

A hybrid decision-making approach for locating rescue materials storage points under public emergencies

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A hybrid decision-making approach for locating rescue materials storage points under public emergencies

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Abstract

Purpose – In modern urban governance, rescue materials storage points (RMSP) are a vital role to be considered in responding to public emergencies and improving a city's emergency management. This study analyzes the siting of community-centered relief supply facilities.

Design/methodology/approach – Combining [grey relational analysis](#), complex network and relative entropy, a new multi criteria method is proposed. It pays more attention to the needs of the community, taking into account the use of community hospitals, fire centers and neighborhood offices to establish small RMSP.

Findings – The research results firstly found suitable areas for RMSP site selection, including Hanyang, Qiaokou, Jiangan and Wuchang. The top 10 nodes in each region are found as the location of emergency facilities, which the network parameters are higher than ordinary nodes in traffic networks. The proposed method was applied in Wuhan, China, and the method was verified by using a complex network model combined with multi-criteria decision-making for emergency facility location.

Practical implications – This method solves the problem of how to choose the optimal solution, and reduces the difficulty for decision makers. This method will help emergency managers to locate and plan RMSP more simply, [especially in improving traffic modeling technology and in providing a reference for future research especially in improving emergency siting modeling techniques and additionally in providing a –reference for future research.](#)

Originality/value – ~~Incorporate RMSP into the emergency supply chain network as a key rescue organization force. The advantage of maintaining the number of emergency facilities. In order to quickly enter the demand point, the urban community-centered RMSP can improve the community's post-disaster emergency response capability. The method proposed in this study is beneficial to improve the decision-making ability of urban emergency departments. Using complex networks and comprehensive evaluation techniques, RMSP is incorporated into the urban community emergency network as a critical rescue force. More importantly, the findings expand highlight a new direction for further the research direction of urban emergency facilities site selection and based on provides a combination of sound theoretical basis as well as empirical evidence gained from real life case based analysis and case basis for urban emergency rescue facilities site selection. concept proposed in this studywards improved The results of this study have highlighted the benefits of iingoverall. This can help to maximize and exploitsavailable improve capability of for the benefit of~~

1. Introduction

~~Public emergencies (droughts, earthquakes, floods or storms, epidemics or man-made damage) are characterized by suddenness, complexity, disruption and persistence (Song *et al.*, 2021), which In recent years, frequent public emergencies (such as the nuclear meltdown in Japan, 2011, urban flooding in Bangladesh, 2015 and the 2019 coronavirus disease pandemic in early 2020) have hasand are known to –seriously affected the safety of public life and property (Amajuoyi *et al.*, 2020; Song *et al.*, 2021). Examples of these emergencies include [the nuclear accident in Japan \(2011\), the urban floods in Bangladesh \(2015\), and the COVID-19 pandemic in early 2020.](#) –Over the past 20 years, there~~

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3 have been more than 6,000 similar incidents, and with the current global Covid epidemic has
4 infected affecting 600 million people and causing killed 6,498,847 fatalities (Kundu *et al.*, 2022)(Kundu
5 *et al.*, 2022). How to rescue the wounded people, distribute materials, and reduce losses has
6 attracted increasing attention from managers and scholars involved in disaster management. When
7 huge disasters occur, in addition to basic needs for food and provisions, a large number of rescue
8 materials are also needed. In response to disasters and natural hazards, a robust and resilient
9 emergency supply system is recognized as a key component of emergency plans and response (Ji and
10 Qi, 2020). Among the As part of this system, the problem issue of optimizing the location and
11 siting of Rescue Materials Storage Points (RMSP) positioning is worth thinking about an important
12 consideration. For example, Okeagu *et al.* (2020) discussed supply chain management,
13 governance and financing, emergency protocols and other issues in the context of emergency rescue.
14 Liu (2022) developed a new approach for evaluating the options for locating emergency shelters,
15 incorporating factors including terrain, resources, transportation and safety.

16
17 In the early stages of a large-scale emergency, it is impossible very difficult to obtain accurate
18 information for example, on the extent and scale of the disaster, the population affected and the
19 impact on critical infrastructure road traffic, etc. Consequently, this means that leads to a high level of
20 at potentially uncertainty in regard to the rescue needs from multiple RMSPs, for example the need
21 quantity, typology and prioritization of resources needed to support to be supported by sufficient the
22 rescue forces from multiple RMSPs. Coordinating and locating This raises the question of how to
23 choose the location of rescue materials storage points with reference to various considerations
24 including safety and accessibility. Rescue Materials Storage Points (RMSP) is one of the issues that
25 must be considered in public emergencies when planning and preparing for disasters. This is because
26 the correct location of these RMSPs will help to improve functions for material distribution, casualty
27 rescue, disaster command and so on. That is, these emergency facilities play a key role in enhancing
28 the resilience and service levels of urban communities. In fact, in the past, academic researchers
29 and humanitarian practitioners have made sufficient various studies and explorations on how to
30 undertake emergency site selection. For example, The emergency material center by (Kundu, Sheu
31 and Kuo, 2022) mainly assumed a response role in the early stages of an emergency to solve the
32 problem of help support a more rapid (Kundu, Sheu and Kuo, 2022)(Kundu, Sheu and Kuo,
33 2022) Other response. Other researchers are still thinking have considered issues such as about the
34 maximum coverage, fair distribution and uncertainty in site selection (Amorim *et al.*, 2020).
35 These studies have highlighted the importance of understanding It is easy to understand that even
36 in the challenges associated with having the ease of limited or in some cases insufficient relief
37 supplies and within a highly uncertain and unpredictable, rapidly changing situation, where the
38 consequences of decision making are paramount. uncertain needs. The positioning of RMSP should
39 focus on aiming to maximize the issue of maximum aggregate coverage and fair equity in the
40 distribution of emergency resources across multiple communities, among recipients. Sarma *et al.*
41 (2019) considered that after a disaster, in order to serve public health systems, humanitarian logistical
42 activities should be used with some urgency. During disaster relief processes, Wang (2020) studied
43 the safe evacuation of victims and proposed a two-stage stochastic planning model. Although these
44 research themes have received much attention, RMSP centered around urban communities has so far
45 been lacking and represents an important direction for future research.

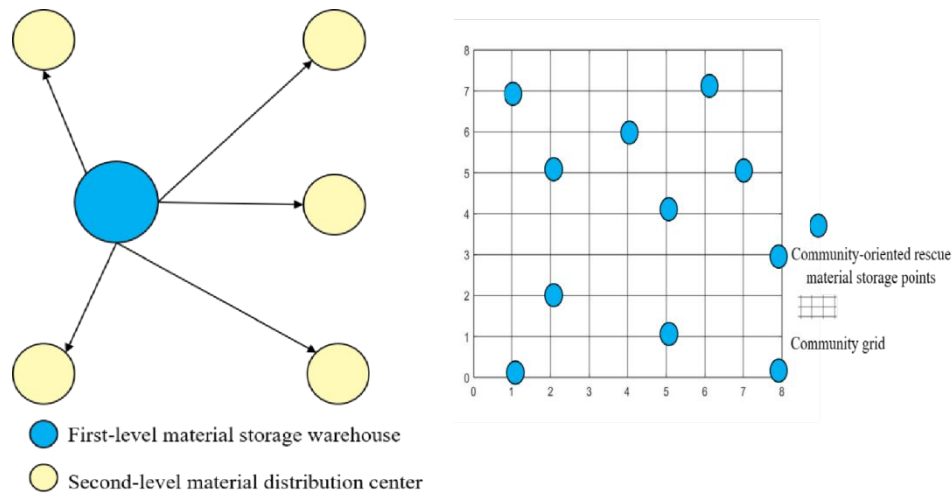


Figure 1. A multi-level material storage system and community-oriented RMSP

Although the siting of emergency facilities siting (EFS) has been fully studied the subject of much research, when it comes to emergency material storage centers, there has been a reliance on the use of choosing large-scale material warehouses, distribution and medical centers, and medical centers has become the stereotyped first choice. Hence, the ultimate aim of this study is to help improve It is obvious that the proper the location of -RMSP location becomes the main task of this study towards supporting more effective emergency rescue. Therefore, based drawing on evidence from a critical review of the -on the literature review, this paper study proposes an urban community-centered RMSP site selection model research goal. For one thing The model incorporates -various risk factors in based on -the nature and needs of the community and -are superimposed. Emergency site selection based on community needs is in line with the characteristics for dense of the population and urgent needs. A For another, a Accordingly, this study focused on investigating the location of RMSP around the needs of urban communities. As shown in Figure 1, a multi-level material storage system requires a large-scale storage center (Wei et al. et al., 2020), while secondary level RMSPs require a smaller area of site, but also need to maintain sufficient quantities of materials to meet disaster relief needs. Figure. 1 demonstrates that these storage points may not necessarily be very large scale, and often there may be many of these located in different parts of a city (Zdb et al. et al., 2022). The intention is to enhance the rescue capability during public emergencies, and improve a city's emergency management and general public service levels.

To marisummarize up, against the background of major public emergencies, -background- an urban community-based RMSP positioning problem challenge is proposed has been highlighted, with the purpose of improving the level of urban emergency management and public services to the public. Based on this understanding, the goals and research limitations of urban RMSP construction are proposed are highlighted, and a two-stage emergency site selection model is established. Taking several community networks in Wuhan, China as an example, the ranking of key decisions and coupled with the use of complex network model algorithms are used to solve the model. Compared with the previous ranking methods, the ranking results of the proposed method are more stable than the single Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method, and the data variance is smaller. The feasibility and reliability of the model are demonstrated through the -and the case analysis, in section 5 proves the feasibility of model. The advantage of the

new hybrid method is that it does not require a complex solution algorithm but makes full use of the statistical characteristics of the emergency site selection area, thereby reducing the difficulty of emergency management decision-making.

In sections 2 and 3, the key topics related to emergency facility siting (EFS) including the research methods are summarized and reviewed. Following this, the research methods and technical routes of this research Emergency Facility Siting (EFS) and proposed technical routes are explained, including gray correlation, characteristic parameters of complex networks, TOPSIS and relative entropy function. Section 4 selects Wuhan, China as the research area, and presents an analysis of the selection of RMSP for the city. The final section provides a concise summary of this research work and identifies the main contributions arising from the study. The limitations of the research and future research plans are also presented.

2. Literature review on method of EFS

2.1 Research Topics on EFS

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 Network: N=241, E=562 (Density=0.0194)
 Largest CC: 188 (78%)
 Nodes Labeled: 1.0%
 Pruning: Pathfinder
 Modularity Q=0.9154
 Weighted Mean Silhouette S=0.9213
 Harmonic Mean(Q, S)=0.9681

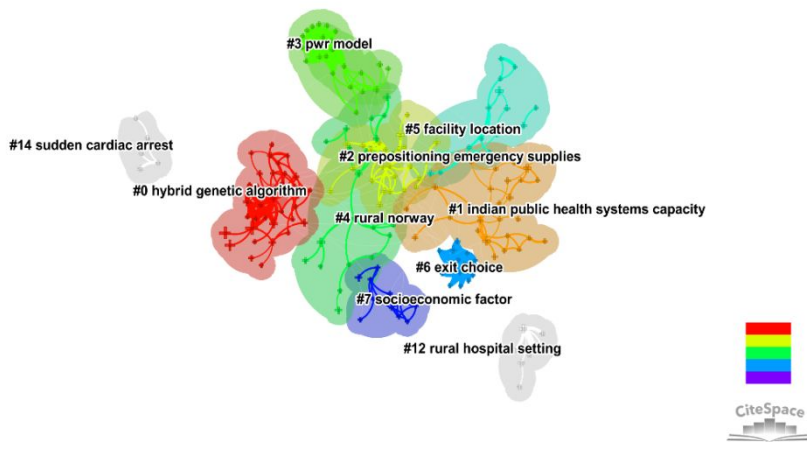


Figure 2. Research direction of emergency facility location

Focusing on emergency site selection, with "emergency management" and "emergency facility site selection" as the main keywords, 459 core journal documents from 2016 to 2021 were retrieved from the Web of Science database. Figure 2 shows the main directions of research on emergency facility location, including public health systems, emergency supply, model construction and algorithm analysis, emergency facilities and so on.

