \text{ convex curve} \\
\pi < 1 & \Rightarrow \text{ concave curve} \\
\pi = 1 & \Rightarrow \text{ straight line}
\end{align*}
\]

Decision variable \( Z^j = \begin{cases} 
1 & \text{if point } j \text{ is selected as the temporary distribution site.} \\
0 & \text{else}
\end{cases} \)

Decision variable \( x_{ji} = \begin{cases} 
1 & \text{if point } j \text{ transports materials to demand point } i \\
0 & \text{else}
\end{cases} \)

(2) Maximize degree of time satisfaction

\[
\max \ f_{\text{SAT}} = \max_{j \in M} \sum_{i \in N} \left( (Z^j \cdot d_{ji}^\text{L} \cdot x_{ji} \cdot e(t^j)) \right)
\]
Among it, $e(t^i) = \begin{cases} 
1, & t^i < RE^e \\
1 - \left(\frac{[t^i - RE^e]}{[RE^e - RE^l]}\right)^\pi, & RE^e < t^i < RE^l \\
0, & t^i > RE^l
\end{cases}$ (3)

(3) Minimize the psychological trauma of the masses
Assume that the initial psychological trauma caused by the epidemic situation to the people of epidemic area is $T_{Psy}$. (1) Increasing coefficient of psychological trauma for every ten additional patients in this area is $\zeta_j$. (2) The psychological state of the masses at the demand point is worse and its change coefficient is $\zeta_n^t$ due to the delay of the arrival of emergency materials.

Establish the psychological trauma cost of the masses:
$$MIN_{Psy} = \min \left\{ h_{Psy} \left( \frac{U}{10} \right)^{\zeta_j}, t^i < RE^e \& RE^e < t^i \leq RE^l \right\}$$

(4) Minimize the delivery cost
Penalty cost function with time window constraint of receiving materials for demand points:
$$f_{PUN} = \begin{cases} 
0, & t^i < RE^e \& RE^e < t^i \leq RE^l \\
(\lambda_{PUN})^\delta \cdot (t^i - RE^l), & t^i > RE^l
\end{cases}$$

Establish a function of minimizing dispatch cost:
$$\min f_{Disp} = \min \left\{ \sum_{j=1}^{M} \sum_{i=1}^{N} x_{ij} \kappa_{2d}^j d_m^i + f_{PUN} + \sum_{j=1}^{m} \kappa_{1g}^j Z^j \right\}$$

(5) Pre-location model of temporary distribution station of urban emergency materials
$$F_{location} = \{ \MIN_{i,j \in \mathcal{N}} \left( \sum_{j=1}^{M} \sum_{i=1}^{N} f(\cos t_{total}), \MAX_{i,j \in \mathcal{N}} \sum_{j=1}^{M} \sum_{i=1}^{N} f_{Sat} \right) \}$$

s.t. \quad \sum_{i} \sum_{j} d_m^i \geq \bar{d}, \forall i \in N, j \in M

(8)

(9)

$$0 \leq \sum_{i} \sum_{j} d_m^i \leq \sum_{i} \sum_{j} t_{max}, \forall i \in N, j \in M$$

$$\sum_{i} \sum_{j} x_{ij} \geq 1, \forall i \in N, j \in M$$

$$e(t^i) = 1, t^i < RE^e, \forall i \in N, j \in M$$

$$e(t^i) = 1 - \left(\frac{[t^i - RE^e]}{[RE^e - RE^l]}\right)^\pi, RE^e < t^i < RE^l, \forall i \in N, j \in M$$

$$e(t^i) = 0, t^i > RE^l, \forall i \in N, j \in M$$

$$\sum_{j=i} Z^j = \bar{R}, \forall j \in M$$

$$\lambda_{PUN} \in [0, 1], \delta \in [0, 1]$$

(16)
\[ Z_j = \begin{cases} 1 & \text{if } j \text{ is selected as the temporary distribution site} \smallskip \text{Else} \end{cases} \] (17)

\[ x_{ij} = \begin{cases} 1 & \text{if } j \text{ transports materials for demand point } i \smallskip \text{Else} \end{cases} \] (18)

