Research Article

Optimal Model of Emergency Medical Supplies Stowage under Traffic Control during the Initial Period of the Epidemic Based on Characteristics Analysis of COVID-19 Epidemic

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In the initial stage, the epidemic area is relatively concentrated, and some traffic modes may be subject to traffic control. In this period, the timely delivery of adequate emergency medical supplies to the epidemic points will play an important role in controlling the spread of the epidemic. However, the existing emergency medical supplies loading optimization model has not taken the initial period of the epidemic as the research time nor fully considered the traffic control situation in that period. Therefore, combined with the characteristics of the initial epidemic period of COVID-19, this study establishes an optimization model for emergency medical supplies stowage at the rescue point, considering the variation in demand for different kinds of medical supplies at the epidemic point in different cycles and the impact of traffic control on the mode of transportation. The model is an integer programming model. The objective function is the least total cost, including total transportation cost and total inventory cost. The constraints include the supply limit of each medical material that can be provided by the rescue point, the transportation capacity limit of the transportation mode, the demand constraints, inventory constraints, nonnegative constraints, and integer variable constraints of various medical supplies in each cycle of the epidemic location. Finally, combining the development of the epidemic situation in Wuhan January 18–23, 2020, a case study was carried out, and the optimal combination of different transportation modes and different stowage schemes in different periods of the rescue point was obtained, which verified the feasibility and practicality of the model. The model constructed in this study can provide a theoretical reference to the optimal decision-making plan of emergency medical supplies of the implementation of traffic control during the initial period of emergency public health events.

1. Introduction

As a public health emergency, the epidemic can be generally divided into several stages, such as the initial period, the development period, the outbreak period, the stable period, and the recession period on the evolution rule of its situation [1–4]. At the same time, the rebound of the epidemic may also make the areas that have entered the recession period return to the initial period. From the analysis of the evolution characteristics of the novel coronavirus in 2020, the initial emergence period of the COVID-19 epidemic is about 60 days. If the epidemic is well controlled during the initial period, the development and outbreak of the epidemic will be effectively suppressed in the later period. Due to the

different control measures taken by China and the United States in the initial stage of the epidemic, the number of infected people in the two countries during the outbreak period of the epidemic is also vastly different, as shown in Table 1.

Wuhan, as the most severely affected area of novel coronavirus infection in China, has adopted stringent and thorough containment measures during the initial period of the epidemic. The relevant measures taken in this phrase changed the evolution pattern of the epidemic. As a result, the epidemic did not appear explosive growth of infection in other provinces across the country. However, in the early stage of the infectious disease outbreak, people lacked an understanding of the epidemic [6]. Coupled with the fierce

TABLE 1: Comparison of prevention and control measures and results of COVID-19 in China and the United States at the initial emergence stage.

