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Research on Collaborative Allocation Strategies for Emergency Logistics Systems in Catastrophic Scenarios from a Resilience Perspective

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Abstract: This paper conducts an in-depth literature analysis of collaborative allocation strategies for emergency logistics systems from a resilience perspective, utilizing the scientific literature analysis tool CiteSpace. It also constructs a cost model for multimodal transportation of emergency supplies. Through the visual analysis of CiteSpace, the research development trajectory and hot topics in the field of emergency logistics are systematically reviewed, revealing key issues such as how to optimize transportation routes, reduce logistics costs, and improve resource allocation efficiency through multimodal transportation in catastrophic scenarios. The analysis results indicate that existing research primarily focuses on transportation efficiency and cost control. However, there is a lack of a systematic theoretical framework for multimodal transportation cost optimization models in complex disaster environments. To address this, this paper proposes a cost model for multimodal transportation of emergency supplies based on resilience theory. This model comprehensively considers factors such as transportation mode selection, transportation time, redundant resource allocation, and system recovery. By establishing a mathematical model, it optimizes emergency logistics costs while enhancing the resilience and adaptability of the system for rapid recovery after disasters. This research provides new theoretical support and practical guidance for the collaborative allocation of emergency logistics systems in catastrophic scenarios.

Keywords: catastrophic scenario; collaborative allocation strategy; resilience perspective; emergency logistics; multimodal transportation.

1. Introduction

In today's rapidly developing globalized and disaster-prone world, the frequent occurrence of natural and human-induced catastrophic disasters poses severe challenges to human society [1]. These disasters not only cause tremendous casualties and property losses but also have far-reaching impacts on socio-economic order [2]. As a crucial link in ensuring the timely delivery of relief supplies, the research on collaborative allocation strategies for emergency logistics systems in catastrophic scenarios is particularly significant [3]. Especially in terms of emergency supplies, their timely, accurate, and efficient distribution is directly related to the life safety and health recovery of people in disaster-affected areas [4]. Therefore, studying the collaborative allocation strategies for emergency logistics systems in catastrophic scenarios from a resilience perspective has profound research backgrounds and significant importance [5].Catastrophic disasters, including natural and human-induced disasters, are characterized by diversity and complexity [6]. Natural disasters such as earthquakes, floods, and hurricanes often occur suddenly, unpredictably, and with strong destructiveness [7]. Human-induced disasters such as wars and terrorist attacks may have greater uncertainty and complexity due to human factors [8]. These disasters not only directly damage infrastructure but may also lead to transportation disruptions and communication blockages, posing significant challenges to emergency logistics systems [9].In catastrophic scenarios, the demand for emergency supplies increases sharply and exhibits urgency and diversity [10]. On the one hand, people in disaster-affected areas require urgent medical treatment due to injuries and illnesses caused by disasters, leading to a rapid increase in the demand for emergency supplies such as medicines, medical equipment, and rescue devices [11]. On the other hand, different disaster types and degrees of damage have varying demands for emergency supplies. For example, earthquakes may result in a large number of injured people needing urgent medical treatment, while floods may trigger infectious disease outbreaks requiring corresponding epidemic prevention supplies. Existing emergency logistics systems often expose vulnerabilities and deficiencies when facing catastrophic scenarios [12]. On the one hand, logistics infrastructure such as roads, bridges, and communication equipment may be damaged by disasters, leading to disruptions in logistics transportation [13]. On the other hand, the collaborative allocation and emergency response capabilities of emergency logistics systems need improvement. Issues such as poor information sharing, limited transportation modes, and inadequate warehousing facilities may affect the timely delivery of emergency supplies [14].

