Catastrophe-oriented emergency medical material dispatching research based on UAV and truck collaboration

Ye Wei[1]

1 Zhoujiadu Community Health Service Center of Pudong New District, Shanghai, China

DOI: https://doi.org/10.56293/IJMSSSR.2025.5415

IJMSSSR 2025
VOLUME 7
ISSUE 1 JANUARY – FEBRUARY **ISSN: 2582 - 0265**

Abstract: Natural disasters and man-made disasters and other emergencies are difficult to avoid, and at the same time will have a significant impact on people's production and life, and damage the life and property safety of residents and the smooth operation of social and economic activities. For this reason, timely and effective emergency medical material dispatching and distribution system is crucial. This paper firstly discusses the current situation and deficiencies of the current medical emergency supplies distribution system through data mining and word cloud statistical analysis methods. The analysis results show that the existing distribution methods have many challenges in terms of efficiency, timeliness and resource allocation. Especially in the face of traffic congestion, natural disasters and other emergencies, the emergency response capability and distribution efficiency of the traditional distribution mode cannot meet the actual demand. Based on these deficiencies, this paper proposes the emerging technology of drones as a solution for emergency distribution. Compared with the traditional transportation mode, UAV has significant advantages: it is not restricted by road interruption, and can bypass traffic congestion, natural disasters and other factors to ensure efficient and timely distribution of materials. At the same time, drones have strong flexibility and can precisely fly to remote or inconvenient areas to make up for the blind areas that traditional distribution methods cannot cover. In addition, the high flight speed of UAV enables it to complete the distribution task in a short time to meet the rapid response demand of emergency materials. On this basis, this paper constructs an operations research model of UAV and truck intermodal transportation, aiming to optimize the distribution path and time efficiency of emergency medical supplies through the synergistic cooperation between the two, so as to solve the deficiencies of the traditional vehicle distribution system, and to improve the efficiency and responsiveness of emergency logistics. This research provides new theoretical support and practical guidance for emergency material distribution.

Keywords: catastrophic scenario; Emergency medical supplies; multimodal transportation; Emergency dispatch optimization.

1. Introduction

Public health emergencies and emergency natural disasters pose a serious threat to the normal operation of society and the safety of people's property. Natural disasters, such as earthquakes, floods, typhoons, etc., not only cause property damage and casualties, but also may cause a series of healthcare events or hazards [1], including traumatic diseases, infectious diseases caused by natural disasters destroying water supply infrastructures, while the panic and despair of losing friends and relatives brought about by a disaster may also lead to psychological disorders. If supplies are not provided in a timely manner, disaster victims will suffer psychologically or physically [2]. Therefore, how to plan and deploy emergency medical supplies such as basic medicines and medical appliances, personal protective equipment, still equipment, medical logistics materials, how to improve the emergency medical supplies storage and logistics channels from the three aspects of material pre-positioning, contractual reserves and emergency procurement [3], etc. for emergency relief is a core issue. Therefore, it is necessary to improve the emergency medical material storage and emergency management scheduling system.

The current emergency medical system mainly focuses on establishing and optimizing the emergency medical system, improving the infrastructure while strengthening the training of personnel and the stockpiling of emergency supplies and the logistics planning of emergency medical supplies [4]. However, there are still many

challenges in the actual emergency medical dispatching practice. The high scale and complexity of emergencies often exceeds the threshold of the emergency response system [5]; the timeliness of emergency material distribution and the precision of medical resources can be affected by various unexpected situations in emergency rescue such as blocked road access, river blockage, transportation tools, human resource limitations and other factors, which greatly affects the rescue efficiency. Uncertainty exists in the deployment of medical supplies and rescue personnel, the type and number of casualties are unpredictable, how to select the location of the site under the uncertainty, further increasing the difficulty of resource allocation [6]. In addition, information technology support and optimization of decision-making means the lack of linkage and synergistic capabilities, the traditional emergency response system relies on manual operations resulting in a reduction in efficiency, affecting the rescue work and the distribution of medical supplies when the uncoordinated. How the warehousing strategy of emergency medical supplies balances the consideration of cost and utilization is also a key issue [7].

