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Casualty rescue path optimization in cities in early post-earthquake period

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Abstract: After an earthquake, decision makers are required to make a rapid response. In order to minimize the damage caused after an earthquake disaster and improve the efficiency of casualty rescue, scientific and effective casualty transportation dispatching is required. Especially for small and medium-sized cities where materials are scarce and transportation is inconvenient, effective optimization of casualty dispatching can minimize the amount of casualties and improve rescue efficiency. Therefore, this paper analyzes and researches the post-earthquake casualty rescue problem against the background of the initial rescue stage after the earthquake disaster in small and medium-sized cities, so as to provide the government and other relevant post-earthquake emergency logistics management departments with decision-making references. By establishing a casualty rescue planning model for small and medium-sized cities pursuing the minimization of total rescue time, and applying genetic algorithm to solve the path optimization model with soft time window constraints. The empirical analysis substitutes the street city simulation data of Wuxi County, Chongqing, and generates the stochastic solution and the optimal solution by MATLAB software, and the study finds that the optimal solution has significantly better travel time than the stochastic solution.

Keywords: Emergency logistics; Casualty rescue; Path optimization; Genetic algorithm.

1. Introduction

In recent years, the frequent occurrence of earthquake disasters has not only brought devastating damage to the affected areas, but also led to huge casualties and property damage. According to statistics, about 5 million earthquakes occur globally each year. China is located in the Pacific Rim seismic zone. China, however, is located between the Pacific Rim seismic zone and the Eurasian seismic zone, and is extruded by the Pacific plate, the Indian plate, and the Philippine plate, making the earthquake fault zone in China unusually active. China is also one of the countries with the most severe earthquake disasters in the world, and the number of casualties caused by earthquakes is the highest in the world. Among them, the 7.8 magnitude mega-earthquake in Tangshan in 1976 caused 435,556 injuries and 242,769 deaths; the 8.0 magnitude mega-earthquake in Wenchuan in 2008 caused 17,923 missing people, 374,643 injuries and 69,227 deaths. And with the rapid development of urbanization, modern cities show the characteristics of three-dimensional buildings and dense population, which also makes the damage caused by earthquakes become more serious.

In response to large natural disasters and public health event emergencies, most of the previous studies have focused on the problems of siting post-disaster material facility sites and material deployment, and fewer studies have focused on post-disaster casualty rescue. In the early post-earthquake period, a large number of casualties emerge and are often accompanied by aftershocks, mudslides and other secondary disasters, so how to shorten the casualty transportation time, improve the efficiency of casualty treatment and reduce the number of casualty deaths is a problem we need to solve. Therefore, this paper focuses on the post-earthquake casualty rescue problem in small and medium-sized cities, and analyzes and researches the post-earthquake casualty rescue problem by establishing a planning model for path optimization in small cities pursuing the minimization of total rescue time, so as to provide decision-making reference for the government and other related post-earthquake emergency logistics management departments.

2. Literature Review

The focus of emergency relief in the early post-earthquake period is casualty rescue, and emergency rescue activities should be organized scientifically to optimize casualty distribution paths and reduce casualties caused by earthquake disasters to a minimum. Previous studies usually describe the casualty transport scheduling problem as a casualty transport scheduling or distribution path problem. For example, Caglayan et al. (2021) applied simulation and statistical analysis to evaluate the impact of using data-driven DST, patient classification, patient prioritization of treatment, number of ambulances, and hospital selection on patients as a means to improve casualty survival and reduce ambulance transport time during the disaster relief phase. Liu et al. (2019) considered casualty triage, deteriorating health status, and equitable allocation of limited of medical resources, a bi-objective optimization model that maximizes the expected number of survivors and minimizes the total operating cost was developed as a way to determine the optimal temporary medical service location and medical service allocation scheme. Li et al. (2020) proposed a three-stage stochastic mathematical model for scenario-based emergency rescue planning considering the correlation between primary and secondary hazards under uncertainty, and an accelerated bending decomposition algorithm was developed to improve the computational performance of the model. Yu et al. (2020) proposed a dynamic optimization model for ambulance dispatch and redistribution to improve response efficiency of the emergency medical services (EMS) system under uncertainty. Caglayan et al. (2021) developed a multi-objective two-stage stochastic planning model aimed at minimizing the number of casualties that cannot be treated after an earthquake, the number of additional ambulances required in the response phase of the system, and the total transport time. Chou et al. (2022) considered the ambulance routes and hospital operating conditions and proposed a patient transport and distribution model for an effective MCI response. In the study of post-earthquake casualty transport dispatch, humanitarian relief is considered one of the most important issues in disaster operations and management. aringhieri et al. (2022) considered impartiality and efficiency as important indicators for launching relief after a disaster, and based on this, investigated how to provide equitable services to patients by considering both impartiality and efficiency factors in humanitarian relief operations, and Mohammadi et al. (2020) proposed a new multi-objective stochastic planning model to solve the problems of rational dispatching of casualties, reliable siting of facilities, equitable distribution of rescue goods, and routing of transport vehicles.