Formula (7) indicates the double-objective location model, in which objective 1 is to minimize the total delivery cost and objective 2 is to maximize the total time satisfaction of all demand points. Formula (8) shows that the total demands of the demand points should be adequately supplied. Formula (9) represents the non-negative variables. Formula (10) means that the actual delivery volume of each temporary distribution station does not exceed its actual supply capacity. Formula (11) represents that there is at least one distribution site at any demand point to supply materials. Formulas (12)–(14) are functions of \( t^j \). Formula (15) indicates that the number of \( R \) distribution sites are selected to service demand points. Formula (16) shows the coefficient between [0, 1]. Formulas (17)–(18) are 0–1 integer variables.

3. The methods

3.1. Pre-location scheme based on non-dominated sorting genetic algorithm

As the model established in this paper is nonlinear, which cannot be solved by conventional genetic algorithm, the non-dominated sorting genetic algorithm is tried to solve the problem. Genetic algorithm (GA) was first proposed by Professor J. Holland of Michigan University in 1975. Non-dominated sorting genetic algorithms (NSGA) was put forward by Srinivas and Deb in 1995, which is an algorithm based on Pareto optimal concept. Three basic operators of this method are as follows.

- Selection operator: Roulette wheel selection mechanism is adopted.
  The fitness function is shown in Fig. 2. We suppose that the fitness value of \( x(i) \) is represented by \( f[x(i)] \), then, the probability of it being selected is: \( p[x(i)] = f[x(i)]/\sum_{j=1}^{n} f_j \) and the cumulative probability is \( q[x(i)] = \sum_{j=1}^{n} p(x_j) \).
- Crossover operator: The uniform crossover method is used for crossover operation.
- Mutation operator: The method of random mutation site is used for antibody mutation.

It is common knowledge that genetic algorithm belongs to heuristic algorithm, and heuristic algorithm is more suitable for practical problems. Therefore, the genetic algorithm will be adopted to solve the pre-location optimization problem of emergency material distribution center with superior universality and robustness. The flow of multi-objective genetic algorithm is shown in Fig. 3.

3.2. Priority analysis based on VIKOR and I-GRA

In this paper, the weight of each evaluation index is constructed by VIKOR (Vlsekriterijumska Optimizacija I Kompromisno Resenje) and the I-GRA (Improved gray relational analysis method), the I-GRA is improved by using the cosine of the included angle of the vector. Then, the I-GRA method is run by MATLAB and VIKOR is implemented by mathematical steps to determine the objective weight of each evaluation index. The comprehensive evaluation value is obtained by linear weighting combined with the subjective weight determination method of online questionnaire. Also, the convenience of transportation, development level of economic, level of medical (i.e., benefit index) and epidemic severity (i.e., cost index) are included as the evaluation indexes (see Table 2).

An initial evaluation matrix is established in accordance with the priority evaluation indexes of the candidate points of the temporary distribution station. The indexes are divided into benefit indexes and cost indexes in line with VIKOR
Fig. 3. Operation process of multi-objective optimization algorithm.

| Parameters | % Parameter definition |
|------------|------------------------|
| $o_{ik}$  | $o_{ik} = l_{ik}/\max l_{ik1}, l_{ik2}, \ldots, l_{ikg}$ |
| $r_{ik}$  | $r_{ik} = u_{ik}/\max u_{ik1}, u_{ik2}, \ldots, u_{ikg}$ |
| $\max u_{ik}$ | $\max u_{ik} = \max(\max(UO))$ |
| $\min u_{ik}$ | $\min u_{ik} = \min(\min(UO))$ |
| $qq$      | $qq = \min u_{ik} + p * \max u_{ik}$ |
| $u+w$     | $u+w = UO + p * \max u_{ik}$ |
| $qq1$     | $qq1 = \min u_{ik} + p * \max u_{ik}$ |
| $u+w1$    | $u+w1 = UO + p * \max u_{ik}$ |

Table 2
The parameters of I-GRA.