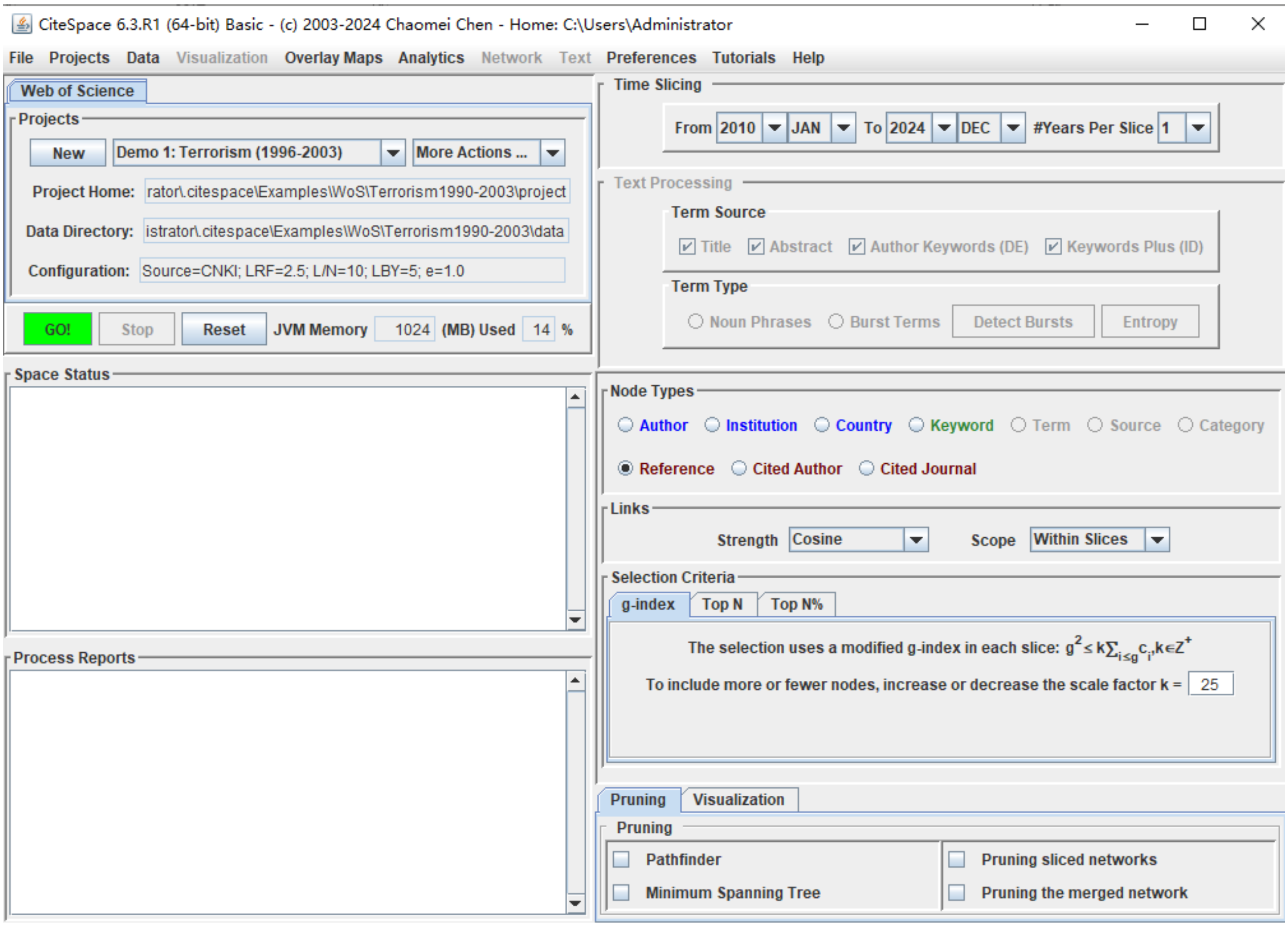
Resilience refers to the ability of a system to rapidly recover and maintain its critical functions in the face of external shocks. Studying collaborative allocation strategies for emergency logistics systems from a resilience perspective aims to enhance the system's adaptability and resilience in catastrophic scenarios. By optimizing system structure, improving the reliability of critical facilities, and strengthening information and communication capabilities, the stability and sustainability of emergency logistics systems in the face of disasters can be enhanced [15].Emergency supplies are critical resources in catastrophe rescue, and their timely delivery is directly related to the life safety and health recovery of people in disaster-affected areas. Studying collaborative allocation strategies for emergency logistics systems can optimize the transportation routes and modes of emergency supplies, improve transportation efficiency and safety, and ensure that emergency supplies are delivered to disaster-affected areas at the first opportunity, providing strong support for rescue efforts [16].Research on collaborative allocation strategies for emergency logistics systems in catastrophic scenarios is not only related to people's life safety and health recovery but also has an important impact on the stability and development of the socio-economy. By improving the collaborative allocation capabilities and resilience of emergency logistics systems, the impact and destruction of disasters on socio-economic order can be reduced, promoting rapid recovery and reconstruction in disaster-affected areas and providing strong support for sustainable social development [17]. Emergency logistics is a complex and important research field, and the innovation and development of its theory and practice are of great significance for improving emergency response capability and rescue efficiency. Starting from the resilience perspective, studying the cooperative configuration strategy of emergency logistics system can promote the innovation and development of emergency logistics theory and practice, and provide new ideas and methods for future emergency logistics research and practice. To summarize, the research on the collaborative configuration strategy of emergency logistics system for catastrophe scenarios from the perspective of resilience has a far-reaching research background and important significance. Through in-depth research and practical exploration, we can continuously improve the resilience and co-configuration capacity of the emergency logistics system, and provide strong support for coping with future catastrophe challenges.

2 Literature Analysis Related to Emergency Response Teams Based on the Scientific Literature Analysis Tool CiteSpace

2.1 Overview of CiteSpace Literature Analysis Tool

CiteSpace is a scientific literature analysis tool jointly developed by Dr. Chaomei Chen of the School of Information Science and Technology at the University of Redeemer and the WISE Laboratory at Dalian University of Technology. The software reveals the research structure and development trend of subject areas through econometric analysis of literature in specific fields. Its main functions include: basic analysis of the literature, such as the number of citations and publications, analysis of key disciplines and journals, research and cooperation of research institutions, and analysis of authors, etc. In addition, it also supports cluster analysis and mutation analysis, and is able to analyze keyword frequency, keyword clustering, and time-zone maps (mutation analysis), etc. [19]. Using CiteSpace for literature analysis can quickly lock the key information and core themes, help sort out the development of a subject area, identify the current research frontiers and future development trends. At the same time, CiteSpace shows the structure, pattern and distribution of subject knowledge through visual means, generates visual knowledge maps, and thus reveals the research hotspots, cutting-edge dynamics, main authors and scientific research institutions, and other related information.

To use CiteSpace, you need to install Java environment and prepare literature data that meets the format requirements for import and processing. Users can choose different node types and parameter settings according to their needs, generate visual maps after running, and further optimize the display effect of the maps by adjusting the controls. Figure 1 below shows a screenshot of the basic CiteSpace interface.



CiteSpace 6.3.R1 (64-bit) Basic - (c) 2003-2024 Chaomei Chen - Home: C:\Users\Administrator

Projects: Demo 1: Terrorism (1996-2003)

Project Home: rator\.citespace\Examples\WoS\Terrorism1990-2003\project

Data Directory: istrator\.citespace\Examples\WoS\Terrorism1990-2003\data

Configuration: Source=CNKI; LRF=2.5; L/N=10; LBY=5; e=1.0

JVM Memory 1024 (MB) Used 14 %

Time Slicing: From 2010 JAN To 2024 DEC #Years Per Slice 1

Term Source: ☑ Title ☑ Abstract ☑ Author Keywords (DE) ☑ Keywords Plus (ID)

Node Types: ○ Author ○ Institution ○ Country ○ Keyword ○ Term ○ Source ○ Category ● Reference ○ Cited Author ○ Cited Journal

Links: Strength Cosine Scope Within Slices

The selection uses a modified g-index in each slice: $g^2 \le k\sum_{i\le g} c_i, k\in Z^+$

To include more or fewer nodes, increase or decrease the scale factor k = 25

Pruning: ☐ Pathfinder ☐ Minimum Spanning Tree ☐ Pruning sliced networks ☐ Pruning the merged network

Figure 1. Citespace Basic Interface

2.2 Keyword co-occurrence analysis

In this paper, the China Knowledge Network (CNKI) database is used as a platform for literature acquisition, and the keyword “emergency logistics” and related literature published from January 2014 to February 2024 are screened by its advanced search function. Finally, 341 effective documents were obtained, and CiteSpace software was used to visualize and analyze the maps of these documents. Keyword co-occurrence analysis is a commonly used text mining and information retrieval technique, which is mainly used to study the frequency, patterns and their interrelationships of the simultaneous occurrence of different words or terms in the same context in a document collection. Through this method, the potential knowledge structures and semantic relationships hidden in a large amount of text data can be revealed. In this paper, the keywords provided in the literature are used as the object of analysis, and these keywords can effectively distill the main content of the literature, representing the research direction and core points of the literature. The high-frequency keywords reflect the academic focus and research trends in the field.