In the early post-earthquake period, a large number of casualties with different injuries appeared in batches within a short period of time in the earthquake area, and a large number of casualties in need of treatment quickly accumulated in the medical system that still had treatment capacity in the earthquake area, far exceeding the actual treatment capacity of the limited local medical resources. Shin et al. (2020) combined the patient prioritization and hospital selection problems and conducted a study on the resource allocation problem of emergency medical services in mass casualty incidents study. Rezapour et al. (2018) divided the casualties in each disaster area into two classes, red and yellow, and studied the problem of how to reasonably allocate search and rescue personnel and medical personnel to the disaster area according to the different classes of victims. Lodree et al. (2019) proposed a heterogeneous medical team with discrete time for the problem of how to allocate heterogeneous medical teams to casualties of three different priority classes after a disaster. stochastic dynamic programming model to solve it. Bronfman et al. (2022) proposed a method to assemble and transport casualties in response to mass casualty events, considering the different ages and injury levels of the casualties after a mass earthquake. The results show that explicitly considering the priority level of victims facilitates the rescue of the injured. Liu et al. (2019) constructed an optimal temporary medical center site selection and medical service allocation model by considering two types of medical service facilities (existing hospitals that treat high-priority casualties and temporary medical centers that serve the lightly injured) and classifying the injured into immediate and delayed categories to represent the probability of survival in different periods after the disaster.

To conclude, most previous studies have not studied the post-earthquake casualty rescue problem from small and medium-sized cities, and this study focuses on optimizing the post-earthquake casualty rescue network in small cities in the early post-earthquake period, considering the casualty rescue time.

3. Model

3.1. Problem description

The goal of emergency rescue in small and medium-sized cities is to rescue the injured people at all costs, time is the life of the injured, to save as many injured people as possible in the shortest possible time and reduce the mortality rate of the injured. Therefore, the goal of casualty transport scheduling should be: minimizing the total rescue time.

3.2. Assumptions

Model assumptions are as following. First, for small cities, there is and only one large medical point for treatment, rescue vehicles to carry out rescue missions only one vehicle to travel throughout the central city, each rescue vehicle from the medical point, to the affected point to receive the wounded must immediately return to the medical point. Second, the number of casualties at each affected site is known. Third, in a single rescue of each vehicle, each disaster site can only be reached once, there is no secondary arrival phenomenon. Four, no consideration of traffic congestion. Five, penalty time is incurred for any rescue vehicle that does not transport a casualty to a medical site within the specified time period. Six, assumed that the rescue vehicles are traveling at a constant speed, i.e., the time taken for the rescue is only related to the distance traveled

3.3. Notations

The parameters are as following.

I: medical points,$\mathrm{i} \in \mathrm{I}$;

J: Gather at the major disaster sites,$\mathrm{j} \in \mathrm{J}$;

K: the individual node ensembles,$\mathrm{f}, \mathrm{g} \in \mathrm{K}, \mathrm{K} = \{\mathrm{I} \cup \mathrm{J}\}$;

H: Transport vehicle pooling,$\mathrm{h} \in \mathrm{H}$;

$\mathrm{d_k}$: The distance between the nodes;

$\mathrm{t_k}$: The travel time between nodes;

$\mathrm{T_j}$: Travel time for the vehicle to reach the affected point;

$\mathrm{Q_i}$: The number of available resources at medical point I;

$\mathrm{Q_j}$: number of casualties in the affected site;

$\mathrm{V_h}$: delivery vehicle h the speed of travel;

β: Rescue time penalty factor;

$\mathrm{t_\beta}$: the penalty time of the first node;

$[\mathrm{ET_j}, \mathrm{LT_j}]$： Major disaster sites j The time window required for the rescue, the $\mathrm{ET_j}$ is the earliest arrival time, and $\mathrm{LT_j}$ is the latest arrival time.

