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Research Article

Study on the Emergency Management System considering Victims' Self-Rescue Abilities

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The research on emergency response systems usually only considers the role of professional rescuers in emergency rescue or the activities taken by the victims in the process of self-rescue, and the joint research of the victims and rescuers in the same environment is relatively few. Multiagent modeling technology is a promising tool for simulating natural disaster emergency response systems. Based on the background of the earthquake rescue operation, this paper studies the related contents of the cooperative emergency response system of disaster victims and rescuers by using the modeling and simulation method of the multiagent. On the premise of making full use of the victims' ability to obtain information and move, it is proposed that the rescuers and the victims move together to the cluster point to complete the treatment to reduce the time wasted by the rescuers moving among the victims. This paper simulates different degrees of disaster through many experiments and simulates the influence of the relative speed of victims and rescuers by changing the moving speed of victims. It can be found that when there are many disaster victims, the collective rescue operation can reduce the overall emergency response time; when the movement speed of the victims is lower than that of the rescuers, the effect of the clustered rescue is similar to that of the victims waiting for rescue. When the movement speed of the victims is similar to that of the rescuers, the clustered emergency response is better than that of the victims waiting.

1. Introduction

The focus of research often concentrates on the allocation of emergency response resources [1, 2], after large-scale natural disasters, or the emergency risk avoidance strategies of disaster victims [3, 4]. With the progress of science and technology and the improvement of information construction, the disaster victims' distress information and their status information can be quickly transmitted to the outside of the disaster area and can be collected by many professional rescuers or volunteers [5]. Zhao et al. have developed mobile phone system software for rapid earthquake assessment, which is convenient for users to install and use. The system can assess the degree of environmental damage caused by the earthquake and the degree of physical injury of the victims according to the disaster information reported by the victims and provide effective real-time earthquake disaster information for decision-makers [6]. In addition to the information provided by the victims, external rescuers can also obtain the disaster information by other means. Stefan Bosse has obtained more accurate disaster information by combining the two [7]. After collecting such information, the emergency response personnel can carry out targeted treatment according to the characteristics of the victims [8]. Because the disaster victims themselves have a certain ability of self-rescue and mutual rescue, it is not reasonable for emergency managers to allocate only the existing professional rescue resources, and the initiative of the disaster victims should be fully considered. Based on the existing research, this paper takes the ability of the disaster victims as the resource of emergency response, taking into account the whole process of emergency response.

The emergency response process of professionals often includes four stages: observing the situation of victims, evaluating the degree of disaster and existing resources, making decisions, and implementing actions. This process is carried out until all emergency responses are completed [9]; through the above analysis, the perplexing victims can provide effective disaster information at the observation stage; in the operation stage, they can carry out simple self-rescue and mutual action. In this paper, victims' capabilities are fully considered in the earthquake emergency response process: on the one hand, victims can send information of body states and surrounding environment state to the Control Center (CC) [10, 11], and the CC can analyze the specific disaster situation in the earthquake-stricken area through information fusion [7]; on the other hand, the victims themselves have a certain ability of self-rescue and mutual rescue and are willing to help the injured acquaintances around them. [12]. Marco Avvenuti constructs EARS (Earthquake Alert and Report System) which realizes earthquake early warning and reporting through opening up crowdsourcing [5]. However, in the process of self-rescue and mutual rescue for the victims, there may be an occupation of the public emergency resources which hinders external rescuers to complete the task on time. Victims sometimes do not take other victims and rescuers into account, which will lead to a 1 + 1 < 2 situation. For example, if the victims want to escape from the disaster area and the rescuers want to enter the disaster area, they will conflict because of competing for the right to use the transport road, resulting in unnecessary waste of time. In the initial stage of earthquake emergency rescue, any meaningless waste of time may lead to an increase in mortality.

To reduce the contradiction between victims and rescuers in the process of cooperation, this paper proposes a concept of the "cluster point". These points are calculated by cluster analysis according to the distribution of victims in the disaster area, so we call them cluster point in the following. The purpose of these points is that the victims can gather together and wait for the rescuers for centralized treatment to improve the rescue efficiency of the rescuers and reduce the time consumed by the rescuers moving between the rescue points. K-medoids clustering algorithm is used to calculate these points, and the value of K is closely related to the number of rescuer teams that at least one rescuer team should be allocated in every cluster point. To complete the task, rescuers will move to the corresponding point and take some time to rescue the victims. To prevent other new victims from reaching the cluster point, rescuers need to wait at the point for some time.

This study pursued two main objectives. The first objective is to develop a dynamic agent-based simulation model for victims' and rescuers' operations after an earthquake. The K-medoids cluster method and centralized task allocation optimal method are used in the task allocation process of the emergency response system combing the internal and external domains (ERSCIED), as shown in Figure 1. Victims firstly send their important information to the CC and then the CC calculates the cluster points and sends them to the experts. Experts will judge the capability of cluster points and send confirmation to the CC. Then, the CC allocates the cluster points to rescuers and sends the relevant information to victims. Victims and rescuers move to the cluster points simultaneously. The second objective uses different parameters to simulate different scales of the earthquake, and then it will find the advantages and disadvantages in the ERSCIED. The result can be used to advise the emergency commander in different environmental conditions.

Multiagent systems (MASs) make it possible to simulate building demolition, damage to urban infrastructure, injuries, search, and rescue teams [13]. MASs deal with complex systems by emphasizing the interaction between agents and dividing the system into subsectors of the environment and other actors MASs [14]. Task allocation plays an important role in coordinating an MAS within a set of agents [15, 16]. Appropriate allocations are critical for the efficient implementation of tasks undertaken in natural hazard environments. Proposing a proper approach to consider uncertainty in task allocations plays an important role in decision-making concerning urban search and rescue (USAR) operations in crisis-stricken areas [17]. Lin Ni et al. employ an agent-based approach to model indoor post-earthquake evacuations. They use a dual-graph model which combines a navigation mesh to support agents' physical movement and a perception graph to model the cognition of the agents [18]. In this paper, the victims' target is unchangeable, and they did not consider the exit ability of each target, so it is very hard for decision-makers to manage the rescue resources for every target. Navid Hooshangi and Ali Asghar Alesheikh propose an approach for dynamic task allocation and establishing collaboration among agents based on contract net protocol (CNP) and interval-based technique for order of preference by similarity to ideal solution (TOPSIS) methods, which consider uncertainty in natural hazards information during agents' decision-making [19]. They take into account the uncertainty in the emergency response process but lack the overall assessment of the needs of the victims, which will lead to excessive uncertainty in the calculation results and lay hidden dangers for the final decision-making. Hai Sun et al. investigated urban people's evacuation behavior under earthquake disaster conditions, established crowd response rules in emergencies, and described the drilling strategy and exit familiarity quantitatively through a cellular automata model [20]. In this paper, the evacuation of disaster victims is described in detail, which is modeled and analyzed in high resolution. If the experimental site area becomes larger, it may be quite different from the actual emergency evacuation phenomenon. This study is more like a supplement to other studies, which organically combines the victims, rescuers, and rescue process, making the emergency rescue process more flexible and efficient.

The main innovation of this research is to present a method that is appropriate to make use of the victim's capabilities in coordination with the rescuers. The K-medoids clustering method is used to find the cluster points and the optimization approach is used for task allocation. Both of them are used to reduce the total rescuers moving distance so that rescuers can spend more time on treatment. The computer modeling and simulation method can be used to simulate the operation process of the system many times and observe the operation effect of the system

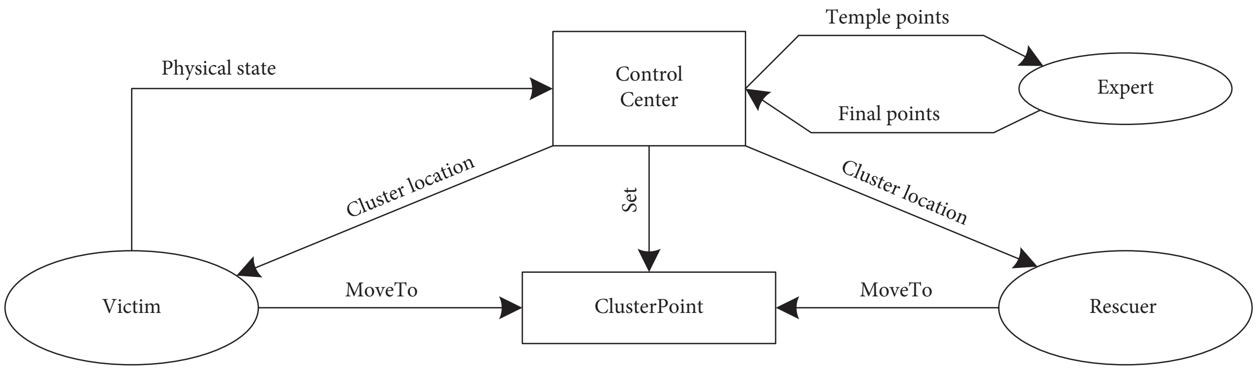


Figure 1: Emergency response system combing the internal and external domains.

under the condition of low human and material resources. The relevant parameters can also be changed to observe the operation state of the emergency response system combining internal and external domains under different conditions, which provides the basis for the actual emergency response depending on reference [21]. According to the multiagent system modeling method, the rationality of the proposed method in this paper is verified by using the multiagent modeling and simulation technology, and the application scope of the method is clarified according to the experimental results, which provides a new idea for emergency decision-makers to formulate emergency rescue plans.

