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Application of Medical Material Inventory Model Under Deep Learning in Supply Planning of Public Emergency

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ABSTRACT The purposes are to solve inventory management problems in emergencies, optimize inventory management structure, and improve management efficiency. The medical material inventory management is taken as the research object. According to previous research, the existing material management model has problems such as management confusion, resource waste, and insufficient data analysis. Hence, the strengths of deep learning algorithms are utilized to address the above problems. A deep learning-based medical material inventory management model is constructed through the reasonable classification of material management methods. This model effectively utilizes the data by analyzing disaster data in different regions and establishes a corresponding inventory management model according to the classification standards. The numerical analysis of three examples further verifies the effectiveness of the proposed model. On this basis, the model is compared with the latest inventory management models to further determine its advantages. Results suggest that the medical supplies management model based on deep learning can interpret and analyze the data well and calculate the optimal inventory and management method of the model with limited funds based on the data. Compared with the latest inventory management models, the proposed model can provide a prediction accuracy as high as 92.45%. Under the same data, the analysis time of the medical material management method based on deep learning is only 35 minutes, which has undeniable advantages compared with other models. The proposed model can provide research ideas for material management in emergencies.

INDEX TERMS Deep learning, material inventory model, public emergency, inventory management, supply planning.

I. INTRODUCTION

With the accelerated pace of China's social transformation and system transformation, Chinese society is in a stage of development where opportunities and risks coexist. Due to climate and geographical factors, the incidence of natural disasters in China is also severe. Human-caused events and various natural disasters are entangled, making China continue to have large-scale and influential emergencies in recent years [1], [2]. In the past ten years, there have been countless large-scale emergencies, including the "SARS" epidemic in 2003, the "12.23" blowout incident in Kaixian, Chongqing, the Songhua River water pollution incident in 2005, the cyanobacteria outbreak in Taihu Lake in 2007, the low-temperature rain, snow and freezing disasters in southern China in 2008, the devastating earthquake in Wenchuan, Sichuan, in 2008, the devastating torrential mudslide disaster in Zhouqu, Gansu, in 2010, and the explosion of the oil pipeline in Qingdao's Huangdao, Shandong, in 2013 [3], [4]. These emergency incidents have caused significant losses to national property and people's lives. In emergency management, the guarantee of emergency supplies has always been a critical link. The occurrence of all emergencies is challenging to predict accurately. When the incident occurs suddenly, the emergency materials used to respond to the incident are difficult to meet both time and space requirements. Therefore, it is usually impossible to achieve immediate responses and efficient processing to emergencies [5]. Therefore, the guarantee of emergency supplies involves many aspects, such as emergency supplies logistics and inventory management. Significantly, the inventory management of emergency supplies directly impacts the effectiveness and efficiency of emergency treatment [6]. According to China's practice in emergency material

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inventory management in recent years, there is a lack of scientific systems and efficient and economical emergency material inventory models to support emergency material inventory management [7].

At present, the inventory management of emergency material reserves is mostly derived from traditional experience and habits. Low-efficiency problems are prone to waste and slow emergency responses in using inventory materials [8]. In terms of the professionalization process of emergency material management, it is necessary to analyze the existing historical data samples and research the best economic inventory of emergency material storage warehouses through mathematical modeling. The best economic inventory model that can meet the characteristics of strong randomness of emergency materials in and out of the warehouse, eternal inventory cycle, and stable variety should be established [9], thereby reasonably determining the critical parameters of inventory management, such as inventory inspection cycle, optimal order quantity, and optimal order point. In this way, the inventory costs can be gradually optimized, the procurement and supply plans can be balanced, the emergency delivery instructions can be responded to in real-time, the overstocking of materials can be avoided, and the demand risks can be stabilized, thereby providing theoretical support for the daily management of emergency materials reserves and further improving the informatization and management of emergency materials [10]. Deep learning is a branch of machine learning. It is an algorithm that uses Artificial Neural Network (ANN) as the architecture to characterize and learn data. Few scholars have reported on the application of deep learning in material management. Kamari *et al.* (2020) automatically detected and segmented the target object in the point cloud model based on the deep learning method. Then they mapped the semantic value to the point cloud model for 3D semantic segmentation to manage the materials. The proposed method could support the systematic decision-making of material management on-site [11]. Akanbi *et al.* (2020) developed a deep learning model to predict the number of items obtained from a building at the end of its useful life before demolition. This model could predict with high accuracy the number of materials recovered from the building after demolition [12]. Dias *et al.* (2020) used deep learning methods to process user interaction data from the new crown epidemic and formed a novel material prediction model that could accurately predict the number of materials [13]. The above analysis suggests that deep learning is feasible in material management. This method could effectively analyze the material management mode and obtain the optimal management method, which has very significant application value for the decision-making of relevant management departments.

The inventory management model of emergency supplies under emergency emergencies is studied. The medical supplies are taken as an example. The emergency supplies are divided into three major categories: importance, scarcity, and timeliness. Furthermore, inventory management models suitable for the characteristics of different categories are constructed. The keys are the scientific and reasonable classification of emergency supplies and the quantitative analysis methods used to determine emergency supply inventory reserves and inventory management based on classification. The research results have significant value for exploring the inventory management models of emergency materials that require quick response and effective inventory. The innovative points are: (i) deep learning algorithms are introduced into the medical material management inventory model for learning and deep mining of data, conducive to processing public emergency events. (ii) The emergency material inventory model is researched, and a scientific and reasonable material inventory model is constructed, which is of great significance for ensuring the optimal level of the material reserve under the condition of limited funds. (iii) The materials are classified scientifically. The emergency material inventory model can reasonably classify materials and control the storage quantity, which is of positive significance for improving material storage capacity and reducing material storage costs. The differences between this model and previous studies are summarized in Table 1. The advantages of the proposed model are explained in terms of research objects, algorithm models, processing methods, classification characteristics, and model advantages and disadvantages.

