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The Mechanism of Operation Effectiveness of Emergency Shelter Rescue Systems

Shaoqing Geng *, Hanping Hou and Jiaxin Geng

School of Economics and Management, Beijing Jiaotong University, Beijing 100044, China; 18113040@bjtu.edu.cn (H.H.); sqgeng@foxmail.com (J.G.)
* Correspondence: shaoqinggeng@outlook.com

Abstract: Natural disasters cause serious damage to buildings and infrastructure, and victims lose a comfortable living environment. A large number of people are left homeless. Emergency shelter is an important component that cannot be ignored in the comprehensive disaster prevention and mitigation plan. However, to the best of our knowledge, no study has collectively taken into account the rapid and accurate resettlement of evacuees by taking stratification of demand, distribution of supplies, and diversion evacuation as an organic model. Given the bottleneck of rapid and accurate resettlement in the complex sheltered environment, we combine field research, literature analysis, and previous case study. This paper explains that the three main factors that affect the resettlement of evacuees are the complexity of demand, the shortage of materials, and the blindness of refuge. Additionally, then an effective analysis framework of the hierarchy of demand, distribution rapidity and refuge accuracy are constructed. Finally, this paper puts forward the structural framework of demand for layered, comprehensive distribution and diversion of evacuees and further explains the structure relationship, mode of rescue and operation strategy of effective resettlement of evacuees.

Keywords: effectiveness mechanism; emergency shelter; resettlement; stratification of demand; distribution of supplies; triage of evacuees

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1. Introduction

Natural disasters have become a factor restricting the social development of various countries and regions. Every year, there are about 400 disasters that cause more than 100,000 deaths and another 120 million people are directly infected [1]. International organizations spend 25 billion dollars a year to deal with frequent disasters. Among them, the 2008 Cyclone Nargis [2], the 2010 Haiti earthquake [3], and the 2011 Japanese earthquake [4] possibly received the highest media attention. However, these are three examples from a long list of disasters with tremendous impacts. It is necessary to organize evacuees to safely take refuge in the government-designated shelters that have planned to protect the lives of victims. Effective and timely post-disaster rescue is the important way to reduce losses.

The role of shelters is fundamental to two types of victims, namely those who cannot be arranged to other safe places, and those with special needs such as medical treatment [5]. They need a physical space that meets their basic living needs after the demand and medical aid [6]. The resettlement of victims and the establishment of shelters should be based on the principle of matching emergency resources supply and demand. Not only are the horizontal and diverse needs of victims are considered to provide living and medical security [6], but also the quality of service should also be gradually improved over time to meet the vertical upgrade demands of victims [7].

In response to disasters, two problems need to be solved, namely, determining the optimal number and location of shelters for the allocation of victims and the distribution of supplies to evacuees [8]. The location of facilities and the distribution of personnel and

materials have been extensively and individually studied in the general context [9–11]. Because the development trend of disasters is invisible and the rescue process lacks visibility, matching supply and demand of emergency resources will become severe under the pressure of cost considerations and lean design [12]. At present, many studies assume the function of emergency shelters is to provide accommodation and develop a variety of methods to optimize the location of shelters and the allocation of victims to improve efficiency [13]. They optimize the response quality of emergency rescue systems by minimizing distance, time, or cost, and determine the number and service scope of emergency facilities [14–16]. Due to the uncertainty of demand, the evacuation strategy should combine the type of need, use time, and material distribution. Existing research has focused on the effectiveness of emergency evacuation to a large extent depending on the location of shelters and emergency resource allocation [17–19]. Emergency supplies should be stored in shelters, local supermarkets, and warehouses, which aims to ensure the supply of basic materials that meet the minimum survival needs of evacuees [20,21]. These studies pay more attention to the allocation of resources on the supply side, but ignore the horizontal and vertical stratification on the demand side, which makes it difficult to match supply and demand. As a result, evacuees cannot be effectively treated.

Furthermore, Thomas and Kopczak proposed to plan, implement and control the flow and storage of resources from the supply point to the demand point to alleviate the suffering of disadvantaged groups [22]. Sheu and Cheng optimized the shelter network, medical service network, and material distribution network by the timing, and analyzed the importance of integrating the three subnets of disaster management [23]. It shows that the shelter location should consider the needs of victims, medical treatment, and material distribution. Noyan et al. studied the location of the medical supplies distribution center and the severity of patients under the limited rescue budget to determine the layout of temporary medical shelters [24]. This paper reveals the relationship between the location of shelters, the needs of patients, and the distribution of materials, and further explains the impact of emergency resources demand and distribution on the shelter location. This paper analyzes the factors that affect the effectiveness of emergency shelter rescue, constructs an analysis frame and a structured frame, and provides a theoretical basis for solving the transfer and resettlement of evacuees.

The remainder of this paper is organized as follows: Section 2 explains the connotation of emergency shelter rescue systems. Section 3 introduces the structure of emergency shelter rescue systems. Section 4 analyzes the structure relationship and operation mechanism. Section 5 summarizes the research conclusions, and possible future research areas are pointed out.

2. Connotations of the Emergency Shelter Rescue System

Disaster management mainly aims to find ways to avoid and mitigate risks [25]. DM includes four stages, namely mitigation, preparation, response and recovery [18]. Mitigation requires active measures to reduce or eliminate the impact of disasters. Preparedness involves organizing and preparing to take appropriate actions when a disaster occurs. Tactical preparations such as deployment of relief operations, establishment of communication channels and assignment of responsibilities need to be completed at this time. Response includes using resources and emergency procedures according to previous plans, participating in the protection of life, property and environment and delivering supplies to the affected area. Recovery is a long-term activity to recover the affected areas to pre-disaster conditions.