This paper is organized as follows: Systems models of three different conditions are constructed in Section 2. Multi-agent system modeling, centralized optional method, and K-medoids algorithms are illustrated in Section 3. Case study and data are depicted in Section 4. The system analysis and design methods are illustrated in Section 5. The results and discussions of the experiments are illustrated in Section 6. Conclusions and prospects are illustrated in Section 7.

2. System Model

To study the impact of the mobility of the victims on the efficiency of emergency response, this paper divides the victims and rescuers into three situations according to their different mobility. They are the situation where the affected person cannot move; a situation in which the rescuer is unable to move; and a situation where both can move.

2.1. Only Rescuer Can Move. As shown in Figure 2, after a rescuer gets a task list, he will move to the task location and finish it one by one. Assuming that the total number of rescuers is n and everyone has the same rescue ability, which is represented by $R = \{r_1, r_2, \ldots r_n\}$. The total number of victims rescued at one time is m and represented by $V = \{v_1, v_2, \ldots, v_m\}$. The priority of v_i is represented by p_{v_i} which is calculated by experts and command center system and $p_{v_i} > p_{v_{i+1}}$ for $(i = 1, 2, \ldots, m-1)$. The $T_j = \{t_{j1}, t_{j2}, \ldots, t_{jk}\}$ $(k \geq 0)$ is the task list after rescuer j make a contract with CC, and the total number of tasks is k. Here, $\cap_{j=1}^{n} T_j = \varnothing$ and $\cup_{j=1}^{n} T_j = V$, which means every task should only be allocated once, and all tasks should be allocated, respectively. The conventional rescue method is for victims to wait for rescuers to arrive at the site of the disaster and then treat the victims. The time spent in this process is mainly divided into the time for the rescuers to move from the current location to the location of the victims and the time for the rescue after the rescuers arrive. The first target t_{j1} in the task list T_j of rescuer r_j needs the time $\text{dis}(\text{pos}_{r_j}, \text{pos}_{t_{j1}})/\text{speed}_j + t_{j1}^r$ to be rescued, where pos_{r_j} presents the location of rescuer r_j, $\text{pos}_{t_{j1}}$ represents the location of victim t_{j1}, $\text{dis}(\text{pos}_{r_j}, \text{pos}_{t_{j1}})$ means the GIS distance from r_j to t_{j1}, and speed_j presents the speed of rescuer (in the research, we assume that every rescuer has the same speed). t_{j1}^r presents the time victim t_{j1} need treatment. In this paper, we assume that the treatment time is evaluated by experts after victims sent their information to the CC. According to the different physical conditions of the victims, the statistics of the treatment time required by each victim in a rescue operation obey the Poisson distribution, and the average treatment time increases with the increase of the severity of the disaster. The treatment time in this paper is generated by a computer random number. The total time the rescuer r_j needs to finish the task list T_j is calculated by $t_{j,\max} = \text{dis}\ (\text{pos}_{r_j}, \text{pos}_{t_{j1}})/\text{speed}_j + t_{j1}^r + \sum_{l=1}^{k-1} (\text{dis}(\text{pos}_{t_j}, \text{pos}_{t_{l+1}})/\text{speed}_j + t_{l+1}^r)$. The finish time set of all the rescuers is presented by $T_{\max} = \{t_{1,\max}, t_{2,\max}, \ldots, t_{j,\max}\}$. The goal of this paper is to minimize the final time to complete all rescue tasks by reasonably assigning rescue tasks to rescuers when the rescue tasks can start in the order of priority:

$$\min \max T_{\max}. \quad (1)$$

The solution given in this paper is that each time the contract network protocol is used to sign the contract. The rescuer uses the completion time of the last task in the current rescue task set and the disaster location of the last disaster victim for bidding. The CC agent can get the task set of each rescuer with the shortest task completion time according to the shortest time calculated by all bidders to complete the current bidding task. This is a greedy method that will go through all contract signing situations.

2.2. Only Victims Can Move. As shown in Figure 3, if the rescuers are only arranged in fixed emergency places, such as

FIGURE 2: Rescuers move to and rescue victims one by one.

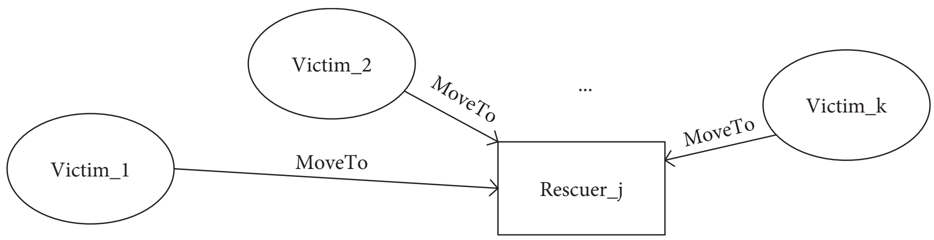


FIGURE 3: Victims move to rescuer at the fixed location.

hospitals, clinics, schools, or air-raid shelters, without considering the capacity limit, the victims can choose the emergency place nearest to their location to seek assistance through the "nearby principle". However, fixed emergency sites have the disadvantage of poor flexibility. The geographical location of the emergency site is fixed. When the victims are far away from the emergency site, they need to spend a lot of time moving to the emergency site. The capacity of emergency places is fixed. When the victims are closely distributed around one emergency place and there are few victims in other emergency places, the uneven distribution of victims will lead to a long queue for emergency treatment. The occurrence of these two situations may cause the timely treatment of the victims, so in the case of the rescuers can move, the flexibility of the rescuers should be fully utilized to determine the emergency site in a more reasonable position according to the actual distribution of the victims. This situation is not the focus of this paper and will not be repeated here.

2.3. Both Rescuers and Victims Can Move. In the initial stage of emergency rescue, the number of victims is much larger than the rescuers. This paper assumes that victims can move to a little distance by their conditions, they can gather to a nearby cluster point to wait for the treatment of rescuers by their mobility, as shown in Figure 4. Such an emergency strategy, even when the victims are moving very slowly, can still reduce the time loss caused by moving between the affected sites by a huge base, without simply waiting passively for the treatment of the rescuers. Even as rescuers treated the victims, they were able to make the most of their time on the move.

The emergence of a cluster point will involve a new problem, the queuing problem. Due to the particularity of the victims, it is significantly different from the conventional queuing problem. The time for the victims to arrive at the cluster point is determined by the location of the cluster point and the speed of the victims' movement. It is already a definite value at the moment when the cluster point is determined. To facilitate research, this paper simplifies the queuing problem, each rescue worker is equivalent to a desk, a single point at most only a rescuer for treatment services, point of waiting for unlimited capacity, number of customers in determining the point at the moment is fixed, and based on first come first service queuing rules of service for the victims.

We assume that the set of cluster points is represented by $C = \{c_1, c_2, \ldots, c_q\}$, and q is the number of the cluster point. The finish time of d th cluster point c_d will be analyzed. We assume that the rescuer r_d has been allocated to the cluster point c_d, and the number of victims allocated to the same cluster point is f, which can be presented as $P = \{p_1, p_2, \ldots, p_f\}$. The time which r_d travels to c_d can be calculated by $t_{r_d \longrightarrow c_d} = \text{dis}(r_d, c_d)/\text{speed}_d$, where $\text{dis}(r_d, c_d)$ is the GIS distance between the rescuer and the cluster point, and speed_d is the rescuer's speed. If the rescuer r_d can start curing, the victims will be judged by if any victim is waiting in the cluster point c_d. If there are already victims waiting, treatment can be started directly; if there are no victims, you need to wait for the victims to arrive before starting treatment. The time for the first affected person to arrive at the cluster point to complete the treatment is

$$t_{d1} = \begin{cases} \dfrac{\text{dis}(r_d, c_d)}{\text{speed}_d} + t^r_{d1}, \dfrac{\text{dis}(r_d, c_d)}{\text{speed}_d} \geq \dfrac{\text{dis}(p_1, c_d)}{\text{speed}_{p_1}}, \\ \\ \dfrac{\text{dis}(p_1, c_d)}{\text{speed}_{p_1}} + t^r_{d1}, \dfrac{\text{dis}(r_d, c_d)}{\text{speed}_d} < \dfrac{\text{dis}(p_1, c_d)}{\text{speed}_{p_1}}, \end{cases} \quad (2)$$

where $\text{dis}(p_1, c_d)$ depicts the first arriving victim's GIS distance from his original location and cluster point c_d, speed_{p_1} presents the speed of the first arriving victim, and t^r_{d1} presents the treatment time needed by the first arriving victim. Because of the uncertainty of the finish time for the first arriving victim and the arriving time of the second arriving victim, the follow-up treatment time shall be determined according to the completion time of the previous treatment. So, the finish treatment time t_{df} for all the tasks in the cluster point c_d should be calculated by $t_{d(f-1)}$, as shown below:

