

A Review of Emergency Resource Allocation under Natural Disasters

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Abstract. The acceleration of urbanization has led to increasingly serious casualties and property losses caused by natural disasters, while also exposing issues such as unreasonable and inefficient allocation of emergency resources. This article elaborates on the location selection of urban emergency resources, prediction of disaster point demand, construction of emergency resource scheduling models, and application of intelligent optimization algorithms by consulting relevant literature. It analyzes some problems in current emergency resource research and summarizes the key points that need to be broken through in future research.

Keywords: Natural calamities; Emergency resource selection; Demand forecast; Emergency resource scheduling

1. Introduction

By 2023, China's urbanisation rate is expected to reach about 70%, with the resident urban population reaching 860 million and the number of cities reaching as high as 653, and the urban population is still increasing. Cities are the core area of China's economic and social development, and a large number of population, industry, capital and information gather in cities, with a huge number of circulating capital. With the acceleration of urbanisation, cities face frequent natural disasters and emergencies; on 12 May 2008, a massive 8.0 magnitude earthquake struck Wenchuan County in Sichuan Province. This earthquake resulted in 69,225 people losing their lives, 17,939 people missing as well as more than 370,000 people injured [1], making it the most destructive and costly earthquake that has occurred in China in the past 60 years. In addition to the damage caused by the earthquake itself, secondary disasters such as collapses and landslides caused by the earthquake also exacerbated the damage; on 17 July 2021, heavy rainfall occurred in north-central Henan Province, with the daily rainfall exceeding the historical extreme. This rainstorm caused 302 deaths and 133.715 billion yuan in direct economic losses. The continuous heavy rainfall led to a waterlogged accident on Line 5 of the Zhengzhou Metro, in which 14 passengers were killed. These disasters and events brought serious casualties and property losses to the city and posed a serious threat to the stable operation of the city. When a sudden disaster breaks out, the timely supply and reasonable distribution of emergency supplies are crucial to the rescue efforts in the affected areas.

Urban emergency resources include resources in terms of personnel, materials, equipment and information. These resources are able to provide important support such as first aid, evacuation and material supply when emergencies occur, helping cities to quickly return to normal operation. However, in reality, the allocation and management of urban emergency resources often fail to meet the needs of disasters, leading to difficulties in responding to emergencies. How to allocate emergency supplies scientifically and reasonably is a hot topic that has been studied by scholars at home and abroad.

This paper firstly summarizes the current research status at home and abroad on the study of emergency material siting and emergency material pre-demand, and analyses the mathematical model involving the optimization of rescue material scheduling. Then a certain summary and analysis of the multiple intelligent algorithms used in solving the optimisation problem of emergency supplies is carried out. Finally, according to the current development status of

emergency relief materials under natural disasters, the research trend of emergency materials distribution optimisation problem is summarised.

2. Study on the siting of emergency relief materials

The study on the siting of emergency relief materials is designed to rationally determine the location of relief material facilities in the event of a disaster, so that the needs of the disaster area can be met in a timely and efficient manner. The study aims to select the best site for materials through scientific methods and techniques, combining factors such as disaster risk assessment, demand forecasting and resource allocation, so as to improve the efficiency and response capacity of emergency relief. Most of the existing studies are based on the conditions of demand certainty, and there are relatively few studies on uncertainty, for which robust optimisation or input fuzzification variables are generally used.

(1) Robust optimisation

A Ben-Tal and A Nemirovski earlier conducted robust optimization research for uncertain demand, proved the applicability of robust optimization, and made a great contribution to its practical application [2]; Kasemsri et al. conducted a study on post-disaster grid planning under uncertainty, and used the ellipsoidal uncertainty set for optimization [3]; Zhizhu Lai used a discrete set of scenarios to describe the disaster-affected point uncertainty of emergency material demand as well as the uncertainty of emergency material transportation cost and transportation time, and at the same time, considering the two objectives of emergency rescue cost and emergency rescue time, a multi-objective emergency logistics centre siting indeed deterministic model and a robust optimization model are established [4]; Peng Chun, on the basis of the nominal model of siting-path optimization of multi-class emergency resource allocation, considers the uncertainty of the cost of multi-class emergency resources, and introduces the two types of uncertainty sets (box and ellipsoid) to portray the uncertainty, and establish the robust siting-path optimisation model for multi-class emergency resources respectively[5]; Mengling Zhang introduced L1 paradigm to describe the uncertainty of demand, established a robust optimisation model for two-phase decision-making of disaster preparedness and disaster relief, and gave a transformation method of the corresponding problem of the robust model [6].

