A Method of Transporting Materials under Emergencies for Residential Communities

Yun Yang*, Qingshan Zhang, Yubo Zhang and Yuhe Tian

***Abstract*—To strengthen property management and to solve the problem for emergency material transport under the sudden emergencies, the property management company redesigned an optimization method of rescue vehicle route choice with considering the transport time (timeliness of emergency logistics) and the time penalty cost (service satisfaction) for the residential communities it serves. The system is solved based on Genetic Algorithm. Also, the demand urgencies of each area were determined with improved Gray Relative Analysis (IGRA), while total demands of each point were calculated using combination of triangular fuzzy number theory and PERT (TFN-PERT). In addition, some parameters will be corrected to compare the running results before and after the optimization. Synchronously. And the objective function values, which were calculated with consideration of demand urgency and without considering it respectively, also are compared. The effectiveness and feasibility of this approach were verified. The result manifests that the model can contribute to both timeliness and service satisfaction. Regarding the calculation of urgency, which can lessen the blindness of dispatching and ensure the fairness of distribution to some extent. Research result combines with the specific process of transportation vehicles under the sudden emergencies. As such, the approach could furnish scientific decision support on emergency system authentically for property management companies.**

***Index Terms*— Property management, Emergency systems, Vehicle route, Demand urgency, Fuzzy theory, Residential communities**

I. Introduction

STRENGTHENING property management in residential communities [6] can effectively improve the quality of life in residential communities, stimulate the vitality of shared governance in residential communities, and increase the satisfaction of residents [7][8]. Under the sudden emergencies, the reasonable vehicle route arrangement is an effective strategy to lessen the fulfillment time and improve the service satisfaction. The work is related to some research steams in this study, which are material distribution, estimate of demand urgency and vehicle route choice.

In order to reduce unnecessary deaths and property losses due to natural disasters, emergencies and other public emergencies for residential communities, a scientific and efficient system for route choice of emergency material transportation vehicle must be established to ensure the timeliness and service satisfaction for material delivery by property management companies. At present, there are plenty of domestic and foreign studies in vehicle routing problem of emergency materials (EMVRP), and researchists generally adopted optimization algorithm for solution [1][2][3].

For instance, Ko et al. applied GA to EMVRP. As the transportation of emergency supplies was a complete set of tasks [4][5][9][10][11]. Furthermore, some foreign scholars had built corresponding mathematical models with diversified objectives and methods under the miscellaneous circumstances, for instance, Liu et al. utilized the emergency material allocation method based on the variation of supply and demand to keep the total response time as short as possible [12], a modular stochastic model based on the distribution scenarios for emergency resource was built by Hu et al. [13], and Jiang et al. proposed a supply model with vehicle scheduling [14].

Currently, the problem of route planning was still a hot topic. It had been studied by Wang et al, Zhu et al, He et al. and Wang et al [15] [16] [17] [18]. Apparently, the service satisfaction of residential community might reflect the effectiveness of relief efforts. Some researchers (Wang et al., Ma et al. and Zhao et al.) set up the multi-dimensional objective functions [19] [20] [21]. Also, Garmen et al. and Tzeng et al. established the dual-objective dispatching model [22] [23]. Similarly, timeliness of transportation emphasizing speed and efficiency of rescue was essential in the process of emergency logistics. Hence, Yuan et al. [24] found out a dual-objective model with the minimizing material delivery time, which was solved through ideal point algorithm. Furthermore, Gan et al., Qiao et al., Xu et al. and Zhou et al. built models on the basis of minimizing the supply transportation time [25] [26] [27] [28]. And, others had conducted major studies on disaster relief routes, i.e., Luis et al. studied the disaster relief route based on reality [29], Huang et al. researched the distribution path of logistics under emergencies based on cellular GA [30]. Actually, robust optimization was an original modeling method to study uncertain optimization problems, which derived from robust control theory. For instance, Yang et al. proposed a multi-dimensional robust EMVRP optimization model, which was solved by a hybrid algorithm [37]. HAGHI et al.

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adopted robust optimization to deal with parameters such as demand, supply and cost and built the relevant functions [31].

For the past ten years, there are frequent outbreaks of various emergencies, and the multi-objective optimization problem of emergency material transportation vehicle route arrangement had become an important topic. Concerning the heuristic algorithm to investigate problem of path optimization, numerous scholars had built some pertinent mathematical models from various perspectives. For example, Liu et al. [32] used SOM neural network and GA to carry out path planning. In respect of the transportation cost, it was indispensable in the process of delivery, consequently, the research objectives of Chen et al. were minimizing direct and indirect costs [33]. Moreover, there were still scholars who had done other correlative studies on EMVRP. Wang et al. figured out the optimization problem of emergency logistics after an earthquake, and the purpose of Ge et al. was minimizing the loss of victims, meanwhile, the calculation results of the model under various circumstances were compared and analyzed in their studies [34] [35]. In addition, Yang et al. developed a multi-objective pre-location model for EMVRP [36]. Lu and Ma bridged inter-city traffic and spatial economics, the aim was to conduct a study of virus spread in a province, China [38]. Moreover, Long et al. and Qian et al. [39] [40] improved the algorithms and applied them to the distribution problem.

In summary, there have been many studies on EMVRP in the context of miscellaneous large-scale emergencies. In practice, the precise demand quantity for emergency supply is sophisticated to capture, therefore, the TFN-PERT method is utilized to acquire the relevant values by property management company in this study. Also, the timeliness of emergency logistics and service satisfaction under the background of high emergencies of this study are considered, and an improved weighted genetic algorithm (IWGA) shall be introduced to compare the two groups of objective function values which were calculated with consideration of demand urgency and without considering it respectively. Then, the optimization rate will be obtained. Eventually, the results indicate that the GA could reformulate the multi-objective problem into single-objective problem. Besides, the method may reduce the complexity and difficulty of calculation and improve the availability of searching solutions. Therefore, the optimal solution can be realized faster.

With the sudden outbreak of emergencies has given rise to the nasty supply-demand disequilibrium of relief resources due to traffic control. Protective materials and daily necessities are primal vital to secure the residents at the large-scale epidemic context. Consequently, it is crucial to ensure that the emergency supplies can be successfully mobilized, satisfied and transported in time to reduce superfluous casualties and economic losses for residential communities it serves. This study analyzes two factors including “timeliness” and “service satisfaction” with respect to EMVRP and designs a method to enhance the rescue efficiency by property management company.

The contributions of this study include: (1) taking the total delivery time and the time penalty cost of vehicle transportation as objectives, simultaneously. (2) designing an improved GRA method to deal with the urgency of each residential community. (3) integrating TFN theory and PERT method to estimate the demand quantity. (4) proposing improved weighted GA (IWGA) to solve the nonlinear mathematical model.

II. MODEL BUILDING

A. Problem Description

In order to strengthen the property management of residential communities, improve the quality of life of residential communities and improve residents' satisfaction. The multi-dimensional objective optimization problem of EMVRP taking into account the demand urgency was studied in this study with the outbreak of some sudden emergencies. Considering the severity of the epidemic, the demands in some residential communities served by property management company B were analyzed. The EMVRP model with “multi-vehicle transportation and multiple residential community” was constructed to obtain the optimized vehicle routes and the optimal function values. In the model, minimization of the total transportation time and the time penalty cost, as well as the load limitation of trucks were considered.