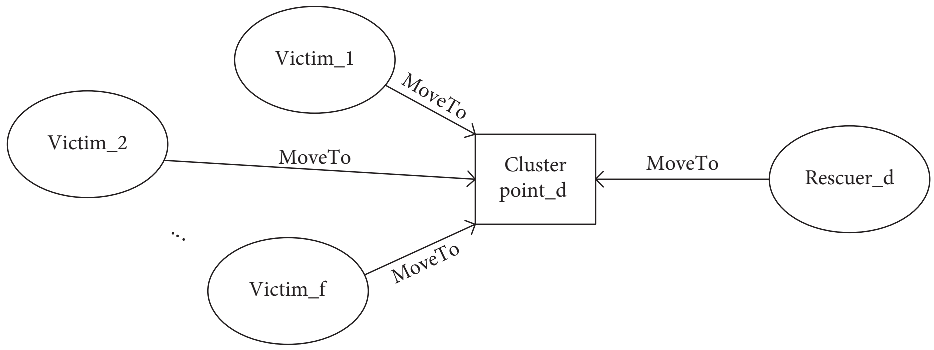


Figure 4: Victims and rescuers move to the cluster point simultaneously.

$$t_{d,\max} = t_{\mathrm{df}} = \begin{cases} t_{d(f-1)} + t^r_{\mathrm{df}}, t_{d(f-1)} \geq \dfrac{\mathrm{dis}\left(p_f, c_d\right)}{\mathrm{speed}_{\mathrm{p_f}}}, \\ \dfrac{\mathrm{dis}\left(p_f, c_d\right)}{\mathrm{speed}_{p_f}} + t^r_{\mathrm{df}}, t_{d(f-1)} < \dfrac{\mathrm{dis}\left(p_f, c_d\right)}{\mathrm{speed}_{p_f}}. \end{cases} \quad (3)$$

The finish time of all the cluster points is presented by $T_{C,\max} = \left\{t_{1,\max}, t_{2,\max}, \ldots, t_{d,\max}, \ldots t_{q,\max}\right\}$. The rescue goal is to reasonably arrange the location of the cluster point, the disaster victims assigned to each cluster point, and the rescuers assigned to each cluster point, to minimize the time for the last of all cluster points to complete the rescue task:

$$\min \max T_{C,\max}. \quad (4)$$

According to the observation formula, there are many uncertainties in the time for each cluster point to complete all tasks, mainly including the moving distance and speed of the victims, the time for the victims to need treatment, and the distance and speed of the rescuers. How many cluster points need to be arranged, how to arrange the location of each cluster point and the number of victims, and how to allocate the matching relationship between rescuers and cluster points are the key problems to be solved by the model.

The number of victims is often much larger than that of rescuers, and the movement speed of victims is generally slow. The location of cluster points should be closely related to the geographical location of the corresponding disaster-affected groups. When the movement speed of the victims is uncertain, the cluster point of each affected group shall be set to meet the close distance of the affected group to the point. A certain distance should be maintained between cluster points so that the coverage of a single cluster point is wider when the total number of cluster points is the same. The number of cluster points should be as many as possible so that the amount of tasks shared by each cluster point is reduced, and the location of selection is more flexible. Each cluster point should have at least one rescuer corresponding to it.

2.4. The Rescuers and Victims Combination Strategy. Combined with the situation of rescuers and disaster victims, this paper gives the emergency response strategy considering that both disaster victims and rescuers have mobility, as follows:

(1) The number of cluster point determination. The number of cluster points is the same as the number of rescuers. Firstly, it ensures that each cluster point is assigned to a rescuer. Secondly, the cluster points can be more evenly distributed on the map. Thirdly, when the total number of tasks remains unchanged, the task average of each cluster point decreases, reducing the task pressure of a rescuer.

(2) Configuration of rescuers. The problem of rescuer corresponding cluster point configuration can be regarded as a task allocation model that assigns n rescuers to q cluster points. How to reasonably allocate them to minimize their total moving distance when $n = q$. After selecting the same number of cluster points as the number of rescuers, if the total moving distance of rescuers is required to be the shortest, then the problem is a simple traveling salesman problem (TSP). TSP is an NP hard problem, which will consume a lot of time using the traditional optimization calculation method. In this paper, the centralized task allocation method is used to allocate the corresponding cluster points of rescuers. A genetic algorithm for solving the STP problem is introduced, which can find a satisfactory solution in a short time.

(3) Configuration of victims. Through the above analysis, our purpose is to minimize the distance and distance from each disaster victim to its nearest cluster point. This is easy to associate with the clustering algorithm based on Euclidean distance. The closer the distance between the two targets, the greater the similarity and can be assigned to a cluster point. In this paper, K-medoids, a clustering algorithm commonly used in machine learning, is introduced to solve the problem of disaster victim configuration in clustering points. The value is the number of cluster points.

(4) Configuration of cluster point location. The center of each cluster group is a GIS location calculated by Euclidean distance, but the cluster point will be set to the nearest victim's location which is the core in the

```
// xy is a city-location matrix
t←1 // t is the current iterations
initialize Pop(t) with N chromosomes Pop_i(t)// N is the pop size
while not (terminating condition) do
  for t←1 to N do
    f_i←f(Pop_i(t)) // f is the fitness function
  for i←1 to N do
    NewPop_i(t + 1) ← randomly choose Pop_i(t) ∈ Pop(t) with p_j = f_j/ Σ_{k=1}^{N} f_k
  CrossPop(t + 1) ← recombine (NewPop(t + 1)) with P_c // P_c is the crossover probability
  MutPop(t + 1) ←mutate (CrossPop(t + 1)) with P_m// P_m is the mutation probability
  Pop(t + 1) ← MutPop(t + 1)
t←t + 1
```

Algorithm 1:A simple genetic algorithm for TSP.

K-medoids algorithm. It should be noted that the cluster center point is determined by the Euclidean distance on the map. However, the actual action route of the disaster victims is obtained through the GIS map and Dijkstra algorithm. When the resolution of the map is high, there may be a large difference between Euclidean distance and the actual route. How to more reasonably place the location of cluster points will be the focus of future research.

3. Method

3.1. Agent-Based Simulated Systems. Multiagent systems (MASs) make it possible to simulate building demolition, damage to urban infrastructure, injuries, and search and rescue teams [13]. MASs deal with complex systems by emphasizing the interaction between agents and dividing the system into subsectors of the environment and other actors MASs [14]. Simulation is one of the major applications of agent-based systems. Simulation provides the decision-makers with a prototype or framework, which can support decision-making, complex behavior observation in processes, and the estimation of optimized strategies in the relevant field. Simulation models provide efficient solutions to analyze the complexity of interactions and urban processes and can be used in planning and policy-making [22]. For many reasons, the utilization of MASs is appropriate in crisis management [13]. They are suitable for finding optimal strategies for widespread incidents and crisis management. Researchers can implement various scenarios of relief and distribution facilities in the same environment through a new attitude to crisis management [23]. A multiagent system can play the role of indoor earthquake disaster early warning through cooperation and can give corresponding countermeasures according to different degrees of earthquakes [24]. A multiagent system is also applied to a large-scale earthquake monitoring system [25]. Sarmad Sadik has adopted a combination of Pi-calculus and Pi-ADL formal languages to model the earthquake management system (EMS) from analysis to design [5]. Using a dynamic simulation model, Michal Lichter estimates the long-run outcomes of two very different urban disasters with an earthquake [26]. In the following, the studies undertaken in the field of preparing an earthquake simulation environment and the methods for task allocation to support cooperation among agents are addressed.

3.2. Task Allocation Methods. Task allocation plays an important role in coordinating an MAS within a set of agents [15, 16]. Appropriate allocations are critical for the efficient implementation of tasks undertaken in natural hazard environments. Proposing a proper approach to consider uncertainty in task allocations plays an important role in decision-making concerning urban search and rescue (USAR) operations in crisis-stricken areas [17]. There are many task allocation methods in multiagent systems: auction-based [27], consensus-based [28], optimization approaches [29], and learning-based [30]. Task allocation includes assigning several workers (resources) to supply the requirements needed for several tasks (consumers) so that the overall desire can be maximized [31, 32]. Many methods have been presented for task allocation. Scientific activity in this area remains a serious challenge for researchers. Several studies used the CNP as a subset of auction-based methods. This study presents an approach and extension to include CNP because of its simplicity, applicability, and popularity [14]. Kai Li designs a shared contract net protocol (SCNP) and proposes two heuristic algorithms to solve the scheduling model [33]. Djamila Boukredera devises an extended CNP that achieves the reliability of the manager agent in the case of contractor crash failure while operating in an open and large-scale multiagent system under time constraints [34]. An improved contract net model is constructed to resolve the low communication efficiency and the low task completion quality of the contract net protocol negotiation mechanism under the generalized cluster [35]. A simple genetic algorithm for TSP is illustrated in Algorithm 1 [36]. We use the genetic algorithm to solve the rescuers' cluster points allocation problem as the centralized optimization approach.

