Review on the optimization of medical supplies distribution under major public health emergencies

Li Xiaohuan\textsuperscript{1, a}, Du Lijing\textsuperscript{1} *

\textsuperscript{1}School of Safety Science and Emergency Management Wuhan University of Technology Hubei, China
\textsuperscript{a}lixh_whut@163.com
\* Corresponding author: dulijing@whut.edu.cn

Abstract—In recent years, frequent public health incidents have brought huge challenges to the economic development and emergency logistics systems of countries around the world. Facing the problems of unfair distribution of medical supplies and low distribution efficiency under major public health emergencies, this article systematically analyzes the literature on material distribution and distribution related to public health incidents in the past 20 years. The literature is reviewed from three aspects: the location and allocation of medical supplies distribution center, vehicle routing optimization, and location-routing optimization. Through the analysis of the existing research, several future research directions are proposed.

1. INTRODUCTION
Major public health emergencies refer to the sudden occurrence of major infectious diseases, mass diseases of unknown causes, major food and occupational poisoning, and other events that seriously affect public health, which cause or may cause serious damage to public health under certain conditions \cite{1}. Major public health emergencies like the COVID-19, Ebola virus, SARS virus, H1N1 influenza, plague virus are sudden, public, severely harmful, comprehensive and systematic in response.

In the process of fighting the COVID-19 in 2020, a large number of medical supplies such as masks, protective clothing, goggles and medical equipment have flooded into the epidemic area. As the management department of medical supplies, the Red Cross has poor professionalism in the management of supplies, insufficient manpower allocation, and uneven distribution across regions, which ultimately caused the embarrassing situation of uneven distribution and oversaturation of regional resources. Medical supplies play a very important role in the emergency rescue process. How to quickly raise and deploy medical supplies when major public health emergencies occurs is a problem that needs to be solved urgently.

Looking at the operation of emergency logistics in the face of the prevention and control of the COVID-19 in my country, there are still certain shortcomings. My country’s insufficient production capacity, insufficient material reserves, chaotic management, uneven distribution, and low deployment efficiency have been exposed one by one.

In order to better protect the public’s life health and property loss, fast delivery of materials is very important in epidemic prevention and control. Therefore, a literature review on the optimization of the distribution of emergency medical supplies in the context of public health events in my country is conducted to analyze the problems and deficiencies in my country’s emergency logistics, and to improve my country’s rapid response and response capabilities in the face of public health emergencies. It also has certain reference significance for future research in this field.
2. REVIEW OF THE LOCATION AND ALLOCATION OF MEDICAL SUPPLIES DISTRIBUTION CENTER

The Location and allocation problem (LAP) of medical materials distribution center is a hot issue in the optimization of material distribution. Distribution center, as the key node of logistics distribution, is the key node of the entire logistics distribution network. Therefore, the location of distribution center will be the key problem in the distribution network, and the LAP problem is to solve the problem of efficiency and fairness in the distribution process. The following documents are sorted out from the three aspects of medical supplies considering only the location of the distribution center, only issue of distribution, and the issue of location-allocation, as shown in Table 1.

| Diseases          | Material types          | Research methods/models | Location allocation considerations                                                                 | Author (year) |
|-------------------|-------------------------|-------------------------|-----------------------------------------------------------------------------------------------------|---------------|
| Only consider site selection | SARS Emergency medical facility | P-center model          | Natural conditions, medical capacity, cost, environmental impact                                   | JIA Jing[2](2008) |
| Biological terrorism | Reserve Storage location optimization model | Cost                     | ZHAO Weina[3](2009)                                                                                   |
| COVID-19 Distribution center | Distribution center location model | Cost                     | CHEN Jingyu[4](2020)                                                                                   |
| Influenza Antiviral drugs, ventilators, wards | Multi-objective mathematical programming model | Age, risk level | Koyuncu Melik et al.[5](2010)                                                                           |
| Allocation problem Influenza Mobile medical team | Heuristic algorithm, SVEIR model | Specific group, time frame | Nikolaos Rachamiotis et al.[6](2017)                                                                |
| The Haitian cholera Ambulances, funds | Hierarchical constraint method, effective inequality | Virus incubation period, time, severity of the disease | Azrah Anparasan et al.[7](2019)                                                                         |
| COVID-19 Medical supplies | PCA, Davies-Bouldin index and K-Means clustering method | Total population, number of confirmed cases, number of medical staff, GDP | LI Yingjie[8](2020)                                                                                   |
| The anthrax attacks Dispensing points | P-Center model, genetic algorithm, queuing approach | Waiting time for service, time to dispensing point, cost | OZGUR M. ARAZ et al.[9](2014)                                                                           |
| LAP Temporary regional distribution centers | Mixed enumeration search, genetic algorithm, mixed integer nonlinear programming model | Emergency response cost | LIU Ming[10](2020)                                                                                     |
| The H1N1 flu Temporary regional distribution centers | Emergency logistics network optimization model | The service level | LIU Ming[11](2020)                                                                                     |