Emergency shelter is a vital component in the regional disaster prevention plan. It is gradually improved and formed to be an emergency shelter rescue system that can be used after natural disasters. Specifically, disasters are usually divided into natural disasters and human-made disasters [26]. The system integrates multiple information sources during the preparation, response, and recovery phases and combines the distribution of residents, surrounding facilities, and materials to carry out rapid evacuation and resettlement activities.

In particular, the origin of disasters may be natural or human-made, and is not within the scope of research, for example, disaster epidemics and animal plagues. Natural disaster operations represent the set of activities performed before, during and after the natural disaster in order to diminish its impact [27]. Hence, the emergency shelter rescue system mainly involves the following concepts.

2.1. The Demand for Emergency Shelter

After natural disasters, the living conditions of evacuees immediately turn into an abnormal state, lack of food and clothing. Whether it is treated locally or transported to a non-disaster area for treatment, timely diagnosis in the disaster area is extremely important. In the meanwhile, as time goes by, evacuees are no longer satisfied with maintaining the basic living environment, and the living conditions of shelters should be gradually improved. Therefore, this study divides the demand for emergency shelter into two dimensions: horizontal and vertical. Horizontally diversified needs refer to the living, medical and psychological treatment demand of the victims during the evacuation and resettlement process during the same evacuation phase. Vertical time-varying demand refers to the requirements at different phases of asylum.

The demand for emergency shelters is constantly changing and runs through all the links of preparedness, response, and recovery stages in disaster management. In the distribution of emergency resources, the horizontal and vertical demand of evacuees should be fully considered to reduce the pressure of rescue, recovery, and reconstruction after the disaster.

2.2. Emergency Shelters

From the perspective of evacuees, emergency shelters are the main space for evacuation life [28]. Emergency shelters are facilities where residents can safely evacuate, support evacuees in the disaster area, and set up command organizations in response to emergencies [29]. The safety, effectiveness, and fairness of evacuation not only depend on the organization, guidance, and advice in time, but also to a large extent depend on the comprehensive disaster prevention capabilities of shelters, the speed and continuity of the provision of multiple services and materials after the disaster.

Reasonable design and construction of emergency shelters is an important measure to improve the disaster prevention and mitigation capabilities of the county or region. Emergency shelters have the following characteristics:

(1) Combination of peace and emergency

The disaster prevention function of emergency shelters is based on the existing disaster prevention functions of public facilities (e.g., schools, parks, and greenbelts), and the disaster reduction function is improved by improving and adding emergency equipment. After the disaster, the emergency shelter is divided into shack areas to distribute living and medical supplies and provide temporary psychological and medical assistance to realize the multiple functions required for the evacuation of victims. After the evacuation life ends, these public facilities will change from an emergency state to a normal state.

(2) Dynamic balance

Emergency shelters need to meet the demand of evacuees and reduce the cost of evacuation life after the disaster. At the same time, the horizontal and vertical demands of evacuees are in dynamic changes, and the situation of roads and materials supply in the disaster area is complex and changeable. From the perspective of system theory, various factors should be combined in a balanced manner, and multiple information sources are integrated to predict the possible changes of various factors and their impact on optimization goals.

(3) Utility

When planning and designing emergency shelters, it is necessary to follow the concept of comprehensive disaster prevention, and fully consider the consistency and coordination among the emergency facilities. It is necessary to ensure that the emergency shelter plays a safe evacuation role, but also to ensure the timely supply of emergency supplies. In the process of construction of shelters, other emergency resources in the territory, including medical care, road network, and warehouses, should be considered to be fully utilized.

2.3. Emergency Supplies Distribution

Emergency shelters are facilities built to respond to disasters, and responding to emergencies is essentially to make full use of resources. Without emergency resources, emergency shelters lose the meaning of rescue [30]. The distribution of emergency supplies is a special resource utilization problem in evacuation life. It is an emergency logistics activity to provide living and medical aid for victims who have no time to prepare for evacuation after a disaster [31].

3. The Structure of the Emergency Shelter Rescue System

Integrating emergency resources and emergency shelters is an important measure to improve disaster prevention and mitigation. The emergency rescue system involves complex and diverse issues. A large number of victims evacuated to designated emergency shelters and began a long-term evacuation life. By analyzing the main factors affecting emergency shelter rescue, a framework for the effectiveness of rescue is proposed, and the structural framework for rescue is further analyzed.

3.1. Main Factors Affecting the Structure of Emergency Shelters Rescue

3.1.1. Complex Demand

The occurrence of major natural disasters is sudden and uncertain, and the losses caused are often beyond imagination. A large number of victims have poured into emergency shelters after the disaster. If there is no reasonable service classification and residential management regulations, it is easy to cause chaos in shelters. Natural disasters have different impacts on different types of people such as children, the elderly, the disabled, and healthy people, and the capacities of shelters to respond to disasters are also different [32]. Besides, life in shelters is a process. In this process, the demands of the victims continue to change over time, including a series of post-disaster issues from basic food supply to disease treatment and psychological comfort. Therefore, the demands of different groups should be paid close attention to during the rescue process in the shelter, and corresponding assistance should be provided as much as possible.

3.1.2. Blind Refuge

To quickly carry out rescue, evacuees are often transferred to the nearest shelters instead of being diverted for refuge [6,33]. This practice ignores that the evacuation life is a process, which makes it difficult to guarantee the basic life of victims and cannot accurately carry out natural disaster operations, resulting in the blindness of evacuation. For example, after the magnitude 7.2 earthquake occurred in Turkey in 2011, due to the lack of planning of emergency shelters in advance, the evacuees had to take refuge in the open air [34]. The rescue of the shelter spans the preparation, response and recovery phases, aiming to create conditions for clothing, food, housing, and medical care. The main steps before the disaster are the planning of different types of shelters, and the number of shelters built to accommodate the demand of victims. Disaster rescue focuses on the horizontal and vertical demands of victims, organizing the residents to take refuge and reduces the casualties, property losses, and mental trauma caused by the disaster.