Decision variables.

$\mathrm{X_{ij}}$: binary variable, if the rescue vehicle from the medical site i driving to j, then take 1; otherwise take 0;

$\mathrm{Y_{fg}}$: binary variable, if the rescue vehicle h goes from node f driving to node g, then take 1; otherwise take 0.

3.4. Mathematical formulation

$$Z = \min \sum_{k \in K} (t_k Y_{fg} + \beta t_\beta) \tag{1}$$

$$t_k = \frac{\sum_{k \in K} d_k}{V_h} \tag{2}$$

$$t_\beta = \begin{cases} -1, & T_j \le ET_j \\ 0, & ET_j \le T_j \le LT_j \\ 1, & T_j \ge LT_j \end{cases} \tag{3}$$

$$Q_i \ge \sum_{j \in J} Q_j X_{ij} \tag{4}$$

$$\beta \ge 0 \tag{5}$$

$$X_{ij}, Y_{fg} \in \{0,1\} \tag{6}$$

Eq. (1) is the objective function of overall distribution time minimization; Eq. (2) represents the expression of transportation time between nodes; Eq. (3) represents the expression function of penalty time; Eq. (4) represents the constraint of the number of salvageable casualties; Eq. (5) represents the penalty factor constraint; Eq. (6) represents the variable constraint.

4. Algorithm

This paper adopts a genetic algorithm for model solving, which is based on Darwin's evolutionary theory and is an algorithm for letting the optimal solution to a problem by placing individual attributes and inheritance methods by natural selection. The basic principle of the genetic algorithm is to use the system to generate a random number of codes that meet the requirements to form one or more "chromosomes", each chromosome represents a solution to the problem, and then generate the initial population, and through the decoding function to obtain the objective function value of each chromosome, i.e., each solution, and then set the fitness function, so that it becomes the standard of "natural selection". The chromosomes with lower fitness in the objective function are eliminated according to the principle of survival of the fittest; and the "chromosomes" with higher fitness need to be continuously replicated, crossed and mutated to obtain the "chromosomes" that can be more adapted to the environment through genetic variation. The more adaptable chromosomes need to be duplicated, crossed over and mutated to obtain a population of chromosomes that are more adaptable to the environment through genetic variation. After the above series of operations, through genetic evolution, we will eventually get a "chromosome" whose solution is the most adapted one, which is the optimal solution to the problem.

(1) Chromosome coding

For the TSP problem with n affected points, the chromosome is divided into n segments, where each segment is the number of the corresponding affected point, and for this path optimization, the TSP problem with 14 affected points is considered, and the encoding is directly as {1,2,3,4,5,6,7,8,9,10,11,12,13,14}, and{1|5|10|14|2|6|8|9|13|3|11|4|12|7}is a chromosome, representing the order of the affected points of the rescue.

(2) Population initialization

After completing the chromosome encoding, an initial population must be generated as the starting solution, so first the number of population initializations needs to be decided.

(3) Select operation

The selection operation is to select individuals from the old group to the new group with a certain probability, the probability of individuals being selected is related to the fitness value, the higher the fitness value of individuals, the higher the probability of being selected

(4) Cross-operation

Partial mapping crosses were used to identify the parents for the crossover operation, and the parent samples were grouped two by two, with the following process repeated for each group:

Generate random integers, determine two positions, and cross the data in the middle of the two positions, e.g:

1	2	3	4	5	6	7	8	9	10	11	12	13	14
5	6	2	9	11	4	14	3	1	12	8	13	7	10

After Crossover:

*	2	*	*	5	4	14	3	1	10	11	12	13	*
5	*	2	*	11	6	7	8	9	12	*	13	*	10

After crossover, there are duplicate supermarket numbers in the same individual, non-duplicate numbers are retained, and conflicting numbers are partially mapped using the method of eliminating conflicts, i.e., mapping using the correspondence of intermediate segments. The results are shown as follows:

6	2	7	8	5	4	14	3	1	10	11	12	13	9
5	4	2	14	11	6	7	8	9	12	3	13	1	10

(5) Variant operation

The variation strategy takes two randomly selected points and swaps their positions by first generating random integers to determine the two positions and swap their positions.

