Emergency Supply Facility Location Design under Disaster Conditions: Emerging Modeling Techniques and Algorithms

Di Dong, Na Cui *

School of Civil Engineering and Architecture, University of Jinan, Jinan 250022, China
Email: 1256500795@qq.com, cca_cuin@ujn.edu.cn*

Abstract: The sudden and frequent natural disasters have brought a series of damages to both the economy and society of all countries in the world and made people to suffer a double loss of life and property. In this context, it raises a claim for emergency rescue activities in terms of more scientific, more accurate and quicker responses. Emergency rescue is taken as one of the most important ways to save lives and reduce losses when natural disasters attack; while proper emergency supply storage facility location is the key to guarantee the effectiveness and efficiency of emergency rescue operations. Based on the characteristics of emergency rescue activities, this paper analyzes the scientific problems in the field of emergency rescue and summarizes the current progress of emergency supply facility location modeling and algorithms with the purpose of laying a theoretical foundation for the future research.

1. Introduction
In recent years, a variety of large-scale natural and man-made disasters have occurred frequently in the world, which caused a large number of casualties and economic losses [1]. Since the 21st century, natural disasters such as earthquakes, floods and hurricanes have caused global economic losses of nearly $3 trillion. China is one of the countries that are most seriously affected by natural disasters. There are many kinds of natural disasters in China, with high frequency and serious situation, and the risks brought by disasters continue to increase. In 2008, the Wenchuan earthquake in Sichuan province caused direct economic losses of more than 800 billion yuan. In 2010, a huge mudslide in Zhou Qu caused nearly 2,000 casualties. In 2015, the floods in the southern region caused nearly 2 million people to be affected in Zhejiang, Hubei and other provinces (cities) [2]. In 2018, typhoon Mangosteen affected nearly 3 million people and caused a direct economic loss of 5.2 billion yuan. These devastating and sudden disasters make our country's disaster prevention, reduction, and relief work increasingly heavy and arduous.

In the context of various catastrophic disasters, just evacuating disaster victims from the disaster affected area is not the end of the emergency rescue activities. It needs to provide reliable and timely humanitarian assistance for disaster-stricken groups evacuated to shelters, temporary medical centers, or other gathering locations. It is an indispensable link to reduce disaster losses and successfully implement disaster relief. Although it is different from the emergency rescue activities that save trapped people in the early stage after the attack of a disaster, the emergency rescue activities that focus on providing humanitarian relief materials are practical problems that need to be faced in the field of emergency management and have practical significance. This paper puts its concentration on one of the critical decisions raised in the supply of humanitarian relief materials, i.e., the locations of key emergency service facilities which play an important role in the emergency rescue operations. Through the summary of the related state-of-the-art studies, the aim of this paper is to lay a foundation for the...
further modeling work.

2. Modeling analysis and literature description

2.1. Multi-objective optimization modeling

To solve the problem of the location of emergency material storage facilities, many studies chose to establish multi-objective programming models. In order to adapt to the different deployment strategies of emergency rescue facilities in major emergencies, Chen Zhizong et al. integrated the maximum coverage model, P-center model and P-median model commonly used in traditional site selection models, and established a multi-objective decision-making model considering the fairness and efficiency of emergency rescue facility [3]. Ding Xuefeng et al. established a multi-objective decision-making programming model by taking equity, efficiency and construction cost [4]. Xi Menghao et al. proposed a P-median problem that considered the regional natural disaster risk zoning (value), time constraints and the cost constraints of the construction of reserve facilities [5]. Zhang Chengyuan et al. combined the unique disaster relief timeliness requirements presented by emergency rescue and the dynamic relief material distribution problems involved in the emergency rescue process and established the objective function from two aspects: demand coverage and optimal paths and constructed a minimum distance optimization model based on demand distribution [2]. Feng Jianrui et al. considered the timeliness and economy of material transportation scheduling, introduced weights to comprehensively cover the timeliness and economy, and used variable weight factors to build auxiliary functions to establish the emergency service location optimization model [6]. Fu Deqiang et al. established a bi-objective integer programming model with the greatest service quality and the lowest service cost [7]. Li Zhouqing et al. minimized the sum of the construction cost and variable storage cost, and the material transportation cost, and minimized the total time of material transportation, and constructed a regional emergency material storage location-allocation multi-objective optimization model [8]. Zhou Yufeng et al. established a RPMP model for facility location of emergency material storage facilities, considering the timeliness and reliability of emergency materials and the different damage probabilities of emergency material storage facilities [9]. Dai Ying et al. established a multi-objective model in which both the emergency resource demand and the emergency rescue time range were fuzzy, aiming at maximizing the total satisfaction of the emergency rescue time and minimizing the total cost of the system [10]. Lopez and Monzon et al. developed a strategic shipment planning model, and incorporated sustainability issues into facility location planning, spatial and regional economic analysis [11]. Konur and Geunes et al. studied the location of facilities under the influence of congestion in the distribution network [12]. Xuke et al. established a multi-objective optimization model on the basis of an in-depth study of the characteristics of emergency logistics, aiming at the characteristics of the facility location of emergency material storage depot and material scheduling [13].