3.1.3. Material Shortage

The lives of the affected people in emergency shelters are different from normal residents' lives. The practice of alyssum in many disasters at home and abroad shows that the asylum life is in a state of very high "poverty" [33]. Usually, the evacuees are first transferred to the nearest shelter, and then supplies are distributed [35]. However, due to the separate consideration of shelters location and material distribution, it was difficult for evacuees to get the materials they need in a short time. Even in Japan, which has a comprehensive emergency evacuation system, victims were evacuated to temporary shelters, but some shelters lacked drinking water, food, and clothing for a while after the 2011 East Japan Earthquake [36]. Hence, shelter rescue must focus on emergency shelter and supplies. The distribution of existing materials cannot be ignored in the construction of emergency shelters. Only by rationally integrating and configuring disaster relief resources can safer and effective refuge be realized.

To sum up, to eliminate the influence of three major factors (i.e., complex demands, blind refuge, and material shortage) in the shortest time, solve the problem of rapid and accurate emergency shelter rescue, this paper proposes an analytical framework of the effectiveness of the emergency shelters rescue.

3.2. An Analytical Framework for the Effectiveness of Emergency Shelters Rescue

Various and complex demands are prone to arise during the evacuation process, including accommodation, medical care, and life disposal [6,35]. It is necessary to focus on the hierarchy of demands of victims and to stratify in two dimensions. Based on demand stratification, to create a good evacuation environment, it is urgent to solve the problem of blind evacuation to achieve evacuation accuracy. In the post-disaster evacuation life, corresponding measures are taken for different types of evacuees so that they can be rescued in a timely and effective manner [23,37]. After the disaster, there is a shortage of supplies, and even the transportation network is interrupted or the communication network is paralyzed [38]. Even if the dispatch of supplies is organized immediately after the disaster, it will take some time to distribute to the evacuees [33]. The rapidity of material distribution makes emergency shelters have higher disaster prevention and mitigation performance. The emergency shelter system should be compatible with disaster relief storage and transfer facilities. The comprehensive allocation of shelters and supplies is beneficial to improve the quality of life in the shelter. Based on the above analysis, the rescue structure frame of the shelter is proposed as shown in Figure 1.

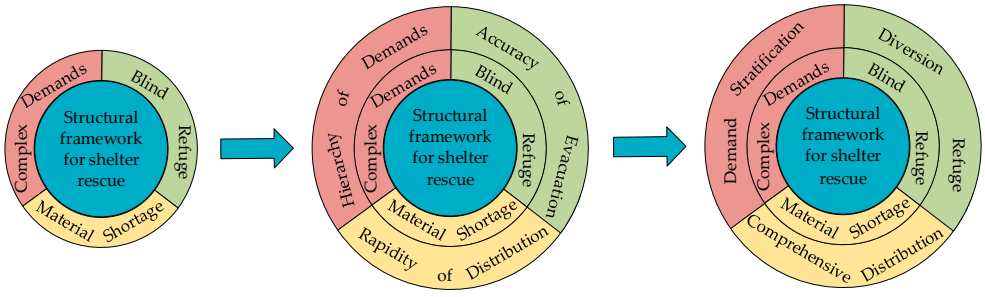

Figure 1. Framework for the effectiveness of emergency shelter rescue.

3.2.1. Demand Stratification

There are differences in the needs of the victims after the disaster, and the vulnerability of the homeless and vulnerable groups has increased. As the disaster situation tends to stabilize, victims have put forward higher requirements for quality of evacuation life, and their demands continue to upgrade. The premise for evacuation measures to be quickly accepted by victims is that the emergency services provided must focus on tracking

the horizontally diverse and vertical changeable stratification needs of victims, thereby changing the vulnerability of vulnerable groups.

3.2.2. Diversion Refuge

In the process of guiding victims to evacuate, the focus is on moving the people to a safe area as soon as possible, and it is difficult to divert and evacuate the evacuees. The diversified needs of the same period after the disaster and the upgrading demands in different periods may lead to repeated planning and unreasonable services. Not only does it cause waste of emergency resources and an increase in rescue costs. According to the length of evacuation time (see Section 4.2 for details), emergency shelters are divided into three types: temporary (3 days), short-term (10 days), and long-term (30 days). From the perspective of the types of services provided, there are basic life and psychological medical services. After the disaster, victims can be resettled and transferred to different shelters in time according to the demands of the victims to ensure the life of evacuees.

3.2.3. Comprehensive Distribution

The main links of shelter rescue include optimizing emergency shelters, reducing casualties, and curing victims' physical and mental trauma. Each link runs through the concept of comprehensive disaster management. In response to the stratification needs of victims, the materials stored in the disaster area and the supplies of the rear support should be integrated and allocated with emergency shelters. It is beneficial to provide materials quickly and accurately by the principle of matching supply and demand and improving the comprehensive strength of the emergency shelter rescue system.

4. Analysis of the Rescue Operation of the Refuge

The three key factors of demand stratification, diversion refuge and comprehensive distribution are complementary and mutually restrictive. If any one element is missing, or any one element fails to achieve its goals, the other two elements will be restricted. Even if the needs of evacuees are divided and integrated distribution can guarantee the delivery of supplies, the purpose of accurate and rapid rescue cannot be achieved when the victims are blindly evacuation.

These three key factors are the optimal trade-off relationship. The overall worst or best does not depend on which factor reaches the lowest or highest state. Only when all factors give full play to their unique core functions in the rescue operation of the refuge can the overall best be achieved. The change of one of the factors will inevitably affect the changes of the other two factors. In order to achieve the goal of rapid and accurate rescue of the refuge, the three key factors are in a state of balance.