II. LITERATURE REVIEW

A. EMERGENCY MANAGEMENT

Emergency management is the management of risks. The Chinese government's definition of emergency management is the activities taken by the government and other public institutions by establishing necessary emergency mechanisms, taking a series of necessary measures to ensure the safety of public life and property, and promoting social harmony and healthy development during pre-prevention, emergency response, in-event handling, and after-care management of public emergencies. On the whole, emergency management is the process of management of public emergencies. It is a dynamic management process that includes four stages: prevention, preparation, response, and recovery.

In handling emergencies, the scope and types of emergency materials involved are enormous, and emergency materials need to be classified scientifically and reasonably for effective management. Emergency materials are for emergencies; hence, compared with traditional materials, they have many characteristics. The first is uncertainty. The quantity, scope of distribution, and transportation of emergency materials are directly affected by the unpredictability of emergency events, leading to substantial uncertainty. The second is the suddenness. The demand for emergency supplies will rapidly expand in a short period due to the sudden impact of emergencies, showing sudden characteristics. The third is irreplaceability. Emergency materials are directly used to deal with emergencies; they have particular purposes and must be activated, which can hardly be replaced by other materials. The fourth is timeliness. Emergency materials can play their best

TABLE 1. The differences between this model and previous studies.

Different references	Research objects	Algorithm models	Processing methods	Classification characteristics	Model advantages and disadvantages
The proposed model	Medical supplies	Deep learning	Classification modeling	Important, scarce, and time-sensitivity	It can effectively learn from the data and requires a large number of datasets.
Panja and Mondal (20190 [14]	Green supply chain	Fuzzy evaluation method	Comprehensive analysis	Standard classification	It has strong subjective classification awareness and quick processing.
AlDurgam et al. (2017) [15]	Green supply chain	Minimal numerical method	Single modeling	Standard classification	Its calculation is relatively simple and convenient, and the cost control is unreasonable.
Shin et al. (2019) [16]	Food industry	Heuristic algorithm	Pairwise modeling	Standard classification	It has relatively simple data requirements, and its calculation method is relatively convenient.
Khojasteh (2017) [17]	Medical supplies	Stochastic programming model	Stochastic optimization method	Random classification	The model is very effective for managing medical supplies, but it will have a large investment.
Zhou (2017) [18]	Medical supplies	Minimal numerical method	Comprehensive analysis	Standard classification	Model processing is faster, but the model performance is poor

role within a time limit and are extremely sensitive to time. The fifth is hysteresis. Emergency supply initiation occurs after the emergency event, which already lags behind the event [19].

Developed countries have researched the management of public emergencies earlier. The United States has accelerated the establishment of the Department of Homeland Security (DHS) as early as after the "9.11" Terrorism Attack. Regarding natural disasters in the United States, the Federal Emergency Management Agency (FEMA) was responsible for the "anthrax" incident. Afterward, the United States quickly developed a three-tier system for responding to public health emergencies: the federal disease control and prevention system Centers for Disease Control (CDC), the regional/state hospital emergency preparedness system Health Resources and Services Administration (HRSA), and the local urban medical emergency system Metropolitan Medical Response System (MMRS) [20]. In terms of international disaster relief, the United States is under the Office of Foreign Disaster Assistance (OFDA) responsibility. The emergency response regulations in the United States are complete, including the Disaster Relief and Emergency Assistance Act, the National Earthquake Disaster Mitigation Act, and the National Emergency Law [21]. As a country with more disasters, Japan has also developed more mature emergency management. Its three-level disaster prevention and relief system includes the Disaster Relief Bureau of the Central Land and Resources Agency, local prefectures, cities, towns, and counties. In general, developed countries have constructed emergency management systems earlier, which are comparatively complete [22].

B. EXISTING MATERIAL MANAGEMENT

Most of the existing emergency material management models are similar to modern logistics management. The main contents are shown in Figure 1. It mainly includes the following aspects: command center, logistics center, and information management center. The emergency command center is responsible for emergency material planning, coordination, and control, including the specific demand analysis, material financing, formulation of specific support plans, total allocation of emergency materials, and information collection on material feedback. The logistics center includes four significant parts: material procurement, storage, transportation, and distribution management [23]. The information management center includes four major sections: emergency material database, query and search, real-time material monitoring, and optimization decision system. The logistics center and the information management center will build an information feedback system and establish contact with the emergency command center through this part [24].

The modern response to emergencies requires analysis from three aspects, including the number of emergency materials, the quality of emergency materials, and the structure of emergency materials. The existing emergency material management model has two contradictions in the management of material inventory. The actual situation is that emergency material management generally requires huge costs, followed by the continuous decline in the quality of services in response to emergencies. Therefore, reducing the cost

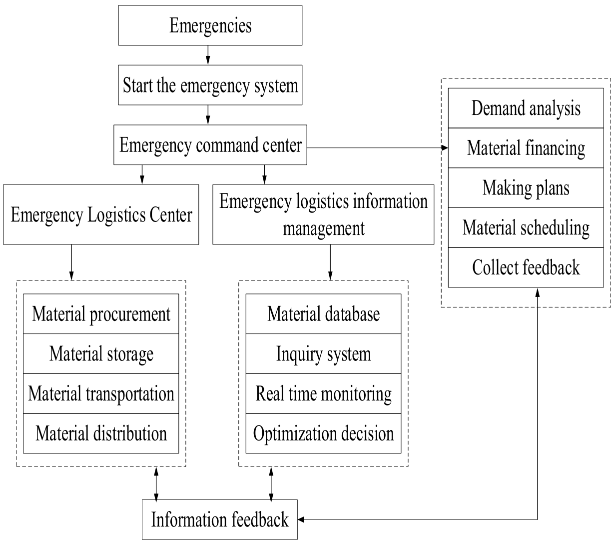

FIGURE 1. International existing emergency material management model.