Based on the analysis of the above literature, the site selection considers factors such as natural conditions, medical capabilities, cost, and environmental impact, and establishes a P-center location model and a distribution center location model. The distribution of supplies took into account the age of the population, risk level, number of confirmed cases, time range and other factors, and applied the multi-objective mathematical planning model, hierarchical constraint method, PCA, Davies-Bouldin index and K-means clustering method to allocate the emergency supplies such as anti-virus drugs, ambulances, hospital beds and funds. The location allocation problem considers service waiting time, cost and other factors, establishes P-center model, mixed integer nonlinear programming model, emergency logistics network optimization model, and uses genetic algorithm and hybrid enumeration search to solve the model.

Future research can also be carried out from the following aspects: 1) The site selection takes into account factors such as physical asset energy, reserve factors, population density, distribution center capacity, and optimal reserves of the reserve warehouse, making the site selection more reasonable and scientific. 2) Considering people's psychological and physiological problems to meet the maximization of material distribution needs will be a major trend of future research. 3) In the future, consider factors such as demand time tolerance and material allocation order to determine the priority of material distribution.
3. Optimization of Medical Material Distribution Route

The traditional material distribution takes benefit as the main goal and takes a long time, while the distribution of emergency materials is characterized by timeliness, multi-objective and weak economy. Therefore, the optimization of the distribution path of emergency medical materials has far-reaching significance for scientific decision-making. Some scholars have conducted in-depth studies on the Vehicle Routing Problem (VRP) in public health emergencies, and the research results are shown in Table 2.

In summary and discussion from the above literature, the VRP problem under public health emergencies mainly starts from the types of materials, the number of models and the number of distribution centers, and takes into account the material delivery time, transportation cost, demand satisfaction rate, transportation distance and delay loss, and urgent demand Degree and other factors to build models. Models include vehicle routing model, distribution optimization model, multi-objective planning model. and use genetic algorithm, water drop algorithm, cluster analysis, optimization theory and other methods to solve the model, and finally plan the optimal solution of the vehicle path to achieve material delivery Requirements for fairness and efficiency.

The research on VRP issues has made great progress, and future research should be further expanded and deepened on this basis. Some studies hypothesize that different types of materials can be mixed and have no substitute for each other, while materials such as vaccines and blood need to be transported through the cold chain, so the optimal distribution of multiple types of medicines needs to be considered in the future. In the study of the vehicle routing problem, considering factors such as multiple material distribution centers, multiple emergency medical supplies, multiple models, road conditions, insufficient supply at demand points, and uncertain demand, the planning model for such multiple distribution centers and multiple specifications drugs will be the focus of future research.