(see Table 3).

\[
(W^g)_{mn} = \begin{bmatrix}
7.10a & 9.72a & 7.02a & 5.10a & 9.20a & 7.03a & 7.21a & 9.10a & 5.11a & 7.24a \\
7.21b & 9.17b & 7.29b & 7.28b & 9.47b & 5.26b & 7.44b & 5.23b & 9.03b & 7.17b \\
5.03c & 3.13c & 4.27c & 5.04c & 6.35c & 7.03c & 4.61c & 5.51c & 6.40c & 3.04c \\
7.19d & 9.01d & 7.08d & 9.05d & 5.02d & 7.17d & 5.70d & 7.80d & 9.05d & 5.41d
\end{bmatrix}
\]

(1) Major parameters of I-GRA code
(2) Key formula of VIKOR
### Table 3

| j  | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  |
|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| h/ | 0.4304 | 0.5077 | 0.2838 | 0.4491 | 0.4072 | 0.3284 | 0.2601 | 0.1142 | 0.3802 | 0.4011 |

### Table 4

Nominal demand analysis.

| d, Demand point i | Parameter ε | ε₀ | ε₂ | ε₃ | d₀ |
|-------------------|--------------|----|----|----|----|
| Demand point 1    | 65.11        | 47 | 40.22 | 48.89 |
| Demand point 2    | 72.09        | 63.11 | 52.38 | 62.82 |
| Demand point 3    | 69.02        | 60.01 | 43.03 | 58.68 |
| Demand point 4    | 87.72        | 76.38 | 69.38 | 77.10 |
| Demand point 5    | 84.72        | 72.11 | 60.73 | 72.32 |
| Demand point 6    | 78.27        | 53.37 | 42.38 | 55.69 |
| Demand point 7    | 90.38        | 75.82 | 62.84 | 76.08 |
| Demand point 8    | 49.28        | 40.37 | 34.64 | 40.90 |
| Demand point 9    | 57.11        | 54.11 | 50.66 | 54.04 |
| Demand point 10   | 73.38        | 67.38 | 50.38 | 65.55 |
| Demand point 11   | 92.38        | 80.93 | 71.03 | 81.19 |
| Demand point 12   | 73.39        | 57.38 | 40.27 | 57.20 |
| Demand point 13   | 64.02        | 50.26 | 43.10 | 51.36 |

(a) \( W = (W^h)_{m,n} \) (The initial evaluation matrix)

(b) \( G^y = \frac{[g^y]}{[\text{MAX}^y]} \)

(c) \( G^g = \frac{[g^g]}{[\text{MIN}^g]} \)

(d) \( y_i^+ = \text{MAX}y_i^j, i = 1, \ldots, n, y_i^- = \text{MIN}y_i^j, i = 1, \ldots, n \)

(e) \( \phi_i = \sum_{j=1}^{n} w_j(y_j^+ - y_j^-)/(y_j^+ - y_j^-) \cdot \psi_i = \text{MAX}[w_i(y_i^+ - y_i^-)/(y_i^+ - y_i^-)] \)

(f) \( h' = \frac{\{\psi_i - \psi_i^{\text{MIN}}\} \cdot [1 - \Lambda] + \{\phi_i - \phi_i^{\text{MIN}}\} \cdot \Lambda}{\psi_i^{\text{MAX}} - \psi_i^{\text{MIN}}} \)

Finally, the priority selection sequence of temporary distribution stations for emergency supplies was obtained: 2→4→1→5→10→9→6→3→7→8.

3.3 Nominal demand analysis based on TFN and PERT

Since there are mass of fuzzy indexes in this paper, the TFN theory (Triangular Fuzzy Number, a method to convert fuzzy and uncertain linguistic variables into certain values) is involved, and the triangular fuzzy numbers are comprised of the most pessimistic value, the most probable value and the most optimistic value (Take \( \xi_1, \xi_0, \xi_2 \) as Triangular Fuzzy Number). Simultaneously, the Program Evaluation and Review Technique method (PERT) is used for estimation of nominal demands.

Finally, the priority selection sequence of temporary distribution stations for emergency supplies was obtained: 2→4→1→5→10→9→6→3→7→8.

