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Research on Intelligent Emergency Resource Allocation Mechanism for Public Health Emergencies: A Case Study on the Prevention and Control of COVID-19 in China

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Abstract: The outbreak of COVID-19 posed a significant challenge to the emergency management system for public health emergencies, especially in China, where the epidemic began. As intelligent technology has injected new vitality into emergency management, applying intelligent technology to optimize emergency resource allocation (ERA) has become a focus of research in the post-epidemic era. Based on China's experience in preventing and controlling COVID-19, this paper first analyzes the characteristics and process of ERA in public health emergencies, and then synthesizes the relevant Chinese studies in recent years to identify the intelligent technologies affecting ERA in China using word frequency analysis technology. We also construct an intelligent emergency resource allocation mechanism in four areas: medical intelligence, management intelligence, decision-making intelligence, and supervision intelligence. Finally, we use the entropy-TOPSIS method to evaluate the impact of intelligent technologies on ERA, and we rank the criticality of intelligent technologies. The experimental results show that (i.) medical intelligence and management intelligence are the keys to developing intelligent ERA, and (ii.) among the identified essential intelligent technologies, artificial intelligence (AI), and big data technology have a more significant and critical role in emergency resource intelligence allocation.

Keywords: public health emergency; emergency resource allocation; intelligent technology

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1. Introduction

Public health emergencies can profoundly impact public health, the environment, the economy, and even politics, and have therefore been the focus of attention from people and researchers in all walks of life and research. In early 2020, COVID-19 sent shockwaves throughout the economic and social order of countries around the world, greatly influencing emergency management systems and governance capacity worldwide [1].

When COVID-19 broke out, the best time for prevention and control was missed because of the delayed response of the Chinese government. This resulted in an inability to reasonably predict the extent of the damage [2], and this had at least two severe consequences: (i.) demand-supply imbalance on medical emergency resources (such as masks and rubbing alcohol, critical medical equipment, etc.) [3], and (ii.) the inaccurate demand information for emergency resources leading to unfair resource allocation, causing secondary harm to the people in the affected area. The isolation policy shortened human resources, increasing the pressure on medical care and epidemic prevention. The above-mentioned problems reflect the fact that the emergency resource allocation mechanism for public health emergencies in China still needs to be improved. There are loopholes in epidemic prediction and decision making, the supervision of information transmission, and ERA and transportation. The traditional way of allocating emergency resources based on human labour now faces significant challenges, and, indeed, COVID-19 has proved a challenge to the national governance system and capacity. It is necessary to improve the national emergency management mechanism in response to the shortcomings and deficiencies exposed during this epidemic.

Intelligent technology's high-performance computing and simulation capabilities as well as the idea of a "machine replacement" provide the direction for solving these problems. Intelligence has become a new approach for countries to solve resource allocation problems, which replaces traditional methods (such as manual labour). China has also made many attempts in this direction during the epidemic, such as online medical services, remote work policy, and infection control in public places through intelligent technologies. However, at this stage, research on the application of intelligent technologies in ERA needs to be improved [4]. As the normalized epidemic prevention and control significantly increases labour costs, the need to realize intelligent ERA is urgent. Therefore, constructing an intelligent emergency resource allocation mechanism for public health emergencies is of great theoretical significance and application value.

The key to solving the problems in ERA for public health emergencies is to use intelligent technology to improve ERA efficiency, which can fully leverage the role of emergency resources in epidemic prevention and control. Therefore, this article focuses on the intelligent technologies in ERA, and it answers the following research questions:

(i.) What are the essential intelligent technologies for intelligent ERA? We solved this problem in Section 3 by using word frequency analysis to extract essential intelligent technologies.

(ii.) How to intelligently allocate emergency resources for public health emergencies? We solved this problem in Section 4 by establishing an intelligent emergency resource allocation mechanism.

We constructed an evaluation index system for essential intelligent technologies through empirical methods in Section 5. The use of this evaluation system to rank the importance of essential intelligent technologies. Finally, Section 6 provides directions for further research on the application of intelligent technologies and suggestions for improving the efficiency of emergency management systems.

2. Related Works

Public health emergencies spread fast and cause significant losses. Since SARS in 2003, the construction of emergency management systems and related research in China has gradually increased [5]. The construction of the health emergency system in China has been significantly improved, but the efficiency in both resource dispatching and decision-making could still be higher [6]. Li et al. [7] have pointed out that the prevention and the control process of COVID-19 revealed many problems in China's emergency management system. These problems include the imperfect monitoring and early warning system, the unbalanced layout of emergency resources, insufficient storage of emergency supplies, and backward management.

2.1. Research on ERA

Before the COVID-19 pandemic, researchers mainly focused on optimizing the ERA decision-making process and site-path selection by constructing ERA models. Ge et al. [8] established a two-stage stochastic planning model for resource allocation in a complex disaster scenario. The model was used to make decisions under different disaster scenarios, such as the location of emergency facilities and the inventory of emergency materials. Peng et al. [9] established a robust site-path optimization model for multiple ERA types. It determines the optimal siting layout and distribution path for emergency resource supply points based on the uncertainty of emergency resource costs. Researchers also realize that emergency management of public emergencies is a complex project with multiple subjects and levels. The disaster situation, time-space distribution, and rescue costs are uncertain, so most studies construct scenarios with static demand for emergency resources. However, the actual ERA process is more complex. Therefore, some researchers studied ERA from the perspective of demand. Zhang et al. [10] established a demand-based emergency resources supply system by analyzing the characteristics of emergency demand

and constructing different emergency resource demand scenarios. Li et al. [11] established a multi-objective mixed integer planning model to solve the fairness problem of ERA among multiple subjects for the demand uncertainty situation. It uses min-max dissatisfaction as the fairness objective and the sum of system utilities as the utility objective. Yang et al. [12] construct an emergency resources demand strategy that can dynamically deploy resources for the demanding state of emergency relief materials. In addition to studying ERA, researchers realize that information resources participate in, guide, and supervise the process. This is vital to guaranteeing efficient ERA.

Digital and intelligent technologies lead the development of the fourth industrial revolution, and have revolutionized how things connect and interact with things, things with people, and people with each other. Therefore, the allocation of resources has undergone new changes. [13]. Researchers have begun to explore the relationship between intelligent technologies, such as AI, big data, and intelligent design, which significantly impact ERA strategy. On the one hand, some researchers believe that the characteristics of intelligent technologies are beneficial to improving the ERA process. For example, Akter et al. [14] argued that big data improves emergency management efficiency because it can visualize, analyze, and predict disasters. Deng et al. [15] proposed that AI can effectively alleviate the pressure of rising labour costs, compensate for the shortage of human labourers, and significantly reduce labour density. Dui et al. [4] argued that AI significantly accelerates epidemic data monitoring and prediction efficiency.

On the other hand, some researchers argue that environmental intelligence changes emergency resource allocation mechanisms to accommodate it. [16]. Chen et al. [17] argue that the big data environment brings increasing implications and challenges for effective data processing and decision-making. Therefore, intelligent techniques are critical in the emergency management life cycle. He et al. [18] argue that the convergence of the Internet, big data, machine learning, and AI has led to a consequent evolution of resource allocation mechanisms. Data intelligence has become the basis for resource allocation mechanisms in the Internet era. Despite the different motivations, both views recognize that ERA intelligence is the development trend of modern emergency management systems.