B. Model Symbols

In respect of EMVRP decision model studied in this paper, the emergency logistics network is signified as $G=(\Lambda,\Upsilon)$. Λ contains two subsets: M stands for the property management company, while N for the residential community. And, Υ is the set of available links. $DS=(ds_{ij})$ represents the distance matrix of two adjacent areas, ds_{ij} denotes the distance from i to j .

$$DS=(ds_{ij})=\begin{pmatrix} ds_{11} & ds_{12} & \dots & ds_{1m} \\ ds_{21} & ds_{22} & \ddots & ds_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ ds_{n1} & ds_{n2} & \dots & ds_{nm} \end{pmatrix}$$

TABLE I

VARIABLES OF THE MODEL

$d_{ijk}(i,j\in N)$	Travel distance of vehicle k from i to j
$Q_{oi}(i\in N)$	Quantity of materials transported from property management company to residential community i
$Q_{ijk}(i,j\in N)$	The quantity of materials loaded in vehicle k
$r_k(k\in K)$	The maximum capacity of vehicle k
$d_{oi}(i\in N)$	The distance between property management company and residential community i
$r_{oi}(i\in N)$	Emergency supplies delivered from property management company to residential community i
$v_{oi}(i\in N)$	Actual driving speed from property management company to point i
$r_{oic_i}(i\in N)$	Emergency supplies c_i transported from property management company to residential community i
$b_i(i\in N)$	The unloading time of vehicles at residential community i
$t_{ri}(i\in N)$	The rest time of vehicles at residential community i
$[PI^e,PI^l]$	Best time window for residential community to receive materials
ϖ,μ,ε	The correlative coefficients for time penalty cost
$M\cdot PI^e$	The upper limit of soft time window for residential community to receive materials
$W\cdot PI^l$	The lower limit of soft time window for residential community to receive materials
$y_i(i\in N)$	The time point when the vehicle arrives at the point i
Θ	An arbitrarily large real number

In addition, where $K(k \in K)$ denotes the set of vehicles. $C(c_i \in C)$ represents the total quantity of emergency materials. ψ_i is the demand urgency of each area. $D(i \in N)$ signifies material demand (tons), Q is the maximum supply of property management company. Both two objective functions take economy as the dimension, where ϖ^1 and ϖ^2 are the unified conversion coefficients of the economy dimension for them. The variables of model are shown in Table I.

C. Mathematical Model

C.1 Sub-model 1→Minimize Transportation Time

The type of multi-vehicle and multi-area EMVRP will be researched, and the road conditions between the two residential community are diverse. To solve this problem, the following assumptions are made. Hypothesis ①:The vehicle type and load limit of the property management company are identical, moreover, the materials are calculated by weight. Hypothesis ②: Transport tasks are performed by multiple vehicles, each vehicle only visits a certain residential community once, and multiple vehicles can visit the same point. Hypothesis ③: There are different road conditions, accordingly, the travel distance and speed of vehicles are disparate. Hypothesis ④:The unloading time of vehicles and the rest time of drivers are considered in the process of material transportation.

$$\min f_1 = \varpi^1 * \{\sum_{i=0,i\neq j}\sum_{j=0}[(d_{oi} * r_{ki} / v_{oi}) + x_{ijk}\cdot(b_i + t_{ri}) + t_{ij}]\} \tag{1}$$

Subject to: $$\sum_k \sigma_{ik} = 1.\forall i \in N.\forall k \in K \tag{2}$$

$$\sum_i D_i \cdot \sigma_{ik} \le r_k .\forall i \in N, \forall k \in K \tag{3}$$

$$Q_{oi} \ge 0.\ d_{oi}, v_{oi}, t_{ri}, b_i > 0.\ (O \in M,\ \forall i \in N) \tag{4}$$

$$r_{ki} = \begin{cases} 1 & \text{Vehicle } k \text{ transports materials to demand area } i \\ 0 & \text{Else} \end{cases} \tag{5}$$

$$x_{ijk} = \begin{cases} 1 & \text{Vehicle } k \text{ travels from demand area } i \text{ to area } j \\ 0 & \text{Else} \end{cases} \tag{6}$$

The equation (1) manifests the pursuit of the shortest total transportation time. Formula (2) shows each vehicle can only visit a demand area once. Formula (3) means that the loading limit of the vehicle k. Formula (4) indicates that the quantity of materials delivered is not negative, while the distance and speed values are positive. Formulas (5) and (6) denote 0-1 integer variables.

C.2 Sub-model 2 →Minimize Time Penalty Cost

There is a finite interval for material-arrival time window, which is related to the real-time demand of the residential community, i.e., the material-arrival time deviations are limited. Since the rescue vehicles may not reach the demand areas within the time window, the time penalty cost of vehicle transportation is taken into account to measure the service satisfaction of residential community.

As the above discussion, a mathematical model for minimizing the time penalty cost of vehicle transportation is established:

$$\min f_2 = \varpi^2 \sum_{i\in N} h$$

Equation (7) is the second objective function, which denotes minimizing the total time penalty cost of vehicle transportation.

$$= \varpi^2 \sum_{i\in N} \begin{cases} \varpi^1 \mu_1^{\varepsilon(\varepsilon>1)}(PI^e - W\cdot PI^e) + \mu_2(W\cdot PI^e - y_i), & \text{when } y_i \le W\cdot PI^e \\ \varpi^2 \mu_2(PI^e - y_i), & \text{when } W\cdot PI^e < y_i \le PI^e \\ 0, & \text{when } PI^e < y_i \le PI^l \\ \varpi^2 \mu_2(y_i - PI^l), & \text{when } PI^l < y_i \le M\cdot PI^l \\ \varpi^1 \mu_1^{\varepsilon(\varepsilon>1)}(M\cdot PI^l - PI^l) + \mu_2(y_i - M\cdot PI^l), & \text{when } y_i > M\cdot PI^l \end{cases} \tag{7}$$

$$PI^e, W\cdot PI^e, M\cdot PI^l, PI^l > 0 \tag{8}$$

$$0 < y_i(\forall i \in N) < \Theta \tag{9}$$

$$PI^e - W\cdot PI^e > 0, M\cdot PI^l - PI^l > 0 \tag{10}$$

Formula (8) manifests each node value in the soft time window is not negative. Formula (9) indicates that the vehicle arrival time at residential community i is positive. Formula (10) means that the numerical relationship for node values in the soft time window.

C.3 Complete Model

The EMVDR model with multi-dimensional objectives is addressed by the method of IWGA, and the specific weight coefficient τ_i is used to weight the following two functions: minimizing the total transportation time and minimizing the time penalty cost. So, the final equation $f_{optimum} = \sum \tau_i \cdot f_i (i \in 1,2)$ is formed, and $\sum \tau_i = 1$. Thereby, only one objective function value can be generated for each transportation scheme, which helps to simplify the problem and obtain the approximate global optimal solution. And the complete EMVDR model is as follows:

$$\min Z = \min[\sum_{i=1}^{2} \tau_i * f_i] = \min[(\tau_1 * f_1) + (\tau_2 * f_2)] = \tag{11}$$
$$\tau_1 * \{\sum_{i=0,i\neq j}\sum_{j=0}(d_{oi} * r_{ki} / v_{oi}) + x_{ijk}\cdot[(b_i + t_{ri}) + t_{ij}]\} + \tau_2 * [\sum_{i=1}^{n} h]$$

s.t: $$f_1 = \varpi^1 * \{\sum_{i=0,i\neq j}\sum_{j=0}[(d_{oi} * r_{ki} / v_{oi}) + x_{ijk}\cdot(b_i + t_{ri}) + t_{ij}]\} \tag{12}$$

$$f_2 = \varpi^2 * \{\min[\sum_{i=1}^{n} h\ (Z_2^i \text{ depends on } y_i)]\} \tag{13}$$

$$\sum_k \sigma_{ik} = 1, \forall i \in N, \forall k \in K \tag{14}$$

$$\sum_i D_i \cdot \sigma_{ik} \le r_k, \forall i \in N, \forall k \in K \tag{15}$$

$$\omega^1, \omega^2, Q_{oi} \ge 0.\ d_{oi}, v_{oi}, t_{ri}, b_i > 0.\forall i \in N, O \in M \tag{16}$$

$$0 < \sum_{i\in N} Q_{ik} < D, \forall k \in K \text{ and } \forall i \in N \tag{17}$$

$$\sum_{i=1}^{n} D_i < Q, \forall i \in N \tag{18}$$

$$0 < PI^e, W\cdot PI^e, M\cdot PI^l, PI^l < \Theta \tag{19}$$

$$0 < y_i(\forall i \in N) < \Theta \tag{20}$$

$$PI^e - W\cdot PI^e > 0, M\cdot PI^l - PI^l > 0 \tag{21}$$

$$r_{ki} = \begin{cases} 1 & \text{Vehicle } k \text{ transports materials to demand area } i \\ 0 & \text{Else} \end{cases} \tag{22}$$

$$x_{ijk} = \begin{cases} 1 & \text{Vehicle } k \text{ travels from demand area } i \text{ to area } j \\ 0 & \text{Else} \end{cases} \tag{23}$$