With the continuous maturity of UAV technology, UAV technology and truck cooperative distribution mode have made significant progress in the logistics field. It is very promising to introduce the UAV truck cooperative distribution mode into the field of emergency medical material distribution [8]. With the characteristics of high efficiency, flexibility and rapidity, UAVs are able to rapidly transport medical materials in complex and inaccessible environments, solving the limitations of traditional transportation methods. In post-disaster rescue and epidemic prevention and control, UAVs are not only able to quickly transport medicines, protective materials, first aid kits and other items, but also provide real-time aerial monitoring and information transmission support for areas in urgent need of medical assistance. This significantly improves the efficiency of emergency medical material distribution, shortens medical rescue response time, and greatly enhances the timeliness and accuracy of emergency response. By combining with other modern technologies such as artificial intelligence, big data and the Internet of Things, the drone is able to carry out intelligent scheduling, real-time data analysis and accurate material prediction during the rescue process, providing more targeted solutions for medical rescue.

2. Study on the status of emergency medical supplies

In order to analyze the current situation of development and research in the field of emergency medical care, this paper uses text data mining and word cloud statistical analysis techniques to analyze the relevant literature of web of science database in the past five years, focusing on the optimization of distribution path of emergency medical care materials, emergency medical care response system, distribution strategy of emergency medical care materials, and forecasting of demand for emergency medical care materials, etc., and under the pycharm compilation environment Data mining was carried out on the text data using python, and data features were extracted by Topic-Rank algorithm, which revealed the research law and cutting-edge dynamics, and also clarified the focus of the research.

The basic idea of Topic-Rank algorithm is to score each word in a document, usually a noun or adjective, and then compute the combination of all the words that follow, i.e., sexually summing the scores of each part, and finally obtaining an importance ranking of the combined words. On this basis, by ranking single and multiple word expressions, i.e., scoring the words directly and then constructing a word map, instead of dividing the document into individual words first and then constructing a word map and then combining them into words.

The strength of the Topic-Rank algorithm lies in its topic-oriented keyword ranking. Unlike traditional word-based ranking methods, Topic-Rank uses document topics for keyword ranking. Each candidate keyword is categorized according to the topic it represents, rather than relying solely on the frequency or importance of individual words. This topic-based sorting is more intuitive and can better represent the overall meaning of the document and cover the key phrase set of the document; secondly, the algorithm can reduce redundancy and enhance keyword expression, Topic-Rank clusters candidate keywords according to the topic and selects a representative keyword from each cluster. This clustering effectively eliminates redundancy and avoids purely repetitive keywords from affecting the ranking. Clustering can better express the diversity and deep semantics of documents, and strengthen the relationship between keywords and the topics they represent; at the same time, to improve the conciseness and semantic expression of the graph, Topic-Rank relies on the complete structure of the word graph, which is able to more accurately capture the semantic relationship between the various topics within the document. This graph structure can express the relationship between words more clearly, thus improving the accuracy of keyword extraction and avoiding the mis-ranking phenomenon caused by the inaccurate graph

structure in traditional methods. Topic-Rank algorithm can avoid the word-level redundancy problem, the traditional Single-Rank method will first score each word in the document, and then calculate the score of the word based on the combination of words. This approach may lead to high scores for certain non-keyword words (e.g., common functional words).Topic-Rank avoids this problem by constructing word graphs directly at the word level, thus improving the effectiveness of keyword extraction; Topic-Rank algorithm better reflects the thematic structure of the document Topic-Rank is able to better capture the thematic structure of the document in the process of graph construction and ranking, rather than just relying on the thematic structure of the document, rather than just relying on the frequency or relationship of words. This makes the extracted keywords more in line with the main idea of the document, and can effectively extract the key phrases that cover the important semantics of the whole text.

