

Research Article

Construction of Earthquake Rescue Model Based on Hierarchical Voronoi Diagram

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Traditional earthquake rescue methods have many problems, such as the impact of road damage on earthquake rescue, the rational allocation of disaster relief materials, and the active division of rescue areas. According to the characteristics of earthquake relief, a new earthquake rescue model is designed from three aspects: high-altitude rescue, road transport relief supplies, and street human resources rescue. In this paper, the hierarchical Voronoi diagram is applied to the earthquake rescue problem, the earthquake rescue model is constructed, and the area affected by the earthquake is reasonably divided. We discussed the earthquake intensity and the proportion of the population in the disaster area and the number of disaster relief materials and other parameters and conducted an in-depth analysis of the model to form a useful earthquake rescue model. Visual simulation results have been obtained by computer simulation. Compared with the traditional earthquake rescue plan, the model proposed in this paper is more effective and scientific in improving the material distribution, personnel rescue, and postdisaster reconstruction after the earthquake, and it also provides a new idea for the rescue of other natural disasters. It has practical social value and broad application prospects. Besides, the models and conclusions given in this paper have been recognized by the Seismological Bureau of Hainan Province and the Mathematics Research Center of Hainan Province.

1. Introduction

Earthquake is a kind of natural phenomenon in which the Earth's crust causes vibration and generates seismic waves during the rapid release of energy. In traditional earthquake rescue, the primary way of emergency response is to combine the mechanism of earthquake occurrence with the emergency plan [1]. The existing earthquake rescue model is categorized by two domains, including the disaster area and the actual rescue implemented since an earthquake happened. The significant issues of the utilization of traditional approach include the following: (1) the mathematical model used in the earthquake disaster is too simple [2]; (2) simple division of the postearthquake disaster area [3]; (3) it failed to consider the actual road damage situation of the earthquake-stricken village [4].

Given the deficiencies mentioned above, this paper proposes to build a seismic rescue model using a hierarchical

Voronoi diagram. The Voronoi diagram is a geometric figure formed by the circumscribed circle center of a triangle; it is mainly used for the prediction of meteorology and precipitation [5–7]. The hierarchical Voronoi diagram completes the refinement of the overall regional space through different granularity levels, which helps to identify the earthquake-affected areas rationally. Based on the specifications of the affected area, a feasible earthquake rescue model can be constructed by investigating the actual road damage level in a different area. Finally, we have formed a new set of a hierarchical earthquake rescue plan with high-altitude exploration, road transport relief supplies, and personnel rescue. Through the computer simulation processes, considering the hierarchical disaster discrete points, the selection of isolated points and individual points, and the construction of hierarchical rescue solutions and models of Voronoi diagram, this earthquake rescue model can analyze the specific situation of the affected villages and

the urgency of disaster relief of the hierarchical disaster discrete points.

The “5.12” Wenchuan earthquake occurred at 14:28:04 on May 12, 2008. The magnitude of the surface wave reached 8.0 Ms, the magnitude of the moment reached 8.3 Mw, and the seismic intensity reached 11 degrees. Most of mainland China and some Asian countries were substantially affected by this earthquake. To be more specific, the earthquake geographically spread north of Liaoning, east of Shanghai, south of Hong Kong, Macau, Thailand, and Vietnam, and west of Pakistan [8,9]. The “5.12” Wenchuan earthquake severely damaged more than 100,000 square kilometers ground. Besides, the earthquake caused 69,227 deaths. 374,643 people were injured, and 17,923 people were missing. According to the statistical data generated since the earthquake, this paper proposes the Construction of Earthquake Rescue Model Based on the Hierarchical Voronoi Diagram to simulate the rescue mode for this deadly earthquake. Also, it will elaborate on some issues encountered in earthquake rescue to carry out the parameters in the model. A set of an auxiliary decision model for earthquake rescue is proposed, which is more efficient and convenient than traditional rescue methods.

In recent years, with the frequent occurrence of earthquakes, research on earthquakes has been refocused by many experts and scholars. The research on earthquake topics generally concentrated on the following. (1) Designing specific survey methods to assess people’s understanding of earthquake rescue factors through questionnaires and analytic hierarchy process (AHP) [10–12]. (2) Through the consideration of land use types, combined with the damage degree of buildings, land use index, population density, and other indicators, a standard database for building damage after earthquakes was developed [13, 14]. (3) By investigating the uncertainty of natural disaster information, a dynamic task allocation method based on contract network protocol (CNP) is established [15, 16]. (4) Assistance in post-earthquake rescue by using drones [17]. Unmanned aerial vehicle (UAV) is a relatively new method to survey seismic areas. We can apply UAV aerial imagery and DEM data technology to seismic exploration regarding complex areas [18]; they can also be utilized to conduct an emergency assessment of road damage [19].

At the same time, scientists are paying more attention to the earthquake that occurred in Wenchuan, China, on May 12, 2008. These studies have focused on geological changes and geophysical studies before and after the earthquake [20–22]; measurement science is a study of earthquake magnitude measurement [23–25]. Many people study public health issues [26, 27]. However, after a sudden earthquake, there is still a long way to go to study the issue of material distribution and personnel rescue [28].

This paper mainly focuses on how to build a time-efficient and scientific earthquake rescue model based on hierarchical Voronoi diagram. Many factors will be considered when constructing our model. A critical comparison between our model and the traditional network format rescue model will also be implemented. For the sake of earthquake relief, factors including improvement of postdisaster

material distribution, personnel assistance, and postdisaster reconstruction need to be concerned as well. The results of the paper have been recognized by authorities of the Hainan Provincial Earthquake Administration and the Hainan Provincial Mathematical Research Center.

2. Constructing Earthquake Rescue Model

2.1. Voronoi Diagram. In mathematics, a Voronoi diagram is a partitioning of a plane into regions based on the distance to points in a specific subset of the plane. That set of points (called seeds, sites, or generators) is specified beforehand. Furthermore, In a region formed by this point, all points have the shortest distance to this set point. These regions are called Voronoi cells. The Voronoi diagram of a set of points is dual to its Delaunay triangulation [29, 30]. Due to the divisional feature of the Voronoi diagram in spatial partitioning, it can be used to solve problems such as nearest points, minimum closed circles, and many spatial analysis problems such as adjacency, proximity, and reachability analysis.