2.2. Research on the Intelligence of ERA

Most of the current academic research on the intelligence of ERA focuses on intelligent information management [19,20], intelligent decision-making of resource allocation [21–23], and intelligent medical applications [24,25]. Regarding the research on intelligent information management, Wang et al. [26] concluded that there are more severe data silos in Chinese public health information systems, which make it difficult to provide real-time data for handling large-scale public health emergencies. Shen et al. [27] argued that emergency response efficiency could be improved through two approaches. One is intelligent information management, while the other is optimizing and integrating various resources to obtain more reasonable decisions. Zeng et al. [28] constructed an intelligence mechanism for public health emergencies by analyzing the information needs of each wave of the epidemic. This mechanism collects, processes, and mines information for public health data intelligence. Liu et al. [29] constructed a mechanism for data collection and feature extraction of public opinion on emergencies on the Internet. They established a computer-aided warning system based on big data and distributed computing technology for network public opinion emergencies.

Regarding the research on intelligent decision-making for resource allocation, scholars believe that intelligent technologies can rapidly and accurately grasp and assess information under dynamic scenarios. Zhu et al. [30] proposed a demand prediction method based on machine learning, big data, and intelligent information processing technologies to assist in intelligent decision-making for ERA. Abdel et al. [31] constructed a novel intelligent healthcare decision support model based on soft computing and IoT techniques. The model facilitates the completion of continuous resource assessment in public health emergencies. Some researchers simulated the evolutionary patterns through intelligent algorithms for quantitative analysis to improve decision-making accuracy. For example, by analyzing the uncertain factors in the evolution, Chang et al. [32] used system dynamics theory and its related intelligent algorithms to simulate the evolutionary process of social security emergencies. Tian et al. [33] modelled different stages of the evolution of network public opinion emergencies as a "social burning life cycle". They simulated the evolution process of such emergencies using the generalized stochastic Petri net theory and its related intelligent algorithms.

For the research on intelligent medical applications, Wang et al. [34] analyzed the application of blockchain, the IoT, and other technologies in the supply chain management of medical supplies. He argued that intelligent technologies could provide a rapid and accurate supply of resources and realize the efficient operation of the emergency supply chain. Du [35] conducted an in-depth study on the regional collaborative emergency system based on big medical data. Chen et al. [36] established a "horizontal-vertical" model to integrate emergency medical resources. The model meets the needs of automatic information integration and intelligent analysis sharing, simplifying the medical process through emergency management visualization and digitizing medical information.

By analyzing related studies, we found that most researchers focus on the ERA from the following two aspects: (1) analyzing the impact of intelligent technologies, such as big data, AI, and information technology on ERA; (2) building intelligent mechanisms from each process of ERA. However, there are few works on quantitative analysis. Although China's public health emergency management capacity is increasing, ERA still has shortcomings. The most concerning factors are insufficient emergency resource reserves, unbalanced and inefficient allocation of emergency resources, and loopholes in the early warning system. This paper aims to optimize the emergency response system for public health emergencies in China and reduce the losses caused by public health emergencies such as COVID-19. We achieve it by taking the development of intelligent technology as an opportunity to build an intelligent emergency resource allocation mechanism and identify essential intelligent technologies. Our work is of great significance in promoting the development of intelligent ERA.

3. Allocation of Emergency Resources for Public Health Emergencies and Identification of Essential Intelligent Technologies

The traditional emergency resources are mainly summarized as material, human, scientific, and technological resources. Material resources include medical material resources for public health prevention and control, and material resources for people's livelihood to ensure the safety of life. Human resources include labour costs of medical, nursing, material production, transportation, and security costs in public health prevention and control. Scientific and technological resources guarantee high-tech public health prevention and treatment.

With the advent of the digital economy, information collection and delivery efficiency have increased dramatically. Information resources (including big data, information, and related facilities and equipment) have become an emerging active element in emergency resources.

3.1. Characteristics of ERA for Public Health Emergencies

Due to the diverse, regional, and unpredictable characteristics of public health emergencies, ERA is a dynamic and complex project. It has multiple supply points, demand points, emergency supplies, and transportation modes. The active information resources also give new characteristics to it:

(1) A multi-subject, multi-level super-network system. Firstly, multiple subjects are involved in ERA for public health emergencies. It requires the support and cooperation of multiple parties, such as the government, market and civil organizations, and the public. Second, because public health emergencies often involve a wide geographical area, the affected areas may be from the provinces, cities, villages, and towns. There-

fore, from the government's perspective, the resource allocation process cascades upward from lower government levels. The ERA system shows multi-level characteristics. At the same time, at least three levels of the deployment network exist from the supply point to the transit point and then to the demand point. The boundaries between supply, staging, and demand points are not apparent for significant public health emergencies. The point of supply for one resource may also be the point of demand for another. Physical networks, financial networks, and information networks are interwoven in the supply-and-demand networks to form a hyper-network system for ERA.

(2) The disaster situation, resource needs, and priorities are dynamic. The initial transmission location of public health emergencies cannot be predicted. Different urban areas have differences in population density, economic level, road network, information communication, and other conditions. Therefore, there are differences in the emergency capacity and supply of emergency resources among different regions. The spread and destructiveness of viruses are not constant. Furthermore, medical resources are time-sensitive and often difficult to replace. Emergency resource needs and priorities change with the dynamics of an epidemic. It requires that each relief department be able to develop strategies and make timely allocation decisions in response to changes in the epidemic. Emergency resource allocation mechanisms must be well adapted to the dynamic variability of the epidemic, and they should also be able to make timely adjustments in response to dynamic demands in time and space.

(3) The role of information resources. The rapid development of information technology has led to changes in the primary way of allocating emergency resources for public health emergencies. Mobile communications and the Internet have accelerated the speed of access and dissemination of information resources. However, due to the multiple sources of emergency information and non-uniform data formats, most demand-related information cannot be accessed timely. It makes the emergency information construction with information silos, information coupling, and poor information communication. Therefore, timely information response, fast transmission, and good analysis capabilities are the key issues to improving the efficiency of ERA. Building an emergency information management platform is a crucial way to improve emergency information management capability.

3.2. ERA Process for Public Health Emergencies

The dynamic variability of emergency resources should change with the status of public health emergencies. The focus of public health prevention and control differs in different development parses. Therefore, to build an intelligent emergency resource allocation mechanism for public health emergencies, we need to clarify: (i.) the cyclical changes in emergency resource demand for public health emergencies, and (ii.) the characteristics of emergency resource types and the demand characteristics of different periods.

The development cycle of the epidemic is mainly divided into the early phase, rising phase, outbreak phase, and stable phase. As the epidemic enters different stages of development, the need for emergency resources changes dynamically. (i.) In the early stage of epidemic spread, information resources still need to be provided. The trend of epidemic changes still needs to be clarified, and the regional information interconnection network has not yet been formed. Therefore, the responses of managers are slow, and the demand for emergency resources is in a more subdued early warning period. (ii.) The risk level is elevated when the epidemic moves into the rising stage. Relevant departments start to pay attention to and adopt prevention and control strategies and mobilize emergency resources, and the demand for emergency resources is in the start-up period. (iii.) The epidemic's severity climbs when the outbreak period is entered. The number of cases increases, epidemic information resources surge, and prevention and control efforts are in full swing. The demand for emergency resources dramatically increases and enters the treatment period of emergency resource supply. (iv.) As the epidemic moves from the end of the outbreak phase to the stable phase, hospital admissions are gradually cleared. The urgent demand for emergency resources decreases, and the demand enters the reserve period. On the one hand, the production department adjusts the resource production plan to the normal production and living level. On the other hand, the management keeps an eye on the epidemic situation to prevent a second outbreak, and the priority of various resource needs changes.