The Topic-Rank algorithm value is calculated using the following formula (1)(2):

$$w_{i,j} = \sum_{c_i \in t_i} \sum_{c_j \in t_j} dist(c_i, c_j) \quad (1)$$

$$dist(c_i, c_j) = \sum_{p_i \in pos(c_i)} \sum_{p_j \in pos(c_j)} \frac{1}{|p_i - p_j|} \quad (2)$$

Where $w_{i,j}$ represents the distance between keyword nodes c_i and c_j in the document, also known as the offset position; $pos(c_i)$ represents all the offset positions of the keyword node c_i.
Then using python programming, a word cloud map of the current state of research in the field of emergency medicine was drawn as shown in Figure 1 by identifying the keywords and word frequencies obtained from the analysis of the field of emergency medicine.

Figure 1. Word cloud on the current state of research on emergency medical supplies

From the above figure, it can be seen that in the field of emergency medical care, site selection and scheduling optimization, collaborative emergency management and cross-discipline cooperation, risk assessment and late recovery, medical resource logistics management, disaster assessment and prediction are the current research focus in the field of emergency medical dispatch, and through the analysis of the data, it can be found that complete emergency medical dispatch system and timely and effective scheduling of emergency medical distribution is one of the important components of emergency management. The following table (1) shows the word frequency statistics after retrieval analysis obtained using python text analysis:

Table 1. Keyword and word frequency statistics for emergency medical supplies research

Keyword	Frequency	Keyword	Frequency	Keyword	Frequency
Medical	690	Algorithm	107	Logistics	69
Epidemic	237	Decision-making	104	Prevention	67
Demand	221	Rescue	96	Coordination	66
Public Health	227	Objective	93	Region	61
Distribution	222	Site Selection	90	Prediction	58
Emergency	209	Cost	88	Urgency	58
Allocation	180	System	82	Network	55
Optimization	169	Path	80	Efficiency	54
Scheduling	151	Government	77	Factors	54
Guarantee	115	Situation	74	Allocation	50
Reserves	113	Hospital	71	Risk	49

From the analysis of the word frequency statistics table and the word cloud diagram, we get the following conclusions:

From the perspective of focus problem: medical emergency management focuses on "risk", "cost" and "time", and risk and cost are usually the constraints or objective functions that researchers need to consider in scheduling optimization. In scheduling optimization, risk and cost are usually the constraints or objective functions that researchers need to consider, and it is the mainstream of research to construct an operations research model to optimize the scheduling of emergency medical delivery by minimizing the comprehensive cost, minimizing the delivery time, or minimizing the system risk and maximizing the satisfaction, etc. Meanwhile, "epidemic", "outbreak", "prevention", and "control" are the most important factors in emergency medical management. Meanwhile, the keywords "epidemic", "outbreak", "prevention and control" reflect that the management and scheduling of emergency medical supplies play a crucial role in responding to epidemics and public health emergencies, involving prevention and control before emergencies, scheduling during emergencies, and optimization after the event. Meanwhile, the key words "demand", "distribution", "dispatch" and "guarantee" reflect the principle of people-oriented emergency medical dispatching. Meanwhile, the key words "demand", "distribution", "dispatch" and "guarantee" reflect the principle of people-oriented, and the starting point of everything is to meet the needs of the affected people and protect their lives. Meanwhile, it also shows that the demand management and reasonable distribution of materials are still the problems of emergency response, such as in the period of the epidemic, faced with the tension of the supply of resources, we need to be more accurate decision-making and more perfect scheduling mechanism.

From the perspective of research methodology: keywords such as "algorithm" and "optimization" indicate that the field of emergency medical dispatching mainly uses optimization algorithms, artificial intelligence, machine learning, etc., to solve the problems of distribution, dispatching and path planning of emergency supplies. For example, optimization algorithms are used to plan the distribution paths of medical supplies to ensure that resources are most efficiently invested where they are most needed; the keywords "prediction", "decision making", and "objective" The keywords suggest that, in addition to optimal scheduling, the field of emergency medical supplies involves the use of methods such as system dynamics to construct predictive models to identify potential needs and risks in advance, and the use of decision science to help decision makers construct scientific decision-making principles and decision-making systems. Based on historical data, outbreak trends, or disaster response, the use of predictive modeling can effectively help decision makers arrange resources and quickly adjust response measures.