2.2. Definition of Voronoi Diagram. Let X be a metric space with distance function d . Let K be a set of indices and let $(P_k)_{k \in K}$ be a tuple (ordered collection) of nonempty subsets (the sites) in the space X . The Voronoi cell, or Voronoi region, R_k , associated with the site P_k is the set of all points in X whose distance to P_k is not greater than their distance to the other sites P_j , where j is any index different from k . In other words, if $d(x, A) = \inf\{d(x, a) \mid a \in A\}$ denotes the distance between the point x and the subset A , then

$$R_k = \{x \in X \mid d(x, P)_k \leq d(x, P)_j \text{ for all } j \neq k\}. \quad (1)$$

The Voronoi diagram also has the following properties:

- (1) Each Voronoi diagram contains only one discrete point data
- (2) The distance from the point in the Voronoi diagram to the corresponding distinct point is the closest
- (3) The distance between the point on the edge of the Voronoi diagram and the discrete points on both sides is equal

2.3. Hierarchical Voronoi Diagram. After the earthquake, the existing science and technology can accurately obtain the epicenter, magnitude, focal depth, and seismic intensity. However, it is urgent to reach the following goals. (i) Grasp the actual disaster situation such as road damage, house collapse, and landscape change in the earthquake-affected area. (ii) Quickly repair the road to the disaster area as soon as possible and distribute the relief materials to various urban villages in time. (iii) Rescuers are formed into small teams and assigned to multiple towns for search and rescue of the smallest units. In order to achieve these goals, we choose a hierarchical Voronoi diagram [31] to build the model of earthquake rescue.

2.3.1. Coarse-Grain Size (First Level). The earthquake occurs mostly in mountainous areas or hilly areas. After the earthquake, the local topography and hydrology are more complicated.

The first step of the earthquake rescue work is to explore the actual situation of the affected area accurately. The traditional exploration is mainly through the liaison officers of the earthquake bureaus stationed in various towns, through the telephone, satellite phone, and other means to feedback the actual situation [32, 33], but this approach lacks integrity and effectiveness. At present, some research departments are considering using drones to survey the rescue area, but the flying time of drones is not long, which will affect the efficiency of the survey. Consider comprehensively that the fundamental division of the rescue is carried out through the Voronoi diagram construction. The coarse-grained construction idea is as follows accurately. (i) Identify the affected area and find the regional population ratio of each town in the disaster area (indicating the ratio of the population of the area divided by the maximum population of the towns in the earthquake-affected area). Use the same method to calculate intensity. Then, we use these two data to calculate the characteristic value of each town or village. (ii) Sort the towns or villages according to the characteristic value. (iii) Take the top 10 towns or villages and construct Voronoi diagrams (1). These ten towns will serve as essential reference data for the next coarse division. (iv) Use remote sensing aircraft or UAV to survey the airspace and to grasp the terrain, hydrology, road damage, and house collapse in the area. According to the above design, we can quickly and comprehensively understand the actual situation of the rescue area.

2.3.2. Medium-Grain Size (Second Level). The coarse-grained division is preliminary, but the intermediate-grained division is to make a more detailed division of the rescue area to ensure that relief materials can be distributed to various urban villages promptly. In the aftermath of the quake, the situation in the affected areas is complicated, with frequent power outages, water outages, and wireless signal outages. The disaster area is also in urgent need of a large number of relief materials, so the rapid deployment of relevant materials into the disaster areas is vital. We are focusing on the timely delivery of relief materials to the towns and villages affected by the earthquake by way of land transportation. In the event of a significant earthquake, the affected urban villages are bound to be more. Therefore, by the smooth flow of the disaster relief area, it is more efficient to use the material diversion to distribute the relief materials to a centralized material distribution center. The real distribution center is issued to the urban villages under the jurisdiction. The divisional thinking of this level is different from the first level. It needs to consider the actual situation such as road damage, topography, and hydrology. Therefore, the intermediate-grained construction idea is as follows. (a) By the coarse-grained division, the selected distance is moderate, and several urban villages with smooth roads serve as regional material distribution centers. (b) Build

Voronoi diagrams (2') with these real distribution centers. (c) Combine actual road mileage and road damage of various towns to their physical distribution centers and apply the clustering algorithm to adjust the Voronoi diagram (2') to form the Voronoi diagram (2). (d) Transport a large number of relief materials to the material distribution center utilizing land transportation and then distribute the relief materials from the physical distribution center to the towns and villages under the jurisdiction. The above ideas can improve the distribution efficiency of relief materials.

2.3.3. Fine-Grain Size (Third Level). The actual disaster relief would work after the earthquake occurs based on the towns. The current typical plan is to divide the rescue responsibility area through the block and distribute the rescue force by the block division method. The essence is the equalization method, which is not suitable for the actual situation of the disaster and the efficiency of search and rescue. Therefore, this paper is still based on the Voronoi diagram to divide the urban rescue responsibility area. Fine-grained division is the third level of division and the smallest level of the Voronoi diagram earthquake rescue model. It will be able to separate the cities from the villages and help them separately. Road damage, topography, hydrology, and other actual conditions are at the fine-grained level. The impact on regional division is small. Given the above situation, we constructed the third level of the Voronoi diagram earthquake rescue model. The fine-grained construction idea is as follows. (a) Choose a flat and open school, hospital, or square as a temporary command center and establish a safe and convenient transportation network. (b) Construct the Voronoi diagram (3) with these temporary command centers. (c) Combine the kilometer grid data of the earthquake emergency platform to determine the disaster situation in the area where the temporary command center is located. (d) According to the actual situation of each disaster area, determine the corresponding rescue personnel. According to the above ideas, a team of rescuers will be assigned to each town to search and rescue the smallest unit.

2.4. Design of Rescue Model. When constructing a hierarchical Voronoi diagram model, it is necessary to determine the corresponding discrete points in the plane. Distinct points are the key to the formation of the Voronoi diagram. For the disaster relief model after the earthquake, we call these points discrete points. In this part, we expound some terms and design links of the level Voronoi diagram rescue model.

2.4.1. Urban Eigenvalues. In this model, urban eigenvalue is a numerical value describing the actual disaster situation of the affected area. It consists of two key factors: population ratio ρ and regional intensity σ [34–37]. The equation expresses the urban eigenvalue η .

$$\eta = \alpha \cdot \rho + \beta \cdot \sigma + \gamma \cdot \tau, \quad (2)$$

where α and β represent the weights of ρ and σ , respectively, and τ indicates other factors that have an impact on earthquake rescue, but actual data cannot measure this part of the elements. To ensure the objectivity of this model, we do not specifically discuss the value of τ in operation.