III. Methods

A. Improved Weighted-GA

The heuristic algorithm is far more applicable in practical problems. Therefore, in this study, the traditional GA will be improved, and the improved weighted-GA (IWGA) will be combined with IGRA to form a new algorithm to solve the model. The real number encoding is used, also, the operational process of IWGA is shown in Fig.1. Actually, the improved weighted-GA proposed in this paper transforms the multi-dimensional objectives into the one-dimensional objective, thus reducing the computational complexity herewith, and achieving the optimal solution faster.

B. Urgency with IGRA

The IGRA method (see Fig.2) is realized through MATLAB software in this study to acquire the objective weight of each evaluation index, and the Delphi method is used to determine the subjective weight. Then, the linear weighting is adopted so as to combine the two weights obtained. Finally, the urgency coefficient ψ_i for demand areas, i.e., the priority order of transport can be acquired. The severity degree, permanent resident population and death rate, etc. are regarded as the evaluation metrics (see Table II) for the demand urgency in this study.

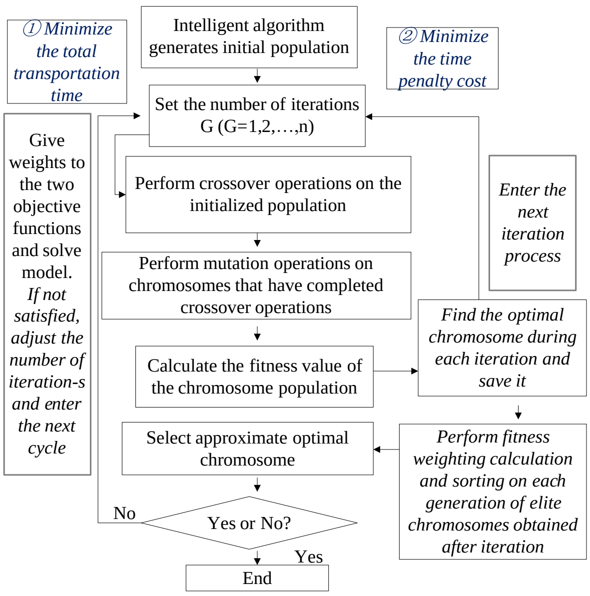

Fig. 1 Operation diagram of IWGA

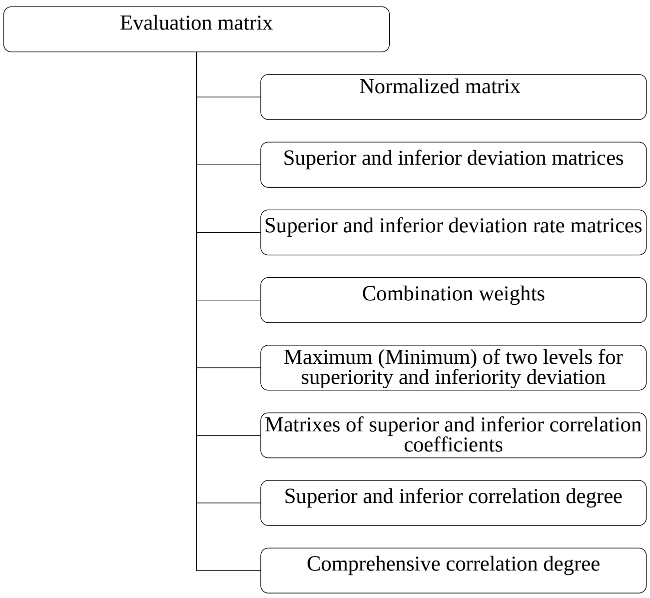

Fig. 2 Calculation flow of the IGRA method

The urgency of material demand will vary between residential community due to different situation in different locations. In order to reflect the situation for residential communities more comprehensively, and to ensure the rationality and relative fairness of the material distributing task for each demand area, the number of infections, along with the afore-mentioned indexes, are selected as the evaluation indicators for the demand urgency.

TABLE II

FUZZY AND DETERMINED EVALUATION INDEXES OF URGENCY

Residential community *i*	Severity degree (level)	Number of residents	Number of people affected	Mortality rate (%)	Material shortage level	Difficulty of material transportation
rc.1	Very serious	1.300	498	4.060	Very serious	General
rc.2	General	0.800	243	1.190	Serious	Difficult
rc.3	Serious	0.900	214	2.010	Serious	Difficult
rc.4	Slight	1.010	99	1.300	Serious	Difficult
rc.5	Very slight	0.830	76	0.260	Slight	General
rc.6	Slight	1.000	98	0.710	Serious	Easy
rc.7	Serious	1.050	63	3.290	Serious	General
rc.8	General	0.400	98	0.910	General	Difficult
rc.9	Slight	0.340	49	0.810	Slight	General
rc.10	General	0.410	71	1.130	General	General
rc.11	Serious	0.500	66	2.870	General	Difficult
rc.12	Very slight	0.380	46	0.000	Slight	Difficult
rc.13	Slight	0.760	37	0.000	Slight	Difficult
rc.14	Serious	0.370	17	5.080	General	General
rc.15	General	0.570	8	2.440	Slight	Easy
rc.16	General	0.320	37	1.320	Slight	General
rc.17	Very slight	0.210	10	0.000	Very slight	Easy

The uncertain indexes are quantified by the Fuzzy Theory: The five-level index values, such as *Very serious* (*Very Difficult*), *Serious* (*Difficult*), *General*, *Slight* (*Easy*) and *Very slight* (*Very Easy*) are transformed respectively into the determined values of 9, 7, 5, 3, 1. In accordance with Table II, the initial evaluation matrix is:

$$I=\begin{pmatrix} 9.0 & 5.0 & 7.0 & 3.0 & 1.0 & 3.0 & 7.0 & 5.0 & 3.0 & 5.0 & 7.0 & 1.0 & 3.0 & 7.0 & 5.0 & 5.0 & 1.0 \\ 1.30 & 0.8 & 0.9 & 1.0 & 0.8 & 1.0 & 1.0 & 0.4 & 0.3 & 0.4 & 0.5 & 0.4 & 0.8 & 0.4 & 0.6 & 0.3 & 0.2 \\ 498 & 243 & 214 & 99 & 76 & 98 & 63 & 98 & 49 & 71 & 66 & 46 & 37 & 17 & 8 & 37 & 17 \\ 4.1 & 1.2 & 2.0 & 1.3 & 0.3 & 0.7 & 3.3 & 0.9 & 0.8 & 1.1 & 2.9 & 0.0 & 0.0 & 5.0 & 2.4 & 1.3 & 0.0 \\ 9.0 & 7.0 & 7.0 & 7.0 & 3.0 & 7.0 & 7.0 & 5.0 & 3.0 & 5.0 & 5.0 & 3.0 & 3.0 & 5.0 & 3.0 & 3.0 & 1.0 \\ 5.0 & 7.0 & 7.0 & 7.0 & 5.0 & 3.0 & 5.0 & 7.0 & 5.0 & 5.0 & 7.0 & 7.0 & 7.0 & 5.0 & 3.0 & 5.0 & 3.0 \end{pmatrix}^T \quad (24)$$

The subjective weight values for each index rely on expert evaluation method.

$$E_k=\{0.214\ 0.090\ 0.301\ 0.062\ 0.236\ 0.097\}.$$

Finally, the combination weights are ensured through the linear weighting method $W_k=p\times C_k+(1-p)\times E_k$. And the crucial parameters of the coding are as follows, the running results are displayed in Table III.