The emergency shelter rescue structure composed of three key factors: demand stratification, diversion refuge and comprehensive distribution is an indivisible whole that is interconnected, restricted and interacted with each other. Only when the relationship between the three elements reaches the optimal state can the ultimate goal of shelter rescue be achieved.

4.1. Operation Scene of Refuge Rescue

In the emergency shelter rescue system, shelters of different sizes play different roles, each performing its duties, and forming organic disaster prevention and mitigation system [6,7]. The temporary shelter is the main rapid resettlement location [39]. Over time, the evacuation environment of short-term and long-term shelters has gradually improved [7,40]. In addition to maintaining the basic living conditions of the victims, temporary and short-term medical shelters can also diagnose and treat some of the wounded in the affected area in time, alleviating the pressure on the use of emergency resources (e.g., rescue team, medication and medical equipment) in hospitals. To further illustrate the important role of the three key factors in the refuge rescue, Figure 2 shows the emergency shelter rescue scene.

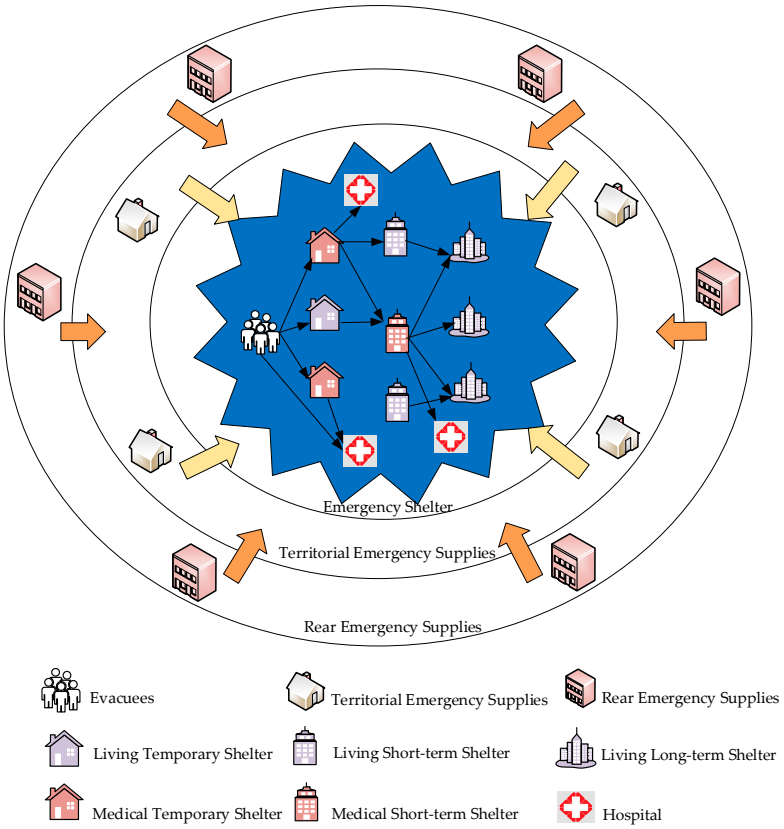

Figure 2. Emergency shelter rescue scene map.

(1) Evacuation of victims considering the stratification of demand

After a severe disaster occurs, not only victims are in a difficult life, but also casualties of varying degrees are caused. In addition to meeting the most basic needs of life, shelter rescue work also needs to ensure that the injured receive timely and effective treatment [23]. At the same time, the requirements of victims for the quality of life of evacuation are gradually increasing, and emergency shelters with better disaster prevention functions are needed [33]. According to the horizontal and vertical demand stratification and material storage, the locations of emergency shelters of different scales and service types are set up.

(2) Rapid and accurate distribution of emergency supplies

The transportation network and material reserves may be damaged after the disaster. Victims do not have their materials. Emergency shelters play the role in providing materials regularly [35]. The refuge rescue system planned in combination with the distribution of material storage facilities can quickly gather emergency supplies and complete the distribution of the territorial supplies. After the evacuation life is stable, the rear materials arrive in the affected area to eliminate the demand gap in the rescue phase of the temporary shelter. With the closure of short-term shelters, the remaining evacuees are moved to long-term shelters [7], where supplies can be distributed in a targeted manner.

(3) Rescue Service Integration in Shelters

In the early post-disaster, emergency shelters are the main bases for evacuees to live [41] and receive medical treatment [42], and it is necessary to provide various evacuation services. The disaster situation has stabilized, and rescue forces from the rear have arrived in the affected area [33]. The emergency shelter is able to meet the life and medical demand of evacuees on time. Finally, the number of people in need decreased, some shelters are closed and victims evacuate to long-term shelters. There is a close connection between the hierarchical evacuation of refugees, the location of emergency shelters, and

the distribution of materials after the disaster. Evacuation time, coverage, and distribution costs are combined to obtain an integrated decision-making plan.

4.2. Action Mode of Refuge Rescue

This paper constructs an emergency rescue network composed of disaster victims' demand points, emergency shelters, and material distribution facilities. The mode of refuge rescue refers to guiding the victims to divert evacuation after a disaster. Firstly, victims are placed in temporary shelters and then transferred to short-term shelters and long-term shelters with better emergency facilities. At the same time, they will be quickly and accurately provided with supplies through storage and distribution facilities. The operation mode of the emergency shelter rescue system consisting of three key factors: demand stratification, diversion refuge and comprehensive distribution is shown in Figure 3.