Thus, we can evaluate a single city with earthquake damage by the following equation:

$$\begin{cases} \eta = \alpha \cdot \rho + \beta \cdot \sigma, \\ \alpha + \beta = 1, \\ \alpha, \beta \in (0, 1). \end{cases} \quad (3)$$

In the face of large earthquakes, we can also select the corresponding parameters to evaluate the collective eigenvalues of each city to determine the overall disaster situation of the affected area (using equation (4)) and determine the level of disaster relief at the macro level.

$$\sum_{i=1}^n \alpha \cdot \rho_i + \beta \cdot \sigma_i, \quad (4)$$

$$\sum_{i=1}^{k_1} \alpha \cdot \rho_i + \beta \cdot \sigma_i + \sum_{i=k_1+1}^{k_2} \alpha \cdot \rho_i + \beta \cdot \sigma_i + \cdots + \sum_{i=k_{j-1}+1}^n \alpha \cdot \rho_i + \beta \cdot \sigma_i. \quad (5)$$

Both equations (4) and (5) represent the overall disaster situation of the affected area. In equation (2), n represents the sum of the number of cities affected by the earthquake. In equation (3), k_i represents the town affected by the same seismic intensity. Therefore, we have $\sum_{i=1}^j k_i = n$. It is not difficult to see that through the fine division of the intensity of the disasters in various regions, we can have a macro understanding of the overall disaster situation to assign equal disaster relief forces. Therefore, it is essential to evaluate the whole disaster situation and the specific disaster characteristics of each town.

2.4.2. Hierarchical Diagrams. Hierarchical Voronoi diagram is constructed based on the existing forms of Voronoi diagram, and then we generate discrete points in each Voronoi diagram and form secondary Voronoi diagram based on these distinct points, thereby fine-graining the original Voronoi diagram.

2.4.3. Discrete Points of Disasters. The formation rules of the Voronoi diagram require the determination of separate aspects of the Voronoi diagram on the plane. In this model, after the rescue area is surveyed by remote sensing aircraft or drone and the actual situation of road damage, topography, and hydrology in the rescue area is obtained [36, 37], the road damage is light (at least one full road exists; the urban villages connected by the outside world are selected as discrete points of disaster).

2.4.4. Isolated Location. Based on the coarse-grained division and by understanding the actual situation of the rescue area, after examining the affected areas with the intensity

above VIII, select the urban villages that have damaged roads in the area as isolated points. At present, many villages in remote mountainous areas of China are scattered [38, 39]. Therefore, when an earthquake occurs in such a remote mountainous area, it is easy to damage the road leading to the village, which brings much inconvenience to the earthquake rescue. The remote mountain village where the village road is destroyed is an isolated point. Because the secluded location is generally in a remote mountainous area with a small population, we use airdrop material and engineering road repair to rescue such separate points at the same time.

2.4.5. Aircraft Base. Select the towns with the top feature values as the center point. Drones are being used in these towns to survey the rescue areas. The rescue area conducts surveys to determine the actual situation of road damage, house collapse, topography, and hydrology in the rescue area. We draw a basic conceptual model of the region, where the red point is the aircraft base (Figure 1(a)).

2.4.6. Material Transportation Center. In the process of intermediate-grained partitioning, based on the coarse-grained division of the Voronoi diagram (1), the rescue area is further subdivided, and the city feature value is selected to rank the top, and the distance is moderate. We chose these points as material distribution centers and constructed the Voronoi diagram (2'). Moreover, considering the actual road damage in the disaster area, we determine the attribution of some particular towns, thus forming the Voronoi diagram (2). We draw a basic conceptual model of the intermediate-grained partition, where the red point is the physical distribution center (Figure 1(b)).

2.4.7. Temporary Command Center. By the coarse-grained and fine-grained classification of the rescue area, the current actual rescue of the earthquake has been solved: timely grasping the real disaster situation of the disaster area and the actual effective allocation of materials. Under the smallest unit, we should consider some possible factors for the rescue of buried personnel. Therefore, in a town to be rescued, buildings such as schools and hospitals with open, safe, and smooth roads are selected as temporary command centers. We build a fine-grained Voronoi diagram (3) for rescue. Because it is divided on a small level, at the fine-grained level, the factors affecting the regional division of road damage, topography, and hydrology are relatively small. The construction mode can allocate rescuers to the towns for the search and rescue of the smallest units. We draw a basic conceptual model of this fine-grained partition, where the red point is the temporary command center (Figure 1(c)).

2.4.8. Residual Analysis. In this model, we cite the statistical method of residual analysis. Through cooperation with the Seismological Bureau of Hainan Province, we collected some actual situations of rescue in the Wenchuan earthquake. We

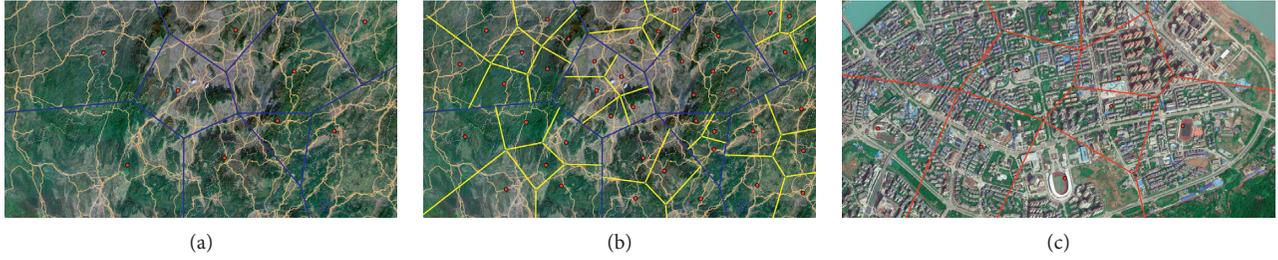


FIGURE 1: Hierarchical Voronoi diagram applied to seismic region partitioning: (a) coarse-grained Voronoi diagram (1); (b) intermediate-grained Voronoi diagram (2'); (c) fine-grained Voronoi diagram (3).

will fit the computer simulation conclusions with the real case and correct the simulation values based on the original to meet the model under the condition that the coefficient of the emergency rescue distribution is determined, and the model can be better. The actual rescue situation provides a set of auxiliary decision-making models for real rescue during the subsequent earthquake rescue process [40, 41]. In practice, we focus on the residual analysis of the selection of discrete points to further determine its rationality as a discrete point. We assume a normally distributed population with mean μ and standard deviation σ . For the towns in the disaster relief area, we select the corresponding X_i , and the sum of the squares of the statistical errors is divided by σ^2 to calculate the chi-square distribution with n degrees of freedom:

$$\sum_{i=1}^n \frac{(X_i - \mu)^2}{\sigma^2} \sim \chi_n^2. \quad (6)$$

It is worth noting that the sum of the squares of the residual and the sample mean can be shown to be independent of each other. Given this, we can also give a form of quotient calculation consisting of a chi-square distribution:

$$\frac{\bar{X}_n - \mu}{S_n / \sqrt{n}}. \quad (7)$$

In summary, we constructed a complete rescue model. The flowchart is shown in Figure 2.