Public health management and emergency supply are frequently considered topics in disaster management, focusing on issues such as risk assessment, mitigation, and rescue services. In the context of COVID-19, Shen et al. (2021) discussed public risk perception levels in response to emergencies from three dimensions: fear risk, severity risk and unknown risk. As the

probability of public emergencies increases, Fathollahzadeh et al. (2022) proposed that disaster risk communication by aid organizations can help improve society's preparedness for disasters. EFS are as important as material scheduling and route optimization, and plays a fundamental role in responding to public emergencies and supporting humanitarian relief and disaster management requirements (Praneetpholkrang and Kanjanawattana, 2021).

Although there has been much research on the topic of EFS, there has been a lack of research concerning the siting around the community. In the past, research on EFS has considered the suddenness, severity and rescue of disasters (Batsaris et al., 2019). However, cost constraints can make it difficult to carry out large scale site selection studies, with facilities dispersed widely on the edges of a city. When large scale emergencies occur, it is hard for materials in marginal locations to meet immediate needs. The conditions of disaster reduction management in cities included communities with high population density and concentrated locations. In the interests of public welfare and humanitarian spirit, it is necessary to locate the emergency material reserve centers around the community (Gössler et al., 2020; Medley, 2020). In addition, the review highlighted a preference for emergency managers to focus on the larger high-level emergency shelters, but with limited consideration of the construction of small and medium-sized shelters in the disaster prevention systems (Wei et al., 2020). As a key transfer point and when it becomes difficult to activate larger shelters, small and medium-sized facilities become increasingly important and hence should not be ignored.

2.2 Methods of EFS

To a certain extent, as show in Table 1(Appendix), classical siting models provide a useful reference for emergency facility siting, such as Centroid method, set cover, P-median, and integer programming, etc. Methods such as ensemble coverage, P-median, and centroid methods are commonly used site selection models (Liu et al. et al., 2021b). However, with the changing demands on the emergency management environment, multi-objective planning has attracted the attention of researchers. A multi-objective, two-stage stochastic, nonlinear, mixed integer mathematical model of disaster relief pre-positioning in disaster management was provided by Mohammad Rezaei-Malek(Rezaei-Malek et al. et al., 2016). Similarly, Edwards et al. (2021) used a multi-stage method to improve the quality of evidence about safety and clinical effectiveness, and used this to classify streaming pathways in emergency departments in England and Wales. Feng et al. et al. (2020) introduced more practical factors and proposed a mathematical model for the location of emergency materials warehouses and minimized total transportation distances and costs. It can be seen that the method of EFS should be adjusted according to the special/particular characteristic of the environment, because these have to ~~is not only to deal~~ not only with the suddenness and relativity of public emergencies, but more importantly, to consider a variety of variables in the model, including traffic, climate, life/people and property, etc.

In addition, dynamic planning and fuzzy programming capabilities must not be underestimated. In emergency response planning, relevant logistical data may change during the response. Another difficulty is the particular characteristics of eachity of disasters. In many cases, there is not-insufficient data to simulate the determined parameters. In response to this situation, a multi-stage dynamic emergency facility location model was developed, including a static pre-disaster stage and a dynamic post-disaster stage. In response to this developed a multi-stage dynamic emergency material supply model, including a static pre-disaster phase and a dynamic post-disaster phase(Yang

et al., 2021). Wang designed an optimization-dynamic model for rescue in a disaster environment, taking into account the urgency of demand points by considering demand characteristics, relief types and waiting time priority scores. Wan et al. (2021) also analyzed the difficulties around locating material distribution centers in large-scale disasters and fuzzy scenarios. Their parameters included demand, capacity, transportation costs, operating costs, and vehicle runtime. The literature also revealed that some studies found that some people have begun to think about consider the robustness of EFS. Scholars claim that robust optimization does not require specific probability distribution functions of uncertain parameters, and the computational complexity of the optimal solution is also significantly reduced (Liu et al., 2019).

Looking further, EFS research methods continue to improve evolve and develop. Technologies such as GIS, unmanned aerial vehicles (UAV), and remote sensing satellites have been applied in emergency site selection (Ejaz et al., 2020; Xiao et al., 2020). When choosing the location of a fire station, some scholars have achieved comprehensive coverage of areas with high fire risk through buffer zone and superposition analysis methods. The case studies of UAV assisted earthquake recovery, wildfire detection and biological disease management networks were discussed in depth, and the implementation challenges and possible UAV assisted solutions were emphasized. However, developing algorithms at scale has become a challenge, especially when decision makers are unfamiliar with these complex technologies. Multi-criteria decision-making (MCDM) techniques, as a large-scale decision-making, have been shown to bypass these obstacles (Labella et al., 2018). Jena and Pradhan (2020) has been (Aydın and Seker, 2021) It is interesting that some people consider eliminating the problem of expert conflict in emergency decision-making. Because of a certain willingness to compromise, the final decision can be made (Xu et al., 2018; Xu et al., 2015).

In order to better serve the decision-making management work, the MCDM decision-making model has been continuously improved after absorbing theories from other disciplines. Some scholars have studied a series of fuzzy conceptual frameworks for evaluating urban traffic management schemes, using the improved fuzzy Einstein Combined Compromise Solution methodology and scalable rough numbers (Deveci et al., 2022b; Gokasar et al., 2023). Detailed research is reflected in the weight of decision criteria. A proposed the Weighted Aggregated Sum Product Assessment algorithm for healthcare system evaluation and sensitivity analysis (Deveci et al., 2022a). Although the MCDM technology has been proved demonstrated in the application to EFS, the previous methods attempts have ignored several problems important considerations. Firstly, the geographical and environmental conditions of the site area, including hydrology, climate, economy, transportation and other factors, were not considered in advance. Secondly, it appears that the final sites chosen have often been located in a complex road networks, and their accessibility under traffic interruption should be has not been fully considered. Therefore, this paper research attempts to put forward a new hybrid location method based on an analysis of the appropriate proposed site selection area of the RMSP site location according to the Grey relational analysis (GRA). Given the probability of traffic interruption probability, all the alternative locations are embedded in the network, and the optimal solution of the alternative locations in a network is ranked by the Relative Entropy TOPSIS, which provides a rigorous and accurate basis for the location analysis of emergency facilities.

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3 A combination of mathematical models and specific scenarios has led to continuous
4 improvement in EFS research methods. However, developing large-scale algorithms has become
5 a challenge, especially when decision makers are not expert in these complex techniques.
6 However, multi-criteria decision-making techniques can circumvent these obstacles (Deogam
7 and Shabbiruddin, 2019). Taking in the findings from the review of the literature, this research
8 attempts to propose a new hybrid site selection method combining both quantitative and
9 qualitative methods. The theories of complex networks and relative entropy, combined with the
10 TOPSIS method, are proposed as the basis for a more rigorous and accurate basis for the analysis
11 of emergency site selection.
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16 3. The proposed method

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18 A proposed hybrid decision-making method for evaluating the location of emergency storage
19 facilities is presented in section 3. Core to this research design was a need to first evaluate all the
20 urban areas of Wuhan and then select the initial area for focus, and then screen the key nodes affecting
21 the location of RMSP through complex network modelling. From the research method presented in
22 Figure 3, first step was the development of a grey correlation model to generate the location areas of
23 the initial RMSP, based on an analysis of factors affecting EFS. Next, in order to simplify the model,
24 an undirected and unweighted traffic network model with constructed using relative entropy and
25 TOPSIS formula to measure the parameter values of the network nodes. Finally, it was necessary to
26 adopt an infectious disease model to verify the capability of critical nodes propagation and compare
27 the test methods. Section 3 presentsdescribes the methods used to develop the a hybrid decision-
28 making method model for evaluating the location of EFS as presented in Figure 2 reveals this method
29 ideal. The first step is to develop the Grey relational analysis based on the analysis of the factors
30 which influence EFS and to generate the proposed location area of the initial RMSP. Next, the
31 candidate nodes are put into the traffic network model in the region. In order to simplify the model,
32 the relative entropy and TOPSIS formula are used to sort the nodes and select the key nodes as the
33 final positions. Finally, it is necessary to use an infectious disease model to verify the transmission
34 ability of key nodes and compare test methods.
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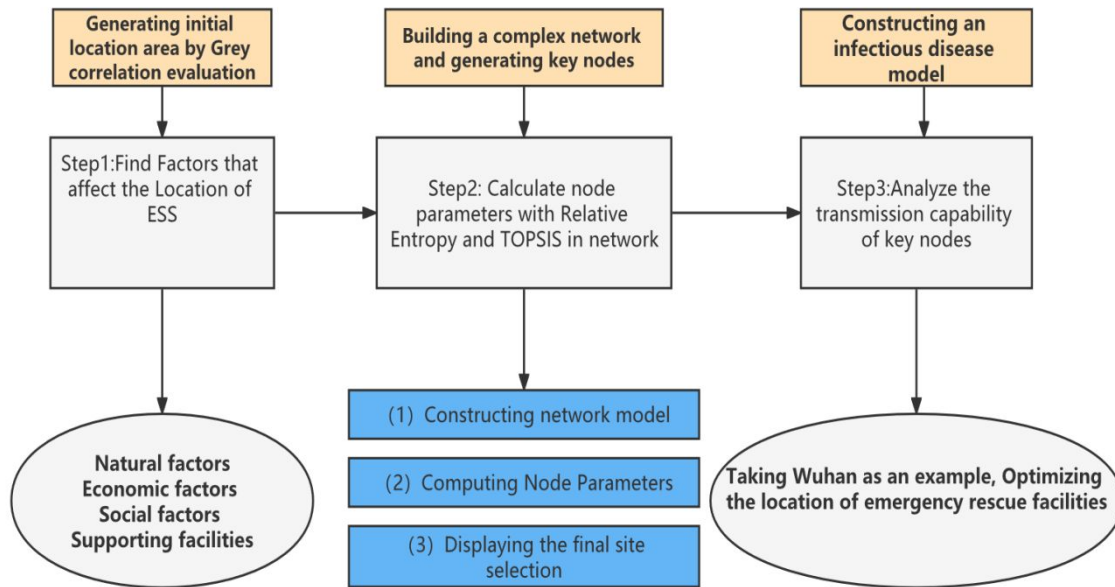


Figure 32. Research methods and technical routes

3.1 Grey correlation model

GRA is an important part of grey theory analysis and has been widely used in engineering, society, economy and other fields. Since the obtained data information can be fully utilized, some scholars have applied it to the site selection problem, including photovoltaic base stations, power stations, warehouses and convenience stores (Chen et al., 2016; Li et al., 2020; Lo et al., 2021). However, there are few studies on the GRA method for analyzing EFS. So, this paper research adopts the relative closeness of grey relation as the evaluation standard to make up for this deficiency. Grey correlation assessment is a part of grey system theory (Rajesh et al., 2021). Its main premise is to determine the appropriate proximity between reference sequences and influencing factors, and study geometric relationship between sequences. The analysis process is as follows.