The ERA process should include resource information management, resource allocation plan design, resource distribution plan decision, and resource allocation supervision (see Figure 1). (i.) Emergency resource information management refers to collecting information during the emergency resource preparation phase of a public health emergency. The information is related to the quantity and supply location of all emergency resources (including reserve resources, resources that can be raised, and resources that can be produced). Information management facilitates understand the distribution, supply quantity, and supply speed of various resource supplies in a short period, and target the distributed mobilization efforts. (ii.)·The design of the resource allocation plan decides when and where to use the type and quantity of emergency resources and makes a reasonable resource distribution plan. It collects information on the demand for emergency resources and considers the distance from the supply point to the demand point, the transportation environment, and the degree of urgency. Finally, responsible decisions are made by combining emergency resource management information during a public health event. (iii.) The resource distribution plan decision is to consider the transportation route and mode of transportation for emergency resource distribution and to choose the optimal plan. (iv.) Resource allocation supervision ensures that ERA information is fair and open, and that resources are distributed in place. It also ensures that each emergency point's needs meet the maximum extent in order to avoid resource misallocation and omission.

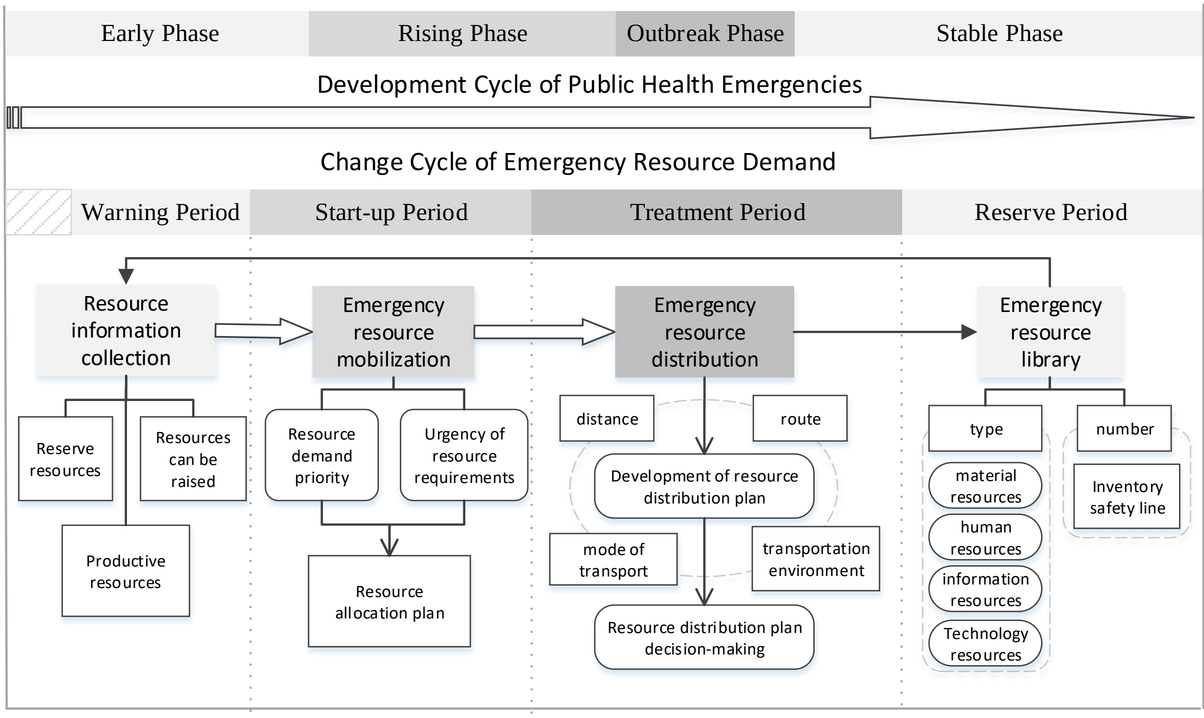

Figure 1. ERA process for public health emergencies.

After analyzing ERA's demand characteristics and process for public health emergencies, we believe that the essential intelligent technologies for ERA should achieve the following functions: (i) to assist public health prevention and relief work; (ii) to improve the efficiency and effectiveness of information management and decision making; (iii.) to reduce human labour force participation rate and time cost; and (iv.) to achieve intelligent supervision of the allocation process and reduce the occurrence of the unreasonable allocation of resources. Clarifying the need for intelligent technology for ERA is a guarantee for identifying vital, intelligent technologies.

3.3. Essential Intelligent Technology Identification

Intelligence is the property of making objects with functions, such as sensing, judging, learning, and executing, with the support of the Internet, big data, IoT, and AI. Intelligence is the goal of digitization, informatization, and networking, while intelligent technology is the deep integration and subsequent extension of digital, information, and Internet technology.

The development of intelligent technology has brought significant changes to people's lives. During the COVID-19 pandemic, intelligent technology has come to the forefront of practical operations to control the spread of the virus. For example, intelligent robots distribute daily medicines and supplies to isolated patients. Big medical data and information systems are also used to trace the route of patients' journeys. Moreover, technologies such as AI and expert systems assist researchers in virus tracing to discover the virus's causes, transmission routes, and hazards. Advanced intelligent technology not only simplifies the treatment process and its difficulty but also helps to improve the accessibility of emergency resources. For example, e-commerce logistics, which has gradually emerged due to epidemic control, provides security for transporting and supplying medical and household materials. Features such as work-from-home, online conferences, and online business processing ensure that people's lives and work are orderly during an epidemic.

Word frequency analysis (WFA) is a text analysis method used to calculate the frequency of each word in a text and to conduct statistics and analysis based on these frequencies. WFA can quickly extract the most widely-used intelligent technology in allocating emergency resources for public health emergencies. It provides a research foundation for constructing an intelligent emergency resource allocation mechanism. This paper used the China National Knowledge Infrastructure (CNKI) as the source of statistical data. We selected years from 2012 to 2022 and searched the journal literature for "intelligent", "intelligent technology", "resource allocation", "emergency public health event", and other related terms. A total of 309 results were obtained by searching the journal literature using "public health emergencies" and other related terms as subject terms. Through further screening and manual removal of non-academic journal literature, such as no-authors and correspondence, we obtained 253 highly relevant works on this topic. We exported sample data in EndNote text format and analyzed the keywords of the sample data using SATI [37], ultimately generating a keyword matrix (see Figure 2). In the keyword matrix, we used "intelligent" as the core related vocabulary of research hotspots in this field. We manually merged synonyms, removed unintentional words, and then sorted the frequency of popular keywords. Finally, we extracted ten intelligent technologies that benefit ERA in public health emergencies. (See Table 1 below.)

Table 1. List of Intelligent Technology Applications for Emergency Resource Management.

No	Name of Intelligent Technology	Application Description of Intelligent Technology in Medical and Resource Allocation
1	Artificial Intelligence	AI technologies can simulate, extend, and expand human intelligence to achieve functions, such as medical imaging-assisted diagnosis, intelligent drug development, intelligent health management, and assisted resource allocation decisions.
2	Internet	The Internet as a carrier and technical means can inform the process of ERA, realize instant communication, remote consultation, online consultation, etc.
3	(Medical) Information System	The Medical Information System can realize the storage, collection and query of information related to ERA. The information system assists emergency resource information management and conducts resource allocation planning.