3. Simulation of the Earthquake Rescue Model

Through the above description of the hierarchical Voronoi diagram rescue model, the primary link of the earthquake rescue plan has been primarily formed. This section mainly introduces the algorithm construction of the rescue model using the hierarchical Voronoi diagram, and through algorithm development, such as data visualization and data analysis. Finally, we used MATLAB to realize computer simulation.

3.1. Computer Simulation

3.1.1. Processing and Analysis of Data. Through the National Seismological Bureau, the Sichuan Provincial Bureau of Statistics, and some network resources, we obtained relevant data on the “5.12” Wenchuan earthquake, including the

longitude, latitude, population, and intensity statistics of earthquakes in various counties and cities in Sichuan Province (180 groups).

The seismic intensity decreases with the distance from the epicenter. The current China Earthquake Intensity Table is determined by the State Bureau of Quality, and Technical Supervision distinguishes the rescue area with a severity level of 6 degrees (VI) [42], and the seismic intensity level is 7 degrees, so the area above is designated as the earthquake rescue area.

For the 180 sets of data in the statistics, we chose the towns with earthquake intensity above 7 degrees as the rescue points. At the same time, we also noted that the town with the largest population in Sichuan Province was 1,090,422 people in Jinjiang District of Chengdu, and the most intense towns were 11 degrees (XI) in Mao County, Sichuan Province, Aba Tibetan, and Qiang Autonomous Prefecture in the Wenchuan earthquake. Combining the maximum population and the most reliable degree, the population ratio ρ and the seismic intensity ratio σ (121 groups) corresponding to each town in the rescue area were obtained.

3.1.2. Computer Simulation Results

- (i) Simulation results of seismic intensity maps: according to the data of the “5.12” Wenchuan Earthquake of the China Data Science and Technology Museum, the intensity distribution map of the earthquake (Figure 3(a)) and the long and short axis values of the intensity region in the map are obtained, and the seismic intensity is constructed by computer to form a computer simulation map (Figure 3(b)).
- (ii) Coarse-grained Voronoi diagram (1) division: the eigenvalues η of each town in the disaster relief area are solved, then sorted, and the affected municipalities are classified according to the eigenvalue size. Ten cities with the top ranking and reasonable distance were selected as the bases of remote sensing aircraft and drones, and their construction was completed using corresponding Voronoi diagram (1) (Figure 4).
- (iii) Intermediate-grained Voronoi diagram (2') (2) division: based on the coarse-grained Voronoi

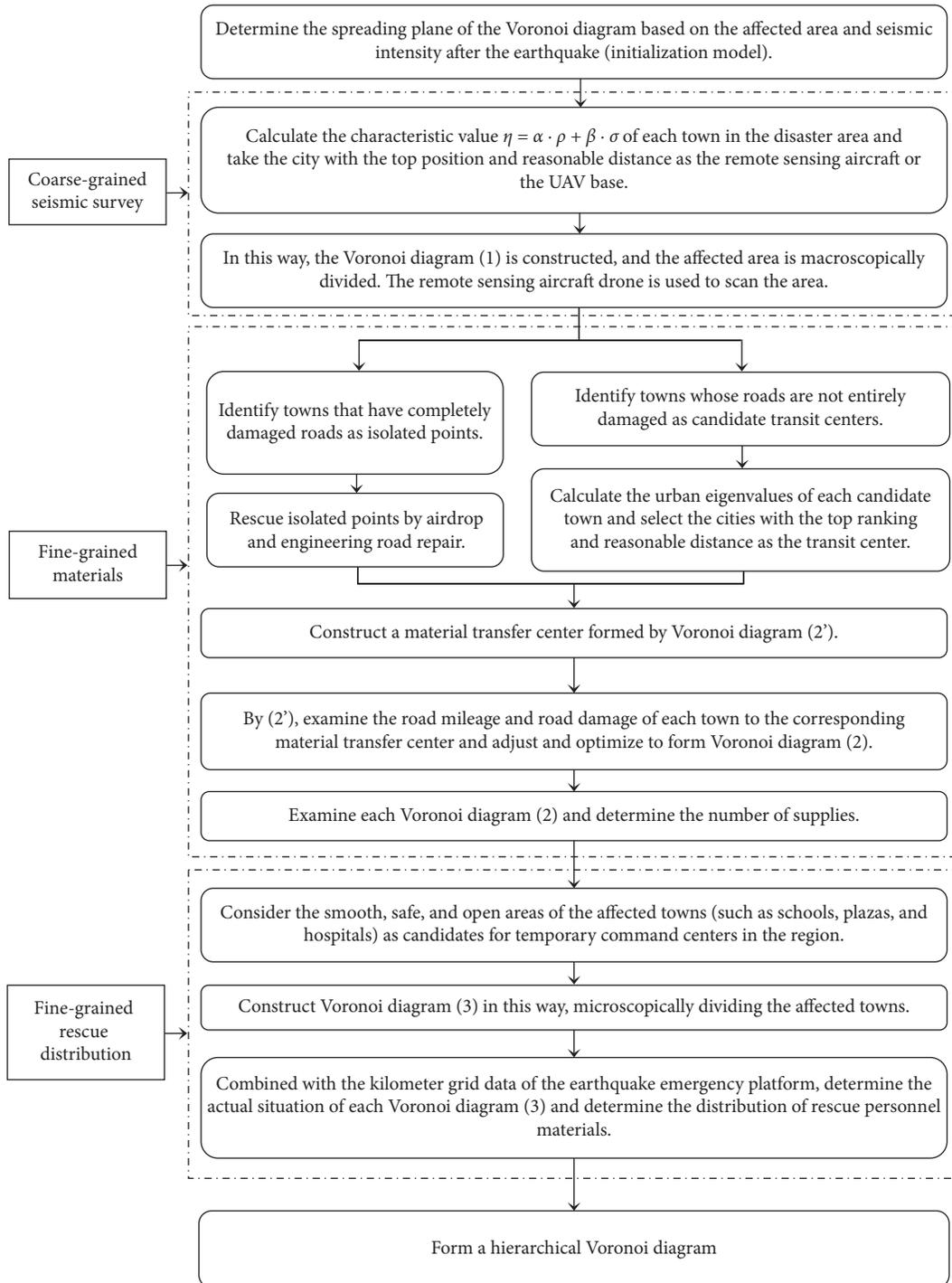


FIGURE 2: Hierarchical Voronoi diagram rescue model algorithm flowchart.

diagram (1), a more significant number of discrete disaster points are selected in the same range as the physical distribution center of the region, and a more fine-grained Voronoi diagram (2') is obtained based on the primary nesting (Figure 5(a)). It was done to allow relief supplies to be distributed more quickly to centralized material distribution centers and then to suburban towns and villages. Through the unique points generated by the Voronoi

diagram (2'), the clustering algorithm can be used to determine the actual attribution of the discrete points of such individual disasters, thus forming the Voronoi diagram (2). In the computer simulation, this method obtained Figure 5(b), where the same color marks the same kind of points.