In the parameter settings of CiteSpace, the time range of the literature is set from January 2014 to February 2024, and the time slice is divided by year, and the whole dataset is divided into 10 time segments; in the selection of node types, “keywords” is used as the analysis node, and the link strength is set as cosine (In terms of node type, "keyword" is used as the analysis node, the link strength is set to cosine, and the scope is adjusted to "within slices". In addition, to improve the visualization effect, "Pathfinder algorithm" was checked in the "Streamlining" option, and the evolution process of each time period was selected to be displayed. In the visualization presets, the "Cluster View-Static" mode and the "Show Merged Network" option were selected to optimize the view of the atlas. The final keyword co-occurrence map is shown in Figure 2.

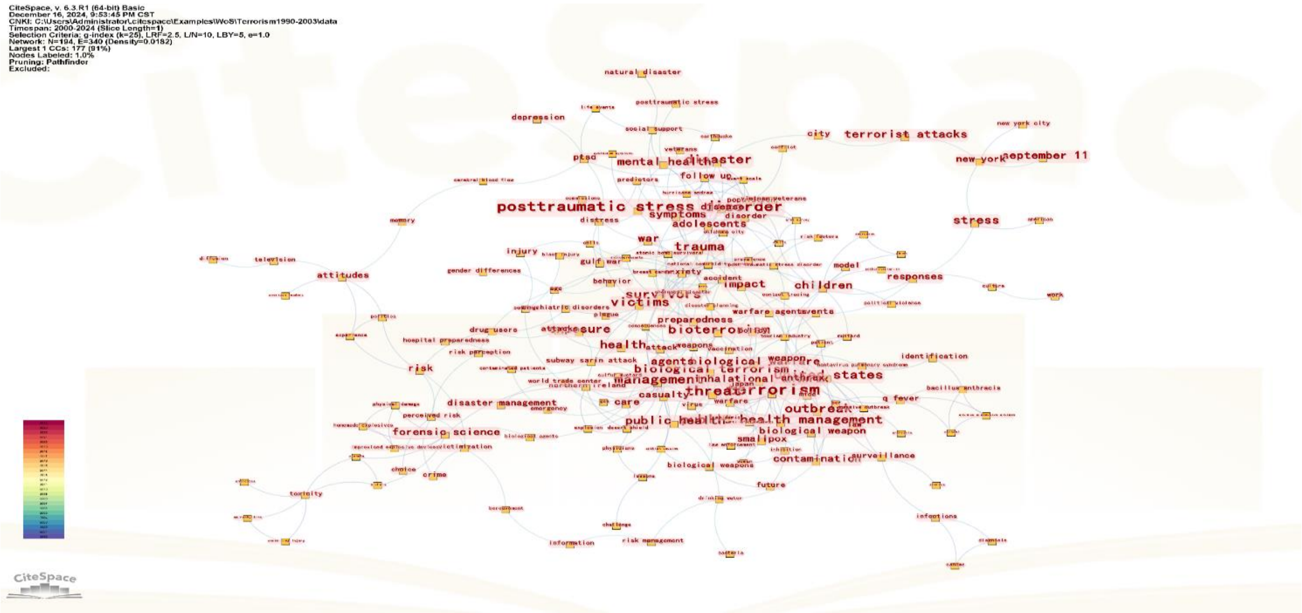


Figure 2. keyword co-occurrence analysis graph

The color transition from cold to warm at the top of the graph represents the evolution of time from 2014 to 2024, i.e., the temporal transition of the literature content from the past to the present. Each node represents a keyword, and the size of the node indicates how often the keyword appears in the literature; the larger the node, the more frequently the keyword appears, and vice versa. The color of the node indicates how the keyword appears in the literature in different years. More circles of different colors indicate that the keyword appeared in more years of literature and vice versa means that the keyword appeared in less years of literature. The connecting lines between the nodes indicate that there is a co-occurrence relationship between these keywords, and the colors of the connecting lines reflect the co-occurrence of the keywords in the literature of different years. By extracting the 10 keywords with the highest frequency of occurrence, we obtained the results shown in Table 1 below:

Table 1. Table of high-frequency keywords

No.	Keywords	Year/year of high frequency occurrence	Centrality	Frequency
1	Emergency Response Team	2014	0.51	33
2	Emergency Management	2014	0.57	29
3	Health Emergency Response	2014	0.14	16
4	Emergency Response Capability	2014	0.26	15
5	Emergency Drill	2016	0.12	8

6	Emergencies	2015	0.10	8
7	Emergency Rescue	2014	0.08	6
8	CDC Organizations	2017	0.04	6
9	Team Building	2016	0.04	6
10	Crisis Management	2018	0.05	6

2.3 Keyword clustering analysis

Keyword clustering is the process of grouping a large number of keywords according to their similarity or relevance, which is widely used in text analysis, information retrieval, search engine optimization and other fields. Through keyword clustering analysis, the potential relationship between keywords can be more clearly revealed.CiteSpace software uses algorithms to cluster closely related keywords and assigns the importance of each keyword in the relationship network, so as to filter out the keywords with the maximum value as the representative of the clustered network.