Table 1. *Cont.*

No	Name of Intelligent Technology	Application Description of Intelligent Technology in Medical and Resource Allocation
4	Information Technology	The use of Information Technology can make the acquisition, transmission, processing, control, display, and storage of resource allocation information intelligent, such as radio frequency identification technology (RFID), sensing technology, network communication technology, etc.
5	The Internet of Things (IoT)	The Internet of Things (IoT) is to connect material resources with the network, exchange communication through information dissemination medium, and complete intelligent identification, positioning, tracking, supervision, and other functions.
6	Big Data	Big Data application technologies include data collection, data pre-processing, distributed storage, machine learning, etc. The deep combination of big data and cloud computing technology can realize functions such as epidemic prediction, intelligent medical care, resource management, and logistic network optimization.
7	Expert System	An Expert System is used to address problems in the field using the knowledge and the problem-solving methods of human experts, and it can assist in clinical medical diagnosis and ERA program decisions.
8	Intelligent Design	Intelligent Design is the application of modern information technology and computer simulation of human thinking activities, combined with neural networks and machine learning technology to assist in the automation of the design process.
9	Wearable Technology	Wearable technology is the embedding of multimedia, sensors, and wireless communication technologies into clothing and software support for data interaction and cloud interaction in order to help achieve real-time monitoring of the health status of a patient.
10	Machine Replacement Technology	Machine Replacement Technology is the use of robotic hands, automated control equipment, or assembly line automation for intelligent technology transformation of enterprises in order to achieve the purpose of reducing staff, increasing efficiency, improving quality, and ensuring safety.

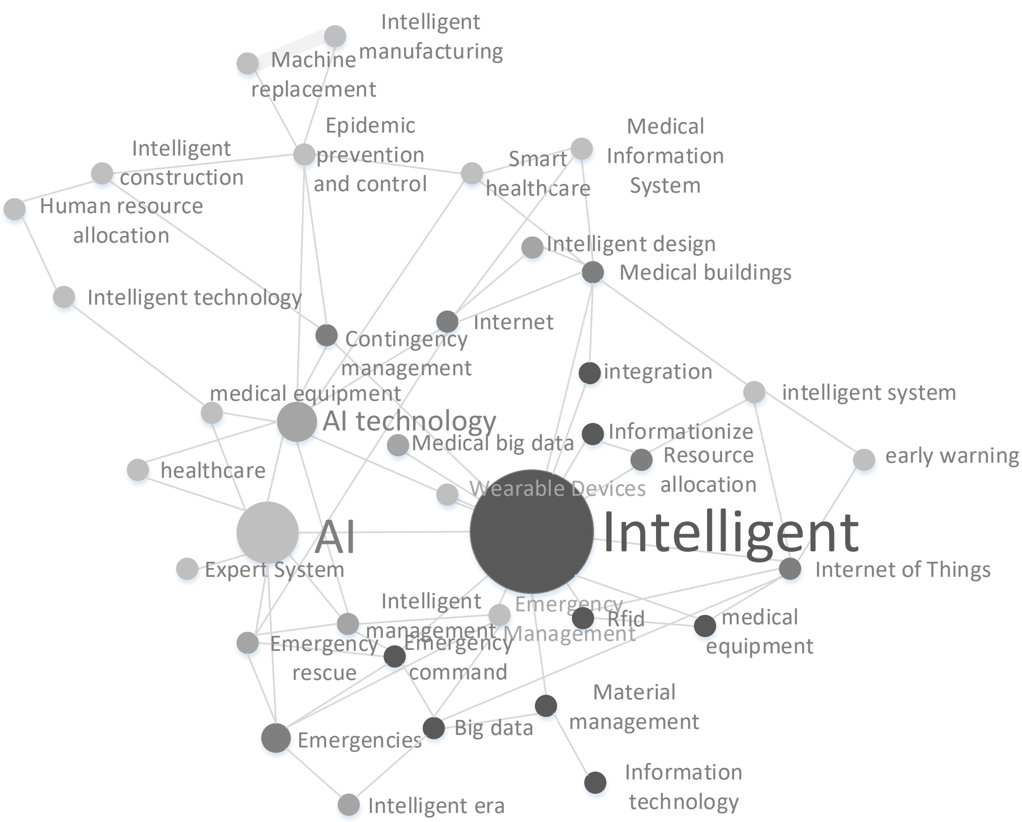

Figure 2. Keyword Matrix Graph of Intelligent Technology for ERA.

4. Intelligent Emergency Resource Allocation Mechanism

Different from the general resource allocation process, intelligent ERA should achieve three targets: (i.) meet the emergency resource demand, (ii.) improve resource allocation efficiency, and (iii.) save resource allocation costs using intelligent technology. Therefore, this study builds an information platform for ERA based on identifying intelligent technologies that combine public health emergencies' characteristics and the ERA process. We also established an intelligent emergency resource allocation mechanism for public health emergencies, including medical intelligence, management intelligence, decision-making intelligence, and supervision intelligence (see Figure 3).