- (iv) Selection of eigenvalue coefficients α , β : after obtaining the population ratio ρ and the seismic intensity ratio σ of each affected area, it is necessary

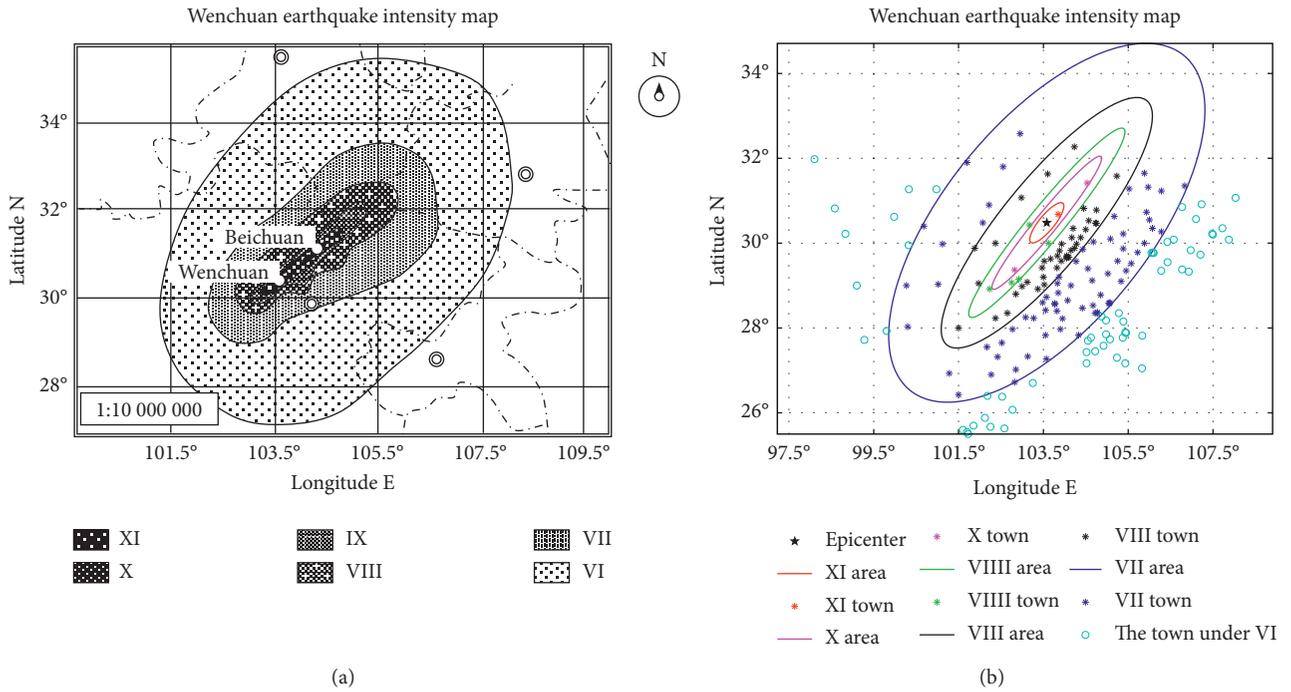


FIGURE 3: Earthquake intensity map generated by computer simulation: (a) Wenchuan earthquake intensity map [43]; (b) computer simulation diagram obtained by the algorithm.

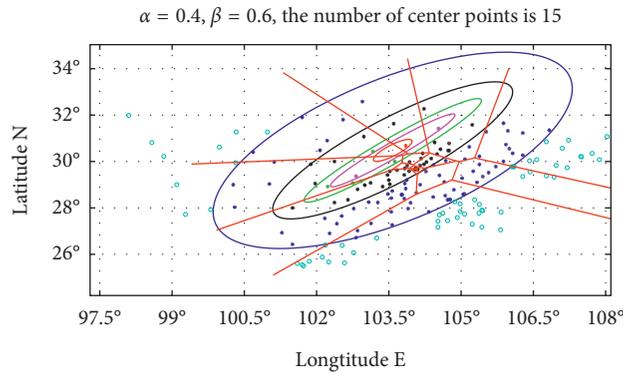


FIGURE 4: Coarse-grained Voronoi diagram (1).

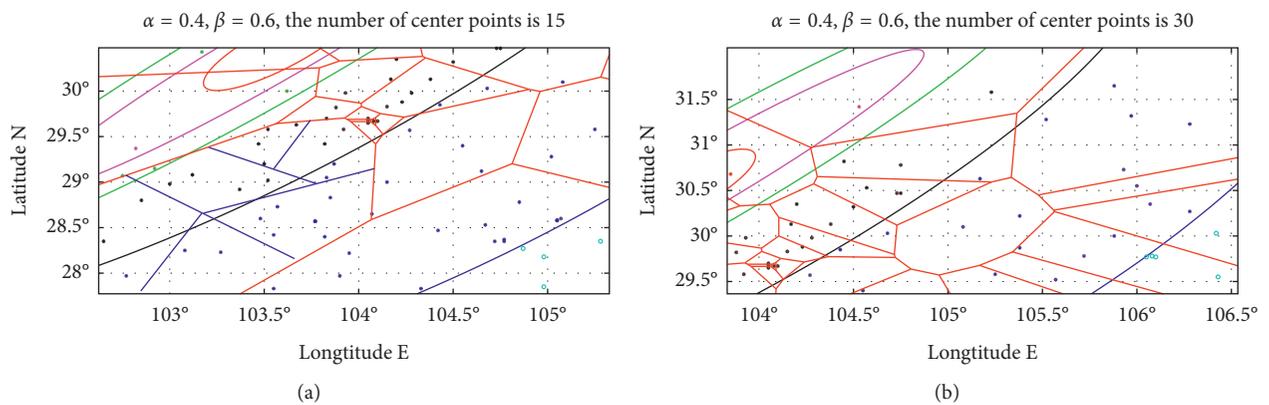


FIGURE 5: Intermediate-grained Voronoi diagram: (a) intermediate-grained Voronoi diagram (2') (single block); (b) clustering algorithm-generated Voronoi diagram (2).

to get the characteristic value η of the city based on the two data and sort the affected town according to the unique value, and the selected precision is 0.0001. The setting is juxtaposed to rank, drawing the Voronoi diagram corresponding to the top city, and $\eta = \alpha \cdot \rho + \beta \cdot \sigma$; the specific value of α and β is required. Thus, we give the following four options:

- (a) $\begin{cases} \alpha = 0.7, \\ \beta = 0.3, \end{cases}$
- (b) $\begin{cases} \alpha = 0.6, \\ \beta = 0.4, \end{cases}$
- (c) $\begin{cases} \alpha = 0.4, \\ \beta = 0.6, \end{cases}$
- (d) $\begin{cases} \alpha = 0.3, \\ \beta = 0.7. \end{cases}$

Moreover, select the top 25 disaster points and the epicenter (Wenchuan County), and the most potent town (Mao County) should also be considered as a physical distribution center.