When performing keyword clustering analysis, the parameters in CiteSpace need to be adjusted appropriately according to the research objectives. In the network mapping interface, keywords are selected as the target to construct the keyword network, and the clustering algorithm is selected from the Log-Likelihood Ratio (LLR: Log-Likelihood Ratio) algorithm. The final generated keyword clustering map can visualize the grouping of keywords. In order to determine the effectiveness of the clustering map, two main indicators need to be examined: the clustering modularity value (Modularity Q) and the clustering average profile value (Silhouette). Among them, Modularity Q is used to assess the significance of the clustering structure, which usually requires a Q value higher than 0.3; the average silhouette value of the clusters measures the reasonableness of the clustering results, and the S value should be greater than 0.5. The keyword clustering map generated in this paper calculates the Q value to be 0.6793, and the S value to be 0.9087, which satisfy the validity requirements of the clustering map. The final keyword clustering map presented is shown in Figure 3 below:

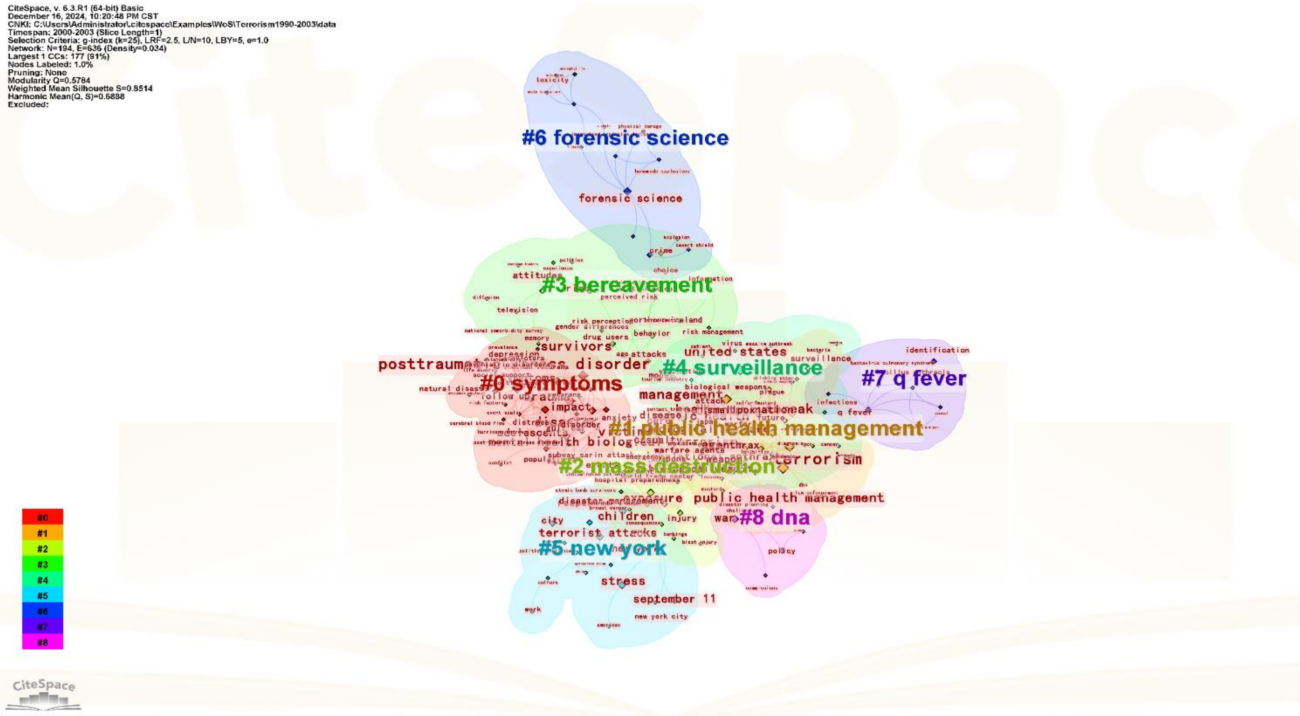


Figure 3. Keyword clustering analysis diagram

Through keyword clustering analysis, ten keyword clustering networks were finally constructed. Different colors represent different clustering modules, and the overlapping area between modules indicates the existence of commonality between each clustering network, and the denser the overlapping area, the stronger the commonality between networks. According to the clustering ordering, the top ten keywords clustering networks are: emergency management, emergency response team, emergency plan, health emergency, emergency response, emergency response capacity, large disaster site, geographic information system, emergency rescue, countermeasures, emergency response. The ranking of the clustering network is based on the number of associated keywords in the network; the more associated keywords, the higher the ranking of the clustering network. In the literature on emergency response teams between 2014 and 2024, “emergency management” was the most frequently mentioned topic. Emergency management in the emergency response team involves multiple levels and fields, and is a complex dynamic management process, covering the formulation of emergency plans, the construction of emergency management systems and mechanisms, the implementation of emergency response and rescue, and post-disaster recovery and reconstruction. China's emergency management system includes “one case and three systems”, namely, emergency plan, emergency management system, mechanism and legal construction. Emergency management is not only the emergency response to emergencies, but also includes all aspects of disaster prevention, detection and disposal. Therefore, as a complex activity covering multiple levels, emergency management has been discussed many times in the literature and has profound theoretical and practical significance.

It is worth noting that the second and seventh ranked keyword clustering networks are highly overlapping, and a large number of keywords about “emergency plan” appear in the “emergency rescue” cluster, which further validates the key role of emergency plan in emergency rescue. Emergency plan clarifies the scope and system of emergency rescue, and provides clear guidance and basis for emergency preparedness and emergency management. It can ensure that when an emergency occurs, the rescue team works quickly and in an orderly manner, avoiding confusion and improving rescue efficiency. The emergency plan formulates corresponding response measures and strategies for different types and levels of emergencies, and also has the ability to be flexibly adjusted to meet the needs of different situations. Through the pre-planned response process, resource deployment and division of labor in the emergency plan, the rescue team can arrive at the scene in the shortest possible time and quickly launch rescue operations to minimize casualties and property losses. In the keyword clustering network, “large disaster site” and “GIS” are the two most characteristic keyword clusters. According to the literature, the most frequently mentioned emergency response location in the research on emergency response teams is the “large disaster site”, which refers to the disaster area where the permanent population of the urban area reaches a certain size. Large disaster sites usually have higher economic vitality and complex social service needs, and their economic structure is more diversified. Because large disaster sites are densely populated, economically active and structurally complex areas, they have more potential risks and emergencies and a greater impact on human activities. Therefore, it is necessary to build emergency response teams in these areas. Emergency response teams should respond quickly in disaster areas to control the development and reduce the damage.