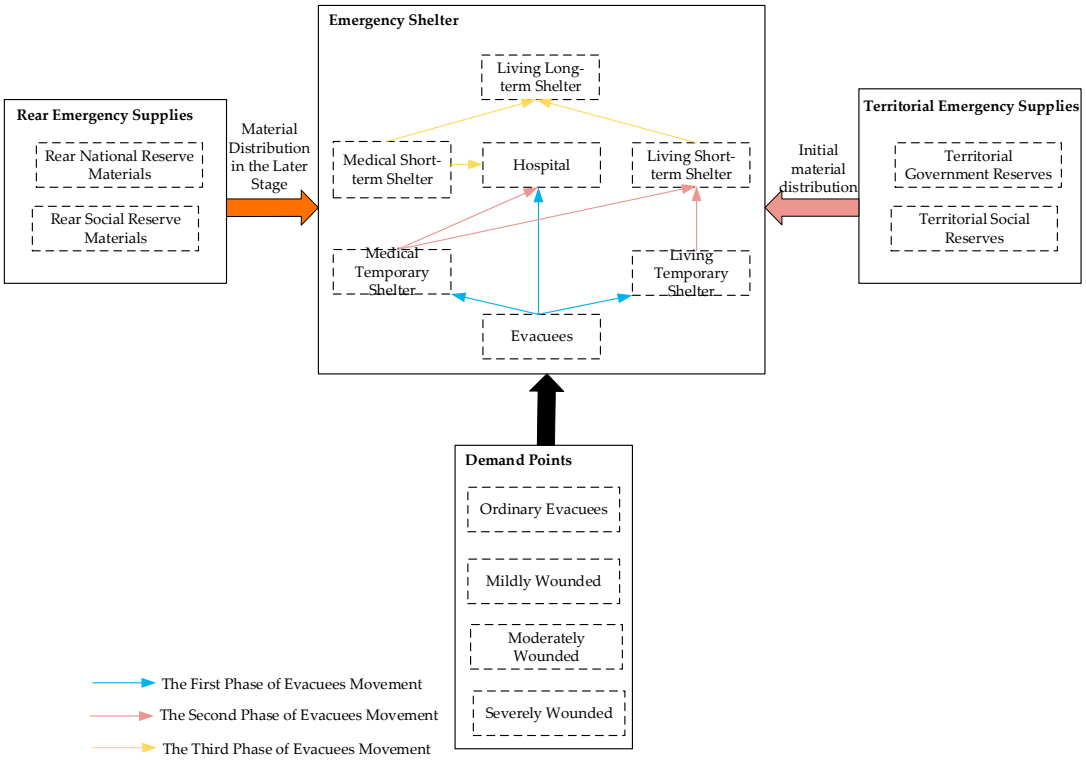

Figure 3. Schematic diagram of shelter rescue operation mode.

(1) Demand points

Evacuees lose their residence due to natural disasters, and their lives are changed from normal to disaster state [43]. This paper studies the refuge rescue operations in the disaster area, which is the transfer and resettlement of the victims at the demand point. Demand points can be divided according to villages or communities, and evacuees are the objects of service and management of the emergency shelter rescue system.

(2) DClassification of shelters based on horizontal needs

(i) Living emergency shelter

To deal with the problems caused by the damage of life systems such as water supply, power supply, and roads after the disaster, living emergency shelters provide basic services such as meals, drinking, and rest for the general victims to improve the poor living environment. In living shelters, if the evacuees need medical treatment and professional care, they will be transferred to medical shelters in the next stage [6].

(ii) Medical emergency shelter

Medical emergency shelters mainly provide timely diagnosis, treatment, and nursing services for moderately victims [42], who have not yet reached the level of being sent to the hospital. When planning an emergency shelter rescue system, it is necessary to take care of the physically and mentally injured [33].

(3) Classification of shelters based on vertical needs

Emergency shelters for natural disasters can be divided into three categories: temporary, short-term and long-term shelters according to the facility configuration and the time for the placement of evacuees, as shown in Figure 4.

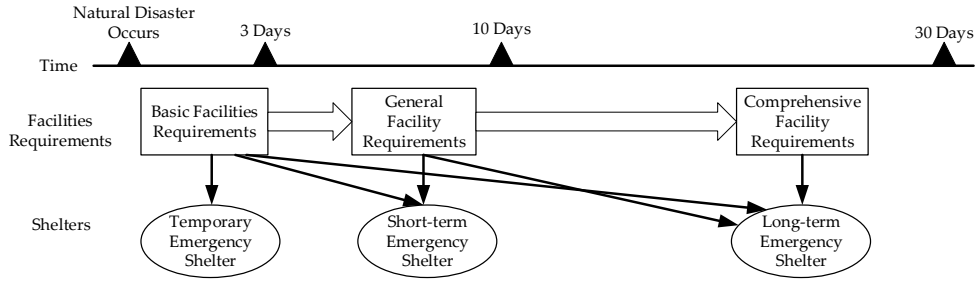

Figure 4. Schematic diagram of classification of emergency shelters based on vertical demand.

(i) Temporary emergency shelter

Within 3 days after the disaster, the evacuation status is unstable [40]. The emergency management department guides different types of evacuees to temporary shelters in an orderly manner. The selected facilities are quickly converted from normal functions to disaster functions to reduce the casualties of the victims. The conditions for living and medical are formed.

(ii) Short-term emergency shelter

Short-term emergency shelters are undertaken by public places with more complete supporting facilities and larger space after emergency facilities planned before the disaster [7,44]. Victims have initially grasped the disaster situation, and their physical and mental health has changed. They are transferred to different types of short-term emergency shelters according to their own needs.

(iii) Long-term emergency shelter

This paper sets public places with stronger living functions and larger effective areas as long-term emergency shelters for centralized management of victims. The socio-economic life of the affected area is gradually restored, and the requirements for the life function of the refuge are higher. Long-term emergency shelters mainly manage food hygiene, temperature environment, and infectious disease control [40].