### 4. Case study

The experimental environment is CPU 1.80 GHz, the development environment is MATLAB R2018a, in addition, the case test is run on computer for Intel(R) Core(TM)i5-8265U CPU @ 1.80 GHz, 8 GB RAM and Windows7 platform. In this paper, we will take Wuhan, Hubei Province as an example under COVID-19, and the whole city is divided into 13 demand points of control areas in conformity with the division of large-scale areas, i.e., Jiang’an District, Jianghan
Table 5
Coordinates and nominal demands of the control areas.

| Serial number of demand point | Longitude       | Latitude       | Nominal demands (ten thousand pieces) |
|-------------------------------|-----------------|----------------|----------------------------------------|
| Control area 1                | 114.316579      | 30.605403      | 48.89                                  |
| Control area 2                | 114.277506      | 30.607282      | 62.82                                  |
| Control area 3                | 114.22146        | 30.587584      | 58.68                                  |
| Control area 4                | 114.225446       | 30.560052      | 77.10                                  |
| Control area 5                | 114.322549       | 30.559567      | 72.32                                  |
| Control area 6                | 114.391493       | 30.646593      | 55.69                                  |
| Control area 7                | 114.350456       | 30.506334      | 76.08                                  |
| Control area 8                | 114.143459       | 30.62592       | 40.90                                  |
| Control area 9                | 114.091515       | 30.314809      | 54.04                                  |
| Control area 10               | 114.03548        | 30.588114      | 65.55                                  |
| Control area 11               | 114.328551       | 30.381564      | 81.19                                  |
| Control area 12               | 114.382454       | 30.887534      | 57.20                                  |
| Control area 13               | 114.807543       | 30.847244      | 51.36                                  |

Table 6
Relevant parameters of candidate points.

| Serial number of demand point | Longitude       | Latitude       | The capacity (ten thousand pieces) |
|-------------------------------|-----------------|----------------|-----------------------------------|
| Facility 1                    | 114.304271      | 30.401403      | 132                               |
| Facility 2                    | 114.177506      | 30.487281      | 150                               |
| Facility 3                    | 114.241460      | 30.577284      | 129                               |
| Facility 4                    | 114.315446      | 30.550051      | 137                               |
| Facility 5                    | 114.302542      | 30.459561      | 126                               |
| Facility 6                    | 114.391490      | 30.636590      | 140                               |
| Facility 7                    | 114.340454      | 30.546301      | 141                               |
| Facility 8                    | 114.153458      | 30.61504       | 122                               |
| Facility 9                    | 114.101511      | 30.334810      | 130                               |
| Facility 10                   | 114.045490      | 30.548091      | 125                               |

Table 7
Time from candidate point (cp. j) to demand point (dp. i) (h)

| i   | j     | cp.1 | cp.2 | cp.3 | cp.4 | cp.5 | cp.6 | cp.7 | cp.8 | cp.9 | cp.10 |
|-----|-------|------|------|------|------|------|------|------|------|------|-------|
| dp.1|       | 1.76 | 1.60 | 1.33 | 0.89 | 1.96 | 1.49 | 1.94 | 1.73 | 1.31 | 1.94 |
| dp.2|       | 2.05 | 2.01 | 1.20 | 1.01 | 2.01 | 1.04 | 2.03 | 2.01 | 1.30 | 1.72 |
| dp.3|       | 1.97 | 3.00 | 1.09 | 2.01 | 1.77 | 1.73 | 2.33 | 1.94 | 1.69 | 0.88 |
| dp.4|       | 0.82 | 1.02 | 1.82 | 0.82 | 0.83 | 1.58 | 3.03 | 0.72 | 1.42 | 0.71 |
| dp.5|       | 0.74 | 0.98 | 1.02 | 1.78 | 0.64 | 2.03 | 1.73 | 0.78 | 1.32 | 2.01 |
| dp.6|       | 1.47 | 1.44 | 2.01 | 1.53 | 1.47 | 2.04 | 1.39 | 1.48 | 2.31 | 1.73 |
| dp.7|       | 2.01 | 2.03 | 2.01 | 1.37 | 2.01 | 3.01 | 2.02 | 2.04 | 2.61 | 1.62 |
| dp.8|       | 1.73 | 2.81 | 3.03 | 1.39 | 1.73 | 1.73 | 1.04 | 1.70 | 1.74 | 2.53 |
| dp.9|       | 2.03 | 1.03 | 2.82 | 1.93 | 2.03 | 1.98 | 1.92 | 2.06 | 2.67 | 2.01 |
| dp.10|      | 1.09 | 2.02 | 2.76 | 2.03 | 1.09 | 1.37 | 1.33 | 1.07 | 2.46 | 2.03 |
| dp.11|      | 0.73 | 2.71 | 2.71 | 2.04 | 0.93 | 1.38 | 1.32 | 0.73 | 2.51 | 1.93 |
| dp.12|      | 1.32 | 1.73 | 1.93 | 1.83 | 1.33 | 1.48 | 0.98 | 1.36 | 1.83 | 0.86 |
| dp.13|      | 1.28 | 1.92 | 1.63 | 1.07 | 1.25 | 1.82 | 1.93 | 1.27 | 1.26 | 1.37 |