3.3. Clustering Algorithm by K-Medoids. The K-medoids algorithm (K-medoids) which divides a given population inhomogeneously into K groups is dedicated to the task of clustering. The number of clusters K is determined by the user according to his expectations [37]. The cluster points obtained by the K-means algorithm may be unavailable. Because the victims and rescuers cannot reach the place easily, such as rivers or lakes. Moreover, K-medoids is better in all aspects such as execution time, no sensitivity to outliers, and reduction of noise but with the drawback that the complexity is high as compared to K-Means [38]. When the location of a disaster victim is relatively special, it is easy to find that the cluster point is not easy to reach. However, the location of the disaster victims is generally within the reach of human resources. Setting the cluster point as the location where a disaster victim sends a distress signal is more in line with the actual emergency rescue situation. Another advantage is that the cluster point generated by the K-medoids algorithm itself has the existence of victims. The rescuers can start treatment after they arrive, and there will be no situation that the rescuers start waiting for the victims after they arrive. In this paper, the K-medoids clustering method is used to calculate the cluster travel of the victims. The K-medoids algorithm is shown as Algorithm 2 [38].

4. Case Study and Data

ERSCIED is suitable for an emergency response to a variety of natural disasters, such as earthquakes, fires, and rainstorms. Especially when the accuracy of GIS is high, the system can play a better role. As a typical human gathering place, the emergency response system in this location is worth studying. This is a typical model test site. This paper selects the rectangular area in the GIS map as the specific test area. As shown in Figure 5, the test area has very complex road network information, and its longitude and latitude coordinates are (103.99346 ~ 104.12387) and (30.62916 ~ 30.69481), respectively. The main components of the urban environment where the agent is located are GIS maps and road network information. Since the calculation of the number of resources needed by victims, the location and deployment of rescuers, and the calculation of rescue capacity are not the main research content of this paper, the victims' agents and rescuers' agents in the experimental environment are directly generated by the database. The agent data in the database is randomly generated and fixed by the computer, including agent names, location information, and resource requirements parameters.

Preparing the environment to simulate search and rescue operations has two important components, such as simulating the environment of earthquake damage and the dispersal of agents. Basic data used in the application include block maps, population, distance from faults, building materials, agent locations, construction years, and building heights. The primary location of injured agents is based on building damage, while the location of population loss assessment search agent groups is randomly generated in a four-vector map. It is a very complicated environment inside the disaster zone. It is difficult to accurately model all disaster victims, considering the different levels of disaster and the composition of victims and the different mobility and psychological states. To effectively respond to and mitigate the effects of threats such as earthquakes, communities must develop effective emergency strategies. Therefore, the research object of this paper is victims who can move on their own and need professional treatment after being taken away from the dangerous area by search and rescue personnel. Through proper coordination with rescue personnel, such personnel can improve the overall efficiency of the response. The biggest difference between ERSCIED proposed in this paper and the disaster victim emergency response system waiting for rescue lies in the need to utilize the action capacity of victims, so the limitations of the model are as follows:

(1) All rescue units have the same capacity.
(2) Displaced people do not deteriorate as they move, i.e., the need for resources does not change.
(3) Victims have a certain ability to move, and speed is the relative speed of the rescue workers. Different relative speeds can be set according to different road conditions caused by different disaster degrees.
(4) After arriving at the assembly point, rescue personnel shall not go out without authorization to continue rescue, to prevent other victims from arriving at the assembly point through CC notice.

5. Analysis and Design

5.1. Emergency Process Analysis of Each Agent. ERSCIED contains three kinds of agent types called the control center agent, victim agent, and rescuer agent. Their characters are illustrated below.

Rescuers:

(1) Send their moving speeds, locations, and rescue resources to the CC
(2) Wait for the task allocation
(3) Move to the corresponding cluster points and finish their tasks after they receive their objective cluster points
(4) Send the finished messages to the CC after they finish all tasks

Victims:

(1) Evaluate their environment and obtain an accurate state (actionability, degree of need for treatment, geographical location, etc.) and environmental information (environmental threat level, safety, material reserve, etc.)
(2) Send the information about themselves and the environment to the CC through the emergency response platform and wait for the instructions of emergency response
(3) Stay at their current location or move to the designated place to assemble or stand by for further rescue after receiving the instruction from the emergency response center

Figure 5: Simulated experimental area.

Input: K_y: the number of clusters, D_y: a data set containing n objects
Output: A set of K_y clusters.
Algorithm:
(i) Randomly select K_y as the medoids for n data points.
(ii) Find the closest medoids by calculating the distance between data points n and medoids k and map data objects to that.
(iii) For each medoids m and each data point o associated with m, do the following:
Swap m and o to compute the total cost of the configuration
Select the medoids o with the lowest cost of the configuration.
(iv) If there is no change in the assignments, repeat steps 2 and 3 alternatively.

Algorithm 2: K-medoids cluster algorithm.

CC:

(1) Collects as much information about the victims as possible, including geographical location, action capacity, number of emergency resources required, etc.
(2) Uses K-medoids for victims' clustering analysis. Cluster points are sent to experts for further safety confirmation
(3) Uses the optimization approach method to allocate the tasks to the rescuer for the shortest total route distance
(4) Sends the centroid location of the cluster group to each victim as its assembly cluster point, at the same time, and sends the cluster points to corresponding rescuers

The earthquake emergency response environment mainly includes victims and rescuers, which represent the tasks and resources in the emergency response system, respectively. Especially after a large earthquake, when it is difficult for internal and external resources to enter the epicenter in a short time, the demand for resources is far greater than the supply. In the short term, the utilization rate of resources is maximized, which reduces the risk of death caused by untimely treatment to a certain extent.

5.2. Agent Behavior and Communication Process Analysis of ERCIED. In this section, we use Petri net to construct the agents' behavior and their communication process. A Petri net (PN) is a graphical tool for the description and analysis of concurrent processes which arise in systems with many components (distributed systems) [39]. Since the Petri net was proposed by Carl Adam Petri in his doctoral thesis in 1962 [40], it has been widely used by researchers in various system modeling and performance analyses in the field of computer science. Petri net is a commonly used mathematical modeling tool, which is composed of four elements: place, transition, arc, and token. It can describe the asynchronous and concurrent computer system model and has the ability of visual and intuitive graphic display. This paper only describes the behavior of agents and their cooperation through PN and does not study the properties of PN built by the system in detail. The PN model of ERSCIED is shown in Figure 6.

According to the above analysis steps, we make the following performance analysis of the ERSCIED shown in Figure 3. Means of all places and transitions mentioned in the figure are as follows.

The finite set of places, P: P_0: a victim is injured; P_1: the victim is waiting for further appliance; P_2: the message is obtained by the CC; P_3: the CC is waiting for the information

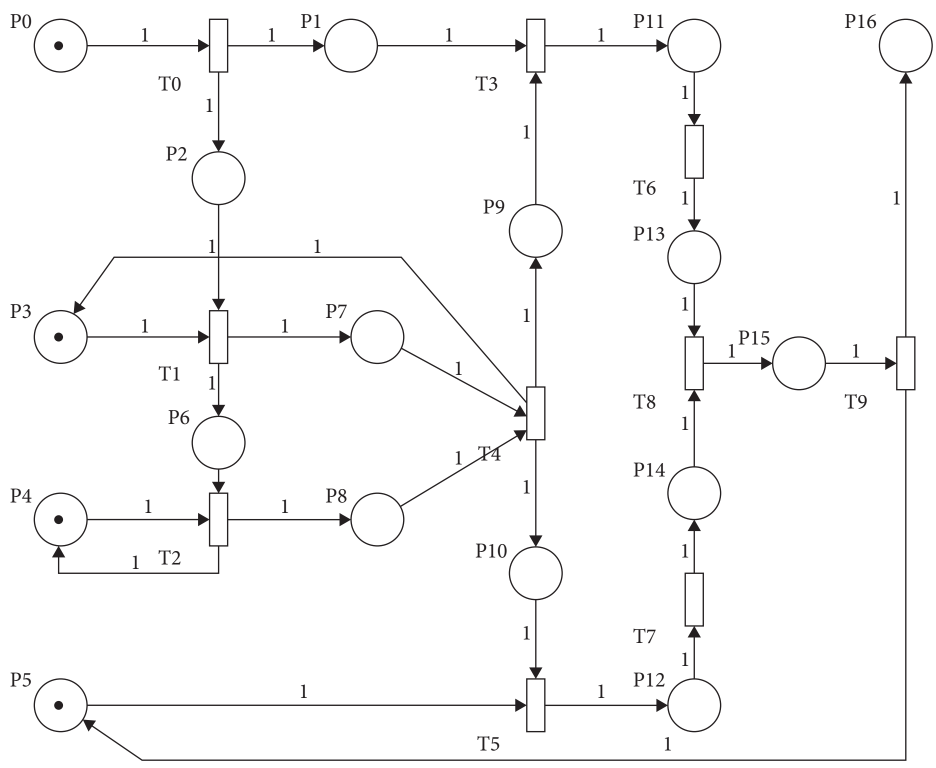


Figure 6: ERSCIED Petri net model.

for help; P_4: the expert is waiting for the cluster point information; P_5: the rescuer is waiting for the task allocation message of the cluster point from CC; P_6: the cluster message is received by the expert; P_7: the CC is waiting for the expert's confirmation; P_8: the conformation message is received from the expert; P_9: the cluster location is received by the victim; P_{10}: the cluster location is received by the rescuers; P_{11}: the victim is ready to move; P_{12}: the rescuer is ready to move; P_{13}: the victim is in the cluster point; P_{14}: the rescuer is in the cluster point; P_{15}; the treatment of task is finished; and P_{16}: the victim is saved.