Step 1: Determine relevant reference sequence X_0 and an analysis array X_i , $X_0 = [x_0(1), x_0(2), x_0(3), \dots, x_0(m)]$, X_i is a $n \times m$ matrix as $D_{(n \times m)}$. n is the number of sequences to analyze, and m represents the amount of data in each sequence.

$$X_i = D_{(n \times m)} = \begin{bmatrix} x_1(1) & x_2(1) & \dots & x_n(1) \\ x_1(2) & x_2(2) & \dots & x_n(2) \\ \dots & \dots & \dots & \dots \\ x_1(m) & x_2(m) & \dots & x_n(m) \end{bmatrix}, i = 1, 2, \dots, n \quad (1)$$

$$X_i = D_{(n \times m)} = \begin{bmatrix} x_1(1) & x_2(1) & \dots & x_n(1) \\ x_1(2) & x_2(2) & \dots & x_n(2) \\ \vdots & \vdots & \ddots & \vdots \\ x_1(m) & x_2(m) & \dots & x_n(m) \end{bmatrix} \quad (1)$$

$i = 1, \dots, n, k = 1, \dots, m$

Step 2: Data standardization by adopting linear proportional conversion. A new result is

$D'_{(n \times m)}$ matrix. The formula is as follows:

$$D'_{(n \times m)} \equiv \begin{bmatrix} x_1(1) & x_2(1) & \dots & x_n(1) \\ x_1(2) & x_2(2) & \dots & x_n(2) \\ \vdots & \vdots & \ddots & \vdots \\ x_1(m) & x_2(m) & \dots & x_n(m) \end{bmatrix} \quad (2)$$

$$x'_i(k) \equiv \begin{cases} \frac{x_i(k)}{\max x_i} \\ -\frac{\max x_i}{x_i(k)} \end{cases} \quad (3)$$

$$D'_{(n \times m)} = \begin{bmatrix} x'_1(1) & x'_2(1) & \dots & x'_n(1) \\ x'_1(2) & x'_2(2) & \dots & x'_n(2) \\ \dots & \dots & \dots & \dots \\ x'_1(m) & x'_2(m) & \dots & x'_n(m) \end{bmatrix}, i=1, K, n \quad (2)$$

$$x'_i(k) = \begin{cases} \frac{x_i(k)}{x_i^{\max}} \\ \frac{x_i^{\max}}{x_i(k)} \end{cases} \quad (3)$$

$\frac{x_i(k)}{\max x_i}$ applies to efficiency index and $\frac{\max x_i}{x_i(k)}$ to cost index. $k = 1, \dots, m; i = 1, \dots, n$
 $k = 1, K, m; i = 1, K, n$

Step3: Create a deviation matrix M by calculating the corresponding difference. $M \equiv$

$$|x_0(k) - x'_i(k)|, M = |x_0(k) - x'_i(k)|, k = 1, K, m; i = 1, K, n$$

Step4: Find the maximum and minimum values of M , the formula is as follows:

$$A \equiv \max_i^n \max_k^m |x_0(k) - x'_i(k)| \quad (4)$$

$$B \equiv \min_i^n \min_k^m |x_0(k) - x'_i(k)| \quad (5)$$

$$A = \max_{i=1}^n \max_{k=1}^m |x_0(k) - x'_i(k)|, k = 1, K, m; i = 1, K, n \quad (4)$$

$$B = \min_{i=1}^n \min_{k=1}^m |x_0(k) - x'_i(k)|, k = 1, K, m; i = 1, K, n \quad (5)$$

Step5: Develop correlation coefficient and grey correlation degree. $\psi_i(k)$ is the correlation coefficient for analysis sequences and reference array. PP is a distinguishing

parameter. $0 \leq P \leq 1$, usually P is 0.5 (Karakoç et al., 2019). $R_{(oi)}$ indicates grey correlation degree. The formula is as follows.

$$\psi_i(k) = \frac{A + P \times B}{M + P \times B} \quad (6)$$

$$R_{(oi)} = \frac{1}{m} \sum_{k=1}^m \psi_i(k) \quad (7)$$

$$\psi_i(k) = \frac{A + P \times B}{M + P \times B}, k=1, K, m; i=1, K, n \quad (6)$$

$$R_{(oi)} = \frac{1}{m} \sum_{k=1}^m \psi_i(k), k=1, K, m; i=1, K, n$$

3.2 Complex networks and measurement of

characteristics

The RMSPP mentioned in this paper will be regarded as some collection of nodes, put into a grid of regions, in order to form a basic site selection network. Due to the large number of nodes, complex network models have to be considered. Although the theory and application of this model is relatively mature, further research is needed in terms of site selection, especially on EFS. Consequently, this will provide a favorable reference point for the subsequent site selection work.

A complex network G can be described by a set $G = (V, E)$, where $V = \{1, 2, \dots, n\}$, $E = \{1, 2, \dots, m\}$. V and E respectively represents a set to which nodes and edges; n and m are the number of nodes and edges. Therefore, a complex network G is defined, where C is the adjacency matrix of with scale $n \times n$. When $C_{ij} = 1$, indicates that node i is connected to node j , otherwise $C_{ij} = 0$.

Degree Centrality. The degree of node i in the complex network is denoted as $DC_{(i)}$ and defined as follows.

$$DC_{(i)} = \sum_{j=1}^n C_{ij}, j=1, \dots, n \quad (8)$$

$$DC_{(i)} = \sum_j C_{ij}, j=1, K, n \quad (8)$$

C_{ij} represents the number of adjacent nodes of node i

Betweenness Centrality. The betweenness centrality measure of node i , denoted as $BC_{(i)}$, is defined as.

$$BC_{(i)} \equiv \sum_{s \neq e \neq i} \frac{G_{se}^i}{G_{se}} \quad i \equiv 1, \dots, n \quad (9)$$

$$BC_{(i)} = \sum_{i \neq j \neq n} \frac{G_{se}^i}{G_{se}} \quad (9)$$

Where $G_{se} - G_{se}$ is the total number of shortest paths between node s and node e , and G_{se}^i is the number of shortest paths between node s and node e through node i .

Closeness Centrality. The closeness centrality measure of node i , denoted as $CC_{(i)}$ is defined as.

$$CC_{(i)} \equiv \frac{1}{\sum_{j=1}^n D_{ij}} \quad j \equiv 1, \dots, n \quad (10)$$

$$CC_{(i)} = \frac{1}{\sum_{j=1}^n D_{ij}} \quad (10)$$

D_{ij} represents the distance between node i and node j .

The greater the value of $DC_{(i)}$, $BC_{(i)}$ and $CC_{(i)}$, the more important the node is, that is a position of key node in complex network (Li and Xiao, 2021). This is a significant foundation to inform the selection of the location of RMSP in a network. However, when considering the actual site selection network, this requires further analysis and exploration. There is also no uniform sort standard for the indicators and therefore, TOPSIS and relative entropy are used to address this problem.

3.3.3 TOPSIS and Relative entropy theory

The "Considering the complex network result sorting processing—" Technique for Order of Preference by Similarity to Ideal Solution " has become the preferred method when considering complex networks and for processing sorting. This is because the initial data can be fully exploited and this has been proven useful in the application of site selection studies (Singh et al., 2020). TOPSIS has the advantages of being more realistic, intuitive and reliable and hence its use in this study. The method process is as follows. The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method represents a comprehensive evaluation method used for multi-objective decision-making able to cope with limitations in data. This method makes full use of the information from original data, so it can achieve a more accurate, more intuitive and more reliable outcome, reflecting the gap between various programs. The method involves the following steps (Chen, 2021).

Based on an initial decision matrix $P \equiv \{p_{ij}\}_{n \times m}$, data is then normalized to derive the normalization matrix $Z \equiv \{z_{ij}\}_{n \times m}$, $Z_{ij} \equiv \frac{p_{ij}}{\sqrt{\sum_{i=1}^m p_{ij}^2}}$, $i \equiv 1, \dots, n; j \equiv 1, \dots, m$

$$Z_{ij} = \frac{p_{ij}}{\sqrt{\sum_{j=1}^m p_{ij}^2}}, i = 1, \dots, n, j = 1, \dots, m.$$

Next, positive and negative ideal solutions need to be determined. The positive ideal solution is reached when all indicators reach the best value in the sample, and the negative ideal solution is derived when all indicators reach the worst value in a sample. The Formula is as follows.

$$Z^+ = (\max \{z_{11}, z_{21}, \dots, z_{n1}\}, \max \{z_{21}, z_{22}, \dots, z_{n2}\}, \dots, \max \{z_{1m}, z_{2m}, \dots, z_{nm}\})$$

$$= (Z_1^+, Z_2^+, \dots, Z_m^+) \quad (11)$$

$$Z^- = (\min \{z_{11}, z_{21}, \dots, z_{n1}\}, \min \{z_{21}, z_{22}, \dots, z_{n2}\}, \dots, \min \{z_{1m}, z_{2m}, \dots, z_{nm}\})$$

$$= (Z_1^-, Z_2^-, \dots, Z_m^-) \quad (12)$$

Finally, every distaneesdistance from each sample to the positive and negative ideal solution is calculated (Euclidean space distance), basing on the closeness of each evaluation object to achieve the optimal solution A_i . Formula is as follows.

$$D_i^+ \equiv \sqrt{\sum_{j=1}^m (z_{ij} - z_j^+)^2} \quad (13)$$

$$D_i^- \equiv \sqrt{\sum_{j=1}^m (z_{ij} - z_j^-)^2} \quad (14)$$

$$A_i \equiv \frac{D_i^-}{D_i^+ + D_i^-}, i \equiv 1, \dots, n. \quad (15)$$

Where the value range of A_i is [0,1]. The closer the value of the closeness of the optimal scheme is to 1, the better (Jatin ~~et al~~ *et al.*, 2021).