After selecting the real distribution centers in each case, the Voronoi diagram (2') corresponding to each physical distribution center is established, and the rescue plan for constructing the level Voronoi diagram is obtained. Figure 6 shows that the rescue plan is limited to 7 levels of intensity. In the region, earthquake zones outside the area can be ignored.

From Figure 6, we can draw the following conclusions. Because the values of α and β are different, which affects the actual ranking of the characteristic values of each town, it also has a significant influence on the rescue scheme of the generated Voronoi diagram. When $\alpha = \beta$, the division at this time is meaningless; when $\alpha > \beta$, that is, the weight of the population is relatively large, the selection of the physical distribution center concentrated in the area with a large population and the formation of the Voronoi diagram was focused. In the field with a large population (Figures 6(a) and 6(b)), when $\alpha < \beta$, that is, the weight of the intensity is relatively large, the selection of the material distribution center concentrated in the area with vigorous earthquake intensity; thus, the formed Voronoi diagram is focused on areas with higher intensity (Figures 6(c) and 6(d)). For severe natural disasters such as earthquakes, attention should be paid to the rescue and rescue of personnel. Therefore, in the model formed, consideration should be paid to the proportion of the population coefficient.

- (v) Selection of the number of discrete points of disaster: the number of aircraft bases and real distribution centers determines the number of Voronoi diagram that has not formed under the level. In the earthquake rescue, if the physical distribution center is selected too small, the disaster area cannot be effectively divided. However, due to a large number of people, it also brings disadvantages

to the occurrence of subsequent secondary disasters. Therefore, in the 121 datasets of the Wenchuan earthquake, the top 50% of the proportion is considered as the physical distribution center, and the number of physical distribution centers is determined according to the balance.

Therefore, we consider the selection of the top 15, 20, 25, 40, and 50 towns as the physical distribution centers and discuss the optimal value of the number of material distribution centers. Let $\alpha = 0.4$, $\beta = 0.6$; we count the cities in the top 50 and perform statistics.

According to the ranking of the discrete points of the disaster situation, different numbers of real distribution centers are selected to generate the corresponding level of the Voronoi diagram rescue scheme (Figures 7(a)–7(c)).

We can draw the following conclusions from the above figure, after determining the fixed weight parameters. If the number of points in the distribution of disaster relief materials continuously increased, the number of Voronoi diagram is also growing, and the division of the affected areas is even more detailed.

- (vi) Regional magnification comparison: through computer simulation, the main body of the hierarchical Voronoi diagram seismic model has been primarily formed. Therefore, we consider enlarging the graph to study the model and examine the local deficiency of the model (Figure 7(d)).

From Figure 7(d), the following conclusion can be drawn. In the case where the population ratio weight α is the same as the earthquake intensity ratio weight β , it can intuitively obtain from the local. With the increase in the number of physical distribution centers during the earthquake rescue process, the division of the affected areas is more detailed. However, this also leads to some invalid partitioning cells. For such a single point of disaster, if it is directly divided by the Voronoi diagram, it needs to allocate a large number of relief materials, and the material transportation is also unfavorable, so we cannot select too many material distribution centers. One aspect proves that the proportion of the physical distribution center (discrete points of the fine-grained Voronoi diagram) was controlled at 20% in the algorithm.

3.2. Result and Discussion. Due to the lack of adequate data, the fine-grained urban search and rescue area simulation can only make a concept division and cannot form a specific simulation map. The computer simulation of the hierarchical diagram rescue model is carried out, and the following conclusions are obtained.

We obtained some rescue information from the “5.12” Wenchuan earthquake by contacting the relevant seismic agencies of the government. The selection of the current discrete points is also optimized by residual analysis to