From the perspective of the research topic: emergency medical supplies focus on emergency supplies scheduling and distribution issues, how to efficiently deploy limited medical resources (e.g., medicines, protective supplies, beds, etc.) to meet the demand during emergencies or epidemics. This includes data-based scheduling models, resource priority allocation, and optimal scheduling strategies with multi-party collaboration. Meanwhile, in the field of supply chain management and optimization, how to ensure the efficient operation of logistics, stockpiling,

and distribution, reduce time delay, and optimize inventory management is the focus of the research. The keywords "supply chain", "logistics" and "reserve" reflect the importance of this topic; in addition, how to assess the potential risks in the material supply chain in the process of emergency response (e.g., transportation delay, material shortage, epidemic, etc.) is the focus of research. transportation delays, material shortages, epidemic spread, etc.), and take corresponding preventive measures to reduce the negative impact of emergencies on the system, the risk assessment and management of emergency medical deployment becomes critical; in order to provide scientific decision support to decision makers, in public health emergencies to build a scientific decision support system to help the government and hospitals and other institutions to carry out rational planning and resource allocation. It involves the research of decision-making models, situation analysis and real-time data updating technologies; at the same time, cross-regional and cross-organizational collaboration is also a key area of research concern, how to build regional synergy mechanisms, and how to better cope with complex epidemics or natural disaster emergency medical deployment situations in multi-party collaboration.

3. Challenges and inspiration for emergency medicine research

3.1 Current challenges in the area of emergency medical supplies

Inadequacies in the construction of the emergency medical material system. Emergency medical management is aimed at responding to the medical needs of various types of public health emergencies and natural disasters, and covers all aspects of material stockpiling, deployment, distribution and utilization. Despite the gradual establishment of the emergency medical system, there is a lack of clear definitions and unified standards for "emergency medical capacity" and "emergency medical material management capacity", which has led to differences in research results and practical operations in related fields. Although academics have put forward different evaluation index systems for emergency supplies, due to the lack of unified standards, it is difficult to form an effective collaborative working mode in practical application, especially in the areas of supplies dispatching and supply chain management, etc. The collaborative mechanism is still imperfect. At the same time, most of the existing research stays at the stage of theory or model construction, lacking in-depth exploration of specific implementation details, indicator weights, material demand forecasting, reserve management and its application, resulting in the lack of an effective assessment mechanism for the emergency medical material system, which cannot fully meet the post-disaster emergency relief needs.

Insufficient application of technological innovation. Although the development of informatization and intelligent technology provides great potential for emergency medical material management, there are still many deficiencies in the application of new technologies in the field of emergency medical material management. First of all, most emergency medical systems lack efficient informationization management tools. In terms of inventory management, scheduling and distribution of materials, there is a lack of information-based management platforms and data sharing mechanisms, leading to information asymmetry, inefficient deployment, excess or shortage of inventory and other problems in materials management. The problems of flow, supervision and use of emergency medical supplies are particularly prominent, especially in the post-disaster environment, where the lack of an informatization system makes it impossible to monitor the flow of emergency supplies in real time and reduces the efficiency of rescue. Secondly, most of the existing technology research focuses on the post-disaster emergency response phase, and the application of infrastructure construction, emergency preparedness, monitoring and early warning technologies is still weak. For example, there is still a lack of sufficient research and technological investment in how to predict and optimize the stockpiling of supplies before a disaster through big data and artificial intelligence, and how to quickly locate the areas and people most in need of supplies after a disaster.

The management system for emergency medical supplies is imperfect and lacks systematization and standardization. The management system of emergency medical supplies usually lacks unified standards and norms, leading to large differences in the emergency response process among various regions and departments. The stockpiling, management and dispatching of various types of medical supplies do not form a closed-loop system management, and often face the situation of "fighting on their own". The deployment and command and coordination of emergency medical supplies lacked a unified chain of command, and information communication was poor, especially in the post-disaster environment of complexity and transportation restrictions, and the poor flow of information seriously affected the timeliness of decision-making and response. Emergency response plans

are generally imperfect and untargeted, and the emergency response plans of many healthcare organizations and relevant departments do not cover all possible disaster scenarios or emergencies, resulting in gaps and blind spots in specific implementation, which affects effective emergency response. Moreover, the frequency of training and drills for emergency personnel in some medical institutions is too low, and there is a lack of enhancement of emergency response capacity, making the emergency response capacity of medical personnel particularly weak in the event of a large-scale public health emergency. At the same time, the lack of an effective evaluation and feedback mechanism makes it impossible to summarize and optimize the improvement of emergency response in a timely manner, leading to the recurrence of the same problems and affecting the progress of the entire emergency medical system.