(4) Emergency material supply point

(i) Territorial emergency material supply point

Under the partial interruption of the transportation network and the warehouse may be in a semi-paralyzed and unsound state [45], the territorial emergency material supply point is close to the affected area. The territorial supply point can immediately distribute relief materials to temporary shelters, saving time for allocation and transportation.

(ii) Rear emergency material supply point

After a large-scale natural disaster occurs, a large number of relief materials and emergency treatment are needed. To create basic evacuation conditions for the evacuees, in addition to the limited territorial emergency supplies [38], the material at the rear is also

required to meet the initial demand gaps, while corresponding to changes in demand that occur during the long-term evacuation phase.

4.3. Operation Strategy of the Emergency Shelter Rescue System

Based on the analysis of the emergency rescue system structure, it can be seen that demand stratification, diversion and evacuation and comprehensive distribution are complementary and mutually restrictive. Without any element, rapid and accurate rescue cannot be achieved. To ensure the normal operation of the emergency shelter rescue structure framework, this section proposes strategies to ensure the effective operation of the shelter system.

The normal function of the emergency shelter rescue system is long-term and gradually improved with the development of the local society and economy. The disaster prevention function is short-lived, only reveals in a short period after the disaster occurs. When the evacuation life ends, it immediately resumes its usual function [39]. The combination of peacetime and emergency is an important strategy for the operation of the emergency shelter rescue system (see Figure 5), which can not only effectively use public facilities, but also increase the coverage of shelters and reduce construction costs.

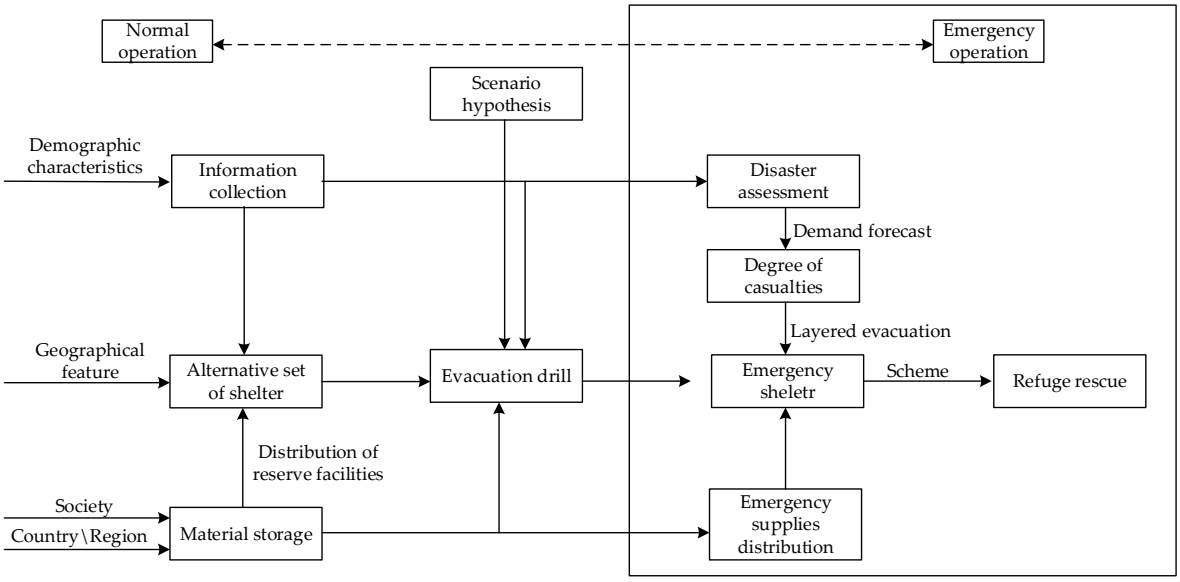

Figure 5. Schematic diagram of peacetime and emergency operation combined.

4.3.1. Normal Operation

The usual information collection can ensure that emergency facilities of various types of functions are activated immediately after a disaster, and the transition from the normal state to the disaster state can be completed. In the meanwhile, the facilities that can be used as emergency shelters are under the unified management of the disaster management institution and follow the maintenance and protection system of disaster prevention and mitigation facilities. In addition to information collection and facility management, it is also necessary to formulate emergency drill plans and form a complete refuge rescue system, which plays an important role in reducing the impact of natural disasters.

4.3.2. Emergency Operation

The emergency shelter rescue system needs a transformation process from its normal operating state to opening the disaster rescue function. All activities such as pre-disaster information collection, facility management, and evacuation drills are terminated. After the disaster, emergency facilities will be activated by the emergency plan. The specific operation process after the disaster is as follows:

(1) Disaster assessment

According to the information reported and real-time monitoring reports, the information before and after the disaster in the affected area is compared, and the damage of buildings, water, and electricity is obtained. The assessment of the location, scale, and impact of the disaster has been completed, making it easy to grasp the degree of casualties in demand points.