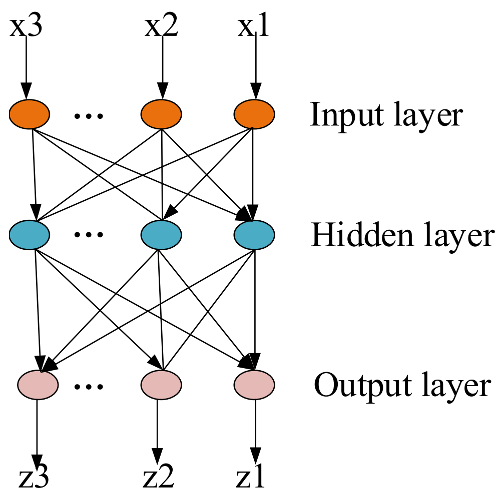

FIGURE 2. A schematic diagram of BPNN algorithm structure.

of emergency material inventory and improving the service level of material response is the key to scientific inventory management. It is necessary to achieve the best combination between inventory costs and service levels.

C. DEEP LEARNING ALGORITHM

ANN is a type of artificial intelligence algorithm with autonomous learning and data processing capabilities. Since this algorithm can effectively analyze and predict medical material inventory management data, it is chosen as the reference model. It is a three-layer Backpropagation Neural Network (BPNN), which can approximate any function [25]. It is a single predictive model that directly uses neural network technology to predict material management. BPNN includes an input layer, a hidden layer, and an output layer. It adopts a parallel network structure, as shown in Figure 2. The value range of hidden layer neurons is 2-10. The transfer function uses the Sigmoid function, and the algorithm operation process is displayed in Figure 3.

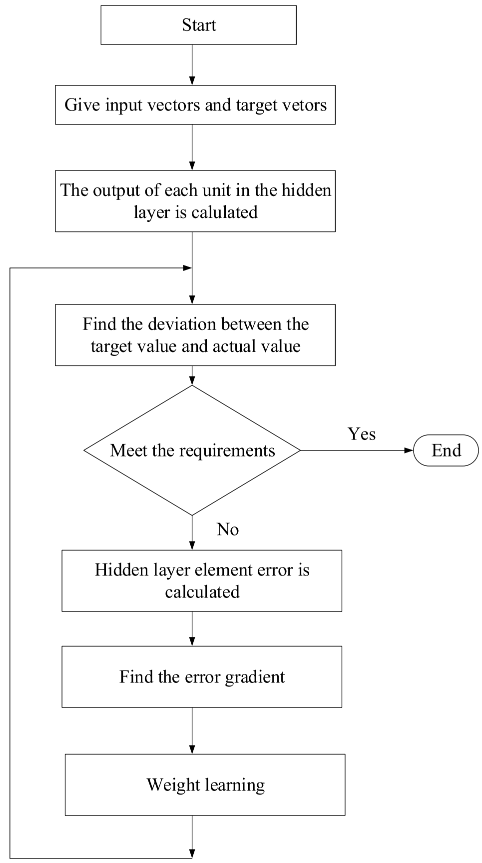

FIGURE 3. A schematic diagram of the BPNN operation process.

III. RESEARCH METHODS

A. CLASSIFICATION OF MATERIAL MANAGEMENT

There are many types of emergency materials required in a critical situation, and the requirements for capital and inventory are high. In particular, inventory takes up many funds, and there are differences in types, prices, and demand. It is unrealistic to adopt the same method for the inventory management of various emergency materials. To realize the scientific management of the emergency material inventory, materials and funds can be effectively used to handle emergency events. The scientific classification method must be used to classify the emergency material inventory and implement targeted management. Different inventory strategies are adopted for different emergency material inventory types to reduce the inventory classification of emergency materials effectively.

The ABC classification method is a quantitative scientific classification management method based on the two indexes of the proportions of the material inventory and variety [26]. The ABC classification method is to divide specific objects into three levels according to the standard. According to different classification characteristics, it is divided into important A-type inventory: the proportion of varieties is 5-20%, the proportion of funds is 60-70%, and the management method is the key attention. Generally important B-type inventory: the proportion of varieties is 20-30%, the proportion of funds is 10-20%, and the management method is

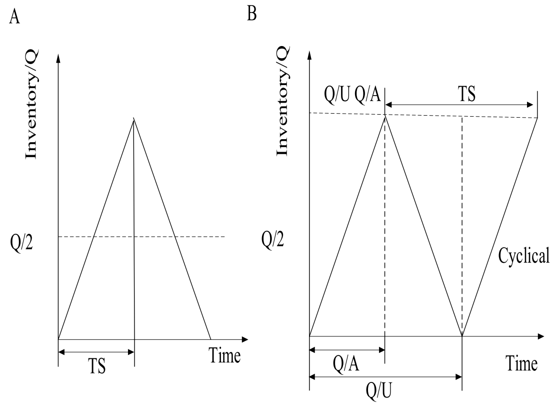

FIGURE 4. Economic order model with unlimited/limited supply rate and no stock shortage.

general attention. Unimportant C-type inventory: the proportion of varieties is 60-70%, the proportion of funds is 5-10%, and the management method is simple attention. The different management measures are taken at all levels to achieve the best economic and management effect.