Table 2. Research on optimization of medical Material distribution Routes under public health Emergencies

| Diseases          | Material types | Research methods          | Research model                        | consideration                  | Author (year)          |
|-------------------|----------------|---------------------------|---------------------------------------|---------------------------------|------------------------|
| Infectious diseases | Vaccine        | Clustering analysis       | Vaccine distribution model             | Transportation cost, quantity out of stock | XU Jingjing [12](2010) |
| Infectious diseases | A single material | Genetic algorithm (GA)    | Multi-objective stochastic programming model, distribution optimization model | Rescue time, transportation cost | WANG Xinping [13](2012) |
| A disease         | Drug           | Water droplets algorithm  | Emergency logistics distribution model | Delivery time, transportation cost | JIANG Jiehui[14](2016) |
| Public health event | Medical supplies | Genetic algorithm (GA)    | Vehicle Routing model                 | Demand urgency, cost            | ZHAO Jianyou [15](2020) |
| Infectious diseases | Medical supplies | Benders decomposition algorithm | Mixed integer programming               | Cost                           | WU Yaqiong [16](2019) |
| COVID-19          | 84 disinfectants, masks | Programming method        | Dynamic distribution model of emergency medical supplies | Demand satisfaction rate, distance | HU Xiaowei [17](2020) |
| COVID-19          | Protective clothing, hat, gloves | Optimization theory, external approximation method | Two-objective model                   | Delay loss, logistics cost      | CHEN Feng[18] (2020) |
4. Optimization of Medical Material Distribution Location-Routing

After a disaster occurs, how to determine the number and location of emergency material distribution centers according to the situation in the disaster area, and how to choose the route is a hot research problem at present. Many scholars have carried out a series of studies on the Location and Routing Problem (LRP) of post-disaster medical supplies distribution, as shown in Table 3.

Analyze from the above literature, consider from a single goal, mainly with the shortest time or the best system as the goal, considering factors such as the priority of material demand, facility protection, road network damage, and the mutual influence of the distribution plan path to establish an LRP optimization model. Algorithms, ant colony algorithm and other intelligent algorithms are used to solve model problems. From the perspective of multi-objective considerations, scholars not only take the minimum time as the goal, but also consider the minimum cost, maximum demand site satisfaction, and minimum resource usage. Considering the risks of overdue vehicle operation, limited operating speed, and facility failure in the distribution process, a multi-objective LRP model, emergency logistics positioning-path robust optimization model is established, and hybrid algorithms and robust optimization methods are used to solve the problem. The research is developing towards multi-objective, multi-factor and hybrid algorithm. The research on LRP problem of medical supplies after disaster has been relatively mature. Wang Chun [29] conducted research on the location-path problem of medical supplies for public health emergencies, but the research is not deep enough. At present, relevant scholars are almost blank in the research on LRP of medical supplies under major public health emergencies. Therefore, from the perspective of fairness and efficiency, how to consider factors such as vehicle transportation time, cost, resources, infectious disease risk, poor road network, and satisfaction of demanders, and how to select the location-route problem of medical supplies under major public health emergencies, location-inventory-routing problem for further study of the future is an urgent need to solve a big problem.

Table 3. Research on LRP of post-disaster medical supplies

| Target attribute | The research methods | Research model | The objective function | Consideration | Author (year) |
|------------------|----------------------|----------------|------------------------|--------------|--------------|
| Single objective | Immune genetic algorithm | OLRP model in facility protection scenario | system optimization | Emergency facilities protection resources limited, damaged road network | LIU Changshi [19] (2017) |
|                  | Genetic algorithm (GA) | Optimize the mold based on priority LRP | Minimum total time | Emergency supplies needs | ZHANG lei[20] (2017) |
|                  | Greedy algorithm, ant colony algorithm | Multi-mode distribution LRP optimization model | Minimum total time | Full load emergency supplies direct distribution, circuit distribution | LIU Changshi [21] (2017) |
|                  | Discrete particle swarm optimization algorithm | Location-routing scheduling problem optimization model | Minimum the emergency rescue time | The mutual influence of distribution center location and distribution path scheme | DAI Jun [22] (2017) |
| multi-objective  | Genetic algorithm (GA) | Multi-objective emergency logistics location - routing model | Minimum operation time and total system cost | Risk of overrunning and capacity of road network | SUN Huali [23] (2013) |
|                  | HGA - Opportunity constraint programming method | Fuzzy multi-objective open position-Routing problem optimization model | Minimum time and total cost | Demand fuzziness, limited period, open vehicle route | MA Zujun [24] (2014) |
|                  | NSGA - II algorithm | Multi-objective position-Routing problem optimization model | Maximize the satisfaction of rescue time and minimize the resource usage | Post-disaster path speed is limited | XU Hao [25] (2017) |
|                  | Two-stage hybrid heuristic solution algorithm | Two-target LRP model | Minimum loss per demand point and total delivery time | Equity, disaster level, road network damage, vulnerability of | SHENG Huyi [26] (2019) |
5. FUTURE RESEARCH

Through sorting out and discussing relevant literature on medical material distribution and distribution in major public health emergencies, future research can also be carried out from the following aspects.