In addition, Geographic Information System (GIS) plays an important role in the construction of emergency response teams.GIS, supported by computer hardware and software systems, is capable of collecting, storing, managing, analyzing, and displaying geographic data in the Earth's surface space to provide spatial data support for various industries. In emergency management, GIS provides decision-making support for emergency teams, optimizes resource allocation and improves rescue efficiency. By integrating topographic maps, remote sensing images, land use data and other information, GIS provides an important basis for disaster monitoring, early warning, assessment and emergency response. Its spatial analysis and visualization capabilities can clearly present key data such as infrastructure conditions, population distribution, road networks, etc. in the disaster area, assisting decision makers in making scientific decisions. In addition, GIS can update geospatial data in real time to help decision makers understand the distribution and demand of resources in the disaster area, so as to rationally deploy relief materials and personnel, and to ensure that the relief work is carried out in an efficient and orderly manner.

2.4 Time line charts

Timeline charts can show the frequency and trend of different keywords or subject terms within a field or topic. With this information, scholars can understand the development history of the field or topic, including important research turning points, emerging research directions, and declining research topics.As shown in Figure 4 below, a timeline map of the literature on emergency response teams from 2014 to 2024 was constructed through CiteSpace:

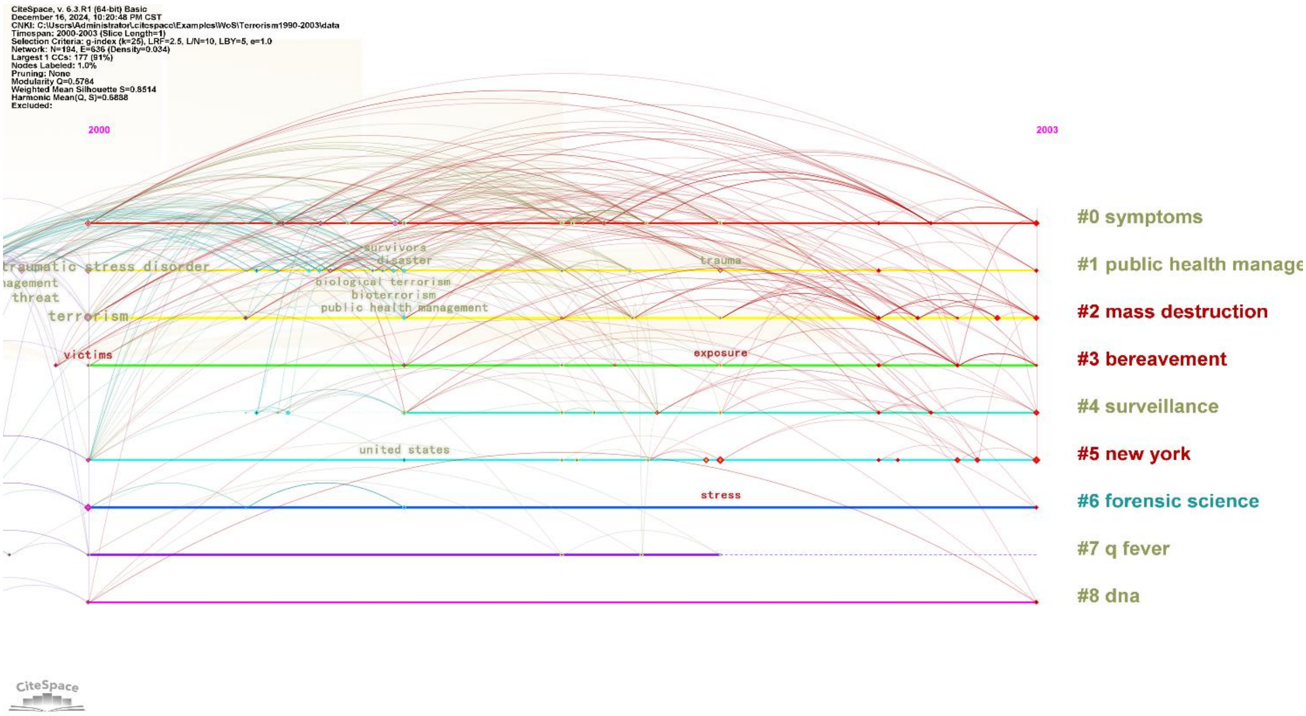


Figure 4. timeline graph

It can be seen that the timeline diagram contains the keywords in the keyword co-occurrence analysis and the clustering network derived from the keyword clustering analysis, and the timeline diagram is machine summarized. In the clustering network of emergency management, there is research literature related to it from 2014 to 2024, and the earliest research direction is the analysis of the research status about emergency management, and with the passage of time the research content is gradually subdivided, and it begins to explore in the branch direction, for example, emergency rescue, emergency security issues, grassroots government prevention and control measures, and optimization of emergency management, which conforms to the keywords derived in the keyword co-occurrence analysis Conclusion. Through the timeline diagram, we can also see the corresponding research timeline of each keyword clustering network. The keyword clustering networks with a longer research timeline of more than 5 years include emergency management, health emergency response, emergency response capacity, and major disaster sites, which indicates that these clustering networks have more research results, richer research content, and more branches of research, which also implies that these keywords have a higher research value. The third ranking of the clustering network, emergency response plan, can be seen in the timeline diagram, more documented studies have appeared from 2016 to 2020, which is because in this period the government attaches great importance to the development and implementation of emergency response plan, and vigorously promotes the improvement of the emergency management system, in order to adapt to and cope with the challenges of increasingly complex emergencies. Against this background, relevant research institutions and scholars have also actively invested in the study of emergency planning, with a view to providing theoretical support and guidance for practical work. It reflects the development needs and policy orientation of China's emergency management work. From the figure, it can also be seen that the research on the application of GIS in the emergency response team is also mainly gathered in the early period from 2014 to 2016, that is because a series of major natural disasters and accidents occurred in China during the period from 2014 to 2016, including the Yunnan Ludian 6.5 magnitude earthquake disaster in 2014, the flooding in the south of the Yangtze River in mid- to late May, the flooding in the south of China in mid- to late June, the flooding in the west of China in mid- to early September, and the flooding in the west of China in mid- to early September. In 2014, there were a series of major natural disasters and accidents, including the 6.5 magnitude earthquake in Ludian, Yunnan Province, in mid- to late-May, flooding in the south of the Yangtze River in mid- to late-June, flooding in the south in mid- to late-September, flooding in western China in mid- to early-July, flooding and mudslide disaster in Yunnan Province in early-July, and the 7.3 magnitude earthquake disaster in Yutian, Xinjiang Province, the 4.25 earthquake disaster in Tibet, and the 8.12 landslide disaster in Shanyang, Shaanxi Province, in 2015, "7-3" Xinjiang Pishan 6.5 magnitude earthquake disaster, '11-13' Zhejiang Lishui landslide disaster; in 2016, Fujian Taining County major mudslide disaster, Jiangsu Yancheng tornado hailstorm special major disasters. The emergence of these disasters has put forward an urgent demand for the application of GIS in emergency rescue, and prompted phase scholars to conduct in-depth research on the role of GIS in emergency rescue. To summarize, the timeline diagram can help scholars to have a comprehensive and in-depth understanding of the development lineage and current status of a certain field or topic, and provide valuable references and inspirations for future research.