(1) $r_{jk}=uo_{jk}\big/[\max_j\{uo_{jk}\}-\min_j\{uo_{jk}\}]$.

% Superior deviation rate.

(2) O is the normalized matrix, and the normalized method is $o_{jk}=i_{jk}\big/\max_j\{i_{1k},i_{2k},\ldots,i_{mk}\}$.

(3) $m_{jk}=lo_{jk}\big/[\max_j\{uo_{jk}\}-\min_j\{uo_{jk}\}]$.

% Inferior deviation rate.

(4) $maxuo=max(max(UO))$.

% Maximum of two levels for superiority deviation $\Delta^u_{\max}$.

(5) $minuo=min(min(UO))$

% Minimum of two levels for inferiority deviation $\Delta^u_{\min}$.

(6) $maxlo=max(max(LO))$

% Maximum of two levels for superiority deviation $\Delta^l_{\max}$.

(7) $minlo=min(min(LO))$

% Minimum of two levels for inferiority deviation $\Delta^l_{\min}$.

(8) $qq=minuo+p*maxuo$

% Numerator of the superior correlation coefficient λ_{uj}.

(9) $ww=UO+p*maxuo$

% Denominator of the superior correlation coefficient λ_{uj}.

(10) $qq1 = minlo + p * maxlo$

% Numerator of the inferior correlation coefficient λ_{lj}.

(11) $ww1 = LO + p * maxlo$

% Denominator of the inferior correlation coefficient λ_{lj}.

TABLE III
URGENCY COEFFICIENT OF DEMAND AREAS

Demand area i	*rc.1, rc.2, rc.3, rc.4, rc.5, rc.6, rc.7, rc.8, rc.9*
Urgency value	0.846, 0.515, 0.594, 0.467, 0.195, 0.294, 0.525, 0.303, 0.237
Demand area i	*rc.10, rc.11, rc.12, rc.13, rc.14, rc.15, rc.16, rc.17*
Urgency value	0.330, 0.509, 0.274, 0.349, 0.418, 0.238, 0.265, 0.114

The running results in accordance with the MATLAB software is: $\psi_1 > \psi_3 > \psi_7 > \psi_2 > \psi_{11} > \psi_4 > \psi_{14} > \psi_{13} > \psi_{10} > \psi_8 > \psi_6 > \psi_{12} > \psi_{16} > \psi_{15} > \psi_9 > \psi_5 > \psi_{17}$. The priority order of material delivery can be known, which is: *rc.1 →rc.3 →rc.7 →rc.2 →rc.11 →rc.4 →rc.14 →rc.13 →rc.10 →rc.8 → rc.6→rc.12→rc.16→rc.15→rc.9→rc.5→rc.17.*

C. Demands with TFN-PERT

As uncertainty of resource demand in residential quarters in a short period of time, so to obtain the quantity of demand, it is necessary to involve the TFN theory, which is a method of converting fuzzy and uncertain linguistic variables into certain values.

In addition, the triangular fuzzy number consists of the most pessimistic value, the most probable and the most optimistic value. The triangular fuzzy values of demand are shown in Table IV. Also, the PERT method (see Table V) was jointly used for estimation.

Suppose there are two triangular fuzzy numbers: $A^1 = (a^{\to s1}, a^{\to m1}, a^{\to u1})$ and $A^2 = (a^{\to s2}, a^{\to m2}, a^{\to u2})$, then the arithmetic of triangular fuzzy numbers is:

$$A^1 + A^2 = (a^{\to s1} + a^{\to s2}, a^{\to m1} + a^{\to m2}, a^{\to u1} + a^{\to u2}) \tag{24}$$

$$A^1 \otimes A^2 \approx (a^{\to s1} \cdot a^{\to s2}, a^{\to m1} \cdot a^{\to m2}, a^{\to u1} \cdot a^{\to u2}) \tag{25}$$

$$1/A \approx (1/a^{\to s}, 1/a^{\to m}, 1/a^{\to u}) \tag{26}$$

$$\kappa \cdot A = (\kappa \cdot a^{\to s}, \kappa \cdot a^{\to m}, \kappa \cdot a^{\to u}), \kappa \in \Omega \tag{27}$$

$$-A = (-a^{\to s}, -a^{\to m}, -a^{\to u}) \tag{28}$$

$$E(A) = 0.5 \cdot [(1-\lambda) \cdot a^{\to s} + a^{\to m} + \lambda \cdot a^{\to u}].\ \lambda \in [0,1] \tag{29}$$

When the triangular fuzzy number is required for data normalization, it is necessary to determine whether the fuzzy number indicates a benefit or a cost indicator.

Provided it is a benefit-based indicator, the standardization process is:

$$A_{ij}^{\prime \text{benefit}} = \begin{pmatrix} [a^{\to s}] \Big/ \sqrt{\sum_{i \in m} \{(a_i^{\to s})^2 + (a_i^{\to m})^2 + (a_i^{\to u})^2\}}, \\ [a^{\to m}] \Big/ \sqrt{\sum_{i \in m} \{(a_i^{\to s})^2 + (a_i^{\to m})^2 + (a_i^{\to u})^2\}}, \\ [a^{\to u}] \Big/ \sqrt{\sum_{i \in m} \{(a_i^{\to s})^2 + (a_i^{\to m})^2 + (a_i^{\to u})^2\}} \end{pmatrix} \tag{30}$$

Provided it is a cost-based indicator, the standardization process is:

$$A_{ij}^{\prime \cos t} = \begin{pmatrix} (1/a^{\to s}) \Big/ \sqrt{\sum_{i \in m} \{(a_i^{\to s})^2 + (a_i^{\to m})^2 + (a_i^{\to u})^2\}}, \\ (1/a^{\to m}) \Big/ \sqrt{\sum_{i \in m} \{(a_i^{\to s})^2 + (a_i^{\to m})^2 + (a_i^{\to u})^2\}}, \\ (1/a^{\to u}) \Big/ \sqrt{\sum_{i \in m} \{(a_i^{\to s})^2 + (a_i^{\to m})^2 + (a_i^{\to u})^2\}} \end{pmatrix} \tag{31}$$

(1) Estimation benchmark for material c_1

A medical mask is about 3.8-4.2 grams. Hence, 4.0 grams is used for calculation in this paper. The weight of disposable medical protective clothing is between 60.0-100.0 grams. For this reason, 75.0 grams is adopted for calculation in this research.

(2) Estimation benchmark for material c_2

Regarding the nutritional requirements of the human body, each person needs approximately 1100.0-1500.0 grams of food per day, regardless of the food type. It is supposed that the infected people (i.e., the special population) are only taken into account for the material transportation task, while the normal people (i.e., the general population) are not considered.