The finite set of transition, T: T_0: the victim sends his information to CC; T_1: the CC calculates the cluster points and sends them to expert; T_2: the expert confirms that the cluster points is appropriate for rescuers and victims; T_3: the victim obtains the cluster point location; T_4: the CC sends the location of cluster points to victims and rescuer and turns to the waiting state; T_5: the rescuer obtains the cluster point location; T_6: the victim moves to the corresponding cluster point; T_7: the rescuer moves to the corresponding cluster point; T_8: the rescuer treats the victim; and T_9: the victim and rescuer separate from each other.

5.3. The Constructure Design of ERSCIED. We use the UML agent class diagram to design the ERSCIED, which is shown in Figure 7. The class diagram contains the attributes and properties of different classes of ERSCIED and the corresponding relationship between them. ERSCIED consists of five tuples, shown as ERSCIED=<CC, searchers, victims, cluster point, environment>. CC is not only an important communication node of ERSCIED but also the main decision-making center. The CC needs to include all the attributes and functions mentioned above, including receiving messages from other different types of agents, calculating temporary cluster points, task allocation, calculating the rescuer most suitable for completing the current task, and sending corresponding messages to other agents. At the same time, the CC class can also store some key intermediate information and calculate the intermediate quantity of the decision-making process. The searcher (acts as the rescuers) class can store its information and obtained messages and has some basic properties of rescuers, such as mobility, treatment capability, distance calculation, and bidding. Victim class contains the basic attributes of disaster victims, such as geographic location information, disaster situation, mobility, and corresponding temporary cluster points. The main capabilities of the victims are also included, such as moving, waiting, sending, and receiving information. The environment class contains the environmental information of other agents. This paper mainly focuses on the GIS environment of earthquake-affected sites, including GIS map, GIS coordinates, and road network information. To facilitate the construction of the model, this paper also adds the cluster point class. This class does not need to be studied separately in the operation process of the actual system. It is only used as coordinate points to facilitate the identification of other agents. It mainly includes the coordinate information, overall demand information, priority, etc. of the temporary cluster point, and all its attributes are the actual results calculated in the CC.

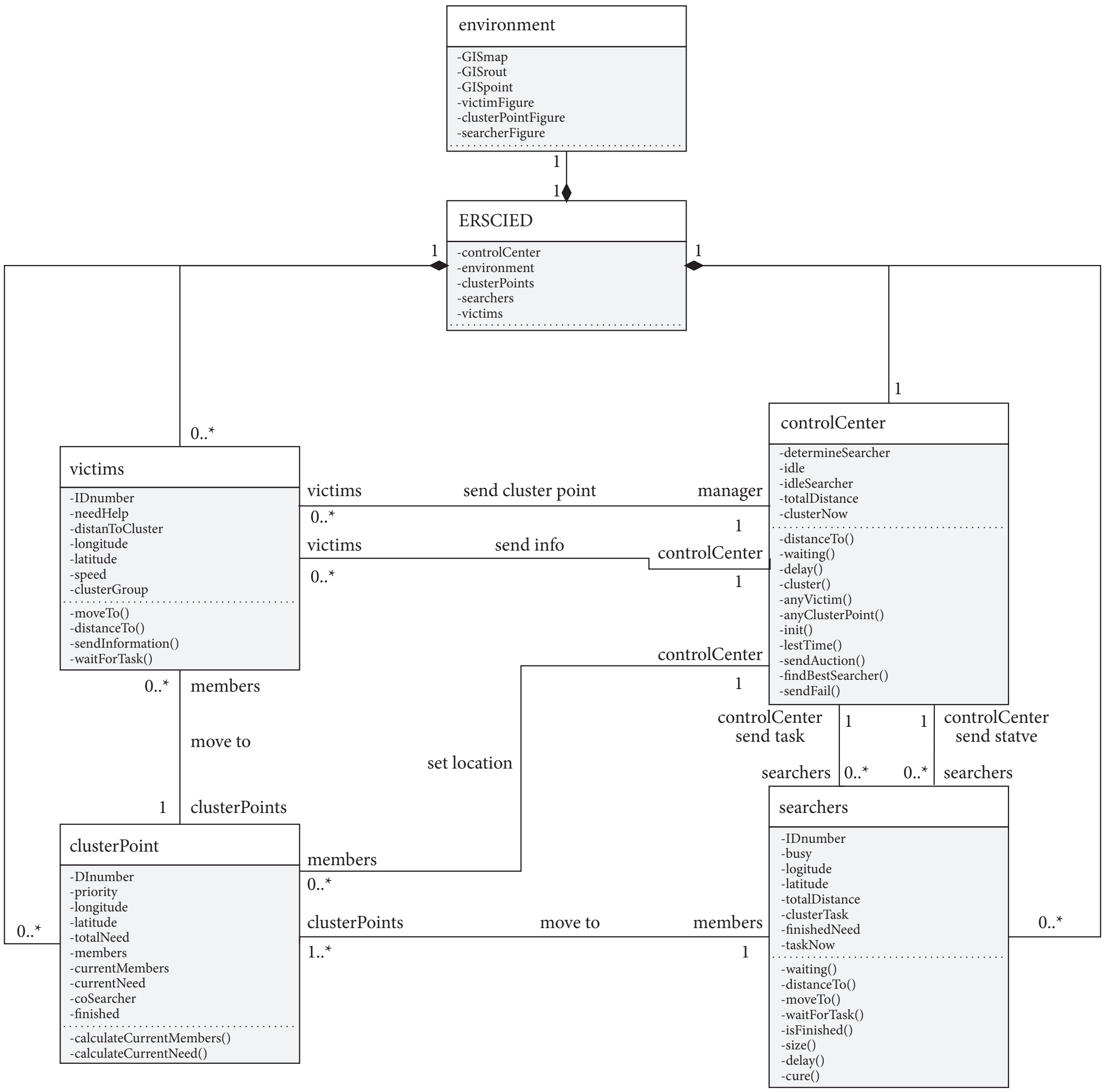


Figure 7: The ERSCIED agent class diagram.

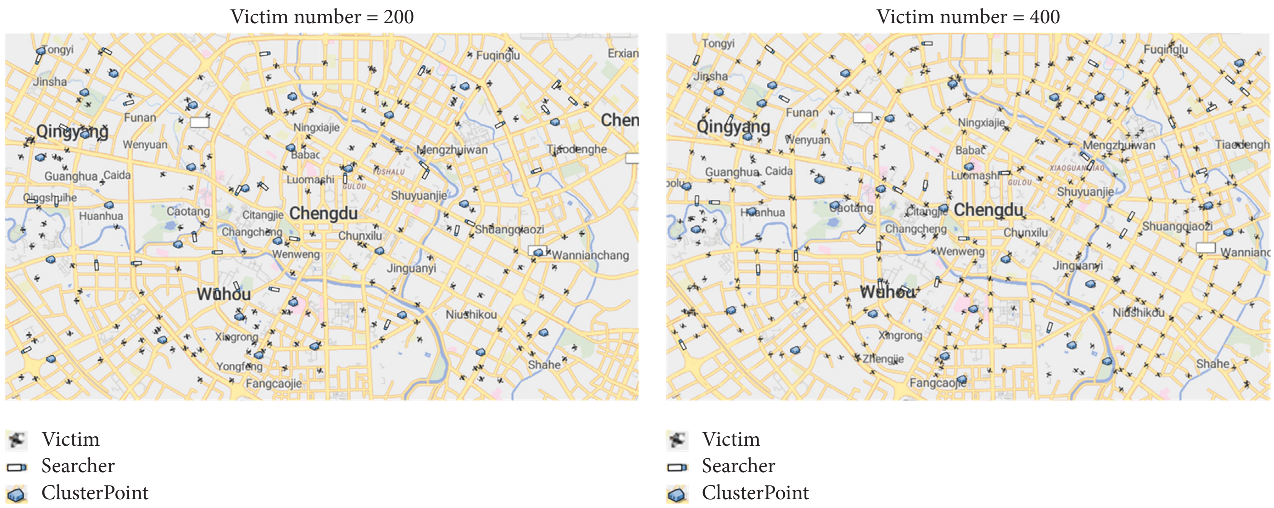
6. Discussion

6.1. VV&A. The design and development process of a new system ends with verification and validation of the new system. Verification is the process of determining whether a model is accurately implemented according to the system description and specifications [41]. Validation is the process of determining whether the model is accurately representing the real world from the perspective of the end-user of the model [41]. We carry through VV&A for the ERSCIED simulation models to analyze these results. As for the conceptual models, we check whether attribute description and interactions, e.g., the entities and their behaviors are consistent with real emergency management situations. As for the program models, emphases are put in data to verify their correctness, dependability, and performance [42].