Relative entropy is a basic concept in probability theory and information theory. Originally used in information theory to measure the difference in the distribution of the signal information of two sources, it was posed by Kullback and Leibler. Relative entropy is an asymmetric measure of two probability distributions. For the two probabilities P and Q, the formula is as follows. Here, it is defined by expected function, and the logarithm e is the base number.

$$D_{KL}(P \parallel Q) \equiv E_x \sim p \left[\log \frac{P(x)}{Q(x)} \right] \equiv E_x \sim p [\log P(x) - \log Q(x)] \quad (16)$$

According to relative entropy, the states of systems X and Y can be measured, and end- result is Kullback Leibler divergence (Fei and Deng, 2017). The formula is as follows.

$$R = \sum_{i=1}^n \left\{ X_i \frac{X_i}{Y_i} + (1 - X_i) \frac{1 - X_i}{1 - Y_i} \right\}, i \in 1, 2, \dots, n \quad (17)$$

R is called the relative entropy of these two systems. The smaller value of R, the smaller difference X and Y. It is a description of the ideal state of a system, so the value of system needs to be determined. Here, TOPSIS method is used to find boundary value between systems. Transform some of above formulas as follows. (The base of logarithm is 10)

$$T_i^+ \equiv \sum_{i=1}^n \left\{ z_i^+ \log \frac{z_i^+}{z_i} + (1 - z_i^+) \log \frac{1 - z_i^+}{1 - z_i} \right\} \quad (18)$$

$$T_i^- \equiv \sum_{i=1}^n \left\{ z_i^- \log \frac{z_i^-}{z_i} + (1 - z_i^-) \log \frac{1 - z_i^-}{1 - z_i} \right\} \quad (19)$$

$$A_i' \equiv \frac{T_i^-}{T_i^+ + T_i^-} \quad (20)$$

4. A real case application of the method

4.1 EFS location area introduction

In this study, EFS sites located in Wuhan City, Hubei Province, China, including 13 urban districts (Jiangnan District, Jiangnan District, Qiaokou District, Hanyang District, Wuchang District, Qingshan District, etc.) were studied, as shown in Figure 4. In 2016, flooding in Wuhan City posed severe challenges to urban governance and caused severe damage to the community, which disaster affected 58712 people in the city. In Early 2020, Wuhan was given by the COVID-19 epidemic and there was a shortage of medical supplies, which led to great difficulties for many patients. Therefore, it is necessary to rethink emergency response and build community-centered emergency facilities to support the effective deployment of rescue forces and medical supplies.

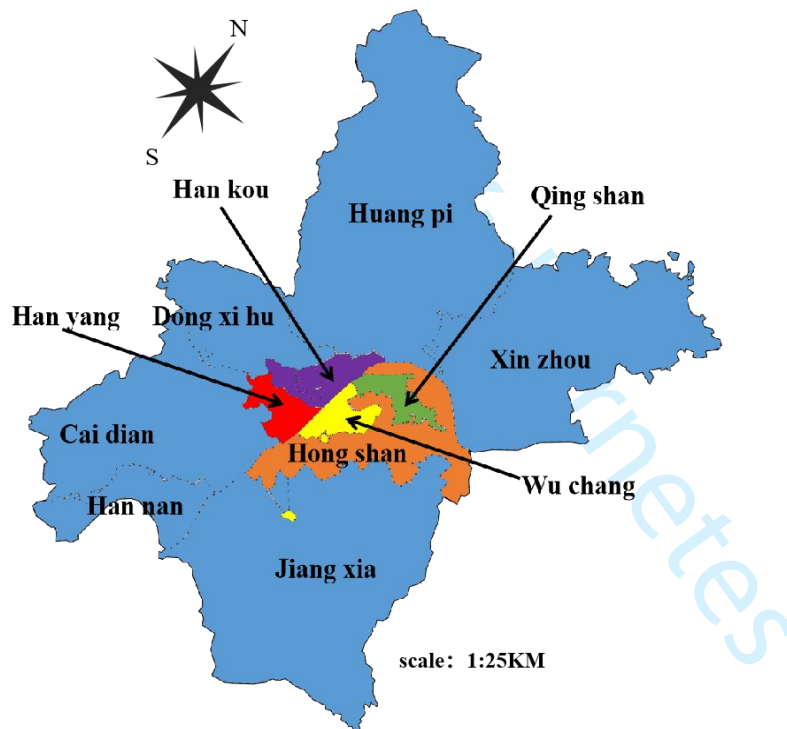


Figure 43. Orientation map of initial site selection area

* Hankou District includes Jiangnan, Jiangnan and Qiaokou District

In this study, EFS sites located in Wuhan City, Hubei Province, China, including 13 urban districts (Jiangnan District, Jiangnan District, Qiaokou District, Hanyang District, Wuchang District, Qingshan District, etc.) were studied, as shown in Figure 3. In 2016, flooding in Wuhan posed severe challenges to urban governance and caused damage to the community, which disaster affected 58712 people in the city. In Early 2020, Wuhan was given by the COVID-19 epidemic and there was a shortage of medical supplies, which led to great difficulties for many patients. Therefore, it is necessary to rethink emergency response and build community-centered emergency facilities to support the effective deployment of rescue forces and medical supplies.

4.2 Characteristics and factors of EFS

Generally speaking, common ordinary facilities are usually located in fixed and permanent locations. Emergency site selection is different from the site selection of ordinary storage facilities which are usually in fixed and permanent locations. In contrast, emergency facilities are usually temporary and changeable to the demands of different emergencies (Adalı and Tuş, 2021). Hence, emergency site selection EFS needs to consider the social benefits, rather than only the economic benefits, in order to support the protection of the public social welfare (Liu et al., 2021a). In fact, there are many factors that affecting EFS site selection, including natural, economic and social factors, traffic conditions and altitude to name a few.

There are many factors affecting EFS site selection, including natural, economic and social factors, traffic conditions, and altitude.

Table 12. The factors of EFS and their abbreviations description of influencing factors

Factors	Symbol	Directions
Altitude	A_{ij}	natural factors
The level of development	E_i	economic factors
The population density	P_D	
Availability of land	$L_A=1/L_P$	social factors
Sustainability of the project	$S_{us}=P_S*A_{cc}$	
Traffic accessibility	$A_{cc}=R_M/A_{re}$	infrastructure

* LP is the average price of land. Are is the area acreage. RM is the regional highway mileage. PS is the region population.

Table 12 summarizes the main factors affecting EFS site selection and their abbreviations as drawn from the extensive review of literature. When a disaster occurs, areas with high population density and high economic levels will be more impacted, and the consequences will be more serious. Hence, this research considers the population density and the level of economic development of the region as key considerations. In addition, it is necessary to consider issues including the availability of land, the altitude of the terrain, and the sustainability of the project. Altitude is a limiting factor, as if this is too low, the area will be more vulnerable to flooding. The sustainability of the project refers to the service coverage of the RMSP. The accessibility of traffic means that if one traffic route is interrupted or blocked, an alternative route is required.

Accessibility for traffic is important and requires alternative routes if one traffic route becomes disrupted or is blocked.

4.3 Case study and data discussion

Firstly, the initial site selection area was determined through grey relational assessment, and then final RMSP site is generated through a mixed decision-making method, which contains complex network methods and relative entropy TOPSIS models.

Generate initial location area

The data on emergency site selection factors were derived from the 2020 Wuhan Statistical Bulletin. Table 2-3 shows the factors and their standardized values (identified through Equation 3) that affect the EFS in each region of Wuhan. From Equations 4-7, Figure 5-4 shows the grey correlation coefficients for 13 regions calculated by MATLAB coding. The standard value is 1. If the value of any region is close to 1, it is considered that there is a small gap between it and the standard ideal level. The top 4 areas are selected as initial site selection areas. Given the above data, the areas selected were Wuchang District (0.9133), Qing shan District (0.8688), Jiang han District

(0.8875) and Jiang an District (0.8433) .--The population density and the economic level in these areas is very high. This means that there is often a huge demand for emergency supplies in densely populated urban areas. Determining the initial area lays the foundation for the next step of RMSP positioning. Next, the network model will be constructed and the ranking of key nodes will be obtained.

The population density and the level of economic development in these areas is very high, which also meets the basic requirements for the site selection of emergency facilities.

Table 23. Statistical results of factors affecting EFS in various Districts of Wuhan

Area	A_{li}	P_D	A_{cc}	L_A	S_{us}	E_l
Jiang an	0.55	0.46	0.46	0.97	0.52	0.82
Jiang han	0.45	1.00	0.62	0.95	0.54	0.88
Qiao kou	0.49	0.84	0.76	0.95	0.78	0.54
Han yang	0.60	0.23	0.42	1.00	0.33	0.47
Wu chang	0.55	0.77	0.65	0.94	1.00	0.93
Qing shan	0.64	0.36	1.00	0.98	0.63	0.53
Hong shan	0.55	0.12	0.18	0.98	0.36	0.65
Dong xi hu	0.40	0.05	0.20	0.98	0.15	0.82
Han nan	0.36	0.02	0.33	0.97	0.05	1.00
Cai dian	0.98	0.03	0.14	0.97	0.13	0.22
Jiang xia	0.82	0.02	0.08	0.91	0.10	0.52
Huang pi	1.00	0.02	0.08	0.94	0.10	0.59
Xin zhou	0.51	0.02	0.13	0.95	0.14	0.54

*The factors that affect the location of emergency facilities in different regions of Wuhan city and the value after standardization.

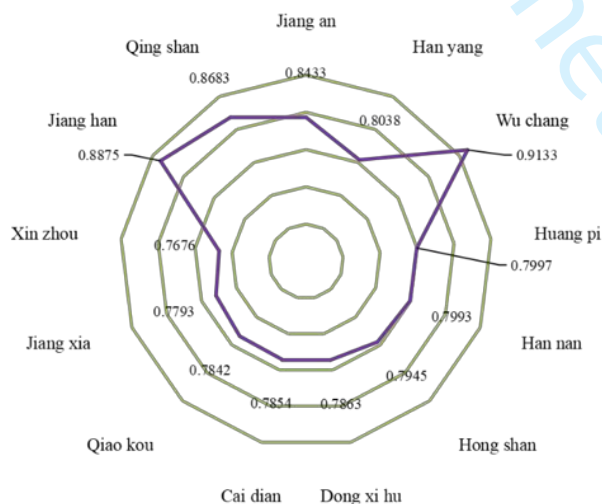


Figure 54. The number of regional correlation coefficient in Wuhan

Measure key nodes parameters

Step1: Constructing network model

The POI (Point of In Need) search tool and the python 3.7 crawler tool were used to search 553 nodes, including 137 site selection nodes (including hospitals, street offices, and fire stations), and 410 demand nodes (mainly communities), and where a network model is formed by the method of map display and clustering. Taking Jiang han District as an example, the 26 site selection points (latitude and longitude) were first displayed on a map. The K-means clustering algorithm is used to obtain the node cluster center coordinates in a location area, which lays the foundation for the

construction of the traffic network model. Figure 5 shows different clustering results, and different K values and these have different numbers of center sites. Next, there is a need to find a suitable value for K. This can be addressed by the elbow rule. K-means minimizes the least square error (Behzadi *et al.*). While LSE are usually noted as distortions, this will decrease with the increasing number of clusters, but for data with a certain discrimination, the distortion will be greatly improved when a certain critical point is reached, and then slowly decreases.