TABLE IV
TRIANGLE FUZZY VALUE OF DEMANDS WITH TFN

Demand area *i*	$\theta_1^{c_1}$	$\theta_0^{c_1}$	$\theta_2^{c_1}$	$\theta_1^{c_2}$	$\theta_0^{c_2}$	$\theta_2^{c_2}$
rc.1	20.31	19.16	17.32	17.09	16.48	15.27
rc.2	3.89	3.12	2.97	3.96	3.41	3.05
rc.3	3.01	2.74	2.14	3.79	3.00	2.33
rc.4	1.77	1.28	0.86	1.94	1.50	0.86
rc.5	1.25	0.97	0.62	1.85	1.14	1.00
rc.6	1.84	1.26	1.02	2.09	1.48	0.98
rc.7	1.93	1.26	1.01	2.31	1.40	0.92
rc.8	2.00	1.29	1.00	2.00	1.52	1.32
rc.9	1.22	0.95	0.84	1.59	1.29	1.20
rc.10	1.32	1.08	0.93	1.78	1.33	1.27
rc.11	1.00	0.87	0.90	1.32	1.18	1.10
rc.12	1.02	0.91	0.75	1.20	1.09	0.78
rc.13	0.78	0.65	0.55	1.86	1.49	1.37
rc.14	0.59	0.49	0.40	1.29	1.16	1.03
rc.15	0.54	0.37	0.29	1.41	0.96	0.89
rc.16	0.60	0.52	0.47	1.44	1.21	1.12
rc.17	0.27	0.13	0.10	0.05	0.02	0.01

Towards TFN (Triangle Fuzzy Theory), the most probable value usually takes up a large proportion, while the most pessimistic value and the most optimistic value both account for a small proportion.

TABLE V
DEMAND ANALYSIS WITH PERT METHOD

da i	Emergency supplies requirement $D_i = (1\times\theta_1 + 4\times\theta_0 + 1\times\theta_2)/6$						
	$D_i^{c_1}$	$D_i^{c_2}$	D_i	*da i*	$D_i^{c_1}$	$D_i^{c_2}$	D_i
*rc.*1	19.05	16.38	35.43	*rc.*10	1.09	1.39	2.48
*rc.*2	3.22	3.45	6.67	*da* 11	0.89	1.19	2.08
*rc.*3	2.69	3.02	5.71	*da* 12	0.90	1.06	1.96
*rc.*4	1.29	1.47	2.76	*da* 13	0.65	1.53	2.18
*rc.*5	0.96	1.24	2.20	*da* 14	0.49	1.16	1.65
*rc.*6	1.31	1.50	2.81	*da* 15	0.39	1.02	1.41
*rc.*7	1.33	1.54	2.87	*da* 16	0.52	1.23	1.75
*rc.*8	1.36	1.57	2.93	*da* 17	0.15	0.02	0.17
*rc.*9	0.97	1.33	2.30	-	-	-	-
Sum of demands				77.36 (tons)			

Moreover, ν, o and π are the weights of three values respectively for defuzzification. So, the formula is:

$$D_i = \nu * a^{\to s} + o * a^{\to m} + \pi * a^{\to u} \tag{32}$$

And the three-point estimation method, also known as the PERT (Program Evaluation and Review Technique) method, is also adopted. Its expected value is:

$$t_E = [1 * t_p + 4 * t_m + 1 * t_o]/6 \quad (33)$$

D. Relevant parameters

On the basis of the modeling assumptions in Section II, multiple trucks with a load-limited weight of 16 tons are used to transport emergency materials. And the specific supply is allocated proportionally based on the principle of demand equity, i.e., 35.43:6.67:5.71:2.76:2.20:2.81:2.87:2.93:2.30:2.48:2.08:1.96:2.18:1.65:1.41:1.75:0.17. Besides, the material transportation quantity and unloading time for each demand area are shown in Table VI.

TABLE VI
DISTRIBUTION QUANTITY AND UNLOADING TIME OF DEMAND AREAS

rc. i	*rc.1*	*rc.2*	*rc.3*	*rc.4*	*rc.5*	*rc.6*
Distribution quantity	29.31	5.52	4.72	2.28	1.82	2.32
Unloading time b_i	240.0	60.0	57.0	27.0	22.0	28.0
rc. i	*rc.7*	*rc.8*	*rc.9*	*rc.10*	*rc.11*	*rc.12*
Distribution quantity	2.37	2.42	1.90	2.05	1.73	1.62
Unloading time b_i	29.0	30.0	23.0	25.00	24.00	22.00
rc. i	*rc.13*	*rc.14*	*rc.15*	*rc.16*	*rc.17*	/
Distribution quantity	1.80	1.36	1.17	1.46	0.14	/
Unloading time b_i	24.00	18.00	16.00	19.00	10.00	/

Table VII shows the latitude and longitude coordinates of each residential community.

TABLE VII
LONGITUDE AND LATITUDE OF DEMAND AREAS

Demand area i	Latitude and longitude	Demand area i	Latitude and longitude
rc.1	(114°31′，30°52′)	*rc.10*	(113°30′，30°70′)
rc.2	(113°91′，31°92′)	*rc.11*	(112°19′，31°02′)
rc.3	(114°87′，30°44′)	*rc.12*	(110°79′，32°65′)
rc.4	(112°23′，30°33′)	*rc.13*	(109°21′，30°39′)
rc.5	(115°09′，30°20′)	*rc.14*	(113°10′，30°60′)
rc.6	(112°20′，32°08′)	*rc.15*	(112°87′，30°47′)
rc.7	(114°88′，30°40′)	*rc.16*	(113°27′，30°22′)
rc.8	(113°37′，31°72′)	*rc.17*	(110°67′，31°74′)
rc.9	(114°28′，29°87′)	-	-

Source of data: Earth OLINE Satellite Maps of the Earth

The method IWGA in this study is put forward based on the traditional GA and the corresponding weight coefficients $\tau_i \in (0,1)$ of the objectives are designed in the model. For the convenience of solution, the values of τ_1 and τ_2 are directly set as 0.5. In addition, the control parameters are set synchronously: Population size $Popse$ is set to 100, mutation probability p_m is set to 0.05, crossover probability p_c is set to 0.89.

IV. CASE STUDY

In the battle against the emergencies, it is necessary to support the residential communities served by property management company B in time and secure the daily necessities and protective materials for residents, so that they can resume normal life as soon as possible. This study integrates the solution accuracy and convergence speed based on IWGA to quickly generate the optimal property service scheme. In addition, the parameters of v_{ij} , b_i , t_0 , $W \cdot PI^e$ and $M \cdot PI^l$ will be corrected and optimized to compare the two groups of running results before and after the optimization. The parameter correction method is as follows: these parameter correction coefficients will be denoted as $\wp^{\sim}$, $\tau^{\sim}$, $\iota^{\sim}$, $\gamma^{\sim}$, $\delta^{\sim}$, $\partial^{\sim}$ and $\lambda^{\sim}$. With reference to b_i, the unloading time will be reduced to some extent by means of augmenting the number of unloading people, so as to serve the next residential community with as little delay as possible.

Correction parameter $\leftrightarrow [v_{ij}] \to v_{ij}^{\sim} = \{v_{ij} \cdot [\wp^{\sim} * \iota^{\sim}]\}$

Correction parameter $\leftrightarrow [b_i] \to b_i^{\sim} = \{b_i \cdot [\gamma^{\sim} * \partial^{\sim}]\}$

Correction parameter $\leftrightarrow [t_0] \to t_0^{\sim} = \{t_0 * \delta^{\sim}\}$

Correction parameter $\leftrightarrow [W \cdot PI^e] \to W \cdot PI^{e\sim} = \{W \cdot PI^e * \lambda_{00}^{\sim}\}$

Correction parameter $\leftrightarrow [M \cdot PI^l] \to M \cdot PI^{l\sim} = \{M \cdot PI^l * \lambda_{11}^{\sim}\}$

The following is a comparative discussion of the optimal property service scheme for emergency material transport vehicles before and after optimization with 500 iterations in MATLAB, and CPU running times are about 66.053333 seconds (without optimization) and 145.753890 seconds (with optimization) respectively.