2.2. Modeling framework incorporating uncertainty

The above studies dealt with the facility location of emergency material storage facilities when the disaster areas and emergency material requirements are determined. However, under natural disasters, the actual disaster environment often brings various uncertain factors, and traditional optimization schemes cannot perform the expected functions in emergency rescue operations. Therefore, comprehensive consideration of the impact of uncertain factors is of great significance to the location of relief supplies.

Carmen G. Rawls et al. established a robust two-stage random mixed integer programming model under the uncertain conditions of the probability of disaster occurrence, emergency material demand, road damage under disaster conditions, and the availability of reserve materials [14]. Murali P et al. studied the location of facilities with capacity constraints in emergency logistics, and established a maximum coverage location model considering distance factors and uncertain demand [15]. Leila Hajibabai et al. constructed a two-level mixed integer nonlinear programming model with the goal of minimizing the total cost (traffic delay cost and road renovation cost) [16]. Li Zhu et al. measured the
relative cost of deprivation to achieve fairness in the route selection process for transporting the casualties, and used time window constraints to emphasize the priority in the rescue process [17]. Gutjahr et al. studied the fairness and deprivation cost in humanitarian emergency rescue, extended the Gini coefficient in economics to deprivation cost, and gave the calculation and solution process of the corresponding model [18]. Lina Yu et al. proposed three measurement methods based on the human suffering, which improved the efficiency, benefit and fairness in the emergency response process [19]. Noel Pérez-Rodríguez et al. proposed a new mathematical model with the purpose of maximizing the benefits of the victims [20]. Nathalie Cotes et al. directly considered the cost of deprivation in the objective function, and constructed a facility location and supplies allocation model for humanitarian assistance [21]. José Holguín-Veras et al. constructed the evaluation process of the deprivation cost function using the conditional value evaluation method [22]. The result showed that the relationship between the deprivation cost and deprivation time of is a non-linear relationship. Feng Chun et al. studied the location of the pre-disaster emergency material reserve warehouse in view of the situation that the disaster areas and emergency demand are uncertain when natural disasters such as earthquakes occur [23]. Wang Haijun et al. studied the LRP model in which the demand and the vehicle driving time are uncertain [24]. A dual-objective model is established with the goal of minimizing total transportation time and minimizing emergency costs, and weighting is used to transform the two goals into a single goal, which increases the flexibility of decision-making. Gao Shuchun et al. used the method of contact number to predict demand, considering that the demand for emergency supplies would show uncertainty due to changes in influencing factors [25]. Bai, Hajibabai and Ouyang et al. analyzed the interaction between biofuel refinery facility location and transportation routes in the network environment, and made decisions about congestion and network capacity expansion [26]. He Shanshan et al. used a relatively robust optimization method to establish a multi-objective mathematical model based on the optimal total time and total cost in the case of the limited carrying capacity of the emergency logistics system [27].

2.3. Application of intelligent optimization algorithm in emergency service facility location problems

Intelligent optimization algorithms include simulated annealing algorithm, genetic algorithm, emergency search algorithm, particle swarm algorithm, simulated plant growth algorithm and so on. However, the location of emergency material storage facilities under disaster scenarios is an NP-hard problem. For the algorithmic solution of the location of emergency material storage facilities after a disaster, domestic scholars have been committed to algorithm improvement and innovation.