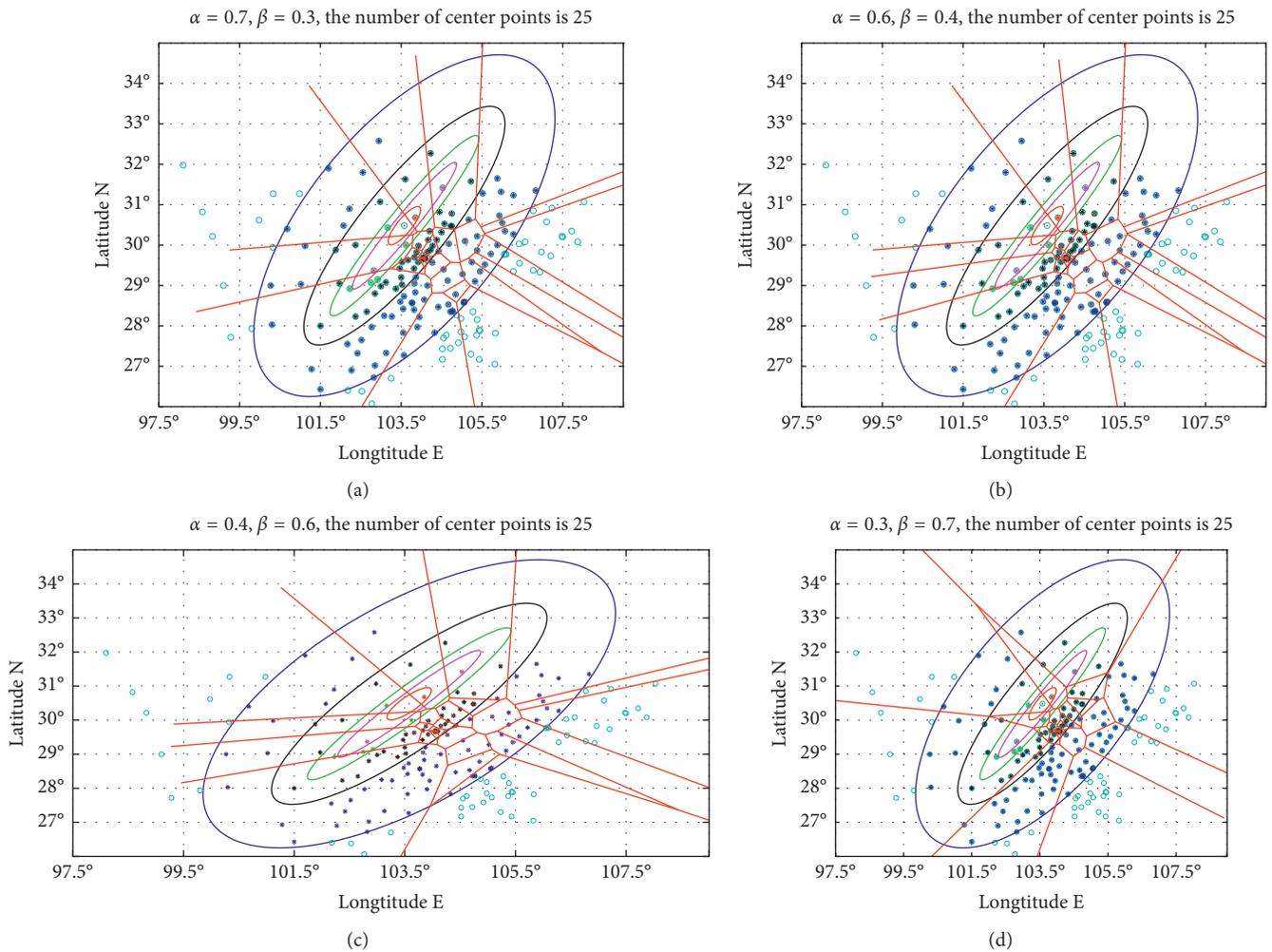


FIGURE 6: Voronoi diagram rescue plan formed by 25 material distribution centers selected under different conditions: (a) Voronoi diagram generated by case a; (b) Voronoi diagram generated by case b; (c) Voronoi diagram generated by case c; (d) Voronoi diagram generated by case d.

redetermine the model to ensure the scientificity and rationality of the given model (Figure 8).

We fit this actual information with the given model and get the real results from the computer simulation. After correcting some of the data and residual analysis, we present a seismic rescue model that is more compatible with reality. Thus, Figure 9 shows the ultimate multilevel Voronoi diagram seismic rescue model.

The model forms a comprehensive set of auxiliary decision-making models and solves the problem of disaster relief area division, material distribution, and postdisaster reconstruction in earthquake rescue. Besides, it provides an excellent example of the rescue and treatment of large-scale disasters.

- (1) The rationality of α and β values: from Figures 2–5, we analyze the influence of the different values of α and β on the generation of the hierarchical diagram rescue scheme. That is, the disparity should not be too significant. If $\alpha = \beta = 0.5$, it is an overly ineffective and straightforward rescue. We observed that there was an inevitable connection between

earthquake intensity and damage to the house, so it will cause people to be buried [30]. Therefore, we consider that we should prefer the weight ratio of the intensity ratio in the selection of weights, that is, satisfy $\alpha < \beta$, so consider taking $\alpha = 0.4$, $\beta = 0.6$, and thus the hierarchical Voronoi diagram is a more balanced graph. We ensure the rationality of Voronoi diagram construction based on the rescue of the affected personnel.

- (2) The rationality of the number of discrete points in the disaster situation: from Figure 7, we analyze that when the weight is fixed, the selection of the separate locations (physical distribution center) will affect the level of the Voronoi diagram rescue scheme. The problem with this is that there are too much damage and too much fragmentation. It also brings about two troubles. On the one hand, it can divide the affected towns more accurately and thoroughly. On the other hand, as the number of divisions increases, a more significant amount of disaster relief personnel and

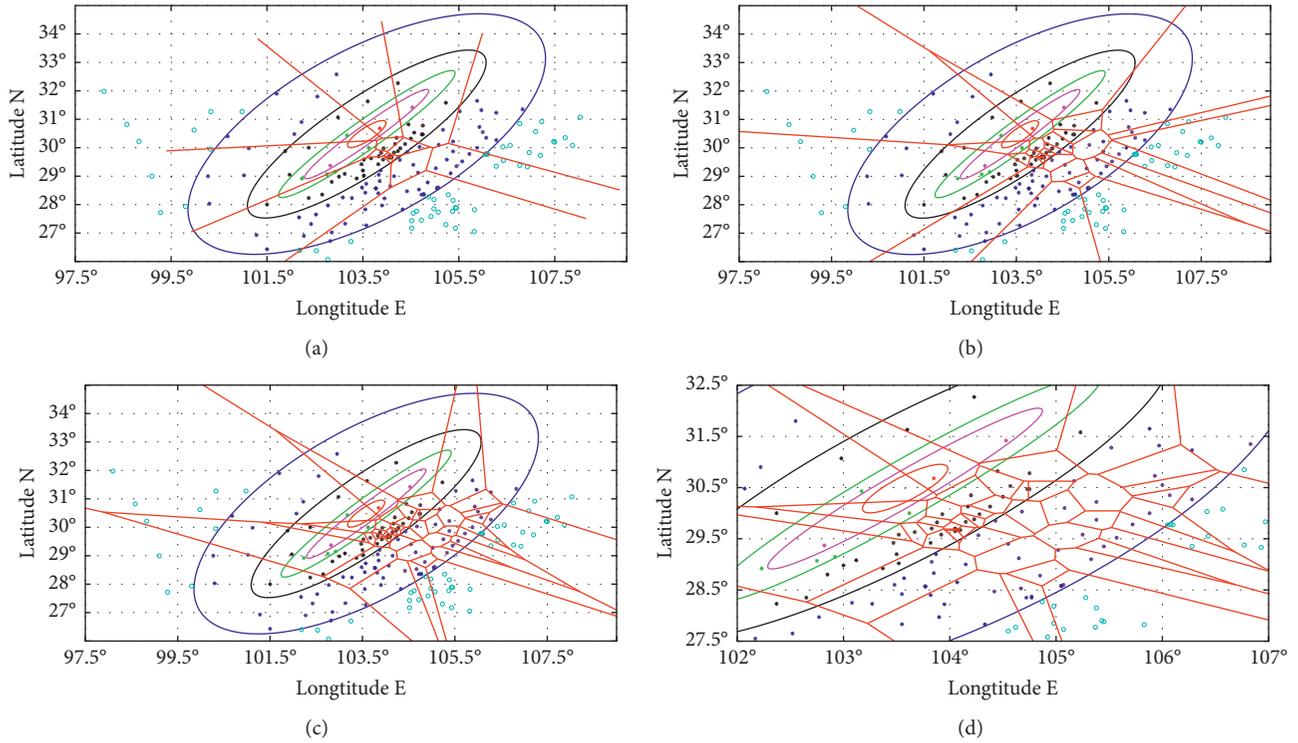


FIGURE 7: As the number of material distribution centers increases, the computer simulation problem changes, when $\alpha = 0.4, \beta = 0.6$: (a) the number of material distribution centers is 15; (b) the number of material distribution centers is 30; (c) the number of material distribution centers is 50; (d) partial magnification of (c).