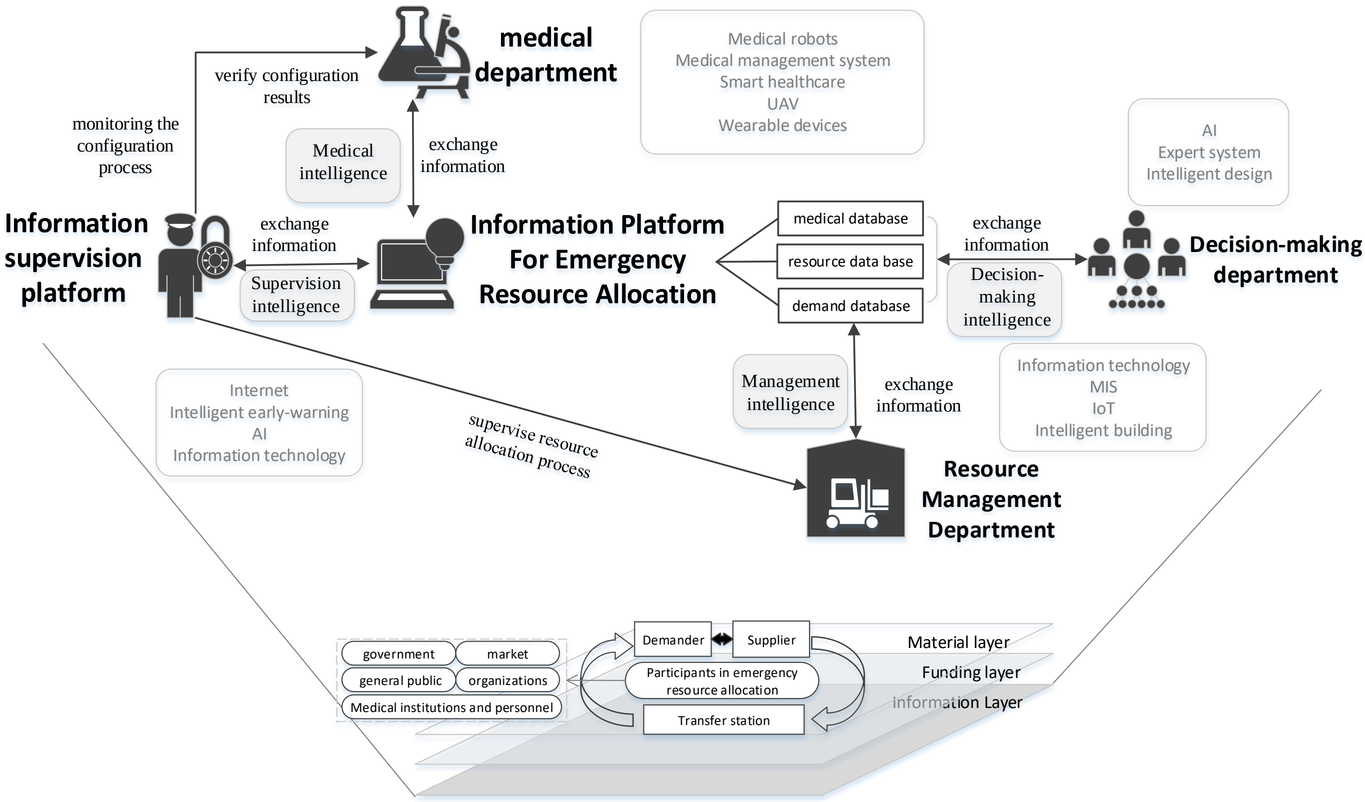

Figure 3. Intelligent emergency resource allocation mechanism for public health emergencies.

(1) Information platform for ERA. The information platform for ERA is a comprehensive platform that realizes the functions of information collection, screening and filtering, identification and error correction, sorting and classification, and transmission and feedback in ERA. It is the central hub of ERA and can store, process, and transmit data. The information platform for ERA comprises a regional interconnection network and database. The regional interconnection network connects the affected areas and supply points horizontally while connecting the management and decision-making departments at all levels vertically. It uses Information Technology and the Internet to form a "horizontal-vertical" interlocking information transmission network to realize information exchange between subjects. The information base includes medical databases, resource databases, and demand databases. Among them, the medical database mainly stores information related to IPC and assists in researching the outbreak of diseases. The resource information base covers the status of emergency resource storage, including (i.) the type and quantity of reserve resources, (ii.) the person-hours and expected quantity of productive resources, and (iii.) the source and quantity of preparable resources. The demand database collects and stores information at each demand point during an epidemic, and updates it instantly to provide a basis for ERA management and decision-making. As the data and information in public health emergencies are complicated, ERA needs the support of an integrated,

networked, and intelligent information platform. Therefore, establishing an information platform for ERA is the cornerstone of the intellectual development of ERA.

(2) Medical Intelligence. Medical intelligence is the most direct manifestation of intelligent ERA during an epidemic. Based on the data support of the Medical Information systems, modern digital medical treatment is realized using the IoT and Internet+. It also creates intelligent medical treatment with online and offline interaction. Therefore, it can improve the sharing of medical resources, simplify time-consuming and labour-intensive manual medical processes, and reduce costs. With the development of intelligent technology, innovative medicine is gradually being realized. It can use intelligent auxiliary medical devices to complete medical work with a high degree of difficulty. Further, it can also realize the interaction between patients and medical personnel, medical institutions, and medical equipment by establishing a regional medical information cloud platform. Medical intelligence reduces medical congestion, shortens the practice of waiting for treatment, and expands medical coverage.

(3) Management Intelligence. Management Intelligence simplifies the management process through intelligent technology and fully uses the information to help achieve the integrated use of resources. Management Intelligence is not simply system software applications for repetitive data processing and exchange. Instead, emergency resource management is based on intelligent buildings to manage people and equipment better, achieving human-machine coordination. It manifests using information management systems and robots instead of traditional human work. The resource information database can control the inventory of resources and then transmit and process resource shipment and inventory information in real time. It uses sensors and other equipment to automate instruction transmission. In addition, it can also intelligently perceive, recognize, and process instruction information and respond. Meanwhile, intelligent warehousing and logistics methods are labour-saving, thereby reducing the risk of infection. Intelligent technology can thus help people achieve efficient resource allocation with less human resource investment, and it is therefore a necessary means for improving the efficiency of ERA.

(4) Decision-Making Intelligence. Decision-Making Intelligence means using the advantages of AI and expert systems to help managers solve complex decision-making problems in collaboration with human intelligence. Due to the dynamic complexity of ERA information, relying on the traditional human and computer approaches for decision-making takes both time and effort. This can easily cause huge losses due to untimely actions during epidemic prevention and control. AI, as an intelligent auxiliary technology, can realize functions such as analyzing the current epidemic situation, optimizing and calculating resource allocation schemes, and predicting the epidemic's trend. Furthermore, the program's feasibility is tested by simulations, which shows that decision-making intelligence saves human resources and improves decision-making efficiency. It also reduces the risk of decision making and reduces the waste of resources.

(5) Supervision intelligence. The timely acquisition, transmission, and management of epidemic information is the key to reducing the harm of public health emergencies. During COVID-19, information is often transmitted through the sequence of "front-line workers and epidemic prevention agencies" ("lower-level managers") and "higher-level managers and research institutions". Due to the vast geographical area and complex administrative divisions involved in the epidemic, information acquisition, analysis, and feedback are prone to delayed transmission, mismatch, and incorrect or missing communications. Therefore, an intelligent supervision mechanism for intelligent ERA should be established to strengthen the supervision and management guaranteeing information security. First, the intelligence of the supervision platform should be realized. Large data centres and information supervision platforms should be built to intelligently supervise various application scenarios, thereby improving the allocation risk prevention and control system. Secondly, intelligent supervision should be realized, i.e., using AI to improve management efficiency through digital management, and achieve rapid risk warnings and alarms through the

Internet of Things data collection and intelligent technology analysis. Finally, to achieve an intelligent regulatory process, the Internet and Information Technology should achieve instant information transfer and feedback, which can promote effective and intelligent data transfer between departments, and which can also help to build a perfect closed loop of active discovery, automatic instructions, rapid processing, real-time feedback, and risk prevention and control.

5. Evaluation of Essential Intelligent Technologies for ERA

5.1. Indicator System Construction

The lack of a mature scale for evaluating essential technologies in ERA makes it hard to build the indicator system. To address this problem, we borrowed indicators from existing works to construct the evaluation index system for essential technologies in ERA. Among them, essential technology evaluation indicators are from [38–40], while medical resource evaluation indicators are from [41]. This evaluation index system combines the characteristics of ERA and intelligent technology for public health emergencies. We integrate relevant research results to construct the system from four aspects: medical intelligence [42,43], management intelligence [35,44], decision-making intelligence [17,45,46], and supervision intelligence [47,48]. The content and description of evaluation indicators are shown in Table 2.

Table 2. Essential Intelligent Technology evaluation index system.