(1) When selecting the location of the distribution center, consider factors such as property assets, population density, and distribution center capacity to ensure the scientific and rationality of the site selection.

(2) Under major public health emergencies, in order to prevent the spread of the epidemic and reduce the flow of people, the implementation of the village and city closure policies will have a certain impact on the road network. Long-term home quarantine, the psychological and physiological factors of residents in affected areas, and the policies issued by the government will all have a certain impact on people's physiology and psychology. Therefore, the above two factors should be included in the consideration of material distribution and distribution.

(3) The location-route problem of medical supplies after the disaster has achieved certain research results. However, under the major public health emergencies, the problem of location-route of medical supplies is still relatively shallow. In the future, we can deeply consider the situation of multiple round-trip delivery of vehicles, the demand of demand points may exceed the capacity of vehicles, and the situation of multimodal transportation of emergency supplies. In the context of major public health emergencies, site selection-stock-path issues should also be studied in depth.

(4) Practicality and scientific of the model: the research model is relatively single, and in the future, it is possible to consider the cross-discipline to construct rich models. Although the model is verified by examples, it still needs further research on whether it is feasible in actual situations. The problem of parameter setting in the model is very subjective, and the setting basis should be given to ensure the objectivity and scientific of the research.

6. CONCLUSION

Under major public health emergencies, problems such as uneven distribution of medical supplies and low delivery efficiency have been exposed one by one. Material distribution optimization considers the three major issues of LAP, VRP, and LRP. Based on the perspective of fairness and efficiency, considering multiple factors, multiple goals and other factors, the model is optimized to make the model better guide practice. The resolution of these problems will enhance the ability to raise and deploy medical supplies in the event of major public health emergencies.

ACKNOWLEDGMENT

We would like to appreciate editors reviews and anonymous for their constructive review. Thanks to the authors of the references for their ideas and ideas. We are very grateful for the sponsor's sponsorship.

Foundation of Social Science and Humanity, China Ministry of Education (Grant No. 20YJC630018); Hubei Provincial Natural Science Foundation (Grant No. 2020CFB162); Fundamental Research Funds for the Central Universities (WUT: 2020VI009)
REFERENCES

[1] Emergency Regulations for Public Health Emergencies (Revised on January 8, 2011). Chinese Journal of Health Emergency Response, 2016. 2(01): Page 64-68.

[2] Jia Jing, Ding Jingzhi and Zou Hui, Analysis of the location of emergency medical facilities for public health emergencies, in 2008 China Railway Society Material Management Committee Material Management and Marketing and Material Circulation System Theory Group Seminar 2008: Beijing. Pages 317-322.

[3] Zhao Weina and Han Ruizhu, Research on the Optimization of the Location of the Emergency Material Reserve in Biological Anti-terrorism. Logistics Technology, 2009. 28(12): 158-161.

[4] Chen Jingyu and Zhang Li, Research on the construction of the distribution center location model in the emergency cold chain logistics of the new land-sea corridor under the epidemic. Logistics Technology, 2020. 43(07): 147-150.

[5] Koyuncu, M. and R. Erol, Optimal Resource Allocation Model to Mitigate the Impact of Pandemic Influenza: A Case Study for Turkey. Journal of Medical Systems, 2010. 34(1): p. 61-70.

[6] Rachaniotis, N., T.K. Dasaklis and C. Pappis, Controlling infectious disease outbreaks: A deterministic allocation-scheduling model with multiple discrete resources. Journal of Systems Science and Systems Engineering, 2017. 26(2): p. 219-239.

[7] Anparasan, A. and M. Lejeune, Resource deployment and donation allocation for epidemic outbreaks. Annals of operations research, 2019. 283(1-2): p. 9-32.