Summarizing the above, it can be concluded from the three charts that most of the studies on emergency response teams in disaster-stricken areas are based on the directions of "emergency management", "emergency response capacity" and "team building", which are related to "emergency management", "emergency response capacity" and "team building", which are all related to "emergency management", "emergency response capacity" and "team building". These keywords provide a strong foundation for the construction of the assessment indicators of emergency response teams in disaster-stricken areas under the perspective of resilience, and the indicators in the assessment system of emergency response teams in disaster-stricken areas under the perspective of resilience should emphasize the existence of these directions. "Emergency management" requires strong organizational leadership of the emergency response team, and the responsibility system and responsibility system in the organizational leadership can be used as an important indicator to examine whether the emergency response team construction is good. "Emergency Response Capability" is a combination of multiple levels of assessment as the focus of an emergency response team at a disaster site. The basic ability and professional ability of the members of the emergency response team as well as the comprehensive quality of the members of the team can be the embodiment of "emergency response capability"; whether the emergency response team can fully utilize the emergency response resources is also the embodiment of "emergency response capability", and the emergency response resources can be divided into equipment, facilities, funds and other resources; the emergency response team can be divided into equipment, facilities, funds and other resources, Whether the emergency team can fully utilize the emergency resources is also a reflection of the "emergency response capability", and the emergency resources can be divided into equipment, facilities, funds and other resources; "team building" can be divided into the direction of team planning and spiritual construction. The term "geographic information system" shown in Figure 4 indicates that the research on emergency response teams in disaster-stricken areas also pays attention to the development and utilization of science and technology, and the informatization and intelligent construction of emergency response teams and the development of technology can also be used as one of the assessment indicators of emergency response teams in disaster-stricken areas, and the updating of technology, the application effect of technology and the cooperation and exchange of technology can be used as the indicators of emergency response team construction in disaster-stricken areas. The updating of technology, the effect of technology application, and the cooperation and exchange of technology can all be examined as the direction of the construction of the emergency response team at the disaster site. Therefore, the relevant map produced by Citespace provides sufficient basis for the establishment of indicators in the assessment of emergency response teams at disaster-stricken sites from the perspective of resilience, and reasonable assessment indicators can be established by combining with the analysis of the map.

3. Constructing a multimodal transportation cost model for emergency logistics

Emergency supplies need to be sent from the emergency warehouse to the disaster site, in the whole transportation process needs to pass through the different disaster sites, some of which can be transformed to the mode of transportation. Every two neighboring points can be used between the three modes of transportation: road, railroad and waterway. In the process of multimodal transportation of emergency supplies, the choice of different modes of transportation, different paths will change the transportation cost accordingly. Compared with general goods, some liquid types in emergency supplies are usually characterized by potential hazards such as combustion and explosion. According to the characteristics of the emergency supplies itself, can meet the transportation requirements including highway, railroad, waterway, the three modes of transportation. Choose each mode of transportation, its cost composition has a certain difference. How to effectively transport mode path combination planning, so that the entire emergency supplies transportation process cost minimization is the most concerned about the emergency department. How to choose a particular mode of transportation needs to be analyzed from the nature of the emergency supplies, transportation costs, transportation time and other factors. Emergency supplies can be selected at the disaster site to change the mode of transportation, in the transfer process, will inevitably produce the corresponding transfer costs. How to find out the best transportation mode and path from the emergency warehouse to the disaster point is the next problem to be analyzed. This paper is standing in the perspective of multimodal transport operators, the whole process of multimodal transportation of emergency supplies to plan and be responsible for the transportation process.

3.1 Basic assumptions of the multimodal transportation problem for emergency supplies

1. In the process of multimodal transportation, at most one transportation mode change is carried out at each node disaster point. In the corresponding nodes of the disaster point can be carried out transportation mode change, but also can not change and use the same mode of transportation.2. In the process of multimodal transport, transportation of goods between the two nodes as a whole, can not be divided into a number of times and batches for transportation.3. In multimodal transportation, the costs incurred as a result of changing modes of transportation are all included in the cost of transshipment. In addition, the storage cost during transshipment is included in the time cost for convenience.4. In multimodal transportation, the costs incurred on the route are proportional to the distance when the same mode of transportation is used.5.In a multimodal transportation network, each transshipment node has the capacity to carry out transshipment operations.6. In the whole process of multimodal transportation, the unit cost and speed generated per kilometer are the same in different paths.7. This paper takes the perspective of multimodal transport operator to make an integrated arrangement and planning for the whole transportation business.

3.2 Notation of the problem

The specific meanings of the relevant symbols are shown in Table 2 below.

Table 2. Meaning of symbols

Notation	Hidden meaning
$x_{i,j}^{k}$	Indicates whether the mode of transportation used between affected point i and affected point j is k, and is a decision variable of 1 or 0.
$y_{i}^{k,l}$	denotes whether transportation mode k has been changed to transportation mode l in the affected point i, and is the decision variable 1 or 0.
$c_{i,j}^{k}$	Indicates the unit cost of transportation consumed at disaster point i and disaster point j for mode k of transportation.
$c_{i}^{k,l}$	denotes the cost of loading and unloading at disaster point i due to a change in the mode of transportation;
${c'}_{i}^{k,l}$	denotes the storage cost at node disaster point i, due to the shift in transportation mode;
c_{t}	denotes the time cost per unit time;
$t_{i,j}^{k}$	denotes the time consumed for transportation from node i to node j using transportation mode k.
$t_{i}^{k,l}$	denotes the time consumed for transportation from node i to node j using transportation mode k;
$d_{i,j}^{k}$	denotes the transportation distance from node affected point i to node affected point j by selecting

	transportation mode k;
$v_{i,j}^{k}$	denotes the transportation distance from node i to node j for transportation mode k;
U_n	denotes the set of nodes in the transportation network;
U_k	denotes the set of transportation modes.