The concept of the cluster point is not imagined out of thin air. It refers to the taxi company's requirement that carpooled passengers gather at one place to wait for the arrival of the taxi, or passengers wait in common places. These points are a collection of points after taxi route optimization, which improves the operation efficiency of the taxi to a certain extent.

The output of the model should be compared to real data, such as a real-time series (that can be compared against the model's simulated time series) on the phenomenon being modeled or output from validated models with a similar application context [43–46].

To verify the universality of the model, the location information of rescuers and victims given in this paper is obtained randomly, but in practical application, their actual data can be input into the computer. To evaluate the impact



(a) (b)

Figure 8: The experiment environment of the ERSCIED (200 victims (a) and 400 victims (b)).

of the cluster points proposed in this paper on the efficiency of emergency treatment, several groups of comparative experiments were designed in this paper. The speed of the victims is 0 as the original input data, which is the standard method of actual postearthquake treatment. The model is compared with the cluster point data proposed in this paper. The experiment that the speed of the victims is 0 can simulate the commonly used emergency rescue methods. The experiment where the speed of the victims is not 0 can simulate the internal and external emergency response method proposed in this paper. For the above key indicators, this paper will introduce them in detail in the following result data analysis.

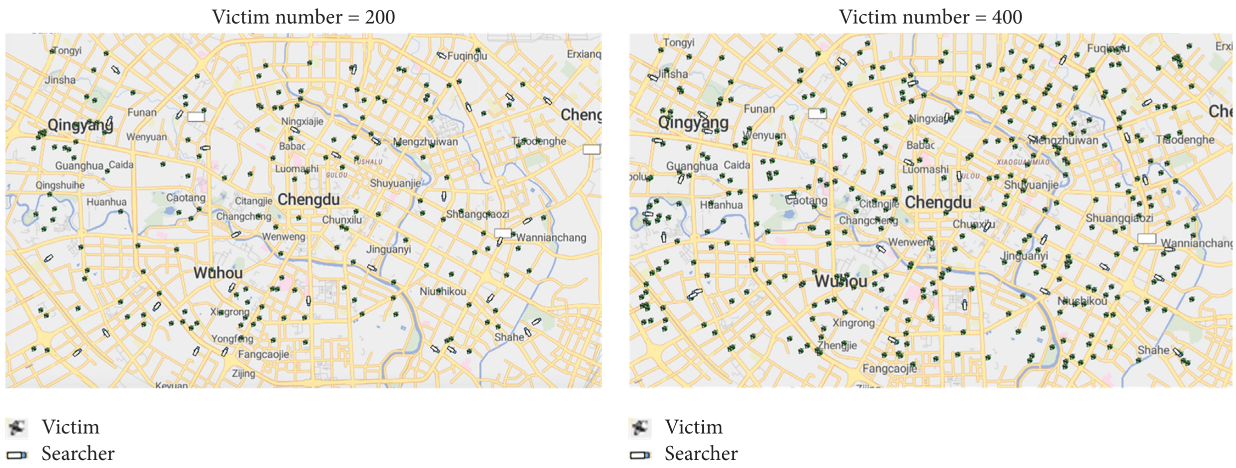
The conceptual models of EMS described by ERSCIED build a bridge between the real world EMS and the simulation system, including the victims and the rescuers, software designer and emergency command center can design the model and implement the simulation system conveniently. The ERSCIED models depict appropriate interactions of different elements in EMS and reflect not only the simulation results of MAS interaction operating but also the corresponding simulation of entities. This is a process of achieving each other. In a word, the simulation experiments prove the validity of the method and results of ERSCIED-based modeling.

6.2. Results. AnyLogic software was used to implement this system, which allows the utilization of GIS data. The search agents are initially in a ready state. They begin their search process when they get the cluster point gathering information from the CC. The relevant agents move along the central line of the road and use the Dijkstra algorithm to find the shortest path. The Dijkstra algorithm is a well-known algorithm for finding the shortest paths in road networks. It turns out that one can find the shortest paths from a given source to all points in a graph at the same time.

To verify the characteristics of ERSCIED proposed in this paper and compare the situation where there is no internal and external combination (only the rescuer moves to the location of each disaster victim), this paper carries out comparative experiments. No cluster point: the disaster victim passively accepts the rescue, and the rescuer saves the disaster victims, according to the CNP method, which is a state of emergency without a cluster point. With cluster points: the combination of internal and external emergency rescue. Rescuers and victims carry out emergency activities together. At this time, there are cluster points. To study the impact of the size and speed of the victims on the emergency response system, this paper conducted 8 experiments by changing the speed and the total number of victims. The settings of the tests are the same, the location of the disaster victims (on the same scale), and rescuers' location and speed are the same, and the resource demand and rescue capacity are the same too. Different scales with 200 or 400 victims and different victims speed with 0, 1, 5, or 10 experiments will be conducted to evaluate the strategy in this paper.

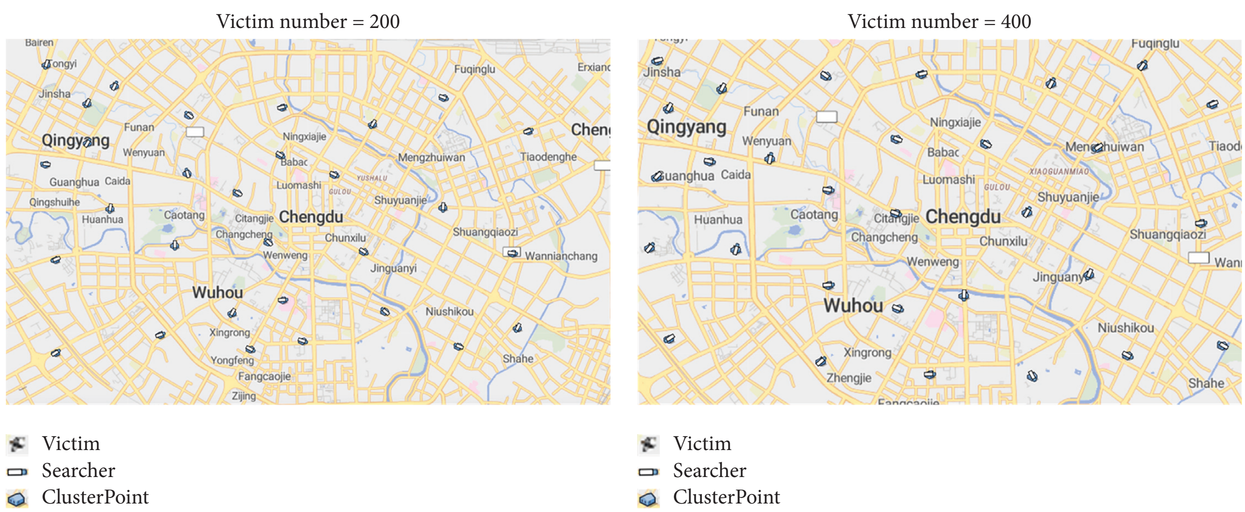
As shown in Figure 8, it is the basic environment of the ERSCIED test. 200 or 400 disaster victims and 30 rescue teams are randomly distributed in the test environment. 30 cluster points are those obtained through K-medoids clustering, which are also marked in the environment.

The result of the experiment with 200 or 400 victims and victim speed is zero is shown in Figure 9. The background origin of the rescued victims turns green. After a period of rescue, the positions of all victims are the same as the initial set positions, and the icon background turns green indicating that all tasks have been completed. The position of the rescuer and the initial position have changed. Through the dynamic test process, it can be observed that the rescue moves to the position of the affected person over time and goes to the next target after treating the affected person for some time until the position of the last affected person stays after all tasks are completed.



(a) (b)

Figure 9: The result of victims' speed 0 experiment (200 victims (a) and 400 victims (b)).



(a) (b)

Figure 10: The result of experiment victims with speed (200 victims (a) and 400 victims (b)).