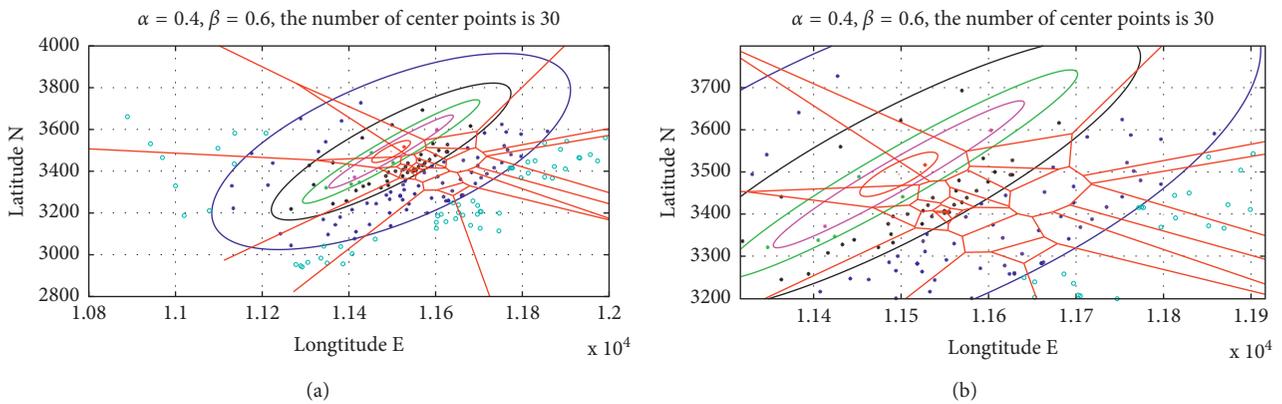


FIGURE 8: Comparison before and after residual analysis and global optimization: (a) performing residual analysis before the global optimization; (b) performing residual analysis after the global optimization simulation.

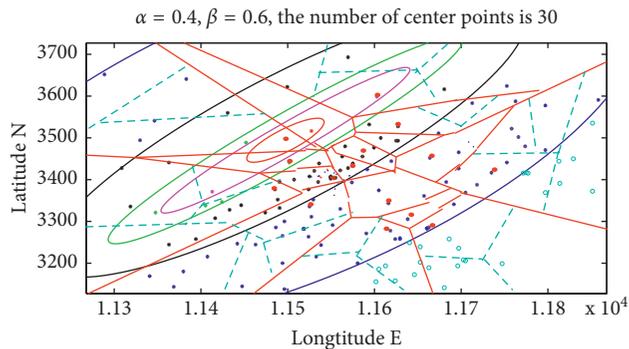


FIGURE 9: Earthquake rescue simulation map.

substances needs to be placed on the disaster areas. Moreover, the placement and distribution of such rescue materials will take some time to implement, which is extremely unfavorable for the relief of large-scale and time-sensitive natural disasters. Therefore, it is not recommended to select a large number of earthquakes in combination with actual earthquake simulation results. It is more reasonable to determine many material distribution centers to control 20% of the total number of disasters.

Moreover, the model is simulated by computer, and in the process of earthquake rescue, the essential parameters are discussed and analyzed. Compared with the traditional rescue scheme, the proposed project has the accuracy and effectiveness of earthquake rescue and significantly improved.

Note that due to the current failure to retrieve all the data of the “5.12” Wenchuan earthquake, the present computer simulation part only includes Sichuan Province, and the data surrounding the earthquake-affected neighboring provinces such as Shanxi, Gansu, and Chongqing are not included in the model. Therefore, it has a particular influence on the effect of computer simulation.

4. Conclusion and Prospect

Constructing an emergency rescue plan and implementing an emergency rescue system in advance are vital for improving rescue capabilities, controlling further deterioration after the disaster, and ensuring people’s safety. This paper mainly discusses the analytic hierarchy process to form a hierarchical Voronoi diagram, which further applies it to the actual operation of the earthquake rescue plan. As a result, we have formed a new set of a hierarchical earthquake rescue plan with high-altitude exploration, road transport relief supplies, and personnel rescue. We also specified the construction ideas and design schemes of this earthquake rescue model and discussed the feasibility of this rescue program. Through computer simulation analysis, we analyze the proposed rescue system framework, optimize the model, and finally form a mathematical model of earthquake rescue based on the hierarchical Voronoi diagram.

This paper makes an in-depth analysis of the mathematical model design of rescue, including the deployment of rescue and rescue materials. Although we have obtained some significant results, some issues are still unsolved and need to be examined in the future due to limited time and cognitive level. The areas still need to be concentrated on in the future are as follows:

- (1) Development of supporting application software: based on the mathematical model of the Voronoi diagram proposed in this paper, computer simulation is carried out to construct the earthquake rescue plan by the third-party development language implemented by MATLAB. ArcGIS Engine, as a development platform, can be used to build a corresponding disaster relief model, which can quickly generate similar solutions and develop friendly human-computer interaction software that ensures

rescue is faster and more efficient. We are going to study these contents in the future.

- (2) Weighted distribution: we need to consider the problems we will face during the rescue and rescue process, such as terrain conditions, rescue site conditions, and the number of rescue workers. However, the weight ratio of these practical factors in the model should be further examined.
- (3) Promotion and application: construction of this complete earthquake rescue and rescue system can provide ideas for other large-scale disasters such as meteorological disasters, geological disasters, and biological disasters. Also, the Voronoi diagram shortest path strategy can be applied to the location of urban facilities such as hospitals, schools, or logistics express points.
- (4) Reconstruction after the earthquake: the restoration of the disaster area after the earthquake can also be processed by using the same mathematical model.

In summary, the use of the hierarchical Voronoi diagram model for in-depth research on postearthquake rescue design and material deployment will help to find the best solution for various types of rescue, especially natural disasters. The model carries out subsequent reconstruction programs designed and schemes of support for the failure.

It is worth noting that although this method was not applied in the actual rescue process, we regard the method as a new way to think when providing a unique consideration for real earthquake rescue. It is believed that through the popularization of big data and cloud computing, it is bound to be more widely used in practical applications by constructing different levels of the Voronoi diagram rescue model system soon.

Data Availability

The data used to support the findings of this study are available in the supplementary materials.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Supplementary Materials

The data of cities and towns in the earthquake area, including latitude, longitude, intensity, and population. (*Supplementary Materials*)

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