The earthquake emergency is taken as an example to build an inventory model of emergency materials. The literature [27] and the classification of emergency materials of *Emergency Support Material Classification and Product Catalog* are referred to. The types of emergency materials related to earthquakes include first aid, medicine, equipment, and post-disaster reconstruction. Since these materials play different roles in the emergency process, they can be classified according to the criteria of importance, scarcity, and time-sensitivity. The results are shown in Table 1 below.

B. CLASSIFICATION MATERIAL MODEL

Important material management model: for the important emergency material inventory model, the method refers to the economic order model with unlimited/limited supply rate and no stock shortage in Figure 4 to make corrections [28]. There are many kinds of inventory materials, and materials need a certain amount of inventory. However, in reality, inventory, occupation of funds, and storage space are usually contradictions challenging to reconcile. Therefore, an economic order model with limited storage space is used. The importance of emergency materials includes many different types of materials, and a variety of materials will continue to be added. Due to the limited storage space of the warehouse, when determining the optimal inventory of different types of materials, it is essential to consider the constraints of the storage site.

(1) Assumption: To manage important materials with limited storage space, the inventory space occupied by each important material is fixed, and the inventory space allocated to important materials is also fixed. The demand rate, order fee, and storage fee rate for a vital material are constant in a certain period. It requires solving the problem of the best order batch for important materials.

(2) Model solution: In actual operation, the inventory management of important materials should have the following constraints.

$$\sum_{\mathrm{i}=1}^{\mathrm{n}} \omega_{\mathrm{i}} Q_{\mathrm{i}} \leq W \tag{1}$$

According to the economic order model with an unlimited supply rate and no stock shortage, the model with the smallest average total cost is as follows.

$$\min C(Q_1, Q_2 \cdots Q_{\mathrm{n}}) = \sum_{\mathrm{i}=1}^{\mathrm{n}} (\frac{1}{2} C_{1\mathrm{i}} Q_{\mathrm{i}} + \frac{C_{3\mathrm{i}} D_{\mathrm{i}}}{Q_{\mathrm{i}}}) \tag{2}$$

$$st. \begin{cases} \sum_{\mathrm{i}=1}^{\mathrm{n}} \omega_i Q_{\mathrm{i}} \leq W \\ Q_{\mathrm{i}} \geq 0, \mathrm{i} = 1, 2 \cdots, n \end{cases} \tag{3}$$

When the constraints are not considered, the best batch of Q_i^* can be obtained according to the EOD equation.

$$Q_{\mathrm{i}}^* = \sqrt{\frac{2 \cdot D_i \cdot C_{3i}}{C_{1i}}}, \quad \mathrm{i} = 1, 2 \cdots, n \tag{4}$$

If Q_i^* meets the constraints, it is the best order batch for each material. Otherwise, the model is solved by the Lagrangian multiplier method, and the Lagrangian function is constructed as follows.

$$L(Q_1, Q_2 \cdots Q_{\mathrm{n}}) = \sum_{\mathrm{i}=1}^{\mathrm{n}} (\frac{1}{2} C_{1\mathrm{i}} Q_{\mathrm{i}} + \frac{C_{3\mathrm{i}} D_{\mathrm{i}}}{Q_{\mathrm{i}}}) + \lambda \sum_{\mathrm{i}=1}^{\mathrm{n}} (\frac{1}{2} \omega_{\mathrm{i}} Q_{\mathrm{i}} - W) \tag{5}$$

The partial derivatives of Q_1 Q_2 Q_3 $\ldots Q_n$ are solved respectively and made zero. Then, there are the following equations.

$$\frac{\partial L}{\partial Q_{\mathrm{i}}} = \frac{1}{2} C_{i1} - \frac{D_i \cdot C_{3i}}{C_i^2} + \lambda \omega_{\mathrm{i}} = 0, \quad \mathrm{i} = 1, 2 \ldots, n \tag{6}$$

$$\frac{\partial L}{\partial Q_{\mathrm{i}}} = \sum_{\mathrm{i}=1}^{\mathrm{n}} \omega_{\mathrm{i}} Q_{\mathrm{i}} - W = 0 \tag{7}$$

It can be obtained that:

$$Q_{\mathrm{i}} = \sqrt{\frac{2 \cdot D_i \cdot C_{3i}}{C_{1i} + 2\lambda\omega_{\mathrm{i}}}}, \quad \mathrm{i} = 1, 2 \ldots, n \tag{8}$$

Q_i and λ can be solved by equations (7) and (8). Due to the complexity of the calculation process, the trial method can be generally used to solve the less demanding scenarios.

$$\sum_{\mathrm{i}=1}^{\mathrm{n}} \omega_{\mathrm{i}} \sqrt{\frac{2 \cdot D_i \cdot C_{3i}}{C_{1i} + 2\lambda\omega_{\mathrm{i}}}} - W = 0 \tag{9}$$

where: Qi is the order quantity of the i-th material. ω_i is the inventory space occupied by the i-th material. W is the maximum storage capacity allocated in the inventory for important materials. D_i is the demand rate of the i-th material.

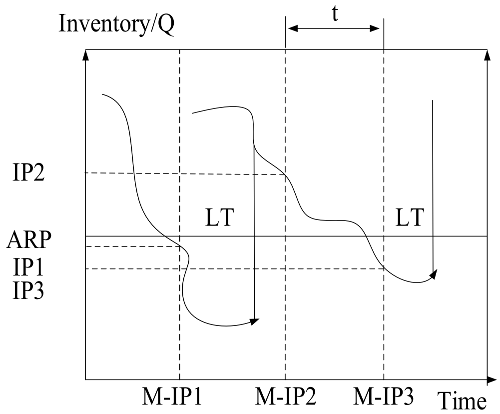

FIGURE 5. Regular order method model.