(2) Fuzzification variables

Dajiang Peng et al. address the difficulty of simultaneously determining the location of emergency resource centres and transport paths under demand uncertainty scenarios, introduce triangular fuzzy numbers to describe fuzzy demand, and propose a fuzzy demand-based path model for the location of emergency resource centres [7]; Chi-Wen Huang et al. propose a capable and reliable siting model under the consideration of demand uncertainty and facility failures, and develop an improved immune genetic algorithm to analyse the sensitivity of the uncertainty level and the probability of facility failure [8]; Zhang Baishang et al. constructed a fuzzy planning model for emergency evacuation of a community with multiple transport synergies under demand uncertainty to help the community in emergency evacuation [9]; A Trivedi proposed a hybrid multi-objective decision-making model based on the analysis of hierarchies (AHP), fuzzy set theory and objective planning methods, and designed a hybrid algorithm for efficient management of site selection and relocation projects to solve the model [10]; Rajali Maharjan used a plausibility based fuzzy chance constrained planning model to account for the inaccuracies inherent in the predicted parameter values during disaster response [11].

3. Optimisation study of the demand for emergency relief materials

After the outbreak of a major natural disaster, an adequate supply of emergency relief materials plays a major role in reducing casualties and property damage. Therefore, it is of great significance to have analysed and calculated in advance the material requirements of each affected area. At

present, the research on the demand for emergency supplies has become more and more mature, and in the early days, the expert experience assessment method was mostly used to estimate the demand for supplies at the disaster-stricken sites. For example, JB Sheu used the empirical assessment method to study the demand for emergency material resources [12], but due to the heavy subjectivity of this method, many more objective and accurate prediction methods have been proposed. The main ones are the prediction method based on statistical modelling, the prediction method based on fuzzy logic, etc.

(1) The forecasting method based on statistical models is based on analysing historical disaster data and relevant statistical data and establishing mathematical models to forecast the demand for emergency supplies. Commonly used statistical models include time series analysis, regression analysis and grey system model. For example, in the grey system model, feng Liu S established an axiomatic system of grey definition, which takes the axioms as the standard for defining the greyness of grey numbers and scientifically describes the degree of uncertainty of grey numbers [13]. On this basis, Zeng Bo normalized the grey heterogeneous data based on "kernel" and "grey scale", established the (1,1) DGM model of grey heterogeneous data "kernel" sequence, and used the model to predict the Ya'an earthquake. The model is used to predict the demand for tents in Ya'an earthquake [14]; Hu Zhongjun et al. combined with the inventory management method to propose an improved GM (1,1) dynamic forecasting model, which has higher forecasting accuracy than the traditional model [15]. The use of grey theory prediction method can deal with non-linear and non-smooth data, but the method has a long prediction cycle and cannot be applied to unexpected situations; in regression analysis, Richard Sui uses historical data training to obtain the influence coefficients of various factors on the prediction of emergency resources, and adopts a kind of multiple regression method based on the grid system emergency material demand prediction model to quickly calculate the demand for various materials [16]. Guo Zixue introduced symmetric triangular fuzzy numbers to represent the fuzzy characteristics of the influencing factors, and established an emergency material demand forecasting model based on multiple fuzzy linear regression [17]. The regression analysis method can provide the degree of influence of each independent variable on the demand for emergency supplies and help to understand the mechanism of demand formation, but it is more demanding on the data, and the accuracy and reliability of the results are greatly affected by the data.

(2) The fuzzy logic-based prediction method combines the principles of fuzzy mathematics and logical reasoning to predict the quantity of material demand by fuzzifying the input variables and fuzzy reasoning. For example, in fuzzy reasoning, Wenmao Liu proposed an emergency resource demand forecasting method based on case-based reasoning (CBR) and risk analysis[18]; Lanying Wang introduced intuitionistic fuzzy sets to describe the imprecise attributes of the cases, constructed the characteristic factor matrix of the source cases on the basis of defining the similarity degree of the intuitionistic fuzzy sets, and proposed a fuzzy case-based reasoning model for forecasting the demand of emergency supplies [19]; Zhang Xiaolei used the algorithm of fuzzy similarity-optimisation ratio to find the best sample case and extract the main factors from the source case database for the demand prediction of the target case [20]; Guo Jidong took into account the characteristics of the poor information of the post-earthquake disaster area, introduced fuzzy sets, established the fuzzy set of seismic characteristics, and calculated the modified measure closeness based on the weights of the characteristic attributes of the old and new cases [21]. The limitation of this method is that the material demand is predicted through historical case data, but in fact the disaster situation is changing all the time after the disaster occurs, so the demand for resources is also changing dynamically, while fuzzy inference is a static prediction method.

As can be seen from the above literature, the current commonly used statistical models and fuzzy inference methods meet the requirements of emergency material demand prediction to a certain extent, but most of these methods are static prediction methods. However, when a disaster occurs, the demand for materials at each disaster site changes dynamically, and how to establish a dynamic

material demand model according to the real-time demand in the disaster area is the focus of future research.

4. Optimising the deployment of emergency relief materials

At present, the problem of post-disaster distribution of emergency supplies is mainly solved by establishing single-objective or multi-objective mathematical models with constraints. The distribution of emergency supplies seeks to scientifically and reasonably distribute the supplies to each disaster site under various constraints, and to achieve the optimisation of the scheduling objective under feasible scenarios [22,23]. Since the emergency material allocation problem is an NP Hard problem, traditional methods are difficult to solve the model. Therefore, the model needs to be solved by intelligent optimisation algorithms, which have the advantages of high computational accuracy and fast computational speed when dealing with discrete combinatorial optimisation problems with many dimensions and variables. Currently commonly used intelligent optimisation algorithms include genetic algorithm, simulated annealing algorithm, firefly algorithm and so on.