(2) Casualty prediction

Based on the results of the disaster assessment, the quantity of ordinary, moderate, and severely affected victims in the affected area and the type and number of supplies needed are obtained. At present, there is a lot of research relating to the demand forecasting model. Considering features of data, such as accessibility, real-time performance, and rapidity, a comparative analysis is made on the existing research on the forecasting model [23,46]. This paper selects the following models for the comparative analysis of the existing scholars' prediction models:

$$D_i^h(t) = \mu(t) P_i \varphi \gamma^h(t) \tag{1}$$

$$\mu(t) = q_1 w_1 + q_2 w_2 + q_3 w_3(t) \tag{2}$$

$$w_3(t) = \min(\alpha_2 e^{-\beta_2 t}, 1) \tag{3}$$

$$\gamma^h(t) = \alpha_1^h e^{-\beta_1(t)} \tag{4}$$

$D_i^h(t)$ refers to the number of people of the h-type (i.e., h = A, B and C indicate ordinary, moderate and severely affected victims, respectively) who need to evacuate at disaster point i at t-th day after the disaster; $\mu(t)$ refers to the proportion of evacuation; P_i is the population of disaster point i; φ is the ratio of victims choosing to take refuge locally instead of taking refuge in other places; $\gamma^h(t)$ refers to the proportion of victims of h-type; q_1 indicates the proportion of victims whose houses are completely damaged; q_2 indicates the proportion of victims whose houses have been partially damaged; q_3 refers to the ratio of victims whose houses are intact or slightly damaged; w_1, w_2 and $w_3(t)$ refer to the proportion of the above three types of people who choose to take refuge in shelters. Among them, $w_3(t)$ represents the change over time of the evacuation needs of victims whose houses are intact or slightly damaged, which is the tolerance to the shortage of basic living services. $\alpha_1^h, \alpha_2, \beta_1$ and β_2 are set according to the actual geographical environment and historical data of the disaster area.

(3) Shelter planning

The candidate set of emergency shelters formed before the disaster is screened. The program is based on two principles: (i) the affected population has the right to live with dignity and receive necessary assistance, and (ii) whenever human suffering is caused by natural disasters, any necessary action should be taken in order to suppress it [29]. Multiple qualitative factors must be considered when selecting emergency shelters, and candidate sites should avoid areas of potential risks. Topography, geological type, and slope are important factors to be considered when planning shelter location [47,48]. The flat terrain can be protected from secondary disasters such as mudslides after the earthquake [47]. Emergency facilities should be far away from the fault line, and the slope of the ground should preferably be between 2% and 4% [49]. Moreover, in rainy areas, vegetation is crucial in strengthening the soil and reducing losses caused by secondary disasters after the natural disaster [5,50]. The presence of trees also protects the affected population from hot weather conditions [39]. Moreover, the electricity supply is an important consideration for the maintenance of daily life [40]. The use of equipment and communications is impossible without electricity [42,49]. In summary, this study summarizes five qualitative factors that affect the location of emergency service facilities: topography (C1), geology (C2), slope (C3), vegetation (C4), and power facilities (C5), which are as shown in Table 1.

Table 1. Qualitative factors of shelter planning.

Factor	Reference
Topography	Kılcı et al. [29], Trivedi and Singh [39], Xu et al. [47], Amin Hosseini et al. [48]
Geological type	Kılcı et al. [29], Trivedi and Singh [39], Amin Hosseini et al. [48]
Slope	Kılcı et al. [29], Trivedi and Singh [39], Knay et al. [49]
Vegetation	Li et al. [5], Yahyaei and Bozorgi-Amiri [50], GB/T33744-2017 [40]
Power facilities	Li et al. [5], Knay et al. [49], GB/T33744-2017 [40], Gu et al. [42]

(4) Distribution plan

The plan for the allocation of evacuees at each stage is formulated according to the obtained demand and the distribution of different types of shelters. Additionally, the emergency material distribution plan is determined based on the storage of supplies around shelters, the demand of victims, and vehicles.

(i) Temporary stage of the model

$$\min f_1 = \sum_{h\in H}\sum_{i\in I}\sum_{s\in S} x_{is}^h d_{is} \tag{5}$$

$$\max f_2 = \sum_{m\in M}\sum_{s\in S} y_s^m F_s \tag{6}$$

$$\min f_4 = \sum_{h\in H} (U_1^h + U_2^h) \tag{7}$$

$$d_{is}x_{is}^h - TD_{shelter}M \le 0 \tag{8}$$

$$\sum_{s\in S} x_{is}^h \ge D_i^h \tag{9}$$

$$\sum_{h\in H}\sum_{i\in I} x_{is}^h \le y_s^m C_s \tag{10}$$

$$y_s^m DH_s \le TD_{hospital} \tag{11}$$

$$y_s^m DW_s \le TD_{warehouse} \tag{12}$$

$$\sum_{i\in I} x_{is}^h \alpha_1^h = U_1^h + \sum_{j\in J} n_{js}^1 \tag{13}$$

$$\sum_{i\in I} x_{is}^h \alpha_2^h = U_2^h + \sum_{j\in J} n_{js}^2 \tag{14}$$

x_{is}^h is the number of victims evacuating from the disaster point i to the shelter s; d_{is} is the distance between the disaster point i and the shelter s; y_s^m indicates the shelter s is chosen as m-type, that is, it mainly provides living (m = 1) or medical services (m = 2); F_s represents the subjective weight of shelter s based on the criteria; U_1^h is the unmet demand of h-type evacuees for living supplies; U_2^h is the unmet demand of h-type evacuees for medical supplies; $TD_{shelter}$ indicates threshold distance to nearest shelter; M is a big positive number; C_s is the capacity of shelter site; DH_s is the distance of site s to the nearest healthcare facility; DW_s is the distance of site s to the nearest storage facility; $TD_{hospital}$ indicates the threshold distance to the nearest healthcare facility; $TD_{warehouse}$ indicates the threshold distance to the nearest storage facility; α_1^h is the unit demand for living supplies of h-type evacuees; α_2^h is the unit demand for medical supplies of h-type evacuees; n_{js}^1 is the quantity of living supplies distributed to shelter s in warehouse j; n_{js}^2 is the quantity of medical supplies distributed to shelter s in warehouse j.

Equation (5) aims to minimize the total evacuation distance to their temporary shelters. Equation (6) maximizes the subjective evaluation performance of the shelters based on qualitative factors. Equation (7) minimizes the total unmet demand for emergency supplies. Equation (8) restricts that no evacuees can be allocated to shelters that exceed

the distance limit. Equation (9) ensures that all evacuees are allocated. Equation (10) states that the number of households assigned to a shelter site should not exceed its capacity. Equations (11)–(12) ensure that if there is no healthcare facility and storage facility with a threshold distance from a shelter, then that site is not selected. Equations (13)–(14) equate the number of distributed supplies and unmet demand to the total demand of evacuees.