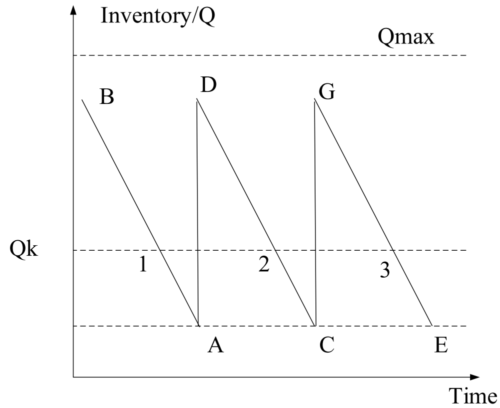

FIGURE 6. Quantitative control method model.

C_{3i} is the subscription fee for the i-th material. C_{1i} is the storage rate of the i-th material. In general, when the number of variables is small, it can be solved manually or analytically. When the number of variables is large, iterative methods or mathematical software packages such as Matlab can be considered.

Scarce material management model: considering the needs of emergency materials, the production cycle of scarce materials is generally long, and the capacity reserve is far from enough. When there is a shortage, it is difficult to make up quickly. Because of this characteristic, the particularity of the scarce material inventory strategy should be carefully considered. The establishment method of the inventory management model adopts the standard order method, as shown in Figure 5 [29]. Inventory management should appropriately increase the amount of safety inventory, establish a scientific inventory management model, reduce inventory, reduce inventory costs, and give full play to the role of funds and materials.

(1) Assumption: Assuming that the emergencies are earthquake-type emergencies, it is considered that the occurrence cycle of earthquake-type emergencies is long, and the unit of time is year.

(2) Model solution: Based on the above analysis and assumption, the calculation equation for the economic order cycle in the event of an earthquake-type emergency is as follows.

$$T = \sqrt{\frac{2 \times S}{C_0} \times R} \tag{10}$$

The maximum inventory quantity Qmax in the regular order method is regarded as the demand quantity within the period of meeting the order period T plus the lead time. Therefore, based on the inventory demand during $T+T_k$, considering the safety inventory set up due to uncertain inventory demand, the calculation equation of the maximum inventory quantity Q_{max} is as follows.

$$Q_{max} = R \times (T + T_k) + Q_s \tag{11}$$

For the revised periodic order method, the maximum and minimum periodic order method, the actual quantity of each order is not a fixed value. The value of the order quantity mainly depends on the size of the immediate inventory. Comprehensively considering the volume of goods in transit and the volume to be shipped, the quantity of each order can be calculated by equation (11).

$$Q_i = Q_{max} - Q_{ni} \text{-} Q_{ki} + Q_{mi} \tag{12}$$

where: T is the order period, and T_k is the average order lead time. S is the single order cost, and C_0 is the annual storage cost of unit materials, and R is the average value of inventory demand. Q_{max} is the maximum inventory quantity, and Q_s is the safety inventory quantity, and Q_{ni} is the volume of goods arrived at the i-th order point, and Q_{ki} is the actual inventory of the i order.

Time-sensitive material inventory model: for the inventory management of time-sensitive materials, based on the traditional fixed-point control method, the quantitative order method can control the inventory of materials. It is similar to the fixed-point control method. The quantitative order method is to organize orders based on fixed-point and order batches. The typical feature is that the order batch is fixed, and the order time is uncertain. The modeling method adopts the quantitative control method, and the specific information is shown in Figure 6 [30].

(1) Assumption: When the inventory drops to the predetermined minimum inventory level, the economic batch is generally used as the standard according to the specified quantity, and the calculation method of the economic batch is used to order the supplement. Therefore, quantitative order can both meet inventory requirements and minimize total costs.

(2) Model solution: As shown in Figure 4, the order point Q_k needs to be determined before implementing the order point control technology. The order batch is Q*. As shown in Figure 4, the order point is composed of safety inventory and average demand for the lead time.

$$Q_s = Q_k - D_1 \tag{13}$$

According to the demand rate concept, the demand quantity D_1 of order lead time can be calculated

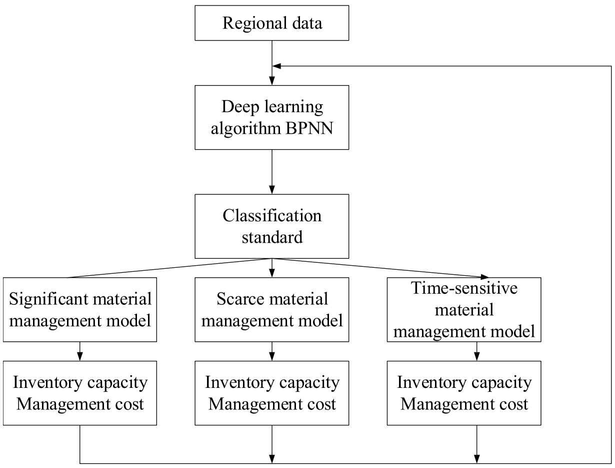

FIGURE 7. Medical material management model based on deep learning.

by equation (13).

$$D_1 = T_k \times R_P \tag{14}$$

The relationship between the order lead time demand D_1 with order lead time T_k and demand rate R_P is given. Then, it can be calculated according to the figure.

$$Q_k = D_1 = T_k \times R_P \tag{15}$$

In a simple economic batch model, only the two most basic costs are considered: inventory holding cost and order cost. According to the principle of the least total cost, the economic order batch equation is as follows.

$$Q^* = \sqrt{\frac{2C_0 - R_p}{C_1}} \tag{16}$$

where: C_0 is the cost of a single order, and C_1 is the inventory storage cost per unit time, and R_p is the demand rate.