4.1 Single-target research

Huang et al. proposed a model that takes into account the evaluation of continuous transport routes while ensuring the minimum dispatch time of emergency supplies, and the research objective is to ensure that the supplies arrive at each disaster site in the shortest possible time [24]; Zhang YL constructed an emergency resource dispatch model by taking the minimum total cost of the rescue operation as the optimization objective [25]; Hu F established an emergency supply dispatching model to cope with the rescue problem [26]; Mohammadi R et al. portrayed the satisfaction of the people in the disaster area and constructed a resource scheduling model with the optimisation objective of maximising the satisfaction [27]; Barbarosoglu constructed a two-stage stochastic planning emergency material allocation model with the objective of minimising the cost of emergency material allocation [28].

4.2 Multi-objective studies

With the gradual maturity of single-objective optimisation research and the development of intelligent optimisation algorithms, many scholars at home and abroad have studied multi-objective emergency supplies optimisation models in order to make the optimisation model more in line with the actual situation in the wake of disasters.

Abounacer established a multi-objective positioning traffic model, and found that the choice of traffic routes during the transport of materials depends on the number and location of the disaster relief distribution points and the needs of the disaster victims [29]; Ghaffari et al. computed the probabilistic transmission time-based "locate-route" problem (LRP), and using Ghaffari et al. calculated the probabilistic transmission time-based "location-path" problem (LRP) and proposed a dual-objective mathematical optimization model to minimize the cost of the whole transportation system while ensuring the minimization of the maximum delivery time [30]; Fuyu Wang constructed an emergency resource dispatch model and solved it using an algorithm with the highest satisfaction of the affected people and the lowest cost of the material dispatch as the optimization objectives [31]; Xingqun Xue et al. constructed an emergency resource dispatch model with the optimization objectives of the shortest time and the lowest cost of the transportation [32]; Chi H, Li J, et al. based on the interrelated nature of the objectives in the emergency material allocation problem, combined the time satisfaction and material satisfaction into one objective, and constructed a nonlinear time evaluation model for emergency material allocation [33].

4.3 Application of intelligent optimisation algorithms

In order to calculate the multi-objective emergency material dispatch model, Qiaoru Li used the second-generation non-dominated sorting genetic algorithm to optimally solve each objective separately [34]; Xiaobing Shen designed an improved genetic algorithm based on matrix integer encoding of the initial solution and stage-by-stage decoding by analysing the characteristics of the emergency material allocation model, which separates the initial solution into three parts for encoding [35]; Xiaodi Qi used the improved particle swarm algorithm to solve the emergency material allocation model considering supply and demand imbalance conditions, and the accuracy of the model solution is improved by introducing the inertia weights in the particle swarm into the nonlinear dynamic improvement strategy [36].

4.4 Insufficient research on emergency resource mobilisation

(1) Some scholars' studies are based on the stochastic optimisation model of a specific scenario, while in fact, the scheduling of emergency resources is closely related to the relevant rescue personnel, rescue vehicles, traffic environment and the evolution of various types of disaster risks, etc., and a variety of relationships need to be taken into account in the process of constructing the model.

(2) In terms of research objectives, due to the fact that emergency resource scheduling involves many influencing factors, the current optimisation objective function needs to be further improved and deepened, for example, by considering the connection between various resources and the sharing of resources between different regions.

5. Research summary and trends

This paper analyses the current status of research on emergency resource siting and resource demand forecasting, and provides an overview of the emergency resource dispatching model and the application of intelligent optimization algorithms for solving the model. Aiming at the characteristics of fuzzy information, large changes and complex types of emergency material deployment problems under natural disasters, the following points are proposed to be solved in the subsequent research:

(1) In existing studies, under the condition that demand is not available, most of them use some static forecasting methods to assess the actual demand in the disaster area. However, after the disaster, the demand in the disaster area changes dynamically, so it is necessary to develop a dynamic demand forecasting method based on the dynamic information of the disaster area. Moreover, after the outbreak of a disaster, the people in each disaster area have diverse types of demands for materials due to different degrees of injuries, which indicates that the construction of a multi-material, multi-stage, multi-objective mathematical model for emergency resource dispatching and the improvement of intelligent optimisation algorithms for the design of model calculations are the focus of future research.

(2) Most of the existing research on emergency resources is only on the one object of resources, and is based on the assumption that there is sufficient power of rescuers. However, in real life, due to the suddenness of the disaster, when the reserve of emergency resources meets the needs of the disaster and the rescue force is lacking, there will still be an increase in losses. Based on the combination of emergency resources and emergency rescue forces is a major focus.

(3) Diversification of emergency resources and geographical research. With the development of the times, emergency resources are not only food, medical supplies and so on, social resources such as network data can also assist in rapid emergency rescue, to ensure that the disaster situation in real time; and, for the deployment of emergency supplies is no longer concentrated in a certain region, cross-regional transport and supplementation of materials is also a key point of the need to break through in future research.

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