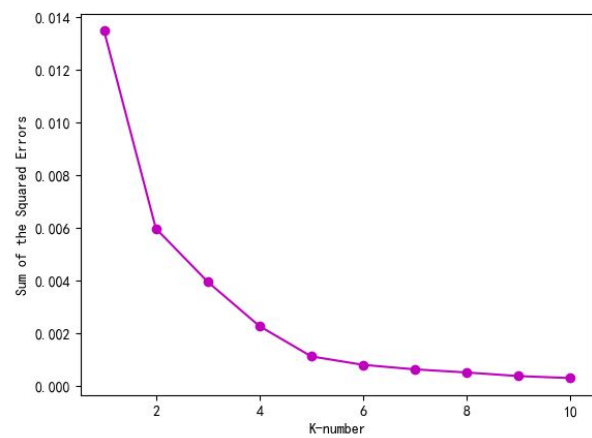
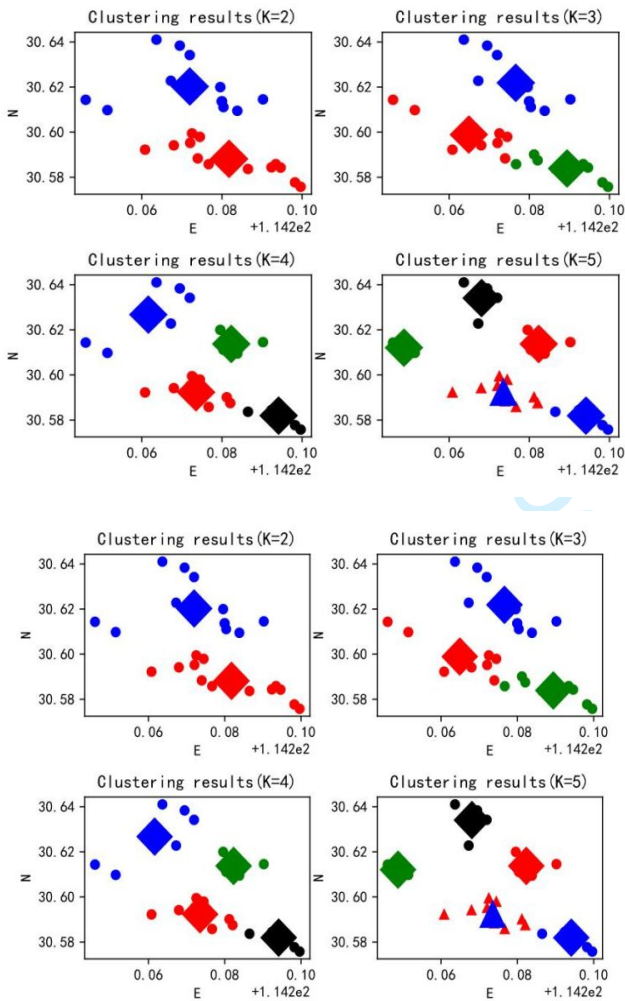


Figure 5. Coordinate clustering of site selection points in Jiang han District

Figure 6. The result of Elbow Method for Jiang han District

Figure 6. Coordinate clustering of site selection points in Jiang han District

The POI (Point of Interest) search tool and the python 3.7 crawler tool were used to search 553 nodes, including 137 site selection nodes (including hospitals, street offices, and fire stations), and 410 demand nodes (mainly communities), and where a network model is formed by the method of map location display and clustering. Taking Jiang han District as an example, the 26 site selection points (latitude and longitude) were first displayed on a map. Through K-means clustering algorithm, the node cluster center coordinates of the location area were found, thus representing the basis of constructing the traffic network model. Figure 6 shows different

clustering results, and different K values and these have different numbers of center sites. Next, there is a need to find a suitable value for K. This can be addressed by the elbow rule. K means minimizes the least square error (Behzadi et al.) (Behzadi et al.) between the sample and the point particle as the objective function. While LSE are usually noted as distortions, this will decrease with the increasing number of clusters, but for data with a certain discrimination, the distortion will be greatly improved when a certain critical point is reached, and then slowly decreases.

According to Figure 76, K=4 is a turning point, so 4-four centers in Jianghan District were selected to build the traffic network model, respectively coordinates being (N 30.623, E 114.267), (N 30.613, E 114.280), (N 30.614, E 114.280), (N 30.586, E 114.293). Considering the road damage, the connection probability of the network is set to 0.14 (Table 34 shows the numerical description of the rest of the regional network models). Similarly, other regional traffic models were constructed, and finally all network model shown in Figure 8-7 (figures 8a7a-8d7d) was formed. It should be noted that the network model changes the relative positions of actual coordinate points, but does not affect calculation results.

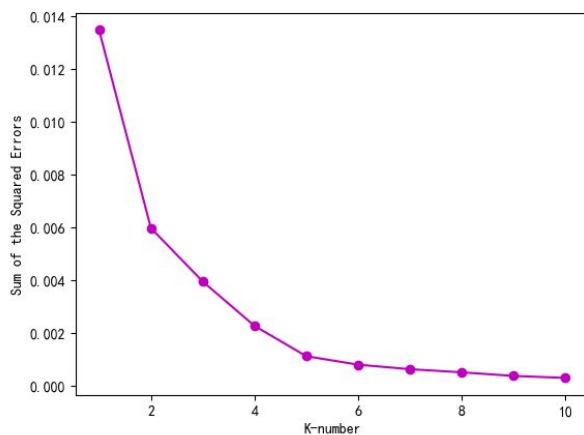


Figure 7. The result of Elbow Method for Jiang han District

Table 34. Numerical description of the network model

Network	Note	Edge	Edge connecting probability
Jiang han	26	46	0.14
Wu chang	45	81	0.07
Jiang an	37	67	0.10
Qing shan	29	62	0.15

Step2: Computing Node Parameters

The nodes in figures 8a7a-8d7d represents the connection relationship of site selection positions, and indicates the EFS-emergency site selection location in the real road network (including hospitals, street offices, and fire stations). Different connections have different network densities. A key question that this research sort to address is how to filter the critical nodes as RMSP. In complex network theory, key nodes are often related to distinct thresholds set by researchers (Yu et al. et al., 2017) and there is no unified standard. In this study, the nodes whose relative entropy value is higher

1
2
3 than the average value of the whole network were selected as the key nodes. In order to unify the
4 findings for the four regions, combined with the previous formula (section 3.2 and 3.3), the top 10
5 nodes were taken as the key nodes. According to the data in Table 4-5 (Table 4 shows the results of
6 ~~part key nodes, and the~~ The detailed data is shown in the Data Availability Statement.), if $DC_{(i)}$,
7 $BC_{(i)}$ or $CC_{(i)}$ are considered separately, the order of nodes will change. For example, if $DC_{(i)}$ is
8 considered separately, node 21 will be ranked in front of node 9, but if considering $BC_{(i)}$ the results
9 will be different. This uncertainty and confusion in the ordering of nodes brings obstacles to decision-
10 makers. Therefore, it is not possible to consider a certain parameter alone for decision-making, but to
11 unify these through the relative entropy TOPSIS.
12
13

14
15 The larger the value of the network parameter of the key node, the more stable the network
16 model, the better the robustness of the network, and the more important the position in the network
17 model. The network parameter value is usually positively correlated with the stability of the network
18 model. The larger the value, the better the network robustness and the more important the position in
19 the network model. In the actual environment (road networks, aircraft routes, transportation routes),
20 can be understood as a transit center or a hub of multiple roads and will be many possible outward
21 routes. Hence, when an emergency occurs, there can be other optional routes to be considered. For
22 example and in line with this situation is when the preferred disaster relief route is damaged in the
23 disaster scenario and an alternative route needs to be used (Adalı and Tuş, 2021; Maharjan and
24 Hanaoka, 2018).
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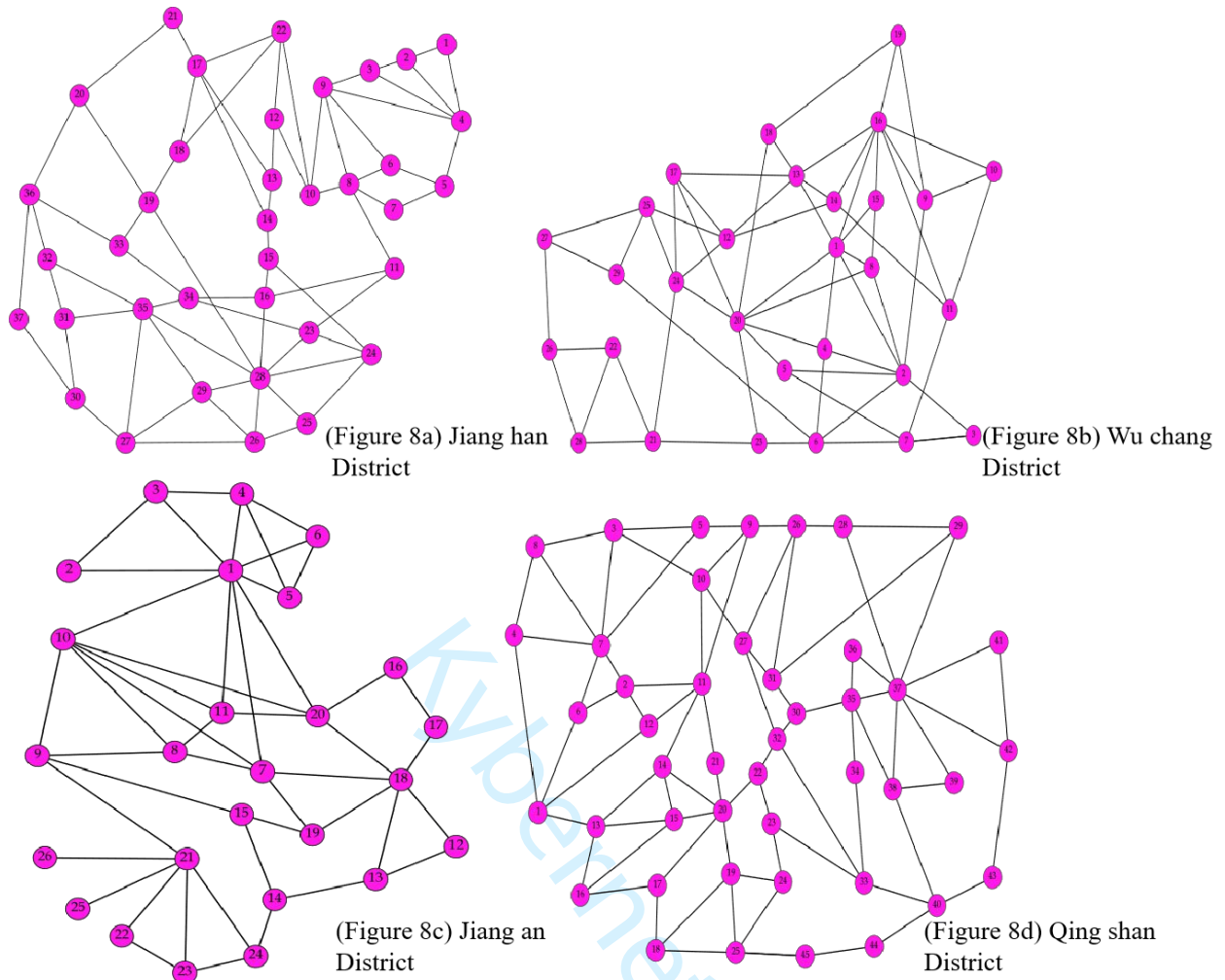


Figure 87. Abstract Road network model of location area from Jiang han District to Qing shan District

~~The larger the value of the network parameter of the key node, the more stable the network model, the better the robustness of the network, and the more important the position in the network model. In the actual environment (road networks, aircraft routes, transportation routes), can be understood as a transit center or a hub of multiple roads and will be many possible outward routes. Hence, when an emergency occurs, there can be other optional routes to be considered. For example and in line with this situation is when the preferred disaster relief route is damaged in the disaster scenario and an alternative route needs to be used (Adah and Tuş, 2021; Maharjan and Hanaoka, 2018).~~

Table 45. Jiang han Distinct

Note	$DC_{(t)}$	$BC_{(t)}$	$CC_{(t)}$	A'_i	Coordinate (N, E)
NO.1	0.45	0.50	0.24	2.11	(30.623,114.267)
NO.21	0.30	0.44	0.20	2.18	(30.586,114.293)
NO.10	0.30	0.37	0.26	1.41	(30.600,114.274)
NO.9	0.20	0.46	0.24	1.94	(30.615,114.290)
NO.18	0.30	0.28	0.22	1.28	(30.597,114.274)
NO.20	0.25	0.21	0.24	0.88	(30.599,114.273)
NO.7	0.25	0.18	0.24	0.76	(30.614,114.280)
NO.14	0.15	0.12	0.18	0.66	(30.587,114.282)
NO.13	0.15	0.11	0.20	0.56	(30.614,114.280)
NO.15	0.15	0.09	0.20	0.44	(30.590,114.281)

*Tables 6 are the top 10 nodes. The corresponding numerical calculations are processed by normalization formula, ranging from [0,1].