Ding Xuefeng et al. considered factors such as fairness, efficiency, construction cost, and other factors when modeling, and used the simulated plant growth algorithm to solve the model [4]. The algorithm can realize the fast search for the optimal solution in the global scope, and the algorithm design is simple and easy to implement, does not have too many restrictions on the objective function and parameter settings. Zhang Chengyuan built the minimum model based on demand distance and the optimal path model, and used the immune calculation and the ant colony algorithm to solve them, so as to not only meet the rescue needs, but also realize the purpose of mutual support of emergency relief materials in the global scope. [2]. Fu Deqiang et al. used a fast non-dominated sorting genetic algorithm with elite strategy to solve the dual-objective integer programming model with the largest service quality and the lowest service cost [7]. Li Zhouqing et al. established a multi-objective optimization model for the location of a regional emergency supplies reserve-allocation, and designed an improved multi-objective genetic algorithm using matrix coding for the characteristics of multiple models and non-linear node costs [8]. Wang Haijun et al. established a dual-objective model with the goal of minimizing total transportation time and minimizing emergency costs, and gave a genetic algorithm to solve the problem [24]. Wang Baohua et al. used enumeration and genetic algorithms to solve a robust optimization model for the location of logistics centers in uncertain environments [28]. Ge Chunjing et al. introduced the concepts of maximum critical distance and minimum critical distance, established multiple quantitative and quality coverage models, and proposed an improved genetic algorithm to solve them [29]. Ma Zujun et al. established an optimization model for multimodal intermodal transportation of emergency supplies.
distribution, and designed a hybrid genetic method combining heuristic rules and two-stage decoding according to the characteristics of the model [30]. Dai Ying et al. established a multi-objective optimization model to maximize the satisfaction of emergency rescue time and minimize the total cost of the system, and proposed a hybrid multi-objective genetic algorithm to solve it [31]. Farvaresh et al. have devoted themselves to the development of accurate global algorithms to solve discrete and continuous problems, mainly by reformulating the two-layer problem as a single-layer structure. Research on equivalence issues [32-33].

3. Critical discussion

Based on the analysis of above domestic and foreign studies, the current results about the locations of emergency service facilities can be summarized as follows:

(1) Previous studies mostly optimized single or overall optimization of factors such as the least time, the shortest distance, and the least cost. However, the post-disaster emergency rescue has the characteristics of weak economics. Therefore, humanitarian assistance is provided for the disaster-stricken people, taking full consideration of whether the victims are not. The cost of loss caused by timely rescue is more important; in the actual rescue process, there are multiple entities participating in decision-making in some rescue stages. Different decision-making entities lead to different decision-making content. Therefore, two-level planning, game theory, two-stage planning and other methods are required. Analyze emergency material dispatch.

(2) The model assumes that the disaster area is known. Disaster area can only be transported from one storage depot. A single mode of transport is often used for the mobile distribution of emergency relief supplies, with little regard for transport capacity restrictions and other conditions. The capacity of the facilities and the transport capacity of the rescue vehicles is large enough to meet the needs of the affected areas. However, there are some obvious features of emergency relief after natural disasters, such as not knowing exactly where the affected area is before the disaster occurs, and having difficulties in storing emergency supplies and difficulties may be encountered in the storage and supply of emergency supplies (such as the original facilities need to allocate part of the reserves goods damaged goods or inadequate reserves redundancy) and the common problems in the process of actual emergency transportation (such as the original plan of travel road is damaged, the material delivery time of intermediate node is too long and there is a lack of rescue resources or vehicles). Therefore, the assumptions of these models are contrary to the actual situations. Under the condition of the affected, considering disaster environment on the emergency rescue supplies and transportation activities may impact, to establish a comprehensive emergency supplies reserves facility location scheme, to improve and expand the emergency rescue planning modeling research has important theoretical significance.

4. Conclusions and future research

This paper presents a literature review on the location of key service facilities in humanitarian emergency rescue, the following improvements and prospects are proposed for the facility location of emergency supplies storage facilities:

In the emergency response, there are many factors that cause uncertainty, and these factors influence each other, making the traditional optimization schemes unable to exert the greatest effect. When a disaster occurs, the psychological changes of the affected people are great, so it is of great significance to comprehensively consider the influence of uncertain factors on the optimization results and the impact of the psychological needs of the affected people on the decision-making.

This paper systematically reviews and summarizes the research status of facility location of emergency supplies storage facilities. The application research of intelligent optimization algorithm in emergency material scheduling is summarized. This paper analyzes the problems existing in the facility location of the existing emergency materials storage facilities, and puts forward corresponding improvement suggestions, which is conducive to the construction of a new method for facility location of the emergency materials storage facilities after the disaster, and further improves the theoretical system of emergency rescue.
When a natural disaster occurs, the loss is huge and the decision-making environment is complex. How to propose an effective auxiliary decision-making scheme to improve the efficiency of emergency response according to the pre-disaster emergency material reserve and post-disaster relief material transportation needs is a key research direction in the field of emergency management in the future.

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