Vulnerability of emergency medical supplies in supply chain management. The supply chain management of emergency medical supplies is one of the core links to ensure the success of post-disaster medical relief, but the vulnerability that exists in this link is still a major challenge in emergency management at present. After a disaster, the transportation, distribution and storage of medical supplies are extremely difficult due to the breaks in the supply chain and the destruction of infrastructure. Especially when transportation is blocked or logistics are poor, the rapid dispatch of medical supplies becomes a huge challenge. In addition, problems such as imbalance in the stockpile of supplies and the backlog of expired supplies further exacerbate the complexity of emergency supplies management. In addition, there are difficulties in cross-sectoral and cross-regional coordination of emergency supplies, and there are large differences in the demand for supplies and the actual resources available in different regions, leading to unfair, wasteful or lagging distribution of supplies during post-disaster relief, which directly affects the effectiveness of post-disaster medical relief.

Overall, there are still many challenges in the field of emergency medical material management, which are specifically manifested in the incomplete system construction, insufficient application of information technology, lack of management standardization and fragile supply chain management. Only by strengthening the combination of theoretical research and practical operation, promoting technological innovation and informatization construction, and establishing a unified standard and a perfect emergency plan system, can we improve the management capacity of emergency medical supplies and the effect of emergency response.

3.2 Inspiration for research in the field of emergency medical supplies

Clarifying emergency medical supplies management capabilities is the key to improving emergency response levels. In the management of emergency medical supplies, it is first necessary to clarify the definition of "emergency medical capacity", and comprehensively consider the management capacity of the whole process and dimension, such as the stockpiling, deployment, distribution and use of supplies. The concept of "resilience" and the theory of "emergency response resilience" can be borrowed from foreign countries in emergency management, combined with the actual situation in China, to clarify the standards and definitions of emergency medical supplies management capacity. This will help to theoretically unify the understanding of all parties and promote the standardization and standardization of emergency medical supplies management capacity. A scientific definition will ensure that resources can be rapidly deployed in emergency situations, improving rescue efficiency and resource utilization.

There is a need to establish a comprehensive system of emergency medical supplies and a system of standardization and evaluation. At present, there are isolated problems with the emergency medical material system and evaluation. It is recommended that a practical emergency medical material management system be established and authoritative standards and norms be formulated on the basis of a clear definition of emergency medical capacity. Combining domestic and international experience, a reasonable evaluation system should be formulated to ensure that quantitative data are used for analysis and the weight of each indicator is clearly defined in the assessment. This system should cover all aspects of emergency medical material management, including material stockpiling, procurement, storage, dispatching and distribution, etc., and also consider post-disaster recovery and reconstruction. By establishing a comprehensive and practically applicable standard system and evaluation system, the management work can be better organized and the efficiency of emergency response can be improved.

Focus on the application of whole-process technological innovation in the field of emergency medical supplies. Technological innovation in the management of emergency medical supplies should not only be limited to the emergency disposal stage, but should also involve the whole process of emergency preparedness, monitoring and early warning, and post-disaster recovery. It is recommended to increase investment in informatization, digitization and intelligent technology, and apply emerging technologies, such as artificial intelligence, big data, Internet of Things, cloud computing, etc., to establish a real-time monitoring and response mechanism. For example, the trend of emergencies can be predicted through big data analysis and artificial intelligence so as to optimize the stockpiling and dispatching of medical supplies. At the same time, a rapid material distribution platform is established through intelligent means to realize real-time scheduling and management of resources in the event of a disaster. Promoting the combination of technological innovation and digital management tools can enhance the efficiency of emergency medical supplies management and response speed.