Step3: Displaying the final site selection

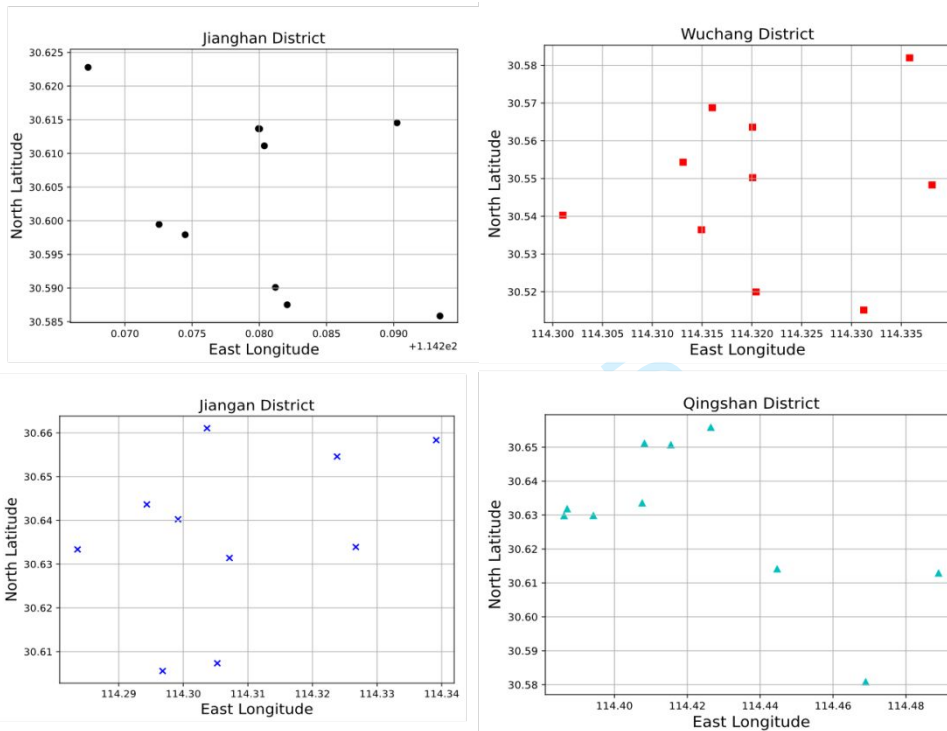


Figure 98. Distribution display of RMSP

Referring to Table 5, Figure 8 shows the calculation results in step 2. Figure 9 shows the results of the calculation in step 2. From the previous research data, the 10 nodes in each area were marked on the latitude and longitude map. First of all, the distribution of nodes in each area is different because the transportation network distribution and network density are different. Secondly, the location distance of the site selection point maybe smaller, for example, the Qing shan District has two adjacent locations near 30.63 degrees north latitude. At this time, the decision-maker for choosing the location of RMSP emergency facilities can further optimize the analysis through mathematical modeling technology. For example, ensemble coverage models and fair welfare function mechanisms can be learned.

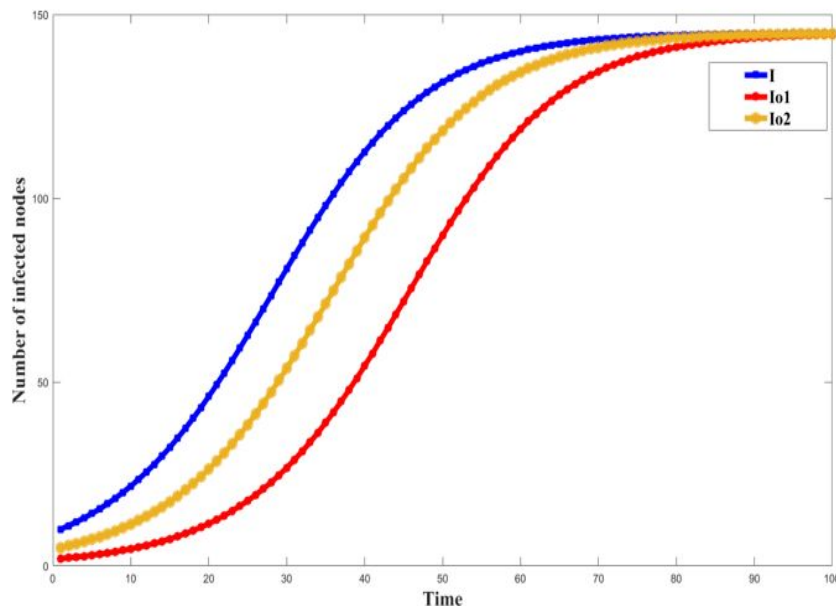
5. allowing issues such as social welfare and community rescue to be considered.

15. Research comparison and verification

5.1 Analysis of the transmission capability

In an actual road network, key nodes correspond to the location of a transportation hub. It is widely recognized that a hub location plays an important role as a link on the transportation network (For example, in Figure 8a7a, node 1 is a hub position relative to node 15). Preliminary research has shown that the final locations of the RMSPs in the four regions of Wuhan, as emergency positioning points, are key nodes on a network. In 4.3.1 and 4.3.2, the selection and data of the final location of four regional RMSP in Wuhan are shown. In this study, the emergency location points are pivotal nodes on the network. However, after positions are generated, the transmission capacity must also be considered. The size of the transmission capability reflects the efficiency and capability of the site selection coverage network. Zhang and Pan (2021).

Figure 10. Dissemination speed and capability of key nodes in Jiang han District



* Curve I represents the propagation speed and capacity of key nodes, Curve Io1 and Io2 represents the propagation speed and capacity of ordinary nodes. The time range is 1 to 100

An infectious disease model can be used to analyze the transmission capability of key nodes (Wei et al., 2013). Susceptible infection models were used to evaluate the transmission capacity of nodes in the network, which can be considered as an expression of the importance of nodes (Lu and Liu, 2019). In this model, each node has two discrete states: the susceptible state and the infected state. A node in a susceptible state will be infected by an infected node, and its probability is β , which represents the influence or driving range of the infected node in the disease transmission network. Next, the transmission capacity of the selected key nodes in each region through the infectious disease model are explained. Taking Jiang han District as an example, there are 26 site selection network nodes and 109 demand (community) nodes. The infection rate is set to 0.1, regardless of the node's recovery rate. From the perspective of the propagation process, the number of simulations using the IS model is less than 5, and the infected node can complete the infection of all nodes.

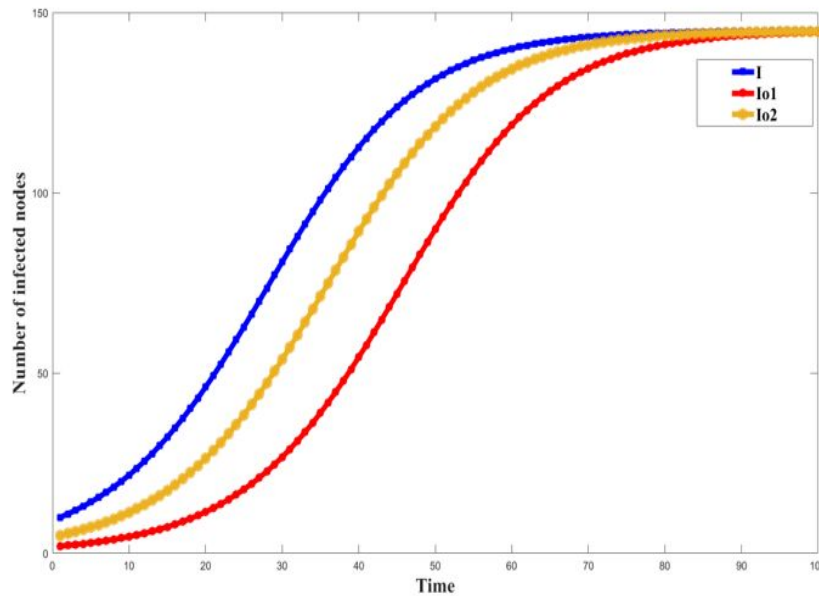


Figure 9. Dissemination speed and capability of key nodes in Jiang han District

* Curve I indicate the propagation speed and capacity of key nodes, Curve Io1 and Io2 represents the propagation speed and capacity of ordinary nodes. The time range is 1 to 100

Figure 10-9 shows the comparison of the propagation capabilities of key nodes and common nodes in Jianghan District. Although the propagation results of the 3 curves are the same, curve 1 is faster. When the number of infected nodes is 50, the propagation time of critical nodes is significantly earlier than that of common nodes. This is because in the actual road network, they are at the hub position, and there are many extension lines connecting to the next node, so that the line can be continuously extended to the next node. For example, in the constructed network model, the core location is often in a radial state. On the one hand, more connections increase the network density and alleviate the risk of road interruption. On the other hand, even if some routes cannot transport disaster relief materials, the emergency site selection site remains and alternative routes have to be considered. Therefore, in the regional network model, it is reasonable for key nodes to serve as storage points for emergency relief materials.

5.2 Comparative analysis of methods

In this research, a combination of relative entropy and TOPSIS was used to select the RMSP. This new method unifies the multi-parameter decision-making under a single field of view for the parameter ordering of the site-selected nodes in the complex network model. Of course, the traditional TOPSIS method can also solve this problem (Jatin et al., 2021).