District, Qiaokou District, Hanyang District, Wuchang District, Qingshan District, Hongshan District, Dongxihu District, Hannan District, Caidian District, Jiangxia District, Huangpi District and Xinzhou District. A number of 10 large open space, stadium or convention center are listed as candidate points to deliver materials for 13 demand points. Tables 5–7 present the relevant parameters of demand points and candidate points.

1) Pre-location scheme of urban emergency logistics facilities

The control parameters of multi-objective genetic algorithm are set as follows: the population size is 200, the mutation probability is 0.9, the crossover probability is 0.8, and the maximum number of iterations is 500.

Fig. 4-a shows the distribution curve when the model is iterated to 500 times, and Fig. 4-b represents that the middle point of Fig. 4-a corresponding to the pre-location optimal scheme, which selects the number of 7 candidate points, i.e., candidate point 2, candidate point 3, candidate point 4, candidate point 5, candidate point 6, candidate point 7 and candidate point 10. The total cost is 13342.2 units, of which the total time cost is 283.7 units. The total time satisfaction of the 13 demand points is 9.4691. In addition, Table 8 is the optimal scheme and the satisfaction of each demand point is shown in Table 9 below.
As we can obtain from Fig. 5-a, the total cost changes slightly in the first 10 iterations, fluctuates greatly in the interval of 11–130 iterations. And changes slightly at the beginning of the 131st iteration, which cannot be shown in the Fig. 5.

(2) Pre-location scheme of urban emergency logistics facilities with priority

Fig. 6-a shows the distribution curve when the model is iterated to 500 times, and Fig. 6-b indicates the pre-location scheme corresponding to the solution of the intermediate point. Five candidate points are selected in this scheme, i.e., alternative point 2, alternative point 4, alternative point 1, alternative point 5 and alternative point 10. The total cost required of this scheme is 9919.7 units, of which the total time cost is 261.7 units and the total time satisfaction value of 13 demand points is 9.6868. In addition, the optimal scheme is shown in Table 10, and the time satisfaction value of each demand point is shown in Table 11.

(3) Comparison of two pre-location schemes as in Fig. 7

Fig. 8 shows the comparison of costs and total time satisfaction value with consideration of priority or not, it is found that the scheme considering the priority of logistics distribution center is more superior with less costs and higher time satisfaction, in addition, the time waste is avoided.

It can be gained from Table 12 that the time cost of the scheme with consideration of the priority is slightly reduced by 7.754%, the total time satisfaction value is increased by 2.299%, and the total cost is reduced by 25.651%. Therefore,
Fig. 5. Pareto solutions for 2 objectives.

Fig. 6. Pareto solution and pre-location optimal scheme with priority.