C. DEEP LEARNING MATERIAL MANAGEMENT

The proposed classification model is combined with the deep learning method. Hence, a medical material management model based on deep learning is proposed, and its structure is presented in Figure 7. At the output end, the same data are used to input different models, mainly the local and classified data of medical supplies. The data are normalized, and the relevant areas can be effectively modeled through data learning. The classification method of the region is obtained. The output data are modeled according to different methods. The required cost and the best inventory capacity are calculated, and the different methods are compared to further predict the number of materials that can be accommodated, thereby optimizing the traditional material management model.

D. MODEL APPLICATION AND VERIFICATION

(i) Important material management model: for the simulation verification of the important emergency material model, taking an earthquake emergency as an example, the inventory management of six types of medical gauze, blood-sucking pads, bandages, alcohol, saline, and blood pressure meter is explored. They are expressed by *M1, M2, M3, M4, M5,* and *M6*, respectively. It is assumed that the maximum storage capacity of a warehouse is 20000m^3. According to the literature, the inventory management data of the six materials are shown in Table 2.

(ii) Scarce material management model: for the simulation verification of the scarce emergency material model, taking an earthquake emergency as an example, the inventory management of six types of medical items such as medical gloves, goggles, disinfectant, ventilator, mask, and protective clothing is explored. They are expressed by *S1, S2, S3, S4, S5,* and *S6*, respectively. It is assumed that the volume of goods arrived is 300 pieces, the actual inventory is 700 pieces, and the materials to be shipped out are 280 pieces. According to the literature, the six types of scarce material inventory management data are shown in Table 3.

(iii) Time-sensitive material inventory model: for the simulation verification of the time-sensitive emergency material model, taking an earthquake emergency as an example, the inventory management of the six types of medical and epidemic prevention materials such as glucose, epinephrine, dopamine, nitroglycerin, coramine, and lobeline is explored. They are expressed by *P1, P2, P3, P4, P5,* and *P6*, respectively. It is assumed that the lead time is eight days, and the average daily consumption is 150 cases, and the maximum daily consumption is expected to be 200 cases. According to the literature, the six types of time-sensitive material inventory management data are shown in Table 4.

TABLE 2. Classification results of emergency materials.

Emergency material category	Material name
Important materials	Medical gauze, blood-sucking pad, bandage, alcohol, saline, sphygmomanometer
Scarce materials	Medical gloves, goggles, disinfectant, ventilator, masks, protective clothing
Time-sensitive materials	Glucose, adrenaline, dopamine, nitroglycerin, colamin, lobeline

TABLE 3. The Inventory Management Data for Six Types of Materials.

Types of materials	Demand rate Di (Piece/year)	Subscription fee C_{3i} (Yuan)	Storage rate C_{1i} (Piece/year)	Take up inventory space w_i (m^3)
M1	3200	50000	1	0.2
M2	2400	50000	1	0.3
M3	2000	50000	2	0.2
M4	2500	50000	2	0.2
M5	3000	50000	1	0.3
M6	2600	50000	1	0.3

IV. RESEARCH RESULTS

A. THE VERIFICATION RESULT OF THE IMPORTANT EMERGENCY MATERIAL INVENTORY MODEL

According to the known conditions, the economic order quantity without considering the limitation of the warehouse area is found: $Q_1^* = 17889$, $Q_2^* = 15492$, $Q_3^* = 15142$, $Q_4^* = 17361$, $Q_5^* = 12247$, and $Q_6^* = 11401$. Then, the situation of

TABLE 4. Six types of scarce material inventory management data.

Types of materials	Annual demand (Piece)	Annual storage fee (Yuan)	Order cost (Yuan)	Average inventory demand
S1	730	600	2000	45
S2	700	600	2000	30
S3	650	600	2000	40
S4	800	600	2000	25
S5	1000	600	2000	55
S6	820	600	2000	50

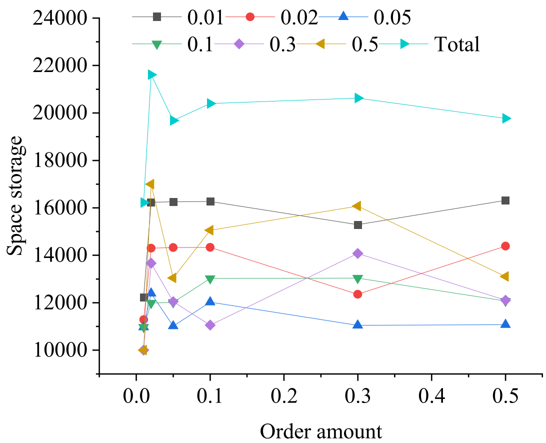

FIGURE 8. The verification of the important emergency material inventory model.

four important materials occupying the inventory space can be obtained: $17889 \times 0.2 + 15492 \times 0.3 + 15142 \times 0.2 + 17361 \times 0.2 + 12247 \times 0.3 + 11401 \times 0.3 = 21820.4(\text{m}^3)$. Obviously, after the above calculation, the best inventory is obtained. Nevertheless, the largest storage space has been exceeded in total. Therefore, it is not feasible to store important materials following this plan.

Therefore, the limited inventory space constraint model needs to be considered. Substituting the different fixed values into the equation can get the results shown in Figure 8. When the value is 0.5, the maximum inventory is 19772.9m^3. At this time, there are 16319 pieces of gauze, 14386 pieces of blood-sucking pads, 11075 pieces of bandages, 12072 pieces of alcohol, 12108 pieces of saline, and 13105 pieces of blood pressure meter. It is the best inventory combination, and such space utilization rate is the largest.