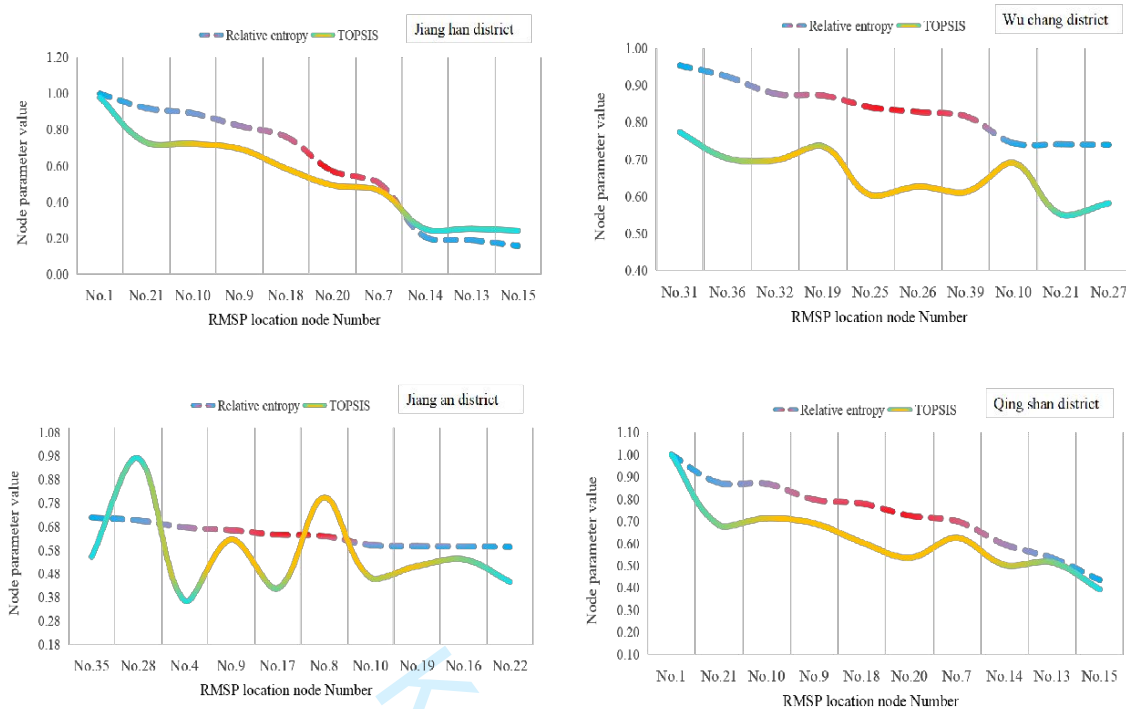


Figure 11-10. Ranking changes of sites in different regions

Figure 11-10 shows the results of the network nodes parameter of the key locations as proposed by the two methods. From the overall trend, the results of the Jiang han and Qing shan District did not change significantly. The trend is consistent, which shows that the calculation method does not have a sudden impact on the ordering status of nodes. This indicates that this method will not interfere with the overall sequencing stability of the site selection. However, some local node ordering will change. According to Figure 10-9 and Table 56, the changes in the ordering of key locations were clearly illustrated in the Jiang an District. Using the traditional method, the ordering is (No.28, No.8, No.9, No.35, No.16, No.19, No.10, No.22, No.17, No.4), while for the research method proposed here, the order was (No.35, No.28, No.4, No.9, No.17, No.8, No.10, No.19, No.16, No.22). Hence, it should be noted that the TOPSIS method changes the results with a variance for Wuchang District and Jiang an District (0.035), and a variance of 0.002 after introducing the relative entropy function. This shows that the combination of TOPSIS and the relative entropy theory can make the calculation results more stable.

Table 6. Ranking of nodes after using the two methods (Jiang an District)

Node	TOPSIS	Ranking	TOPSIS and relative entropy	Ranking
No.35	0.553	4	0.719	1
No.28	0.970	1	0.707	2
No.4	0.367	10	0.677	3
No.9	0.626	3	0.666	4
No.17	0.418	9	0.646	5
No.8	0.804	2	0.640	6
No.10	0.464	7	0.603	7

No.19	0.513	6	0.598	8
No.16	0.541	5	0.596	9
No.22	0.446	8	0.594	10

6. Conclusions

It is clear that in the future, EFS will face greater uncertainty, such as the needs of more frequent and severe flood events and possible further global epidemics. In this environment, developing an emergency supply network must select an appropriate RMSP, taking into account emergency response stakeholders (urban communities or businesses, etc.), emergency facilities, and emergency relief supplies. ~~In this environment, the construction of emergency material supply networks must confront how to choose RMSP, taking into consideration the needs of various emergency response stakeholders (government or enterprise, etc.), emergency rescue facilities (such as rescue material reserve or distribution center, etc.) and emergency rescue materials.~~ In the past, EFS has tended to ignore the urgency and scale of the communities (Wei et al., 2020). ~~In an emergency environment, researchers are more willing have tended to focus to analyze on large-scale warehousing and distribution center location issues.~~ Based on this understanding, urban community-focused emergency site selection issues are raised. ~~Based on this, researchs and this research has shown that in the event of a~~ This research offers decision-makers with solutions for EFS, and provides reliable technical support information to support the management of ~~for emergencyies management in urban communities, relying drawing on complex networks and multi-criteria decision-making.~~ These finding will helps to quickly locate EFS in response to disaster relief efforts. In practical terms, the society application of these methods will help ~~The research method to develops a refereneemore robust decision-making framework for building a sound improved urban emergency systems and more comprehensive urban rescue.~~ Of course, emergency departments are urged to change their traditional thinking and this research has shown that in the event of a disaster, small-scale material storage points can meet large-scale needs.

~~as part of modern urban risk management practices, urban managers need to improve disaster relief management platforms and provide comprehensive urban rescue forces to build robust urban emergency rescue systems. In addition, managers need to adapt to new ways of thinking and be prepared to innovate. When a disaster occurs, it is difficult for a small number of material storage points to meet large-scale needs. Therefore, we propose considering the community as the center, making full use of community hospitals, fire centers, and sub-district offices to establish both small-scale and large-scale RMSP.~~

At the level of theory and method, this study introduces a new hybrid multi-criteria decision-making method, which abstracts the actual road network into a complex network model to provide the RMSP location of the region. This method solves the historic problem of how to choose the optimal solution, and reduces the difficulty for decision makers. Finally, the validity and stability of the research method were verified, thus providing a strong basis for urban emergency rescue work and planning. Therefore, decision-making departments can use these findings to evaluate disaster relief options to establish the best storage point for EFS emergency relief supplies. Without doubt, this method is also applicable to other decision-making problems, in the fields of project management,

society and economy, including urban infrastructure site selection, emergency resource scheduling and planning, social public opinion analysis, financial risk communication and forecasting, etc.

Notwithstanding these key findings, this study has certain limitations. There are still some factors that need to be improved when determining the index level of the initial site selection area. For example, in practice, the availability of land may not be such a key factor, as the social benefits could be considered more important than the economic benefits. In addition, the final RPMSP location also needs to be adjusted according to the actual disaster situation, when it comes to coverage, rescue time, inventory cost and uncertainty-disaster situation. In the future, the research will design stochastic programming or robust models based on key nodes as site selection nodes, adopt optimization algorithms and simulation ideas, and as well as to consider factors such as roads, weather, and demand uncertainty to serve emergency site selection needs. In new disaster relief scenarios, results are verified using new digital technology-means, such as 5G and remote sensing satellites, GIS, and Internet of Things technology(Xiao, Zhou and Zhang, 2020).

~~In addition, key node identification includes structural holes, clustering coefficients, feature vectors, community discovery, etc.~~

~~In the future, this research will establish an integer programming model based on the identification of key nodes as site selection nodes, using mathematical optimization and simulation methods, considering factors such as roads, weather, and demand uncertainty, to serve material distribution and path planning needs.~~

Data Availability Statement: Some or all data, models, or code generated or used during the study are available in a repository online in accordance with funder data retention policies. <https://figshare.com/s/f2185a3f01d567fbaf9c>

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Appendix

Table 1. Method of site selection for emergency facilities

Model	Topic	Methodology/ Instrument	Author (years)
Classic model	Relief material warehouse location	Coverage location model	(Guan <i>et al.</i> , 2021;Liu <i>et al.</i> , 2016;Zhang <i>et al.</i> , 2020)
	product crisis management	Hierarchical clustering-centroid method	
Multi-objective function	Non-emergency medical transportation	Mixed integer programming	(Feng <i>et al.</i> , 2019;Feng <i>et al.</i> , 2020)
	Chemical Park emergency response	Variable Weight Algorithm	
Dynamic programming	Emergency dispatch of rescue station	Multi-objective optimization model	(Liu, Li and Zhang, 2019;Rivera-Royero <i>et al.</i> , 2016;Yang, Liu and Yang, 2021)
Fuzzy programming	Relief materials management after-floods	Dynamic optimization model	(Ejaz <i>et al.</i> , 2020;Xiao, Zhou and Zhang, 2020)
Robust optimization	Pre-positioning of relief materials	fuzzy random constraints	
Digital scene technology	Medical service station location	Outer approximation (Jahre <i>et al.</i>)algorithm	(Aydin and Seker, 2021;Feng <i>et al.</i> , 2020;Jena and Pradhan, 2020)
	Fire assessment and fire station siting	Buffer analysis and overlay analysis	
	Assist in earthquake disaster management	Unmanned aerial vehicle	
MCDM	Seismic risk assessment	Neural Networks and Improved TOPSIS Grey analysis	(Aydin and Seker, 2021;Feng <i>et al.</i> , 2020;Jena and Pradhan, 2020)
	Site selection for medical waste facilities	Delphi, Best–Worst Method, and interval type-2 fuzzy	
	Epidemic isolation hospital location selection	Technique	

Response to Reviewer 1 Comments

Dear Editors and Reviewers:

Thank you for your letter and for the reviewers' comments concerning our manuscript entitled "A hybrid decision-making approach for locating rescue materials storage points under public emergencies" (ID: K-07-2022-1060). Those comments are all valuable and very helpful for revising and improving our paper, and we appreciate this helpful guidance. We have studied the comments carefully and have made detailed and comprehensive corrections which we hope will meet with your approval. The revised portions are marked **in blue colour** in the paper. The main corrections in the paper and the responses to the reviewer's comments are as follows:

Responses to the reviewer's comments:

Reviewer #1

Comments

- **Point 1:** In proposed model's absence, would the results be significantly different? Please discuss in the introduction.

Response 1: (page 3) Thanks for your attention. According to the proposal, in the page 3, the author briefly explains the difference between the research results of the proposed method and other methods, and has a specific description in the fifth section.

- **Point 2:** Is the proposed hybrid model generalizable for which other problems?

Response 2: Thanks for the comment. The generalization and application of the research model has been explained by the author in the conclusion section (page 16). In addition to the field of emergency location selection, the proposed method is also suitable for sociology, engineering, finance and other fields, and is used to study the characteristics of nodes in the network through sorting based on multi-criteria decision-making method.

- **Point 3:** What is the advantage of your hybrid model?

Response 3: (page 3) We appreciate your comments. Based on your suggestions, we hope that the proposed hybrid decision-making idea can reduce the difficulty of decision-making as much as possible in the research direction of emergency site selection. Therefore, the new method focuses on multi-criteria decision-making. At the same time, combined with the idea of complex network, the alternative locations are constructed into a transportation network model to achieve the research goal.

- **Point 4:** Some fuzzy based MCDM papers should be discussed in the manuscript as follows:
 - (i) A novel rough number based extended MACBETH method for the prioritization of the connected autonomous vehicles in real-time traffic management.
 - (ii) A fuzzy Einstein-based decision support system for public transportation management at times of pandemic.
 - (iii) A Decision Support System for Assessing and Prioritizing Sustainable Urban Transportation in Metaverse.
 - (iv) Prioritization of healthcare systems during pandemics using Cronbach's measure based fuzzy WASPAS approach.