Primary Indicators	Secondary Indicators	Tertiary Indicators	Indicator Description	Indicator Attribute
Medical intelligence A1	Medical resource savings B1	Occupancy of medical devices C1	The impact of intelligent technology on reducing medical device congestion	Positive
		Waiting time savings C2	The impact of intelligent technology on reducing unnecessary waiting time for medical treatment	Positive
		Human resource savings C3	The impact of intelligent technology on reducing the demand for medical personnel	Positive
	Use value B2	Reaction time C4	The reaction time consumed when intelligent technology provides interactive functions	Opposite
		Consultation time C5	The time spent on diagnosis and treatment using intelligent technology	Opposite
		Operational difficulty C6	The operational difficulty of intelligent technology, i.e., the ability requirements for relevant operators	Opposite
		Cure rate C7	The impact of intelligent technology on improving the cure rate	Positive
	Economic benefits B3	Technology maturity C8	The impact of intelligent technology on the accuracy and risk of medical diagnosis	Positive
		Application breadth C9	The application scope and popularity of intelligent technology in medical institutions	Positive
		Additional services C10	The possibility of intelligent technology providing additional services	Positive
Management intelligence A2	Management cost savings B4	Time-cost savings C11	Quantitative indicators of time-cost savings in ERA using intelligent technology	Positive
		Manpower cost savings C12	Quantitative indicators of manpower costs for ERA that can be saved by utilizing intelligent technology	Positive
	Management effectiveness B5	Reduction of resource mismatch C13	The impact of intelligent technology on reducing adverse phenomena such as resource mismatch and missed allocation	Positive
		Managing information security C14	The impact of using Intelligent Technology on resource management information security	Positive

Table 2. *Cont.*

Primary Indicators	Secondary Indicators	Tertiary Indicators	Indicator Description	Indicator Attribute
Decision-making intelligence A3	Decision-making efficiency B6	Information transmission speed C15	The Impact of intelligent technology on the Transmission Speed of Decision Information and Decision Instructions	Positive
		Decision duration C16	The reduction in decision-making time caused by intelligent technology	Positive
	Effects on decision-making B7	Fault tolerance of decision-making C17	The impact of intelligent technology on improving scheme fault tolerance and reducing decision risks	Positive
		Effectiveness of decision-making C18	The impact of intelligent technology on improving the effectiveness of decision-making plans	Positive
Supervision intelligence A4	Regulatory timeliness B8	Alert response time C19	The impact of intelligent technology on reducing the early warning response time of resource allocation regulation	Opposite
		Inspection time C20	The impact of intelligent technology on reducing the inspection time of resource allocation supervision	Opposite
		Correction time C21	The impact of intelligent technology on reducing error correction time for resource allocation supervision	Opposite
	Social benefit B9	Social stability C22	The impact of intelligent technology on improving social stability	Positive
		International image C23	The impact of intelligent technology on improving a country's international image	Positive

5.2. Evaluation Model of Essential Intelligent Technologies for ERA Based on Entropy Value-TOPSIS Method

In this paper, medical practitioners, emergency resource managers, and intelligent manufacturing-related researchers were selected to score the evaluation indexes of each Intelligent Technology. The research subjects are from major cities in China, such as Beijing, Harbin, and Wuhan. This selection aims to reduce individual experts' subjectivity in determining indicator weights and ensure the comprehensiveness and professionalism of the evaluation results as much as possible. The scores are from 0 to 9, representing the importance of the technology to the evaluation index from low to high. For the reverse index, the higher the score, the lower the importance of the technology. We distributed seven questionnaires, all of which were returned, and we obtained the original evaluation data.

5.2.1. Entropy Power Method

The basic idea of assigning weights using the entropy method is to determine the objective weights according to the magnitude of the variability of the indicators. If the information entropy E_j of the indicator is small, its weight will be larger, indicating that the indicator value plays a more significant role in the comprehensive evaluation. Experts are susceptible to subjective factors such as experience, interest preference, and personal habits. Combining the entropy method to assign the index weights can weaken the influence of subjective factors to a certain extent. The evaluation data are normalized to obtain the standardization matrix $E = \{Y_{ij}\}$, based on determining the specific indicators of essential Intelligent Technology evaluation. Y_{ij} denotes the value of the jth index of the ith technology after standardization. According to the information entropy to determine the formula (Equation (1)):

$$\begin{array}{ll} E_{\mathrm{j}} = -\frac{1}{\ln n}\sum_{n=1}^{n} p_{ij}\ln p_{ij} & \mathrm{E}_j \geq 0 \\ p_{ij} = Y_{ij}/\sum_{i=1}^{n} Y_{ij} & , \end{array} \tag{1}$$

where if $p_{ij} = 0$, then $\lim_{p_n \sim 0} p_{ij} \ln p_{ij} = 0$ is defined. The weight of each indicator is then calculated by the formula:

$$w_i = \frac{1 - E_i}{k - \sum E_i} \ (i = 1, 2, \cdots, k), \tag{2}$$

According to the formula, the information entropy and weight values of each essential Intelligent Technology evaluation index are obtained (see Table 3).

Table 3. Information entropy and weight of essential Intelligent Technology evaluation index.

Index	Entropy	Weight (%)
C1 Occupancy of medical devices	0.903	4.16
C2 Waiting time savings	0.909	3.91
C3 Human resource savings	0.907	3.99
C4 Reaction time	0.926	3.20
C5 Consultation time	0.903	4.17
C6 Operational difficulty	0.912	3.77
C7 Cure rate	0.814	8.00
C8 Technology maturity	0.871	5.57
C9 Application breadth	0.896	4.50
C10 Additional services	0.920	3.44
C11 Time-cost savings	0.932	2.94
C12 Manpower cost savings	0.865	5.82
C13 Reduction of resource mismatch	0.853	6.32
C14 Managing information security	0.907	4.00
C15 Information transmission speed	0.914	3.69
C16 Decision duration	0.929	3.05
C17 Fault tolerance of decision-making	0.903	4.19
C18 Effectiveness of decision-making	0.869	5.62
C19 Alert response time	0.917	3.57
C20 Inspection time	0.926	3.19
C21 Correction time	0.907	4.00
C22 Social stability	0.865	5.82
C23 International image	0.929	3.07

From the calculation results, it can be concluded that the top five indicators in the weight of the 23 indicators are: C7, C13, C12, C22, and C18. Intelligent Technology significantly impacts the ERA for public health emergencies in these five aspects. Moreover, these five indicators are mainly distributed in medical and decision-making intelligence, indicating that medical and management intelligence is essential for developing intelligent ERA.

5.2.2. Use TOPSIS Method to Identify Essential Intelligent Technologies

TOPSIS is an approaching ideal point ranking method that can rank a finite number of evaluation objects according to their relative proximity to the ideal solution. The evaluation object selected by this method should be as close as possible to the positive ideal solution and as far as possible from the negative ideal solution. TOPSIS can fully use the original data information to reflect each intelligent technology's gaps accurately. It can rank the degree of influence of Intelligent Technology on intelligent ERA. The research steps are as follows:

(1) Create the original decision matrix A:

$$A = \begin{array}{c} \\ x_1 \\ x_2 \\ \vdots \\ x_m \end{array} \begin{array}{c} \begin{array}{cccc} \mathrm{o}_1 & \mathrm{o}_2 & \cdots & o_\mathrm{n} \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \end{array}, \tag{3}$$

where x_m is the mth intelligent technology, o_n is the nth evaluation index, and x_{mn} is the numerical result of the nth evaluation index of the mth intelligent technology.

(2) Normalize each numerical result by converting the decision matrix A into a canonical decision matrix $E = \{u_{ij}\}$, i.e.,

$$u_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}, \quad (4)$$

For the inverse indicators, the data are reversed before the normalization process in order to ensure the consistency of the evaluation data.

(3) Construct a weighted decision matrix based on the index weights determined by the entropy weighting method.