A. Discussion 1

In the case where the demand urgency is not taken into account, i.e., the emergency degree of each residential community is 0 or the same. The operating results are as follows.

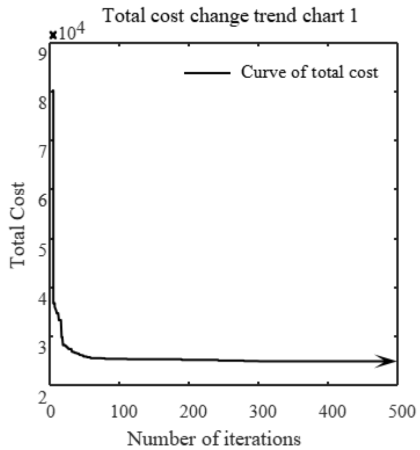

Fig. 3 Iterative graph of the total objective function before optimization.

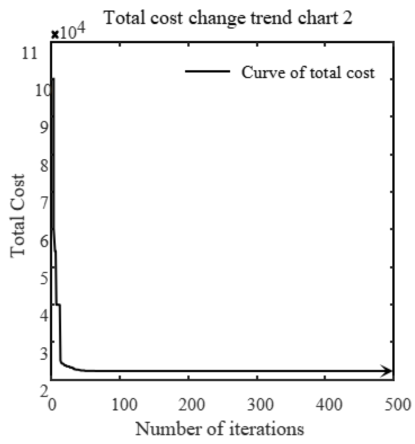

Fig. 4 Iterative graph of the total objective function after optimization.

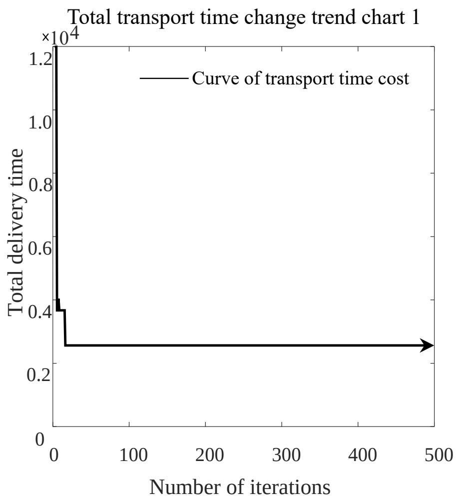

Fig. 5 Iterative curve of transport time cost before optimization

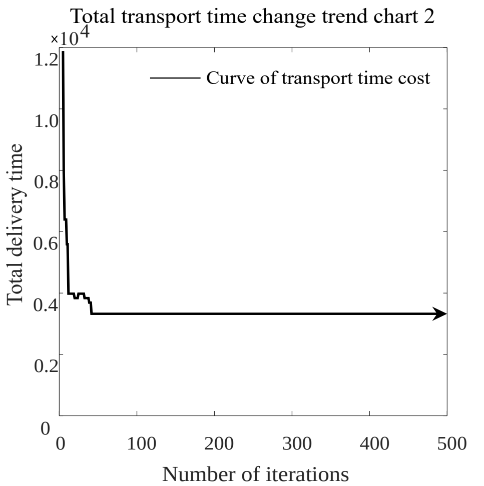

Fig. 6 Iterative curve of transport time cost after optimization

Fig. 3 and Fig.4 are iterative diagrams of the total costs. As shown from Fig.5, the time cost tends to be stabilized after the 20th iteration probably. For Fig.6, the time cost changes greatly in the first 18 iterations, and is stable in the interval of 18-36 iterations. Yet, it varies slightly from the 45th to the 500th iterations, and the changes could not be presented virtually in the figure.

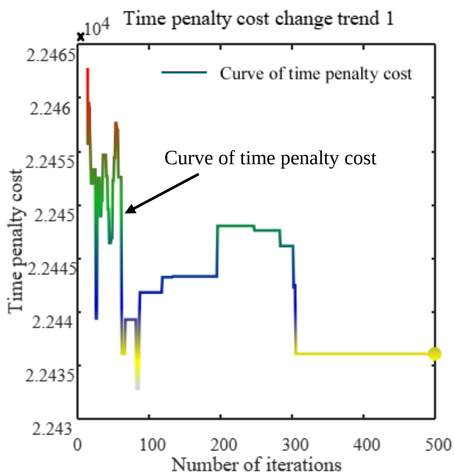

Fig. 7 Iterative curve of time penalty cost before optimization

From Fig.7, the time penalty cost changes pretty obviously in the first 60 iterations.

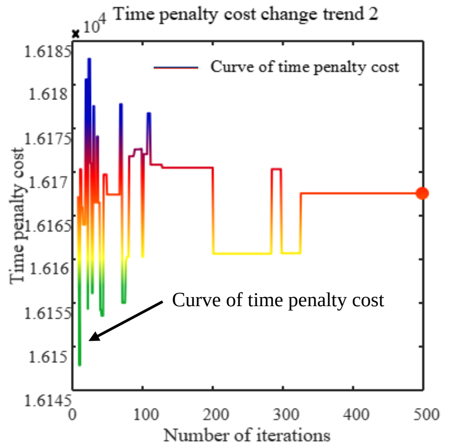

Fig. 8 Iterative curve of time penalty cost after optimization

In comparison, after optimization (Fig.8), the time penalty cost changes dramatically in the first 100 iterations. These ups and downs indicate that the change rate is high. Also, the iterative curve tends to be stable after the 320th iteration.

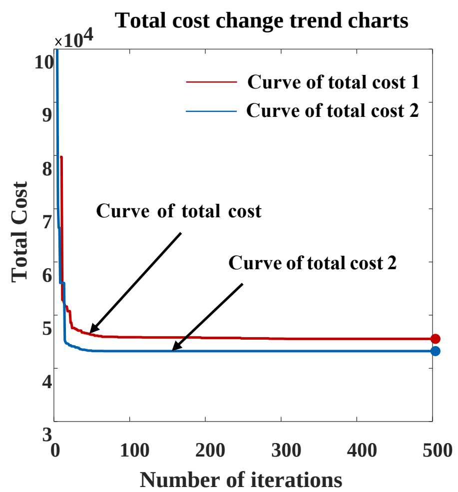

Fig. 9 Iterative curve of two total costs

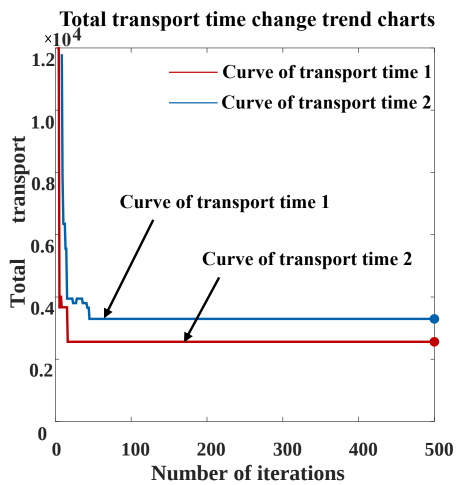

Fig. 10 Iterative curve of two transport time costs

In Fig.9-Fig.11, the red line signifies the results before the optimization of parameters, while the blue line stands for the results after their optimization. Fig. 9 shows the comparison for the two iterative curves concerning total costs. Likewise, Fig. 10 presents the comparison for the two iterative curves concerning delivery time costs.