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3 Response 4: (page 4) Considering the references provided by the reviewers, we decided to
4 select articles appropriate to the topic of this research and discuss them in the literature review
5 section.
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9 **Additional Questions: 1.**

10 **5.Originality:** Does the paper contain new and significant information adequate to justify
11 publication? New and significant information adequate to justify publication

12 Response 5: (page 1)

13 Thanks for this valuable suggestion. My co-authors and I have paid great attention to the
14 originality of this study, in terms of novelty, using the techniques of complex networks and
15 comprehensive evaluation, applied in the field of emergency site selection. At the same time,
16 from the research perspective, combined with the community disaster relief management work,
17 it is beneficial to expand the research on the location of urban emergency facilities. The
18 research value is to provide theoretical and decision-making basis and guidance for the site
19 selection of community emergency rescue facilities. We have highlighted these aspects in the
20 conclusions and the abstract.
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24 **6.Relationship to Literature:** Does the paper demonstrate an adequate understanding of the
25 relevant literature in the field and cite an appropriate range of literature sources? Is any
26 significant work ignored? Literature Review is enough

27 Response 6: (page 3-4)

28 We appreciate your comments. We have reorganized the method of site selection for
29 emergency facilities in the literature review section. Mathematical models and solvers are the
30 mainstream methods for emergency site selection, such as integer programming, stochastic
31 thinking, and robust optimization. The same multi-criteria decision-making model also has
32 applications. Of course, the purpose of the literature review is to propose the decision-making
33 method of this paper, and there are specific descriptions of the results in the appendix.
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37 **7.Methodology:** Is the paper's argument built on an appropriate base of theory, concepts or
38 other ideas? Has the research or equivalent intellectual work on which the paper is based been
39 well designed? Are the methods employed appropriate? Methodology can be improved

40 Response 7: (page 5-6)

41 We have revised the account of the method to make this clearer and easier to follow – see
42 pages 5-6, taking into account the previous comments. The applicability and advantages of the
43 method have also been added, as well as the motivation for using these. In the case analysis
44 and method validation, the research method was compared with the traditional method to show
45 the stability and feasibility of the method results, and an infectious disease model was also used
46 to test the feasibility of the site selection results.
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50 **8.Results:** Are results presented clearly and analysed appropriately? Do the conclusions
51 adequately tie together the other elements of the paper? Results should be improved.

52 Response 8:

53 Thank you very much for your endorsement and comments. We made minor revisions
54 and refinements to the Results and Discussion sections, mainly in "Generate initial location
55 area" and "Measure key nodes parameters". In conclusion, we once again linked this study with
56 previous studies to illustrate the significance of the research question.
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3 **9.Implications for research, practice and/or society:** Does the paper identify clearly any
4 implications for research, practice and/or society such as teaching, public policy or the effect
5 on society? Implications is not enough.

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7 Response 9: (page 16)

8 Thanks again for the reviewer's comments. All authors are well aware of the social value
9 of this research (page 16). Therefore, in the conclusion part, we have reiterated that, based on
10 this understanding, in terms of practical application, the method proposed in this paper provides
11 a reference decision-making framework for building a robust urban emergency system and
12 providing comprehensive urban rescue. Likewise, we urge emergency departments to realize
13 that when disaster strikes, emergency siting centered on urban communities needs to be taken
14 seriously.
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17 **10.Quality of Communication:** Quality of Communication: Does the paper clearly express its
18 case, measured against the technical language of the fields and the expected knowledge of the
19 journal's readership? Has attention been paid to the clarity of expression and readability, such
20 as sentence structure, jargon use, acronyms, etc. The paper clearly express its case.

21
22 Response 10:

23 Thanks for this valuable suggestion. Sentence structure, jargon usage, acronyms, etc. have
24 been refined accordingly in the paper. The English expression has also been revised with the
25 assistance of our native English-speaking co-author.
26

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30 We appreciate the Editors/Reviewers' warm work earnestly, and hope that the corrections
31 will meet with approval. Once again, thank you very much for your comments and suggestions.
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Response to Reviewer 2 Comments

Dear Editors and Reviewers:

Thank you for your letter and for the reviewers' comments concerning our manuscript entitled "**A hybrid decision-making approach for locating rescue materials storage points under public emergencies**" (ID: K-07-2022-1060). Those comments are all valuable and very helpful for revising and improving our paper, and we appreciate this helpful guidance. We have studied the comments carefully and have made detailed and comprehensive corrections which we hope will meet with your approval. The revised portions are marked **in blue colour** in the paper. The main corrections in the paper and the responses to the reviewer's comments are as follows:

Responses to the reviewer's comments:

Reviewer #2

Comments

- **Point 1:** Why I could not see the responses (point to point to reviewers' comments)? Thus, I could not know the comments I raised in the former review, and do not know how the comments are considered in the revised version.

Response 1: We are sorry that the reviewer was unable to view it due to a problem with the last system when uploading. However, the author has carefully revised the paper according to your comments, and hope that the new revision can be approved.

- **Point 2:** In the introduction, "Such as the", this is a sentence?

Response 2: (page1) Corresponding changes have been made in the introduction viewing on content and writing requirements.

Point 3: For the emergency decision making, please see:

A conflict-eliminating approach for emergency group decision of unconventional incidents, KBS, 2015.

A two-stage consensus method for large-scale multi-attribute group decision making with an application to earthquake shelter selection, CAIE, 201.

In the large-scale decision making, there are recently papers: Applied Soft Computing, 2022, 117: 108373. Applied Soft Computing, 2022, 126, 109249

Response 3: Thanks for this valuable suggestion on large-scale decision making. In the literature review, new reviews and comments were added by us on urban emergency management. Please review.

Point 4: In eq. (1) and above, why $D_{(n \times m)}$? why not just $D_{n \times m}$?

Response 4: Thanks for your attention. First of all, eq. (1) has no problem in terms of form and content. GRA needs to derive the geometric relationship between the analysis sequence (X_i) and the reference sequence (X_0). $X_0 = [x_0(1), x_0(2), x_0(3), \dots, x_0(m)]$, just a set of line vectors. Of course, during calculation, it needs to be transposed. X_i is represented by $D_{(n \times m)}$, which is a real matrix, where n represents the count of sequences, and m indicates the number of elements in each group of analysis sequences, respectively belonging to sets i and k . We believe that the formula in the article has been clearly expressed, and there are corresponding documents for readers to refer to in the method introduction.

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3 **Point 5:** In Eq. (1), it is X_i , how about this, as i is a variable, and it is $i = 1, \dots, n$? Thus, this
4 means that X_1, X_2, \dots, X_n are all same? Is this right?
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6 Response 5: Thanks for your attention. Dear reviewer, there is no problem in
7 understanding $i = 1, \dots, n$. X_i may have the same value when $i = 1, \dots, n$. But it will not be exactly
8 the same, because it will lose the research value. In addition, on data cleaning, meaningless
9 and duplicate original data will be filtered.
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12 **Point 6:** Page 8 (and other pages), last line, there still exists mess characters, $k = 1, K, \dots, m$,
13 K should be ..., please check the whole paper.
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15 Response 6: We appreciate these comments. According to this suggestion, the original
16 symbols have been modified and deleted to reduce unnecessary mesh characters.
17

18 **Point 7:** In eq. (3), x_i^{max} , it is the normalization method, it is preferred to be $max x_i$.

19 Response 7: Thank you for your attention. We have made changes, but we and the
20 reviewers also understand that they are only formal changes, and the meaning of expression
21 has not changed.
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24 **Point 8:** In eq. (7), the sum(sigma), only k and the upper bound is 1? It may be $k = 1$, and
25 the upper bound is m ? Please check.
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27 Response 8: The initial value of K is 1, and the upper bound should be M . We have
28 modified the error.
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31 **Point 9:** In eq. (8), $j = 1, \dots, n$ may be $i = 1, \dots, n$, as j has been summed (in sigma). Why
32 $DC_{(i)}$? why not just DC_i ?
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34 Response 9: Thanks for this valuable suggestion. $j = 1, \dots, n$ has been corrected to $i = 1, \dots, n$.
35 In eq (8), both $DC_{(i)}$ and DC_i can be used as the expression of node degree centrality. In general,
36 it is recommended to use $DC_{(i)}$ form.
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39 **Point 10:** In eq. (11)(12), why there are $i = 1, \dots, n, j = 1, \dots, m$? As there is no i and j in Eqs
40 (11)(12). This is also for Eq. (13,14,15), only $i = 1, \dots, m$ is needed.
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42 Response 10: In eq. (11) (12), unnecessary identification has been deleted. Eq. (13,14,15),
43 we give the numerical identification of variables as required. $i = 1, \dots, n, j = 1, \dots, m$.
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Additional Questions:

1. Originality: Does the paper contain new and significant information adequate to justify publication? Yes.

2. Relationship to Literature: Does the paper demonstrate an adequate understanding of the relevant literature in the field and cite an appropriate range of literature sources? Is any significant work ignored? Yes.

3. Methodology: Is the paper's argument built on an appropriate base of theory, concepts or other ideas? Has the research or equivalent intellectual work on which the paper is based been well designed? Are the methods employed appropriate? Yes.

4. Results: Are results presented clearly and analysed appropriately? Do the conclusions adequately tie together the other elements of the paper? Yes.

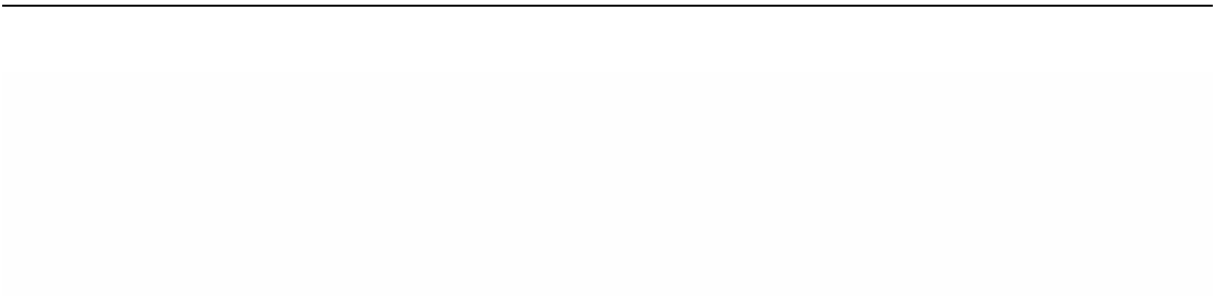
5. Implications for research, practice and/or society: Does the paper identify clearly any implications for research, practice and/or society such as teaching, public policy or the effect on society? Yes.

6. Quality of Communication: Does the paper clearly express its case, measured against the technical language of the fields and the expected knowledge of the journal's readership? Has attention been paid to the clarity of expression and readability, such as sentence structure, jargon use, acronyms, etc.: Yes.

We sincerely thank the reviewers for their review and recognition. In order to promote the successful publication and dissemination of this study, we still improve the research value, application and other parts of the paper.

We appreciate the Editors/Reviewers' warm work earnestly, and hope that the corrections will meet with approval. Once again, thank you very much for your comments and suggestions.

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Highlights:

- 1 Material reserve points are incorporated into the emergency supply network to maintain the advantage of quantity.
- 2 Build emergency site selection facilities centered on urban communities.
- 3 Use a complex network model to select the location of emergency supplies storage sites.

Kybernetes

Keywords

Emergency Facility Location; Grey Correlation Evaluation; Relative Entropy-TOPSIS;
Complex Network Model

Kybernetes

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