5	6	2	9	11	4	14	3	1	12	8	13	7	10

After mutation as:

5	6	2	9	11	1	14	3	4	12	8	13	7	10

5	6	2	9	11	4	14	3	1	12	8	13	7	10

(6) Reversal operation

To improve the local search ability of the genetic algorithm, multiple successive evolutionary reversal operations are induced after selection, crossover, and mutation. After reversal, the individuals with improved fitness values are retained. Firstly, random integers in the interval are generated to determine two positions that will swap their positions.

5	6	2	9	11	1	14	3	4	12	8	13	7	10

After evolutionary reversal as

5	6	2	9	11	4	3	14	1	12	8	13	7	10

5. Computational experiments

5.1. Case description and data

Wuxi County is a county directly under the jurisdiction of Chongqing, located in the northeastern part of the city, at the junction of Chongqing, Shaanxi and Hubei provinces, and is a typical mountainous agricultural county. The example simulation in this paper uses street data from Wuxi County, Chongqing, and assumes that the largest medical point within Wuxi County after the earthquake is located in the nearest town around the urban area, Phoenix Town, Wuxi County. The Phoenix Town medical site provides treatment services to a total of 14 disaster sites within Wuxi County. The specific model solution and simulation uses the Octopus tool to capture data for Wuxi, Chongqing, and quantifies it using a coordinate system, and then solves it through MATLAB software. The location data and the number of casualties in each specific street and community are shown in Table 1. The average speed of the vehicles is 40km/h, the number of casualties that can be treated at medical points is 800, the total number of rescue vehicles is 10, and the time penalty factor is 10.

Table 1. Location of the affected sites and number of casualties

Serial number	Affected spots	Coordinates (x,y)	Number of wounded
1	Whitehorse Community	(16.47,96.10)	25
2	Murdoch Community	(16.47,94.44)	22
3	Feng Yi Community	(20.09,92.54)	35
4	Xinhua Community	(22.39,93.37)	65
5	Poplar Street	(25.23,97.24)	42
6	Baixin Community	(22.00,96.05)	73
7	Ninghe Street	(20.47,97.02)	38
8	White Goose Community	(17.20,96.29)	82
9	RingCity Community	(16.30,97.38)	26
10	Pioneer Community	(14.05,98.12)	64
11	Nine Phosphorus Community	(16.53,97.38)	45
12	Plaza Community	(21.52,95.59)	57
13	People's Community	(19.41,97.13)	73
14	Environmental Community	(20.09,92.55)	39

The distribution of the affected sites was drawn according to the data in the table, as shown in Figure 1.

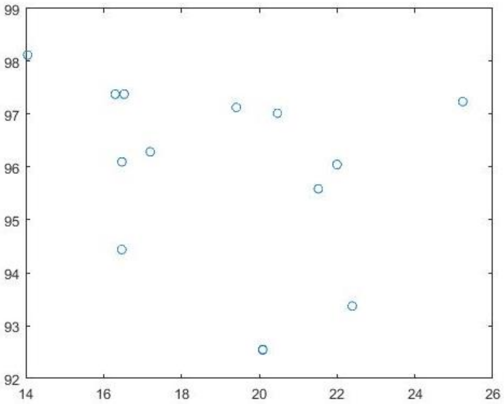

Fig. 1 Distribution map of affected sites

5.2. Calculation results

Set the population size as 100, the maximum number of iterations as 200, the crossover probability as 0.9, the variation probability as 0.05, and the population generation gap as 0.9. Write the algorithm in MATLAB software and run it, and get the algorithm iteration diagram as shown in Figure 2, the stochastic solution of rescue vehicle path planning as shown in Figure 3, and the optimal solution of rescue vehicle path planning as shown in Figure 4.