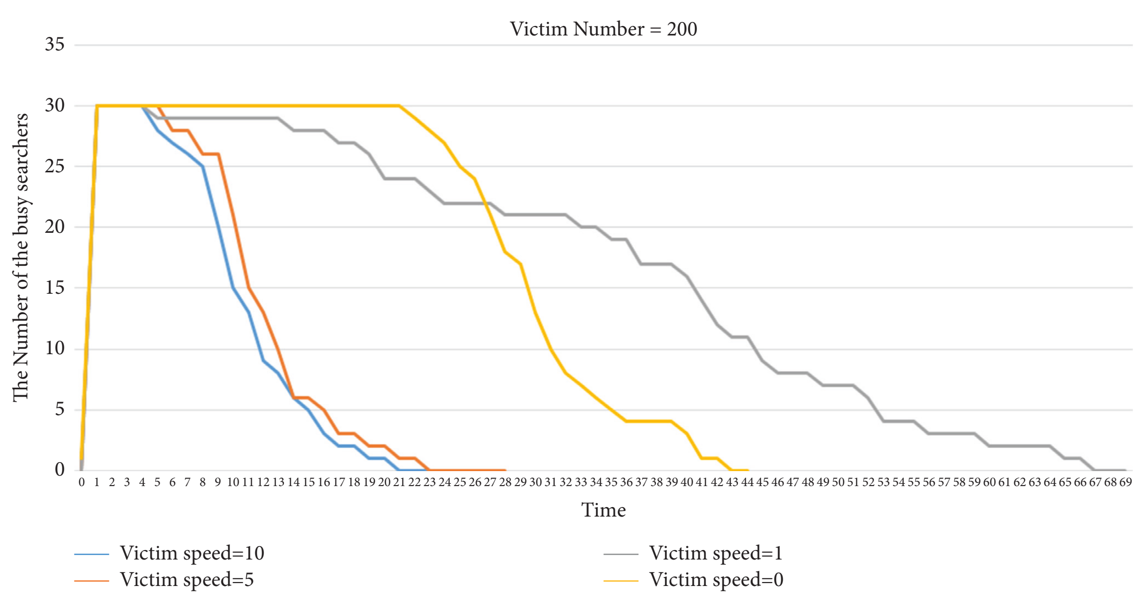


Figure 11: The number of the busy searchers over time (victim number = 200).

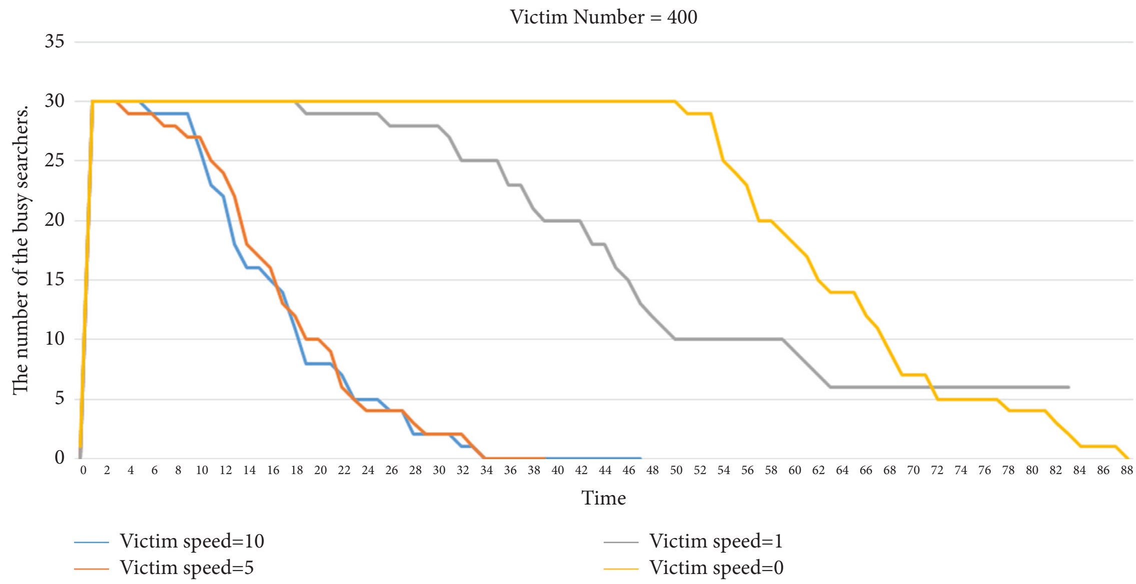


Figure 12: The number of the busy searchers over time (victim number = 400).

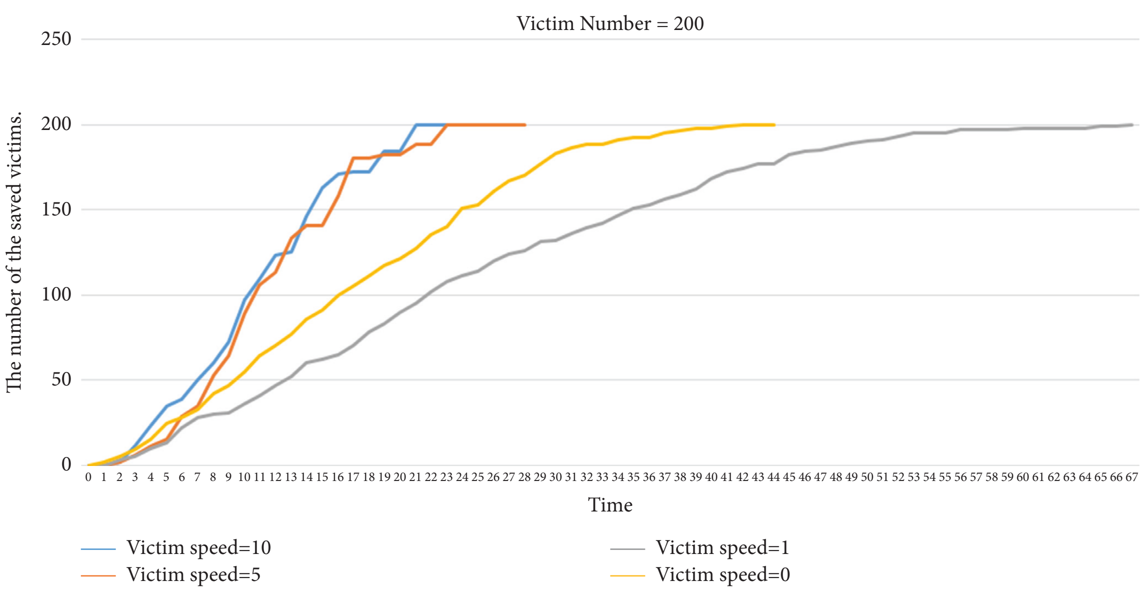


Figure 13: The number of the saved victims over time (victim number = 200).

The result of the experiment with 200 or 400 victims and their speed is not 0 is shown in Figure 10. At the end of all the experiments, victims and rescuers are assembled at the cluster points, though the victims' speed is different in these experiments. Compared with the initial position, the positions of rescuers and victims have changed and moved to the corresponding cluster point. The icons of cluster points, victims, and rescuers coincide on the map. All temporary cluster points have a rescue team corresponding to them, and there is a certain distance between the two temporary cluster points. Even though the number of cluster points is the same in these experiments, their locations of them are different because of the different distribution of victims' locations. This embodies the flexibility of temporal cluster points in the emergency response process.

The number of rescuers to victims and the relative speed between them play a vital role in the efficiency of ERSCIED. When the moving speed of the searcher agent is fixed to 10, the situations with different disaster degrees are simulated by changing the moving speed of the victim agent. Set the movement speed of the disaster victims as 10, 5, 1, and 0, respectively (compare the speed of the rescuers to 100%, 50%, 10%, and 0%). After eight different experiments, we obtained the experimental data varying with time: the number of busy rescuers, the number of rescued victims, the moving distance of all the victims, and the moving distance of all the rescuers. The specific experimental results are shown in Figure 11.

When a rescuer is moving or treating a victim, his state will turn to busy. The time-varying curves of the number of

Figure 14: The number of the saved victims over time (victim number = 400).