Optimize the supply chain and deployment of emergency medical supplies. Supply chain management of emergency medical supplies is crucial. In order to ensure that post-disaster medical relief can be carried out efficiently, it is necessary to ensure that medical supplies are adequately stocked and that the location and quantity of storage are reasonably planned. Scientific planning is recommended to avoid excessive stockpiling and wastage, and to improve the efficiency of deployment. The supply chain design of emergency medical supplies should optimize the distribution network to ensure that the supplies can reach the disaster areas in time when emergencies occur. Establishing a scientific planning strategy analysis can optimize the stockpile layout and transportation routes of medical supplies by simulating various emergency scenarios, shortening the response time, improving the efficiency of material utilization and reducing unnecessary costs.

Strengthening the Government's leadership and better utilizing its role. At present, although a certain amount of research has been focused on system construction, planning and evaluation of emergency medical material management, research in some key areas such as emergency early warning system, departmental linkage mechanism, and emergency preparedness of medical materials is still relatively weak. The government should further play a leading role in promoting policy guidance and financial support to facilitate the combination of research and practice in the field of emergency medical material management. Through policy encouragement and financial support, cross-sectoral collaboration can be strengthened, technological innovation and application can be promoted, and the construction and optimization of emergency medical material management system can be accelerated. The government should increase its leadership in the management of emergency medical supplies to ensure the timely provision and coordination of all types of emergency medical supplies, so as to provide strong protection for emergencies and post-disaster recovery.

Strengthening cross-sectoral collaboration and the construction of an information platform for emergency supplies. At present, there is a lack of a unified informatization platform for the management of emergency medical supplies, and there are difficulties in sharing information and coordinating resources among different departments. It is recommended that the government and relevant departments strengthen the construction of information technology platforms, build cross-departmental medical supplies management information systems, and realize real-time monitoring, scheduling and sharing of various types of medical supplies. By integrating the resources of all parties, the timely flow of information can be ensured, the synergy of emergency response can be improved, and duplication of resources and dispatching errors can be avoided. The establishment of a unified informatization platform can improve the transparency and response speed of emergency medical supplies management, and ensure that all parties can coordinate their work quickly and accurately during emergencies.

At the same time, by citing new technologies and new methods can provide a new perspective for the medical emergency field, this paper also constructs a truck drone synergy model, aiming to optimize the distribution path and timeliness of emergency medical supplies through the synergistic cooperation between the two, so as to solve the deficiencies of the traditional vehicle distribution system, and improve the efficiency and responsiveness of the emergency logistics.

4. Truck UAV Collaborative Modeling

4.1 Description of the problem

In a specific region where a public health event or a natural disaster is assumed to occur, there is a specially set up emergency warehouse and a number of hypothetical affected points, there are a number of trucks carrying drones in the emergency warehouse as a means of distributing emergency medical supplies, the vehicles start from the emergency warehouse and distribute to the affected points, and it is required to optimize the model by minimizing the distribution time.

4.2 underlying assumption

1.Each truck carries a drone, and each truck can only carry one drone.2. The disaster site can accept multiple trucks or drones for delivery, but the needs of the disaster site must be fully satisfied.3. The trucks and drones do not carry more than their maximum capacity.4. The drone sends out from the truck every time it dispenses, and then it lands on the truck after completing the delivery and meets with the truck at the disaster site. If the drone or the truck arrives at the recovery point out of sync, the faster one needs to wait. 5. Disregarding the time of charging, landing, taking off and recovering the drone, every time the drone returns to the truck, it will be charged and refueled, so every time the drone takes off, it is at its maximum endurance.