3.3 Modeling the cost of multimodal transportation of emergency supplies

A model based on the goal of minimizing the total cost of the multimodal transportation process for emergency supplies.

$$\min C = \sum_{k\in U_k, j,j\in U_n} x_{i,j}^{k} \times c_{i,j}^{k} \times d_{i,j}^{k} + \sum_{k,l\in U_k} \sum_{k\in U_n} y_i^{k,l} \times \left(c_i^{k,l} + c_i^{k,l} \times t_i^{k,l}\right) + \left(\sum_{k\in U_k, j,j\in U_n} x_{i,j}^{k} \times t_{i,j}^{k} + \sum_{k\in U_k} \sum_{i,j\in U_n} y_{i,j}^{k} \times t_i^{k,l}\right) \tag{1}$$

$s.t.$

$$\sum_{k\in U_k} x_{i,j}^{k} = 1 \; \forall i,j \in U_n \tag{2}$$

$$\sum_{k,l\in U_k} y_i^{k,l} = 1 \; \forall i \in U_n \tag{3}$$

$$v_{i,j}^{k} \times t_{i,j}^{k} = d_{i,j}^{k} \; \forall i,j \in U_n \forall k \in U_k \tag{4}$$

$$x_{i,j}^{k}, y_{i,j}^{k} \in \{0,1\} \tag{5}$$

$$\forall c_{i,j}^{k}, d_{i,j}^{k}, c_i^{k,l}, c_i^{k,l}, t_i^{k,l}, t_{i,j}^{k} \geq 0 \tag{6}$$

Equation (1) is the objective function to minimize the costs incurred throughout the transportation of liquid dangerous goods; Equation (2) is the choice of transportation mode between two affected points can only be one; Equation (3) is the maximum of one conversion mode of transportation in each transshipment affected point; Equation (4) is that only one activity of transportation is carried out between two node affected points; and Equation (5) indicates that the two decision variables are 0, 1 variables; Equation (6) is the interval of values for the parameters.

4. Strategies for coordinated configuration of the emergency logistics system

With the increase of global climate change and sudden-onset disasters, the role of emergency logistics system in post-disaster response becomes more and more important. Emergency logistics not only involves the rapid deployment and distribution of materials, but also needs to efficiently organize emergency response teams to ensure the smooth progress of post-disaster relief. How to efficiently configure the emergency response team and materials in the limited resources and complex environment after a disaster has become a key issue of concern in the academic and practical fields. This paper proposes a coordinated configuration strategy for emergency logistics system by analyzing the literature related to emergency teams based on CiteSpace, a scientific literature analysis tool, and combining the construction of multimodal transportation cost model for emergency supplies.

4.1 Coordinated Configuration Strategy of Emergency Response Team Based on CiteSpace Analysis

Efficient coordination of emergency teams is the core element to ensure timely and effective post-disaster response. According to the combing of related literature by CiteSpace analysis tool, the current research on the emergency response team mainly focuses on the following aspects: the optimization of emergency response team scheduling, the synergy mechanism between the teams, the timeliness of the team's response and the coordination and cooperation between the team and other rescue organizations. Combined with the results of literature analysis, this paper proposes the following strategies for coordinated configuration of emergency teams.

(1) Establish a multi-level emergency response team coordination mechanism

When a disaster occurs, the emergency response team usually involves multiple levels and multiple organizations, including local governments, the central government, nongovernmental organizations (NGOs), military rescue teams and volunteers, etc. Therefore, the establishment of a cross-sectoral and cross-functional coordination mechanism for the emergency response team is essential to the success of the disaster. Therefore, it is crucial to establish a cross-sectoral and cross-regional coordination mechanism for emergency response teams. As mentioned in the literature, the existing organizational structure of emergency response teams is usually too homogeneous and lacks effective multi-level coordination. For this reason, it is recommended to establish a multilevel coordination mechanism based on an information sharing platform to achieve cross-level and cross-regional resource deployment through the establishment of an emergency response command center. Through the sharing of real-time location, task progress and other data of each emergency response team, it is possible to quickly mobilize the relevant teams when a disaster occurs, and avoid duplication of resources and delayed scheduling.

(2) Dynamic Dispatch and Intelligent Support System

Based on the results of CiteSpace's literature analysis, the application of big data and artificial intelligence technology in emergency team scheduling is gradually becoming a trend. Existing studies show that the dispatching of emergency teams is often affected by multiple factors such as traffic conditions in the disaster area and changes in the demand for materials, so it is particularly important to establish a dynamic dispatching mechanism. It is proposed to develop an intelligent dispatching system based on real-time information flow by combining big data technology and Internet of Things (IoT) technology. This system can adjust the deployment and task allocation of the team in real time according to the changes in the disaster situation and realize the optimal allocation of the team's resources. In addition, the accuracy and timeliness of team scheduling decisions can be further improved by utilizing artificial intelligence algorithms (e.g., deep learning and machine learning).

(3) Constructing a multi-body collaboration model for emergency response teams

In the process of post-disaster rescue, there is often resource competition and collaboration between emergency teams. Through the literature analysis of CiteSpace, we found that the existing research is less involved in the collaboration game model between teams. For this reason, it is proposed to construct a collaboration model for emergency teams based on game theory and multi-subject collaboration theory. The model can simulate the resource competition and cooperation among different teams, and optimize the task allocation and resource allocation. For example, when different teams need to grab limited resources (e.g., means of transportation, medical equipment, etc.), the optimization of the game model can enable the teams to maximize the overall effectiveness of post-disaster response while ensuring their own interests.