The weights w are assigned according to the degree of importance of each evaluation attribute, and the formula is:

$$\overline{F} = \left(\overline{X}_{ij}\right)_{m\times n} = w \cdot F, \quad (5)$$

The weighted decision matrix is obtained.

(4) Define the positive ideal solution as x^+ and the negative ideal solution as x^-, then $\overline{x}_j^+, \overline{x}_j^-$ are, respectively:

$$\begin{cases} \overline{x}_j^+ = \max\{x_{1j}, x_{2j}, \cdots x_{mj}\} \\ \overline{x}_j^- = \min\{x_{1j}, x_{2j}, \cdots x_{mj}\} \end{cases} \quad (j = 1, 2, \cdots n), \quad (6)$$

The positive and negative ideal solutions for the 23 indicators are shown in Table 4.

Table 4. Ideal solution for evaluation indicators.

Index	Positive Ideal Solution	Negative Ideal Solution
C1 Occupancy of medical devices	0.016	0.008
C2 Waiting time savings	0.016	0.007
C3 Human resource savings	0.017	0.010
C4 Reaction time	0.012	0.008
C5 Consultation time	0.016	0.011
C6 Operational difficulty	0.014	0.009
C7 Cure rate	0.031	0.020
C8 Technology maturity	0.022	0.012
C9 Application breadth	0.018	0.011
C10 Additional services	0.013	0.008
C11 Time-cost savings	0.011	0.007
C12 Manpower cost savings	0.020	0.016
C13 Reduction of resource mismatch	0.027	0.013
C14 Managing information security	0.015	0.010
C15 Information transmission speed	0.014	0.010
C16 Decision duration	0.013	0.007
C17 Fault tolerance of decision-making	0.018	0.008
C18 Effectiveness of decision-making	0.024	0.012
C19 Alert response time	0.014	0.008
C20 Inspection time	0.013	0.007
C21 Correction time	0.016	0.010
C22 Social stability	0.022	0.014
C23 International image	0.012	0.008

(5) The Euclidean distances of each intelligent technique from the positive ideal solution x^+ and the negative ideal solution x^- are defined as:

$$D_i^+ = \sqrt{\sum_{j=1}^{n} \left(\overline{x}_{ij} - x_j^+\right)^2} \quad (i = 1, 2, \cdots, m), \tag{7}$$

$$D_i^- = \sqrt{\sum_{j=1}^{n} \left(\overline{x}_{ij} - x_j^-\right)^2} \quad (i = 1, 2, \cdots, m) \tag{8}$$

(6) Calculate the relative closeness of each intelligent technique to the positive ideal solution, which can be defined as:

$$\varphi_i = \frac{D_i^-}{D_i^+ + D_i^-} \quad (i = 1, 2, \cdots, m), \tag{9}$$

$\varphi_i \in [0, 1]$. Moreover, the larger φ_i is, the more significant the contribution of its corresponding Intelligent Technology to the intelligence of ERA in public health emergencies.

5.2.3. Experimental Results

(1) Based on the above experimental process, the evaluation results of essential intelligent technologies were obtained (see Table 5). The experimental results show that AI technology significantly impacts the intelligent ERA for public health emergencies, with a TOPSIS closeness of 0.766. They were followed by Big Data technology and expert systems, with a TOPSIS closeness of 0.683 and 0.529, respectively. In contrast, wearable technology has a negligible impact, with a TOPSIS closeness of 0.276.

Table 5. Evaluation Results of Essential Intelligent Technologies.

Intelligent Technology	Di+	Di-	TOPSIS Closeness φ_i	Sort
AI	0.009	0.030	0.766	1
Internet	0.021	0.020	0.485	7
Information System	0.020	0.022	0.518	4
Information Technology	0.020	0.020	0.497	6
The Internet of Things	0.020	0.021	0.513	5
Big Data	0.013	0.027	0.683	2
Expert System	0.020	0.022	0.529	3
Intelligent Design	0.027	0.016	0.367	9
Wearable Technology	0.029	0.011	0.276	10
Machine Replacement Technology	0.026	0.017	0.405	8

The chart shows the experimental results (see Figure 4). AI and big data technology in Intelligent Technology are the most critical. Moreover, the positive ideal solution closeness of the expert system, Internet, information system, information technology, and IoT technology is around 0.5, which are more critical and less different. Machines for human technology, intelligent design, and wearable technology have a lower degree of positive ideal solution closeness. They are less critical to intelligent ERA than other intelligent technologies.

(2) Combining the weight data in Tables 2 and 3, and further processing the experimental results resulted in Table 6. To compare the contributions of A1–A4 to the intelligence of ERA, we obtain the weights of A1–A4 by adding the weights of the corresponding tertiary indicators. However, the number of tertiary indicators corresponding to each primary indicator differs. We average the weights of primary indicators to eliminate the impact of the number of tertiary indicators on indicator weights. According to the calculation results (see Table 6), it can be concluded that the average weight of A1 and A2 is higher. It indicates that the relevant indicators of medical intelligence and management intelligence significantly impact the intelligent ERA for public health emergencies.

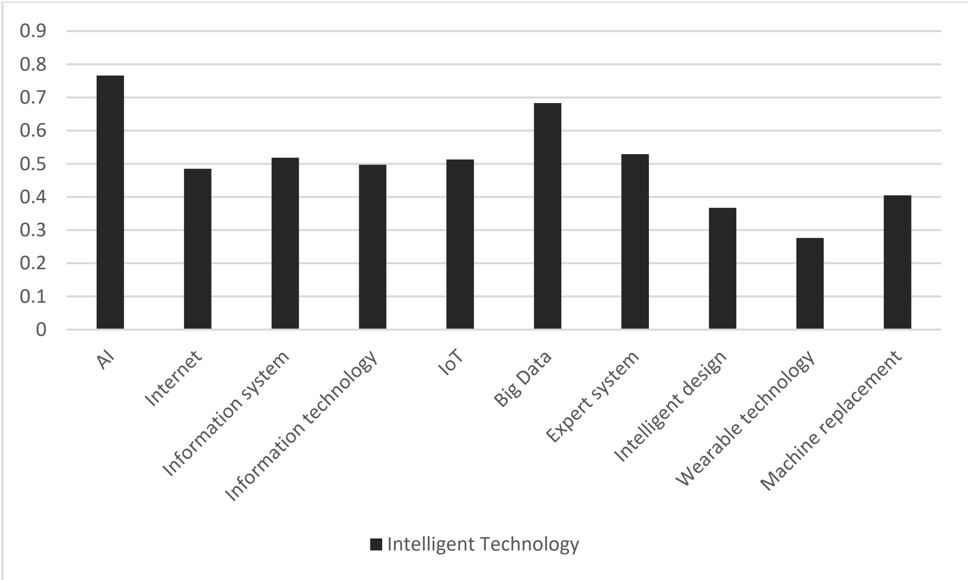

Figure 4. TOPSIS closeness of essential intelligent technologies.

Table 6. Average Weight of Primary Indicators.

Primary Indicators	**Medical Intelligence A1**		**Management Intelligence A2**		**Decision-Making Intelligence A3**		**Supervision Intelligence A4**	
Secondary Indicators	Medical resource savings B1	12.06	Management cost savings B4	8.76	Decision-making efficiency B6	6.74	Regulatory timeliness B8	10.76
	Use value B2	19.14	Management effectiveness B5	10.32	Effects on decision-making B7	9.81	Social benefit B9	8.89
	Economic benefits B3	13.51						
Weight	44.71		19.08		16.55		19.65	
Average Weight	4.47		4.77		4.13		3.93	

6. Conclusions

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation, and the experimental conclusions that can be drawn.