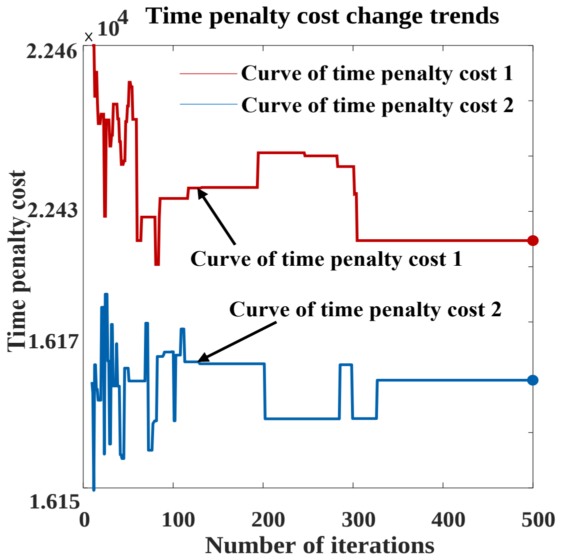

Fig. 11 Iterative curve of two time-penalty costs

Similarly, Fig. 11 illustrates a comparison of two iterative curves for the time penalty cost.

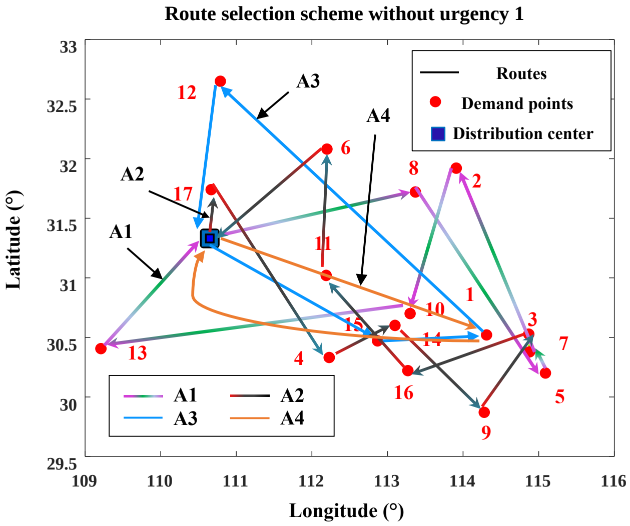

Fig. 12 Vehicle routes without demand urgency before optimization.

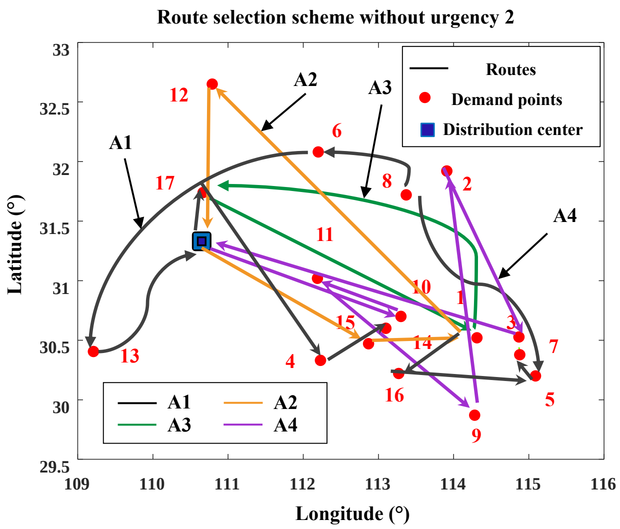

Fig.13 Vehicle routes without demand urgency after optimization.

TABLE VIII

THE VEHICLE ROUTINGS WITHOUT CONSIDERING URGENCY

	Results before optimization
TR. 1	0→8→5→7→2→10→13→0
TR. 2	0→15→1→12→0
TR. 3	0→17→4→14→9→3→16→11→6→0
TR. 4	0→1→0
	Results after optimization
TR. 1	0→10→11→9→2→3→0
TR. 2	0→15→1→12→0
TR. 3	0→17→4→14→16→5→7→8→6→13→0
TR. 4	0→1→0

It can be gained from section III that the demand quantity of area 1 is large in a sense, which has exceeded the loading limit of one vehicle. Therefore, residential community 1 appears twice in the transportation route in Table VIII above, it indicates that two vehicles are required for service: given that a vehicle can only visit a residential community once, and multiple vehicles can visit the same point for many times in this paper, it is reasonable and viable that two vehicles are needed to serve simultaneously the demand area 1. In addition, Table IX is illustrated that the departure time of vehicles from each station.

TABLE IX

DEPARTING TIME FROM EACH STATION OF VEHICLES (NO URGENCY)

	Departure time from each station before optimization
R1	371.08→604.95→695.37→900.32→1187.010→1451.513→1867.50
R2	290.015→694.01→1036.512→1559.50
R3	399.017→507.44→638.714→816.59→1012.03→1200.616→1389.411→1544.36→2024.00
R4	882.01→1504.00
	Departure time from each station after optimization
R1	256.011→390.015→472.04→664.09→783.05→854.57→932.53→1694.50
R2	568.014→676.016→948.01→1570.00
R3	388.017→621.012→784.06→942.08→1086.02→1356.010→1604.013→2020.00
R4	792.01→1414.00

Table above shows the departure time of vehicle k from each station, i.e., the departure time when the vehicle k leaves residential community i for the next residential community $i+1$ of each transportation route.

The running result 1 of the optimal vehicle route solution without consideration of demand urgency before optimization is as follows: The number of vehicles in use is 4. It needs to be noted that the demand area 1 requires both vehicle 2 and vehicle 4 to serve. The transport time cost of distributing materials is 3901.35units. Time penalty cost of vehicle transportation is 24021.03 units. The total objective function value is 27922.38.

The running result 2 of the optimal vehicle route solution without demand urgency after optimization by MATLAB is as follows: The number of vehicles in use is 4. Likewise, the demand area 1 requires both vehicle 2 and vehicle 4 to serve. The transport time cost of distributing materials is 3047.23 units. Time penalty cost of vehicle transportation is 19952.83 units. The total objective function value is 23000.06.

B. *Discussion 2*

In the case where the urgency value of each residential community is taken into account, the priority distribution order has been obtained from section III. Also, the iterative process is carried out for 500 times, and the calculation results are as follows:

TABLE X
VEHICLE ROUTING BEFORE &AFTER OPTIMIZATION WITH CONSIDERATION OF URGENCY

Transportation Route (TR)	The same vehicle routes
TR.1	0→1→16→15→17→0
TR.2	0→3→2→14→10→6→0
TR.3	0→7→4→13→11→12→8→9→5→0
TR.4	0→1→0

Vehicle routes before and after optimization with consideration of urgency are shown in Table X. The parameter optimization model aims to minimize the cost. However, under the circumstance of the priority distribution, demand urgency rather than the cost would be considered. Therefore, the two operation results remain unchanged before and after the parameter correction with consideration of the urgency.

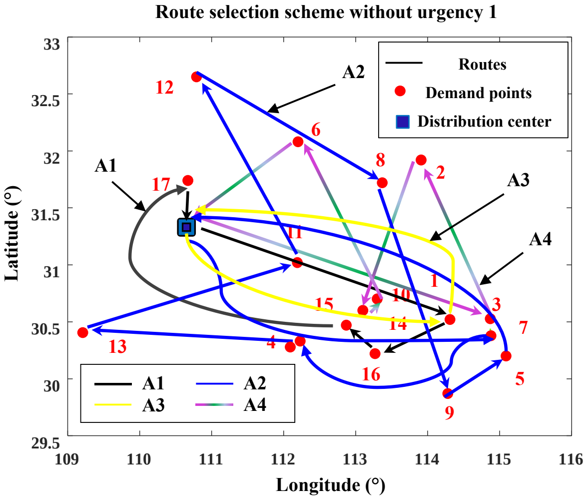

Fig. 14 Vehicle routes with demand urgency before optimization

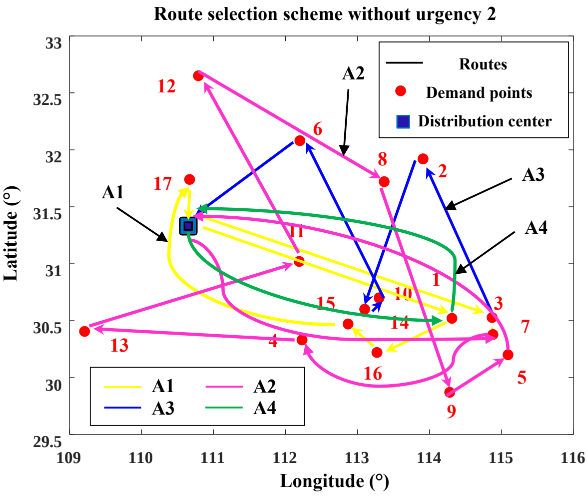

Fig. 15 Vehicle routes with demand urgency after optimization

TABLE XI
DEPARTING TIME FROM EACH STATION OF VEHICLES (CONSIDER URGENCY)