[8] Li Yingjie, Medical material distribution model based on PCA and K-Means clustering. Technology and Innovation, 2020(15): Page 16-17.

[9] Araz, O.M., J.W. Fowler and A.R. Nafarrate, Optimizing service times for a public health emergency using a genetic algorithm: Locating dispensing sites and allocating medical staff. IIE transactions on healthcare systems engineering, 2014. 4(4): p. 178-190.

[10] Liu Ming, Cao Jie and Zhang Ding, Data-driven dynamic adjustment and optimization of the epidemic emergency logistics network. System Engineering Theory and Practice, 2020. 40(02): 437-448.

[11] Liu Ming et al., Optimized design of emergency logistics network based on service level in an outbreak environment. Chinese Management Science, 2020. 28(03): Page 11-20.

[12] Wang Haiya, X., Dynamic vaccine distribution model based on epidemic diffusion rule and clustering approach. Journal of South east University(English Edition), 2010.

[13] Wang Xinping, Multi-epidemic area and multi-period coordinated optimal dispatch of emergency supplies. System Engineering Theory and Practice, 2012.

[14] Jiang Jiehui and Ma Liang, Multi-objective emergency material path optimization and its improved intelligent water drop algorithm. Computer Application Research, 2016. 33(12): p. 3602-3605.

[15] Zhao Jianyou et al., Urban emergency medical supplies distribution under major public health emergencies. Journal of Traffic and Transportation Engineering, 2020. 20(03): 168-177.

[16] Wang Yajing, Wu Yaqiong, Han He, Emergency rescue logistics scheduling optimization based on SEIR infectious disease model. Journal of Jiangsu University of Science and Technology (Natural Science Edition), 2019.

[17] Hu Xiaowei, Research on optimal dispatch of urban emergency medical supplies under major public health emergencies. China Journal of Highway and Transport, 2020.

[18] Chen Feng, Optimization of medical supplies dispatching in the early stage of public health incidents. China Journal of Highway and Transport, 2020.

[19] Liu Changshi, OLRP of emergency supplies distribution after an earthquake in the protection of key facilities. Journal of Hunan University of Science and Technology. Social Science Edition, 2017.

[20] Zhang Lei, LRP optimization decision-making model for emergency supplies after earthquake based on priority. System Science and Mathematics, 2017.
[21] Liu Changshi, LRP research on multi-mode distribution of emergency supplies after disasters under undecided road network scenarios. System Engineering, 2017.
[22] Dai Jun, Wang Jing and Yi Xianqiang, Research on LRP Model and Algorithm of Emergency Resource Distribution after Disaster. China Work Safety Science and Technology, 2017. 13(01): Page 122-127.
[23] Sun Huali, Uncertain demand emergency logistics positioning considering route risk-route problem. Journal of Shanghai Jiaotong University, 2013.
[24] Ma Zujun, Dai Ying and Li Shuanglin, Fuzzy multi-target open positioning-path problem for emergency material distribution after earthquake with limited period. Journal of System Management, 2014. 23(05): pp. 658-667.
[25] Xu Hao, Li Jiachuan and Han Chuanfeng, Multi-target positioning under the condition of limited speed after the earthquake: a study on path problems. Journal of Management Engineering, 2017. 31(04): 147-155.
[26] Sheng Huyi, Liu Changshi and Lu Ruoyu, Research on the positioning-path problem under the emergency supply shortage scenario in the early post-earthquake period. Operations Research and Management, 2019. 28(06): pp. 41-47.
[27] Liu Changshi, LRP research under uncertain failure scenarios of emergency logistics facilities after the earthquake. Fuzzy Systems and Mathematics, 2019.
[28] Sun Huali and Xiang Meikang, Emergency Location of Uncertain Demand under the Risk of Facility Failure-Research on Robust Path Optimization. Chinese Journal of Management Science, 2020. 28(02): 199-207.
[29] Wang Chun, Positioning of Emergency Logistics System under Uncertain Information-Research on Path Problem. Value Engineering, 2019. 38(36): 154-157.