6.1. Research Findings

With the development of the digital economy, intelligent technology, and the influence of the normalization of COVID-19 prevention and control, intelligence becomes the future development direction of ERA for public health emergencies. Therefore, this paper constructs an intelligent emergency resource allocation mechanism for public health emergencies. It identifies the essential intelligent technologies affecting intellectual development, and conducts an essential evaluation. Firstly, we determined essential intelligent technologies' evaluation indicators and weights through expert consultation and the entropy weight method. Then, the TOPSIS method was used to evaluate the criticality of Intelligent Technology in ERA. This method considers the distance between Intelligent Technology and ideal points as the essential criterion. It combines objective analysis with experts' subjective judgments, which makes the evaluation results more scientific and reliable. The main conclusions drawn from the study are as follows:

(1) ERA for public health emergencies is a multi-subject, multi-level super network-system, and the demand and priority of emergency resources change with the devel-

opment of the epidemic. This paper categorizes emergency resources into material, human, information, and scientific and technological resources, and it focuses on the role of information resources. Information resources meet resource needs in ERA for public health emergencies while also playing the role of central control and auxiliary supervision. Intelligent emergency resource allocation mechanism gives full play to the characteristics of information resources. Based on establishing an information platform for ERA, this paper uses Intelligent Technology to make each allocation link intelligent, including medical intelligence, management intelligence, decision-making intelligence, and supervision intelligence, in order to achieve efficient resource allocation and cost savings.

(2) We conclude essential intelligent technologies through word frequency analysis of research on ERA for public health emergencies. Intelligent technologies include AI, the Internet, information systems, information technology, the Internet of Things, big data technology, etc. These intelligent technologies all play an essential role in developing intelligent ERA for public health emergencies.

(3) This study establishes an evaluation index system for the essential intelligent technologies of ERA in four aspects: medical intelligence, management intelligence, decision-making intelligence, and supervision intelligence. We used the entropy weight and TOPSIS methods to build the evaluation model for each intelligent technology. The results show that the evaluation indexes with greater weights are in medical intelligence and management intelligence. This indicates that medical intelligence and management intelligence are the focus of developing ERA intelligence. Furthermore, AI and big data technology have a significant key role in the ERA intelligence.

6.2. Key Research Insights

The development of intelligent technology has brought significant changes to ERA for public health emergencies, providing new possibilities to improve efficiency and reduce the cost of resource allocation. During the COVID-19 pandemic, the application of intelligent technology has emerged, but there is still room for optimization. We focus on essential intelligent technologies for ERA for public health emergencies. Therefore, our study can also provide directions and suggestions for further research on the application of intelligent technology in emergency resource management. We proposed the following management insights:

(1) Pay attention to the role of information resources. Applying intelligent technology to acquiring, screening, storing, processing, and transmitting information resources in ERA is essential. This can help reduce the flow time of information resources and the response time of management departments, speed up the interaction rate, and ensure information security and timeliness. An information platform for ERA should be established promptly during the prevention and treatment of public health emergencies. All entities and levels should improve their information infrastructure and strengthen the application of big data, information systems, and information technology, forming a multi-level and regional information interconnection network crisscrossed vertically and horizontally. The management department should fully utilize intelligent devices for resource management and decision making. Intelligent decision making can enable all departments to respond quickly to changes in the epidemic.

(2) Medical intelligence is the focus of ERA intelligence. Accelerating the process of intelligence in medical institutions and building intelligent buildings can help alleviate the phenomenon of medical resource tension, medical equipment congestion, and lack of medical personnel. Medical building intelligence is the introduction of Intelligent Technology and facilities and the improvement of internal organizational structure. The intelligence of medical buildings refers to the management style and the intelligence of management personnel. It is necessary to popularize the concept of competent healthcare, fully leverage the advantages of AI and logistics network technology, and improve the efficiency of medical resource utilization.

(3) The resource management department should strengthen the application of information technology in intelligent resource management, and should use information systems to simplify management processes. "Machines replace humans" can reduce the labour-cost and block infection channels to the maximum extent. Departments related to decision making should use AI and expert systems to make ERA decisions, which can improve effectiveness and reduce the risks of decision making. The government should establish a specialized supervisory agency and use information technology to monitor the ERA process in real-time. This can ensure that resources are allocated and emergency resource needs are met, it can avoid problems such as information mismatch, allocation omission, or unfair allocation of resources.

Simultaneously conducting the intelligent allocation of emergency resources for public health emergencies is needed as China possesses a high level of research and development in intelligent technology. China's vast territory and large population present both a disadvantage and an advantage when distributing emergency resources for public health emergencies. The government should integrate the capabilities of scientific research institutions, enterprises, the public, and other subjects, and should give full play to the advantages of a large country. This can help to form an intelligent system of ERA that is suitable for the conditions of China.

6.3. Boundedness and Future Works

The word frequency analysis method only considers the frequency of words appearing in the text while ignoring the semantic and contextual information of the words. Words with the same frequency may have different meanings in different contexts, and word frequency analysis cannot capture this difference. Therefore, the essential intelligent technology extracted solely through word frequency analysis technology cannot reflect the importance of this technology, and so we further obtained the evaluation index system for key intelligent technologies through the entropy weight TOPSIS method. We have obtained the importance ranking of intelligent technologies through essential technology evaluation, making the research results more comprehensive.

Based on existing research on public health emergencies, we identified essential intelligent technologies for ERA using word frequency techniques, and we ranked their importance. The importance ranking reflects the degree of attention paid by researchers to each intelligent technology in ERA, which is somewhat subjective. The importance of intelligent technologies in ERA will change as intelligent technologies are continuously updated. Therefore, the essential intelligent technologies identified in this paper only apply to the post-epidemic era and the development stage of the digital economy.

We propose an intelligent direction for ERA in public health emergencies. After empirical research, we find that medical intelligence and management intelligence are the keys to intelligence. Therefore, future works will focus on (1) the specific application of key intelligent technologies in ERA, such as the study of medical building intelligence, and (2) research on intelligent management processes, emergency resource allocation mechanisms, etc.

Most of the research data in this article comes from China. The experience of ERA adopted by China in epidemic prevention and control may have particular reference value, but its applicability depends on the specific situation. There are several factors to consider here. (1) Differences in countries and regions. Each country and region's social, economic, and healthcare systems have different characteristics. When applying China's ERA experience to other countries and regions, it is necessary to consider particular local circumstances and actual needs. (2) Types of public health emergencies. The research experience of this paper focuses on the prevention and the control of COVID-19. If faced with other types of public health emergencies, such as natural disasters, infectious diseases, etc., adjustments and adaptations must be made according to the specific situation. (3) Policy and institutional environment. China has taken strict measures and actions in epidemic prevention and control, which involve government leadership, resource allocation, social cooperation, and other aspects. The policy and institutional environment of other countries and regions may differ, so it is unsuitable to apply China's experience directly elsewhere.

Nevertheless, China's experience in epidemic prevention and control can provide some helpful guidance and inspiration. Other countries and regions can learn from China's practices. However, they must adjust and customize according to the local environment and needs. International cooperation and experience sharing can also promote countries and regions to better respond to public health emergencies.

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