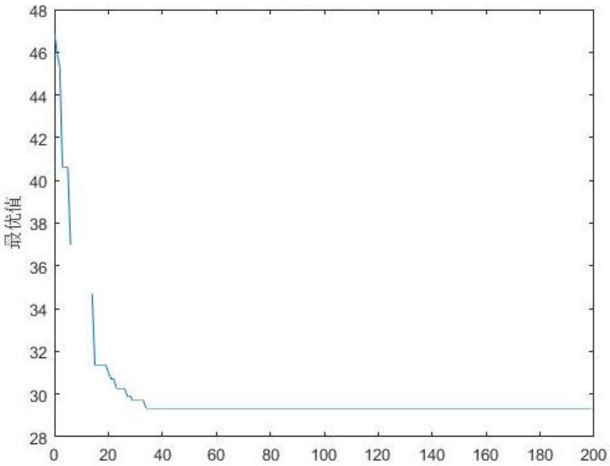

Fig. 2 Iteration diagram of genetic algorithm

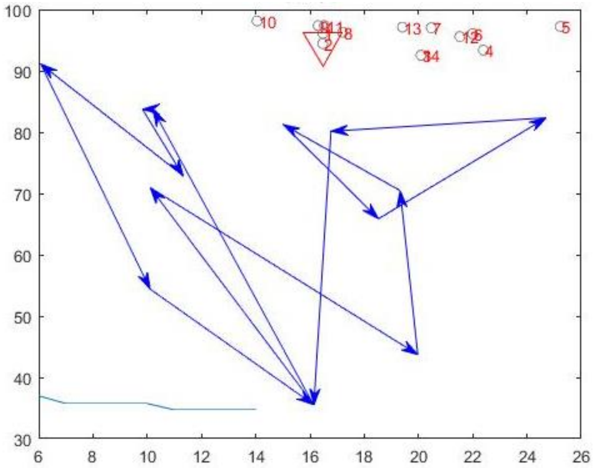

Fig. 3 Randomly generated random solution

According to the algorithm solution, we can get a random solution of the rescue vehicle travel path: 5->12->7->6->1->13->4->14->2->9->10->11->3->8, run according to the above random solution, the total distance traveled by each vehicle is 54.3449km, and the total travel time of the vehicle is 1.3586h.

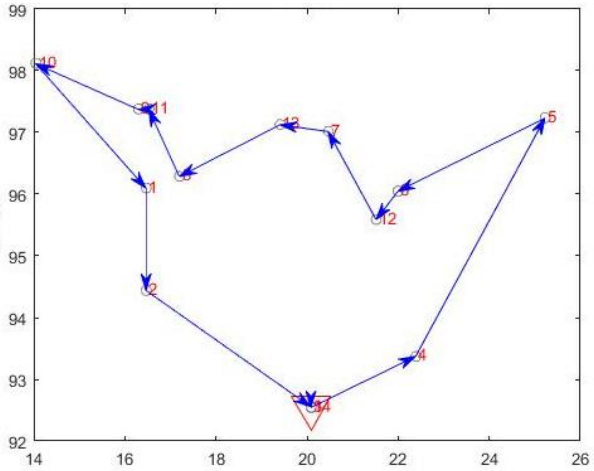

Fig. 4 Genetic algorithm iterative optimal solution

According to the algorithm solution, an optimal vehicle path solution can be obtained: 3->4->5->6->12->7->13->8->11->9->10->1->2->14, run according to the above random solution, the total distance traveled by each rescue vehicle is 29.3405km, and the total travel time of the rescue vehicle is 0.7335h.

6. Conclusions

Earthquake is a very destructive natural disaster, which causes huge losses to human society, not only huge property damage, but also tragic casualties. As the key rescue period of post-earthquake rescue and relief, fully grasping this golden rescue period and launching scientific and efficient emergency rescue activities such as casualty transportation and casualty treatment play a decisive role in the rescue effect. This paper draws the following conclusions from a study of post-earthquake casualty rescue in small cities:

(1) Based on the construction of emergency logistics rescue system for small cities, a path planning model pursuing the minimum rescue time is established, and the path optimization model with soft time window restriction is solved by using genetic algorithm, which can effectively solve the post-earthquake casualty rescue problem in small cities.

(3) Empirical analysis applies the constructed model to a practical example of street community rescue in a small city. The 14 communities in the county of Wuxi County, Chongqing, were selected as the affected points, and the paths of the vehicles were planned to generate random and optimal solutions respectively, and the comparison found that the optimal solution was better than the other solutions both in terms of vehicle transportation distance and transportation time. It shows that the path optimization of this emergency logistics rescue is of practical significance.

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Declarations

Conflicts of Interest: The authors declare no conflict of interest.

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