4.3 Parameter and decision variable setting

The basic parameters of the model and the decision variables are set in the following table:

Table 2. Keyword and word frequency statistics for emergency medical supplies research

Notation	Hidden meaning
Q^r	Capacity of trucks k;
Q^u	Capacity of drones u;
D_i	Demand for materials at disaster site i;
lr_{ij}	Vehicle travel distance from affected point i to affected point j;
lu_{ij}	Round-trip UAV flight distance from node i to node j;
L^d	Range of the drone;
t_{ki}	Time for truck k to reach node i from the warehouse where it is located.
t'_{kij}	Time for the drone on truck k to take off from point i and return to the truck after completing the distribution at disaster point j;
ω_{ki}	Number of vehicles k or vehicle-mounted drones delivering supplies to disaster site I;
ζ_{ki}	Time for truck k to reach node i;
ζ'_{ki}	Time for the drone on the truck k to complete the disaster site i delivery back to the truck;
α_{ki}	Boolean variable, 1 if truck k moves to point i, 0 otherwise
β_{kij}	Boolean variable, 1 if the drone on truck k launches at point i to deliver emergency supplies to disaster point j, 0 otherwise;

4.4 Operations Research Model (ORM)

$$\text{Minimize}\, Z_1 = \sum_{k\in K} \max\{\zeta_{ki}, \zeta'_{ki}\} \quad (1)$$

$$\sum_{i\in C\cup N} \alpha_{ki} \le 1 \qquad \forall k \in K \quad (2)$$

$$\sum_{j\in C} \beta_{kij} = \alpha_{ki} \qquad \forall i \in N, k \in K \quad (3)$$

$$\sum_{i\in N}\sum_{j\in C} \beta_{kij} \le 1 \qquad \forall k \in K \quad (4)$$

$$\alpha_{ki} \ge \beta_{kij} \qquad \forall j \in C, k \in K, i \in N \quad (5)$$

$$\sum_{k\in K} \omega_{ki} = D_{ei} \qquad \forall i \in C, \forall e \in E \quad (6)$$

$$\sum_{i\in C} \omega_{ki} \le Q^r \qquad \forall k \in K, i \in C \quad (7)$$

$$lu_{ij}\beta_{kij} \le L^d \qquad \forall i \in N, \forall j \in C, k \in K \quad (8)$$

$$\zeta'_{kj} \ge \zeta_{ki} + t'_{kij} - M(1-\beta_{kij}) \qquad \forall i \in N, \forall j \in C, k \in K \quad (9)$$

$$\zeta_{ki} \geq t_{ki}\alpha_{ki} \quad \forall i \in N \cup C, k \in K \quad (10)$$
$$\alpha_{ki} = \{0,1\} \quad \forall k \in K, i \in N \cup C \quad (11)$$
$$\gamma_{ki}, \beta_{kji} = \{0,1\} \quad \forall k \in K, i \in C, j \in N \quad (12)$$
$$\omega_{ki} \geq 0 \quad \forall k \in K, i \in C \quad (13)$$
$$\zeta_{ki}, \zeta'_{ki} \geq 0 \quad \forall i \in N \cup C, k \in K \quad (14)$$

Objective function (1) to find the shortest time to complete the distribution of all vehicle usage time and drone distribution time; constraint (2) to limit that each vehicle should depart from the emergency warehouse at most once; constraint (3) truck and drone synergy constraint; constraint (4) to limit that the drone carried in the same truck can be launched only at most once; constraint (5) to limit that the vehicle carrying the drone can launch the drone at the j point only when it passes by the i point; constraint (6) constraint that the demand at the affected point is satisfied; constraint (7) truck capacity constraint; constraint (8) drone endurance constraint; constraint (9) end time of using the drone; constraint (10) end time of using only the truck; constraints (11)(12) 0-1 variable constraints; and constraints (13)(14) floating-point decision variable constraints;

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

With the above constructed truck-drone cooperative scheduling model trucks and drones are set up in a cooperative manner, where one vehicle carries one drone to distribute medical supplies to the disaster-stricken points. Part of the needs of the affected points in the emergency distribution are met by the vehicles, and the other part of the needs of the affected points are met by the drones. In actual distribution, when encountering problems such as winding roads or blocked roads, the drone is used to go directly to the disaster site for distribution, which makes such obstacles no longer a factor affecting the efficiency and timeliness of the emergency distribution process. Minimization of the total distribution time is achieved, thus increasing the efficiency of rescue, enabling emergency medical supplies to be sent to the disaster site at the first time to meet the needs of the people in the disaster area.