B. THE VERIFICATION RESULT OF SCARCE EMERGENCY MATERIAL INVENTORY MODEL

According to known conditions, the economic order cycle of scarce materials can be obtained: $T_1 = 35$, $T_2 = 34$, $T_3 = 33$, $T_4 = 36$, $T_5 = 38$, and $T_6 = 36$. As shown in Figure 6, under different order batches, the changing trend of the highest inventory can be obtained as follows. When the economic order cycle of scarce materials is 35 days, and the order batch is 630 pieces, the highest inventory is 1350 pieces, and the warehouse utilization rate is the largest. For the order method, the batch size of each order is difficult to be determined in actual operation. Therefore, it is impossible to formulate the best economic order batch, and there are significant disadvantages in terms of operating cost and economy. The efficiency

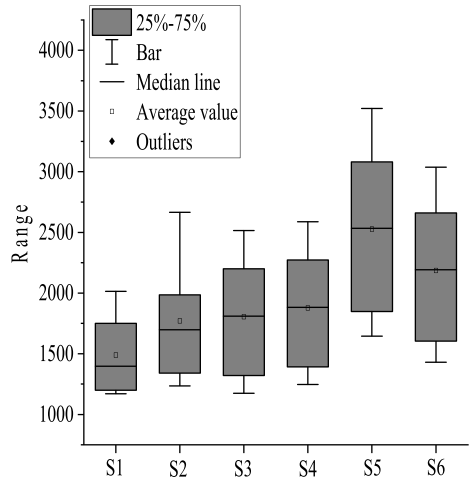

FIGURE 9. The changing trend of the maximum inventory with the order batch.

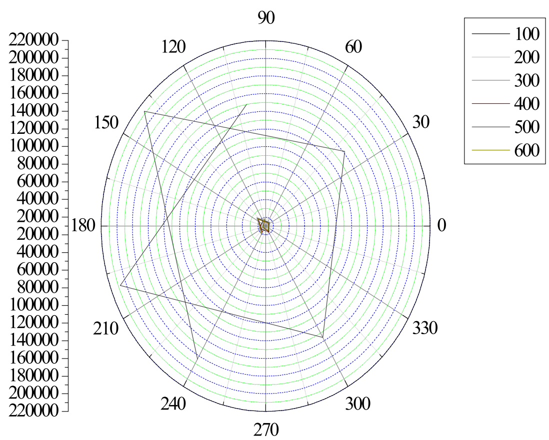

FIGURE 10. The changing trend of the maximum inventory with the order batch.

is low in practice. Thus, the order method is only suitable for more important and scarce materials with few varieties and high value.

C. THE VERIFICATION RESULT OF TIME-SENSITIVE EMERGENCY MATERIAL INVENTORY MODEL

According to known conditions, the order batch of time-sensitive materials can be obtained: $Q_1^* = 16100$, $Q_2^* = 16757$, $Q_3^* = 15179$, $Q_4^* = 14697$, $Q_5^* = 14199$, and $Q_6^* = 14940$. Under different safety inventories, it can be concluded that the changing trend of time-sensitive order batches is shown in Figure 10. The calculation shows that the safety inventory of the materials is 400 cases, and the order point is 1600 cases, and the order batch is 16100 cases. At this time, the utilization rate of the warehouse is the largest.

D. MODEL PERFORMANCE VERIFICATION AND COST ANALYSIS

The proposed model is compared with the latest models, and its complexity is expressed as the algorithm processing efficiency per unit time. The results are presented in Table 6. The latest medical material management methods are compared

TABLE 5. Six types of time-sensitive material inventory management data.

Types of materials	Annual demand (Box)	Annual storage fee (Box/Yuan)	Order cost (Yuan)	Average inventory demand
P1	36000	5	1800	150
P2	39000	5	1800	200
P3	32000	5	1800	120
P4	30000	5	1800	100
P5	28000	5	1800	88
P6	31000	5	1800	92

TABLE 6. Model performance verification.

Types of materials	Operation cost	Analysis time	Prediction accuracy	Management cost
The proposed model	2560.36 CNY	35min	92.45%	1236.56 CNY
Panja and Mondal (2019)	5240.69 CNY	65min	90.16%	2214.69 CNY
AlDurgam et al. (2017)	3610.25 CNY	39min	85.36%	1985.36 CNY
Shin et al. (2019)	3230.26 CNY	42min	82.44%	2014.58 CNY

without changing the experimental conditions. The difference between the management method and the deep learning management method is analyzed from the four aspects of model operation cost, analysis time, prediction accuracy, and management cost. According to Figure 6, the proposed model has lower operation and management costs than other latest models. Its prediction accuracy is 92.45%, indicating the performance of the proposed model is the best. In contrast, the method proposed by Panja and Mondal (2019) provides a prediction accuracy of 90.16%. Under the same data, the analysis time of the medical material management method based on deep learning is only 35 minutes, which has undeniable advantages compared with other models.

E. MODEL SENSITIVITY ANALYSIS

Table 7 gives the result of the model sensitivity analysis. When the area of the material warehouse changes, the relative income drops by 13.43% because if the area of the material warehouse is higher than the limit, a decrease in revenue will occur. In contrast, changes in the prices of other materials, the personnel costs, and the material types will increase relative revenue. The largest increase occurs in the price change of medical materials. Hence, the price of medical materials is an essential factor affecting the management of emergency supplies.

V. DISCUSSION

In recent years, public emergencies, including accidents, disasters, public health incidents, social security incidents, and various natural disasters, have occurred frequently in China. Studying the emergency management of public emergencies and improving the ability to respond to public emergencies has become a reality and a hot research issue. When dealing with public emergencies, the emergency material guarantee is the vital link, and emergency material inventory management

TABLE 7. Model sensitivity analysis.