(ii) Short-term stage of the model

After the first day of being resettled in temporary shelters, evacuees will be reallocated to short-term shelters for longer evacuation and better services.

$$\min f_5 = \sum_{h\in H}\sum_{s\in TS}\sum_{s'\in SS} x_{ss'}d_{ss'} \tag{15}$$

$$\max f_6 = \sum_{m\in M}\sum_{s'\in SS} y^m_{s'}F_{s'} \tag{16}$$

$$d_{ss'}x^h_{ss'} - TD_{shelter}M \le 0 \tag{17}$$

$$\sum_{s'\in S} x^h_{ss'} \ge D^h_{s'} \tag{18}$$

$$\sum_{h\in H}\sum_{s\in S} x^h_{ss'} \le y^m_{s'}C_{s'} \tag{19}$$

$$y^m_{s'}DH_{s'} \le TD_{hospital} \tag{20}$$

$$y^m_{s'}DW_{s'} \le TD_{warehouse} \tag{21}$$

$$\sum_{s\in TS} x^h_{ss'}\alpha^h_1 \le \sum_{j\in J} n^1_{js'} \tag{22}$$

$$\sum_{s\in TS} x^h_{ss'}\alpha^h_2 \le \sum_{j\in J} n^2_{js'} \tag{23}$$

Equation (15) aims to minimize the total evacuation distance from the temporary shelters to the short-term shelters, where TS is the set of temporary shelters obtained by solving the model's stage and SS′ is the set of candidate short-term shelters. Here, it should be noted that the shelters chosen as temporary shelters can also be candidate short-term shelters if they meet the requirements of being the short-term shelter [7]. Equation (16) maximizes the subjective evaluation performance. Equation (17) indicates distance constraint. Equation (18) ensures all evacuees are reallocated to short-term shelters. Equation (19) is a capacity constraint. Equations (20)–(21) ensure the selected short-term shelters have medical and storage facilities within the threshold distance. Equations (22)–(23) ensure all material needs are met.

(iii) Long-term stage of the model

After ten days, the evacuees will be reallocated to the long-term shelters, because the long-term shelters cannot meet the requirements of the evacuees. Long-term shelters should provide comprehensive services to ensure the living of evacuees. Therefore, the overall service quality and construction investment are optimization goals.

$$\max f_6 = \sum_{m\in M}\sum_{s''\in LS} y^1_{s''}F_{s''} \tag{24}$$

$$\min f_7 = \sum_{s''\in LS} y^1_{ss'} \tag{25}$$

$$d_{s's''}x^A_{s's''} - TD_{shelter}M \le 0 \tag{26}$$

$$\sum_{s'\in SS} x^h_{s's''} \ge D^A_{s''} \tag{27}$$

$$\sum_{s' \in SS} x^{A}_{s's''} \leq y^{1}_{s''} C_{s''} \tag{28}$$

$$y^{1}_{s''} DH_{s''} \leq TD_{hospital} \tag{29}$$

$$y^{1}_{s''} DW_{s''} \leq TD_{warehouse} \tag{30}$$

$$\sum_{s \in TS} x^{h}_{ss'} \alpha^{h}_{1} \leq \sum_{j \in J} n^{1}_{js'} \tag{31}$$

$$\sum_{s \in TS} x^{h}_{ss'} \alpha^{h}_{2} \leq \sum_{j \in J} n^{2}_{js'} \tag{32}$$

Equation (24) maximizes the subjective evaluation performance. Equation (25) aims to minimize the number of open long-term shelters, where LS is the set of candidate long-term shelters. Here, it should be noted that the shelters chosen as short-term shelters can also be candidate long-term shelters if they meet the requirements of being the long-term shelter. Equation (26) indicates distance constraint. Equation (27) ensures all evacuees are reallocated to long-term shelters. Equation (28) is a capacity constraint. Equations (29)–(30) ensure the selected short-term shelters have medical and storage facilities within the threshold distance. Equations (31)–(32) ensure all material needs are met.

5. Conclusions

This paper studied the operation of the emergency shelter rescue system in detail. Firstly, the concepts and characteristics of emergency refuge demand, emergency shelter, and emergency material distribution are defined. Combining the influence of complex requirements, blind refuge, and shortage of materials on the structure of the emergency refuge rescue system, this paper proposes a shelter rescue structure framework consisting of demand uncertainty, refuge accuracy, and rapid distribution. The emergency shelters are divided horizontally into two categories, providing living and medical security, and vertically divided into three levels of shelters: temporary, short-term and long-term. It has important practical significance to meet the changes in the needs of evacuees and the rational allocation of emergency resources. The role of theoretical guidance has further enriched and improved the theory of emergency shelter rescue. Based on the analysis of the rescue function of emergency shelters, the operation scene of refuge rescue is constructed, and the operation strategy of the emergency shelter rescue system is formulated. Combining the demand stratification, evacuees with different needs are systematically allocated to shelters with different functions, thereby improving the adaptability and effectiveness of resettlement after the disaster.

The structure of the emergency shelter rescue system can be applied to carry out rapid rescue by forecasting the number of evacuees, determining emergency shelters with different rescue functions, and formulating the plan for the distribution of evacuees and supplies. In the future, we will focus on further improving the emergency shelter location-allocation model method. Based on the effective operation mechanism of the emergency shelter rescue system proposed in this article, we will integrate the demand-layered network, the emergency shelter network and the material supply network to find a better emergency shelter rescue plan.

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