Efficient distribution of emergency medical supplies can be realized through the truck-drone cooperative scheduling model constructed above. The model combines trucks and drones to work together, combining the advantages of both, to ensure that disaster-stricken sites can receive the necessary emergency medical supplies in a timely manner in case of road obstruction or complex terrain. In the actual emergency distribution process, the coordinated scheduling of trucks and drones optimizes the configuration and scheduling of emergency medical supplies, avoiding the impact of road obstruction and other factors on the efficiency and timeliness of distribution, and thus achieving the shortest distribution time. This efficient distribution not only improves the emergency response capability of medical supplies, but also enhances the timeliness and precision of post-disaster relief, which helps to meet the emergency medical supplies needs of the disaster-stricken areas faster and better. Ultimately, this emergency medical material distribution mode can enhance the public's trust in the emergency management system and increase people's sense of safety and security in the event of a disaster.

5. Summary

Disasters, as a highly destructive and unpredictable natural event, such as earthquakes, typhoons, floods, etc., pose a serious threat to society and the safety of people's lives and property. Under such circumstances, a timely and effective distribution system for emergency medical supplies is particularly important. Timely scheduling and distribution of emergency medical supplies is related to the efficiency of post-disaster rescue, which directly affects the effect of life rescue and post-disaster recovery. How to improve the efficiency of emergency medical supplies distribution and the rationality of resource allocation is a core issue that needs to be solved in the field of emergency management. This paper analyzes the current situation of the existing emergency medical material distribution system through data mining and N-Gram statistical analysis, and finds that the current emergency medical response system still has problems such as low efficiency, untimely response, and irrational resource allocation in the face of sudden disasters. Based on the problems existing in the process of emergency medical material stockpiling and distribution, a summary of the current research and policy recommendations are given. Meanwhile, in order to cope with such difficult problems, this paper establishes an operation research model for

the collaborative distribution of trucks and drones for emergency medical materials, aiming to optimize the resource allocation and enhance the speed of emergency medical response, so as to better cope with the challenges posed by disasters. This not only enhances the city's ability to cope with extreme disasters and reduces the damage of disasters to people's lives and properties, but also optimizes the efficiency of resource utilization and avoids shortage or waste of supplies. Through scientific and rational planning, it can ensure that emergency supplies can be quickly and accurately deployed to where they are most needed in the event of a disaster to provide the necessary support, thereby enhancing the sense of security and confidence in society.

References

1. Wang Q, Zhang R, Luo L. Emergency medical supply planning considering prepositioning and dynamic in-kind donation management in healthcare coalitions. [J]. Risk analysis: an official publication of the Society for Risk Analysis,2024,
2. Shi W, He J, Wang M, et al.A dynamics model of the emergency medical supply chain in epidemic considering deprivation cost[J].Socio-Economic Planning Sciences,2024,94101924-.
3. Xu A, Wang Q. Integrated emergency medical supply planning considering multiple supply channels in healthcare coalitions[J]. International Journal of Disaster Risk Reduction,2024,113104823-104823.
4. Zhang J, Cao Z, Zhou X, et al.The Influencing Mechanism of Robustness of Emergency Medical Logistics: Mediating Role of Knowledge Integration[J].Systems,2024,12(10):424-424.
5. Ghaffar A M, Peng L, Aslam U M, et al.Vehicle-UAV Integrated Routing Optimization Problem for Emergency Delivery of Medical Supplies[J].Electronics,2024,13(18):3650-3650.
6. Yong L, Meiru W, Yong W. Location Decision of Emergency Medical Supply Distribution Centers Under Uncertain Environment[J]. International Journal of Fuzzy Systems,2024,26(5):1567-1603.
7. Huang A, Zhang W, Shi X, et al.Optimal reserve policies for emergency medical supplies: Joint consideration of reserving safety stocks, production capacity, and capital[J].Transportation Research Part E,2024,189103653-103653.
8. Lin Z, Xu X, Demir E, et al.Optimizing task assignment and routing operations with a heterogeneous fleet of unmanned aerial vehicles for emergency healthcare services[J].Computers and Operations Research,2025,174106890-106890.