Analysis dimensions	Changes in the material warehouse area	Changes in medical material prices	Changes in personnel costs	Changes in material types
Investment income	7.72	33.62	25.26	25.9
Relative income	-13.43	+12.37	+4.11	+4.75
Relative rate of change	-0.67	0.62	0.21	0.48

is an important aspect of emergency material guarantee. The rationality and feasibility of dividing emergency materials into three major categories: importance, scarcity, and time-sensitive are explored, and corresponding emergency material inventory models are constructed according to their characteristics. The emergency material inventory management models that require rapid response and high service standards are demonstrated in-depth, which is vital to improving the overall delivery timeliness of emergency materials, fully guaranteeing the total number of emergency materials delivered, and increasing the level of emergency materials reserve, and reduce storage costs. The practical application value lies in the following three aspects. (i) Research on the emergency material inventory model under emergencies is conducive to constructing a scientific emergency material inventory structure and has important value for improving the overall delivery timeliness of emergency materials. The key to handling emergency emergencies is timeliness, which puts forward high requirements for the timely arrival of emergency materials. Whether emergency materials arrive within adequate time determines the effect of emergency treatment. Hence, a reasonable inventory structure and the material quantity are conducive to improving the storage capacity and efficiency of emergency materials, better-improving the response capabilities of emergency materials in response to emergencies, and enhancing the timeliness of emergency materials. (ii) Research on the emergency material inventory model is conducive to scientifically and reasonably determining the overall delivery quantity and capacity of materials. One of the critical elements of emergency material inventory management is to maintain a reserve level. However, in practice, the number of material reserves is limited by the emergency budget funds, and the uncertainty of emergency events also makes the problem of emergency material reserves full of difficulties. Studying the emergency material inventory model and constructing a scientific and reasonable material inventory model is of great significance for ensuring the optimal level of the material reserve under limited funds. (iii) Research on the emergency material inventory model is conducive to reducing the cost of material storage. The inventory of emergency supplies will take up a lot of space and funds and requires a steady stream of maintenance costs. However, it is difficult to determine the occurrence of an emergency. Therefore, in regular times, the storage cost of emergency supplies needs to be emphasized. A scientific emergency material inventory model can rationally classify materials and control the storage quantity, which is of positive significance for improving material storage capacity and reducing material storage costs.

For the important emergency material inventory model, the economic order method of limited inventory is used. It is possible to allocate space equally according to the use of materials without considering the limitation of the warehouse area to maximize the use of space. The order quantity calculated according to the specific situation can significantly meet the storage capacity of the warehouse, which is consistent with the results of Dai *et al.* (2019). They believe that the procurement time and quantity strategy of materials cannot be formulated solely based on the price of materials and the current inventory level. It is necessary to establish a scientific limited inventory management model to achieve effective use of materials [31]. For the scarce emergency material inventory model, the revised periodic order method is adopted. The production cycle of scarce materials is long, and the global demand for materials is considerable. Therefore, only planned purchases can be made, which is consistent with the results of Liu *et al.* (2017). Their results show that this method can ensure the implementation of emergency rescue measures and help decision makers determine appropriate emergency material planning schemes to achieve a balance between time benefit and cost benefit goals [32]. For the time-sensitive emergency material inventory model, the quantitative order method based on safety inventory is used. This method can realize the dynamic monitoring function of materials and timely understand the information of emergency materials, which improves the ability to respond to risks. It is similar to the conclusion of Liu *et al.* (2018). They proposed introducing a third-party procurement company to achieve rapid procurement of time-sensitive materials [33]. The model of this investigation can play the same value effect as the third-party company.

VI. CONCLUSION

The important emergency material inventory model, scarce emergency material inventory model, and time-sensitive emergency material inventory model are proposed and applied through consulting and sorting out a large number of documents. Among them, the economic order method with limited inventory is used to establish the important material model. The revised periodic order-maximum and minimum period methods are used to establish a scarce emergency material inventory model. The quantitative order method based on safety inventory is used to construct the time-sensitive emergency material inventory model. Taking the earthquake emergency as an example, the model establishment process and method are explored. Also, the models are solved, and the application examples are given. The emergency materials are divided into three categories: importance, scarcity, and time-sensitivity. Compared with the existing inventory management method, it is more reasonable and feasible, which can significantly improve the space and capital utilization and optimize emergency material management. It fully guarantees the low-cost and high-efficiency of emergency materials and improves the ability to respond to risks, which is greatly valuable for responding to public emergencies.

Due to limited conditions, there are still many shortcomings that need to be explored. (1) To further refine the investigation on the classification of emergency material inventory, according to the current situation of many emergency materials and difficult inventory management, the emergency materials are divided into three categories: importance, scarcity, and time-sensitivity. However, the classification in the investigation is mainly for quantitative research from a qualitative perspective, and there is still a lack of quantitative research. The next step is to comprehensively use the analytic hierarchy process and fuzzy evaluation method to conduct an in-depth investigation on the classification of emergency material inventory. (2) Through in-depth construction and verification of the emergency material inventory model, the traditional best economic batch method, quantitative order method, and conventional order method are mainly used to manage different inventory materials. Although the above methods have been improved to make it more suitable for different emergency material inventory management types, the model test is conducted. The application work is not deep enough. For example, it is necessary to further flexibly grasp the quantitative order method when using multi-variety joint order. Issues regarding the determination of a reasonable scale of safety inventory need to be further strengthened. In the follow-up, more in-depth investigation and demonstration of different inventory models need to be conducted.

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