TR.1	$822.0_{1}\rightarrow 1021.5_{16}\rightarrow 1103.6_{15}\rightarrow 1533.6_{17}\rightarrow 1902.6_{0}$
TR.2	$838.5_{3}\rightarrow 1040.6_{2}\rightarrow 1196.0_{14}\rightarrow 1406.6_{10}\rightarrow 1640.46\rightarrow 2120.4_{0}$
TR.3	$648.4_{7}\rightarrow 898.8_{4}\rightarrow 1200.4_{13}\rightarrow 1572.2_{11}\rightarrow 1780.6_{12}\rightarrow 2042.6_{8}\rightarrow 2273.4_{9}\rightarrow 2409.3_{5}\rightarrow 3041.3_{0}$
TR.4	$882.0_{1}\rightarrow 1504.0_{0}$

Analysis of Table XI (Taking *TR1* as an example): Vehicle *k* starts from the property management company. It unloads and takes a rest when arrived at point 1. Then, the time to leave point 1 for point16 is 822 units. After arriving at point 16, vehicle k unloads and rests, and the time to leave point 16 for point 15 is 1021.52 units. Next, it unloads and rests again after arriving at point 15, and the time of leaving point 15 for point 17 is 1533.56 units. Finally, as usual, the vehicle unloads and rests after arriving at point 17. The time to leave point 17 and return to property management company is 1906.56 units.

As a result, when the demand urgency is considered, the optimal solution before optimization is as follows: The transport time cost is 3017.15 units. Time penalty cost of vehicle transportation is 20809.34 units. The total objective function value is 24726.49 units. The optimal solution after optimization is as follows: The transport time cost is 2600.98 units. Time penalty cost of vehicle transportation is 15927.01 units. The total objective function value is 18527.99 units.

C. Discussion 3

Next is an eventual comparison analysis for four groups of the running results, which are: (1) the objective function values with consideration of demand urgency before parameter optimization, (2) the objective function values with consideration of demand urgency after parameter optimization, (3) the objective function values without demand urgency before parameter optimization, (4) the objective function values without demand urgency after parameter optimization.

TABLE XII
COMPARISON OF OBJECTIVES BEFORE OPTIMIZATION

Objective function	No urgency	With urgency	Change rate (%)
transport time	3901.35	3017.15	-22.6639%
time penalty	24021.03	20809.34	-13.3703%
total costs	27922.38	24726.49	-11.4456%

Table XII demonstrates the objective function values before parameter optimization. It can be concluded that the total cost is reduced by 11% when demand urgency is taken into account, compared to the value when it is not considered. This is attributed to the fact that when urgency is considered, the shortage of materials and the demand variability of each area are deemed important. In this way, the rescue efficiency is improved to a large degree and the total cost is slightly decreased.

TABLE XIII
COMPARISON OF OBJECTIVES AFTER OPTIMIZATION

Objective function	No urgency	With urgency	Chang rate (%)
transport time	3047.23	2600.98	-14.6444%
time penalty	19952.83	15927.01	-20.1767%
total costs	23000.06	18527.99	-19.4437%

Table XIII presents the objective function values after parameter optimization. There is a slight reduction of 19% in cost when considering the demand urgency.

TABLE XIV
COMPARISON EXHIBITION OF TWO RESULTS

Total costs	Before optimization	After optimization	Chang rate (%)
No urgency	27922.38	23000.06	-17.6286%
With urgency	24726.49	18527.99	-25.0683%

In addition, Table XIV reveals the comparison of total cost before and after parameter optimization. It may be obtained that the total cost will be diminished after parameter optimization.

V. Conclusions

This paper mainly studies the property service scheme that property enterprises provide material support to the residential areas served under emergencies. Actually, emergency material transport vehicle route choice is viewed as a significant task in responding to emergencies. Whether supplies can be delivered to the residential community in time directly determines the service efficiency of property company, so time is of the essence. Additionally, the time window constraint can be utilized as an indicator of service satisfaction for the residential community. Consequently, it is supremely critical to conduct a reasonable vehicle route arrangement considering the demand urgency. In brief, strengthening property management in residential communities can effectively improve the quality of life in residential communities, stimulate the vitality of shared governance in residential communities, and increase the satisfaction of residents.

(1) With respect to minimizing the transport time, i.e., the timeliness of emergency logistics: After the outbreak of sudden emergencies, the transportation of relief material is an exceedingly pivotal link in the rescue work. For people in residential communities, it is important that they could obtain the relief supplies as soon as possible. Hence, this paper analyzes the urgency for residential community. Further, the corresponding mathematical model for complying with timeliness is conducted, which can be better applied in practice.

(2) Concerning minimizing the time penalty cost of vehicle transportation, i.e., measurement of the service satisfaction: The time penalty cost is an index to weigh up the satisfaction of arrival time for transporting emergency supplies. And the time factor is adopted as a constraint in the model of this paper. Its adoption has the following three functions. First, it can meet the time requirement for the demand areas more accurately. Second, it can increase service satisfaction of the residential community to a greater extent. Third, it can further achieve the maximum service efficiency of property management companies.

(3) Due to the various conditions in each residential community, the urgency on materials will also vary between different residential community. As a result, the precise demand data for each locality is not accurately available. Thereby, fuzzy statistics were conducted based on related information, including the number of deaths and other data in each area in this study. And the triangular fuzzy number theory and the PERT method were combined to determine the nominal demand, through defuzzification of uncertain variables and other operations.

(4) It may have different degrees of impact on more regions when a large-scale emergency is extremely severe, and the demand urgency for materials will also vary from place to place. For areas with the higher urgency, their demand of the emergency materials should be met first. Contrarily, the rescue sequence can be slightly postponed for areas with the lower urgency. Thus, this paper argues that it is significant to assess the demand urgency for each demand area. The requisite estimation for urgency will produce a fairer emergency supply distribution method and present a more exact service scheme for property management company.

(5) The results show that the total cost will be decreased after parameter optimization. Moreover, when the demand urgency of each area is considered simultaneously, the total cost will be further reduced. It is because that the demand variability and material shortage of each residential community are valued. Obviously, the rescue efficiency can be promoted while the cost can be lessened.

In conclusion, the study is conducive to making reasonable and scientific arrangements for EMVRP (vehicle routing problem of emergency materials) in the circumstances of public emergencies, and it establishes a new approach for further research in emergency logistics. And, for the decision-makers of property management companies, this study can be beneficial to transport sufficient materials to the residential quarters through cargo trucks, so as to provide a basis and direction for property management enterprises to further establish a robust material support service scheme in the next stage.

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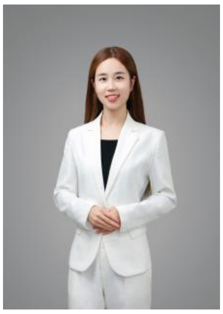

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