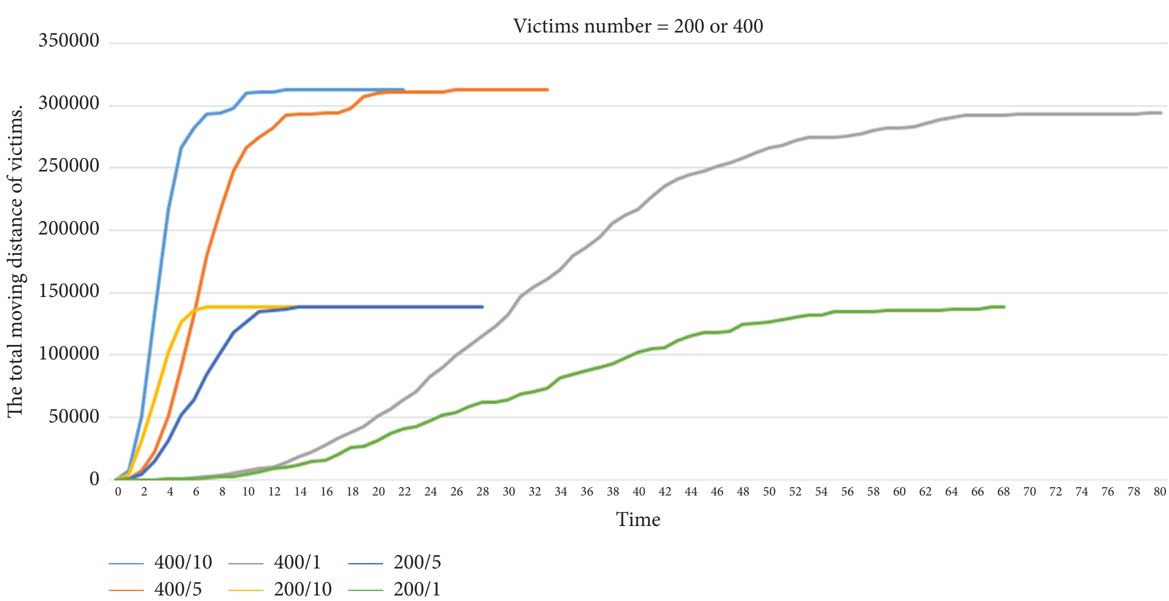


Figure 15: The total distance of all the victims over time.

busy rescuers are shown in Figure 11 (victim number = 200) and Figure 12 (victim number = 400). As we can see through the figure, when the speed of victims is 5 or 10, ERSCIED can quickly finish all the rescue tasks no matter the number of victims is 200 or 400. We can infer that the bottleneck of emergency response efficiency lies in the moving speed and rescue ability of rescuers in these experiments. When the victim speed is 1 in the experiment of 200 victims, the rescuers have to wait for a long time for their arrival. We infer that the slow-moving speed of victims leads to this result. The total efficiency of the rescuers is lower than that of the one in the experiment in which the victims wait for treatment. But we can see that the ERSCIED will release more rescuers in the early experiment, and these rescuers can join in other rescue actions. When the total victim number increases to 400, the results are similar to 200. The performance of ERSCIED is better than without cluster points until time 72. We can draw a preliminary conclusion: when the disaster victims have the ability to move and have little difference with the moving speed of the rescuers, the strategy of reaching the cluster points together with the rescuers will help to improve the emergency efficiency to a certain extent. Moreover, we infer that when the scale of victims increases, ERSCIED will bring more dividends. The time-varying curve of the saved victims also supports our view.

As shown in Figures 13 and 14, when the victims scale is 400, the total saved victim number in the ERSCIED increases faster than that in the experiment with 0 victim speed, even if the victim speed is 1. But in Figure 13, the result of moving to

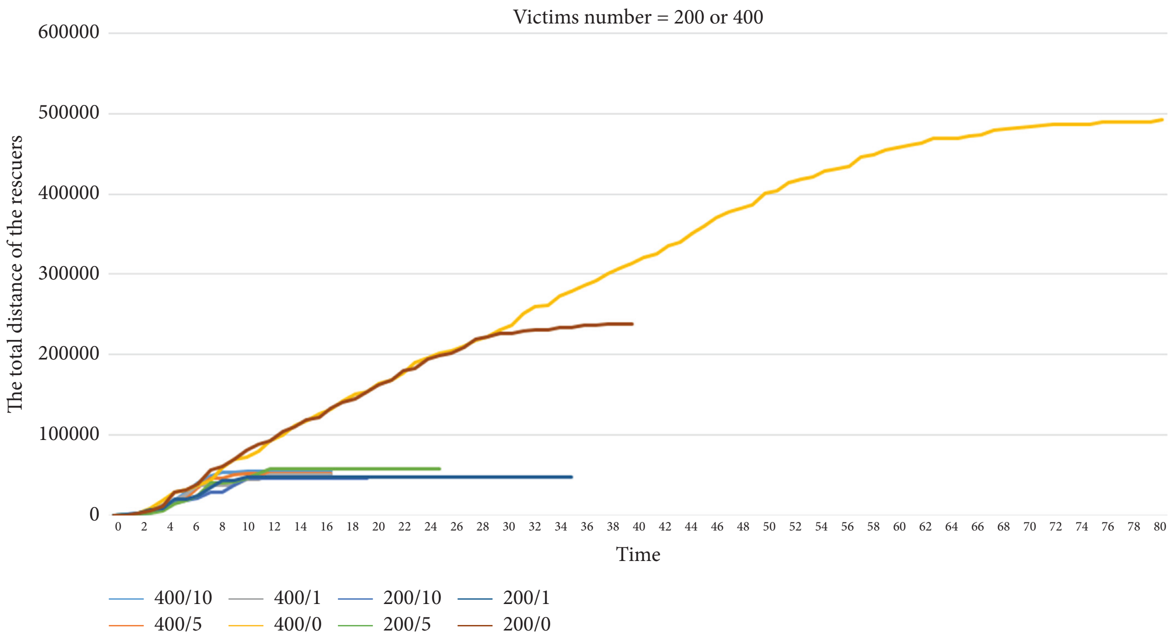


FIGURE 16: The total distance of all the rescuers over time.

the location of victims is better than ERSCIED with 1 victim speed. We can infer that when the victims' speed is slower than rescuers' and the victims' scale is not large, ERSCIED will waste a lot of time waiting for the victims, and this will lead to a lower efficiency.

As shown in Figure 15, with the increase of the scale of the victims, the overall moving distance of the victims has doubled. The average moving distance of 400 and 200 is 780 and 691, respectively. The per capita moving distance changes by 12.88%, we speculate that it is the result of more disaster victims distributed at the edge of the map, which is a random phenomenon. ERSCIED can stably solve the problem of gathering victims of different scales.

The total distances of all the rescuers in different experiments are depicted in Figure 16. The legend (number 1/number 2) of the figure means in this experiment victims' number is number 1, and victims' speed is number 2. As shown in Figure 15, the total distances of rescuers are varied in each experiment. Because of the randomness of the genetic algorithm, the routes of the rescuer to the cluster points may be different. Even though the total distances are different in each experiment, their difference is less than 10% which can be regarded as a satisfactory solution. Compare the situation of rescuers moving to the location of the victims for treatment, the ERSCIED overall moving distance of rescuers has been greatly reduced, about 89.73% (victims number = 400) and 76.81% (victims number = 200). It can be seen intuitively here that ERSCIED can effectively reduce the overall moving distance of rescuers, thus leaving valuable emergency response time for treating more victims.

7. Conclusions and Prospects

The cluster point proposed in this paper can effectively use the movement abilities of the victims to reduce the time loss caused by the movement of rescuers among the victims. When the scale of the victims is large, even if the victim movement speed is very slow, it is still very considerable macroscopically. Because the distance between the different victims and the cluster point is different, there is a certain gap in the time of reaching the cluster point, which alleviates the high task pressure of rescuers at the same time. Victims and rescuers are considered simultaneously in ERSCIED. The information collection and mobility of disaster victims are fully applied to the construction process of the system model. The flexibility and efficiency of the cluster point proposed in this paper are better than, in some special environments, the self-evacuation of the victims or the continuous rescue of the rescuers to a certain extent. The results of the current research enable appropriate decisions to be made to deal with the crisis during an earthquake or the simulation of earthquake conditions.

ERSCIED can solve part of the road traffic congestion caused by large earthquake disasters with the acting ability of rescuers being limited. It is difficult for rescuers to reach the disaster areas and treat the victims one by one. In the early stage after the earthquake, when the number of rescuers is far less than that of the victims, and there is little difference in the moving speed between the victims and the rescuers, the effect of ERSCIED has been significantly improved than that of traditional rescue, and most rescue tasks can be completed in a very short time. However, when the moving speed of the victims is much slower than that of the rescuers, the rescuers have to wait for the arrival of the victims at the temporary cluster point, which wastes the emergency rescue resources to a certain extent. Therefore, decision-makers can adjust the emergency rescue methods according to the current earthquake disaster situation to adapt to the different problems faced by different degrees of disaster. The model developed in the present study is flexible, due to having multiple and effective parameters for adapting to the environment and can be used in other areas by considering its favorable results.

Some cases arising from the results and limitations of this study can be investigated in future research. By observing the dynamic experiment, the author found that the path used in AnyLogic is a commonly used GIS vehicle path. When the speed of the victim agent is slower than that of the searcher agent, it can be considered as walking to the cluster point. It is inappropriate to use the path of vehicles. ERS-CIED is applied to the ability of disaster victims to obtain information and movement. Not all disaster victims have this ability, and disaster victims may also have other capabilities with more emergency characteristics. The description of the victims in this paper is not comprehensive enough. It is hoped that the follow-up research can dig into other abilities of the victims and enhance the overall emergency effectiveness.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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