4.2 Coordinated allocation strategy of emergency supplies based on multimodal transportation cost model

The timely distribution of emergency supplies is directly related to the effectiveness of post-disaster response. According to the literature analyzed by CiteSpace, the current research on optimization of material distribution in emergency logistics mainly focuses on transportation cost, transportation time, and transportation mode selection. This paper proposes a coordinated allocation strategy for emergency materials based on multimodal transportation to achieve high efficiency, low cost and fast response of material transportation.

(1) Multimodal transportation mode selection and optimization

Multimodal transportation refers to a mode of logistics distribution through multiple modes of transportation (e.g. highway, railroad, aviation, waterway, etc.). In emergency logistics, multimodal transportation can effectively overcome the limitations of a single mode of transportation and ensure that the materials can be quickly transported to the affected areas after the disaster. Combined with the literature analysis of CiteSpace, it is proposed to establish a multimodal transportation selection model based on the balance of demand and cost. The model can dynamically select the best combination of transportation modes according to different disaster types, material demand and traffic conditions. For example, in the case of traffic congestion or serious road damage, air or rail transportation can be preferred, while in the case of smooth roads, road transportation with lower cost can be chosen.

(2) Optimization design of material distribution path

Path optimization of multimodal transportation is the key to improve the distribution efficiency of emergency supplies. Existing research shows that traffic congestion, infrastructure destruction and other factors in disaster areas usually lead to the failure of traditional distribution paths. Therefore, the emergency logistics system needs to have the ability of rapid response and path optimization. It is recommended to design the distribution path for emergency supplies based on optimization algorithms such as shortest path algorithm and genetic algorithm. The path should take into account the traffic conditions, material demand, transportation capacity and other factors in the disaster area, and dynamically adjust the optimal path to reduce the transportation time and cost. In this process, it is also necessary to introduce redundant designs, such as alternate transportation routes, to cope with unexpected situations such as traffic disruption in the disaster area.

(3) Dynamic multi-objective optimization scheduling

Emergency logistics systems face the balance of multiple objectives, such as transportation time, cost, risk and resource allocation. In the context of multimodal transportation, how to find the best balance between different objectives is the core problem of logistics system optimization. It is suggested to use multi-objective optimization algorithms (e.g., particle swarm optimization algorithm, ant colony algorithm, etc.) to optimize the scheduling of emergency supplies. These algorithms are able to adjust the distribution plan in real time under multiple constraints to ensure that the distribution of materials is completed in the shortest possible time, while minimizing costs and risks. For example, in the case of a surge in demand for supplies in the disaster area, the algorithm can prioritize the deployment of transportation modes with strong transportation capacity to ensure that the supplies can arrive on time.

(4) Coordination Mechanism for Emergency Material Inventory and Distribution

The efficient operation of multimodal transportation mode cannot be separated from a reasonable inventory and distribution strategy. It is recommended to establish an inventory management system for emergency supplies, which can adjust the inventory level in real time according to the immediate demand, supply capacity and transportation conditions in the disaster area. Through synergy with the multimodal transportation network, it ensures that emergency supplies can be deployed and transported at any time. In the early stage of a disaster, the materials can be distributed quickly through centralized stockpiles; while in the recovery stage, the system can be dynamically adjusted according to changes in demand.

In summary, the CiteSpace-based literature analysis of emergency teams and the construction of multimodal transportation cost model for emergency materials can provide theoretical basis and strategy support for the coordinated configuration of emergency logistics system. By improving the coordination mechanism of emergency teams, introducing intelligent scheduling system, optimizing the transportation path of materials, and combining the advantages of multimodal transport, the response efficiency and resilience of emergency logistics can be improved, thus reducing the losses caused by disasters and safeguarding the life safety and living needs of people in disaster areas. In the future, with the continuous progress of technology and in-depth theory, the emergency logistics system based on big data and intelligence will be widely used worldwide.

5. Summary

With the frequent occurrence of natural and man-made disasters around the world, the enhancement of emergency logistics and emergency response capability has become an important issue of common concern in both academic and practical circles. Through the bibliometric analysis based on CiteSpace, a scientific literature analysis tool, this paper has systematically sorted out the research lineage, hot issues and development trends in the field of emergency response team and emergency logistics, and on this basis, constructed a multimodal transportation cost model for emergency supplies from the perspective of toughness, and put forward a collaborative configuration strategy of the emergency logistics system for the mega-disaster scenario. This study not only provides theoretical support for the organization and dispatching of emergency teams, efficient distribution of emergency supplies and cost optimization of multimodal transportation, but also provides an important decision-making framework for future catastrophe emergency response practice. Through CiteSpace's literature analysis, this study first reveals the main research directions in the field of emergency team and emergency material management. In terms of the organization and scheduling of emergency teams, most of the existing studies focus on the dynamic scheduling of teams, task allocation and response timeliness, but there are still fewer studies on how to achieve rapid coordination and optimal allocation of resources of emergency teams in complex disaster situations. As a key factor to enhance the efficiency of emergency logistics, multimodal transportation has been widely studied in other logistics fields, but its application in emergency logistics is still in the preliminary exploration stage, especially in the multimodal transportation cost optimization of emergency supplies in catastrophic situations, the relevant literature is relatively scarce. Therefore, this paper focuses on this gap area, combines the toughness theory, and proposes a multimodal transportation cost model for emergency supplies, focusing on the consideration of the choice of transportation mode, transportation time, resource redundancy allocation and other factors, in order to achieve a balance between system efficiency and cost. In the process of model construction, this paper comprehensively considers the applicability of different types of transportation modes after a disaster, as well as the time, cost and capacity constraints of each transportation mode, and proposes the optimal synergistic configuration strategy of the emergency logistics system in the post-disaster environment through the multi-objective optimization method. This strategy can not only effectively improve the distribution efficiency of emergency supplies and reduce transportation costs, but also enhance the adaptability and recovery ability of the system after a disaster. Based on this strategy, this paper further explores the redundant resource allocation in the transportation of emergency materials and the synergy of emergency response teams, and proposes a more resilient emergency response model. Overall, the research in this paper provides a new perspective for the theoretical development and practical application in the field of emergency logistics, especially in the optimization of logistics cost and team synergy under catastrophic situations with strong innovation and practical value.

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