Table 10
Pre-location scheme and each value.

| Demand point (dp.) $i$ | Candidate point (cp.) $j$ | Function values of sub-objective |
|------------------------|--------------------------|----------------------------------|
| dp.9+ dp.5             | cp. $j$ = cp.2           | $\sum_{j=1}^{M} \sum_{i=1}^{N} [f_{cost}] = 9919.7000$ |
|                        |                          | $\sum_{j=1}^{M} \sum_{i=1}^{N} [f_{TIME}] = 261.7000$ |
|                        |                          | $\sum_{j=1}^{M} \sum_{i=1}^{N} [f_{SRT}] = 9.6868$ |
| dp.4+                  | cp. $j$ = cp.4           |                                  |
|                        |                          |                                  |
| dp.13+                 |                          |                                  |
| dp.8+                  |                          |                                  |
| dp.2+                  |                          |                                  |
| dp.1+                  |                          |                                  |
| dp.7                   |                          |                                  |
| dp.11                  | cp. $j$ = cp.1           |                                  |
| dp.10+ dp.6            | cp. $j$ = cp.5           |                                  |
| dp.3+ dp.12            | cp. $j$ = cp.10          |                                  |
Table 11
Time satisfaction value of demand point $i$.

| Demand point (dp.) | Value of $f_{SAT}$ | Demand point (dp.) | Value of $f_{SAT}$ | Demand point (dp.) | Value of $f_{SAT}$ |
|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| dp.9               | $f_{SAT}^9 = 0.999$| dp.2               | $f_{SAT}^2 = 0.940$| dp.10              | $f_{SAT}^{10} = 0.001$|
| dp.5               | $f_{SAT}^5 = 0.998$| dp.1               | $f_{SAT}^1 = 0.632$| dp.6               | $f_{SAT}^{6} = 0.010$ |
| dp.4               | $f_{SAT}^4 = 1.000$| dp.7               | $f_{SAT}^7 = 0.824$| dp.3               | $f_{SAT}^{3} = 0.696$ |
| dp.13              | $f_{SAT}^{13} = 1.000$| dp.11              | $f_{SAT}^{11} = 1.000$| dp.12              | $f_{SAT}^{12} = 0.579$ |
| dp.8               | $f_{SAT}^8 = 1.000$|                    |                    |                    |                    |

\[
\sum_{i=1}^{13} f_{SAT} = 9.6868
\]

Fig. 7. Pareto solutions of 2 objectives with priority.

Fig. 8. Comparison of function values with or without location priority.

The consideration of the location priority can not only lessen the cost, but also heighten the time satisfaction value to some extent in practice, which indicates the scheme with the location priority is better.

5. Conclusions and limitations

To sum up, the pre-location of emergency logistics plays a significant role in dealing with emergencies. This paper establishes a pre-location mathematical model in conformity with the characteristics of the location for emergency logistics.
logistics facilities. Firstly, the priority of each candidate point is evaluated by means of comprehensive evaluation methods in accordance with the factors concerning pre-location to be considered. Then, a multi-dimensional objective optimization model with time window constraints is established, which is solved by non-dominated sorting genetic algorithm. Finally, the validity and feasibility of the model & algorithm are verified by a case study of a pre-location problem for urban emergency materials distribution station in Wuhan, Hubei Province. Furthermore, a comparative analysis of the optimal pre-location schemes with a consideration of priority or not shows that the scheme considering priority is better, which takes the form of the time reducing by 7.754%, the cost decreasing by 25.651% and the total satisfaction improved by 2.299%. Consequently, the research provides theoretical support and practical ideas for the solution of the location problem of urban emergency logistics facilities.

(1) Minimize the delivery time: The delivery of relief supplies is an exceedingly pivotal link in the rescue work after a disaster, one minute earlier the arrival of relief supplies may arrest more deaths and economic losses. Besides, total cost minimization corresponds to economic logistics. Therefore, this paper builds a mathematical model in conformity with timeliness, which can be better applied to practice.

(2) Maximize the total time satisfaction: This paper introduces the concept of time satisfaction into the pre-location problem on account of the pivotal role of time concept in the logistics chain, which will ensure the location decision result of service station is more superior as far as possible and make the rescue efficiency better.

Ultimately, this paper studies the location of candidate points of emergency logistics under static conditions, in addition, the Pareto solutions before & after considering priority are compared, and the corresponding amplitude of variation is obtained. Nevertheless, no matter the epidemic situation or other forms of emergencies are time-varying or dynamic. Therefore, further research is required on how to accurately select emergency logistics facilities at the future decision-making moment under dynamic circumstances.

CRediT authorship contribution statement

Yun Yang: Methodology, Software, Formal analysis, Writing – original draft. Changxi Ma: Writing – review & editing. Gang Ling: Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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