Comparison item	China	The United States
Place of the first occurrence	Wuhan (Hubei, China)	Washington State
Prevention and control measures at the initial stage	The first stage, from 2019.12.10 to 2020.1.17 (i) In late December 2019, Hubei Provincial Hospital of Integrated Chinese and Western Medicine received several cases of pneumonia of unknown etiology. On December 29, Wuhan Center for Disease Control and Prevention began an epidemiological investigation (ii) On December 31, the National Health Commission (NHC) sent a working group and an expert group to Wuhan to guide the epidemic handling and conduct on-site investigations (iii) On January 1, 2020, the NHC set up the leading group on the disease response. On January 3 and 4, the NHC and the Health Commission of Hubei Provincial formulated nine documents, including Diagnosis and Treatment Protocol for Viral Pneumonia of Unknown Cause (for Trial Implementation) and produced Treatment Manual for Viral Pneumonia of Unknown Cause, which were issued to all medical and health institutions in Wuhan [5] (iv) On January 7, Xi Jinping, general secretary of the CPC Central Committee, presided over a meeting of the Standing Committee of the Political Bureau of the CPC Central Committee and issued instructions on the prevention and control of a possible epidemic of pneumonia of unknown cause in Wuhan. On January 8, the second group of experts from the NHC went to Wuhan (v) On January 13, the NHC convened a meeting to deploy and guide Wuhan to further strengthen social management, strengthen the temperature monitoring of personnel at ports and stations, and reduce crowd gatherings (vi) On January 15, the NHC released the first versions of the Diagnosis and Treatment Protocol for Novel Coronavirus Pneumonia and Protocol on Prevention and Control of Novel Coronavirus Pneumonia (vii) On January 17, the NHC sent seven inspection teams to guide local epidemic prevention and control The second stage, from 2020.1.18 to 2020.1.23 (i) On January 18, the NHC sent a high-level expert group headed by Academician Zhong Nanshan to Wuhan to inspect the local epidemic prevention and control (ii) On January 20, President Xi Jinping gave important instructions on fighting the novel coronavirus, emphasizing the need to resolutely stem the spread of the virus and enhance international cooperation. On the same day, Premier Li Keqiang presided over the executive meeting of the State Council and invited Zhong Nanshan and Li Lanjuan to attend (iii) In the early morning of January 23, Wuhan City Novel Coronavirus Prevention and Control Command Center issued the No. 1 public notice declaring temporary closure of the city's outbound routes at its airports and railway stations at 10 o'clock. Wuhan announced the lockdown of the city The third stage, from 2020.1.24 to 2020.2.1 (i) After the city was on lockdown, Wuhan gradually established a traffic control and quarantine system to curb population flow The fourth stage, from 2020.2.2 to 2020.2.6 (i) Community prevention and control in Wuhan have been strengthened, and the community public health management model of "leave no household, no one behind" has been proposed. At the same time, the Huoshenshan Hospital, Leishenshan Hospital, and the makeshift hospital have completed the delivery and put it into use. Medical rescue teams from 20 provincial large-scale tertiary general hospitals rushed to help, further improving the prevention, control, and medical level of Wuhan	The first stage, from 2020.1.22 to 2020.2.10 (i) On January 22, the day before the lockdown of Wuhan, China, US President Donald Trump declared: "We have it totally under control. It's one person coming in from China. It's going to be just fine" (ii) On January 25, Trump praised China for its very hard work to contain the novel coronavirus (iii) On January 30, Trump declared to the American public: "We only have five people. We pretty much shut it down coming in from China" (iv) On January 31, the United States banned the entry of any foreign citizen who had been to China in the past 14 days (v) On February 7, the heads of China and the United States conversed. Trump praised China for strict prevention and control (vii) On February 10, Trump said that the virus would disappear after hotter weather in April The second stage, from 2020.2.11 to 2020.2.26 (i) On February 11, the heads of the Centers for Disease Control and Prevention of China and the United States conducted technical exchanges (ii) From February 16 to 24, the WHO-China Joint Mission on COVID-19, including two American experts, visited China (iii) On February 24, Trump declared: "The Coronavirus is very much under control in the USA" The third stage, from 2020.2.27 to 2020.3.11 (i) On February 27, the White House issued an order prohibiting government medical and health experts from publicly discussing the epidemic (ii) On February 29, the first death case occurred in the United States (iii) On March 2, Trump asked pharmaceutical companies to develop a vaccine within a few months but was refused (iv) On March 9, Trump used the death toll of influenza to tell Americans that the epidemic was not terrible The fourth stage, from 2020.3.12 to 2020.3.23 (i) On March 13, Trump declared a state of emergency in the country (ii) A total of 1992 cases have been confirmed in the United States (iii) On March 14, the US House of Representatives passed a plan that includes free COVID-19 testing (iv) On March 19, the cumulative number of confirmed diagnoses in the United States exceeded 10,000 (v) On March 23, 46,332 people were diagnosed in the United States
Peak cases	The peak period occurred in June 2020, with a total of 83,000 confirmed cases and more than 4,000 deaths	As of February 8, 2021, the cumulative number of confirmed diagnoses exceeded 26 million and the death toll exceeded 450,000

attack of the epidemic, Wuhan did not reserve enough medical supplies in time. With the development of the epidemic, there were a serious shortage of medical supplies and a missed opportunity for more effective control of the epidemic. By contrast, the number of confirmed cases in the United States is nearly 270 times that of China because it has not taken timely preventive and control measures [7]. Therefore, it is of great significance to study how to optimize the stowage scheme of various transportation modes in the initial stage of the epidemic so that the rescue point can provide sufficient medical supplies to the affected area in time within the specified time limit, which can effectively control the number of infected people in the affected area and a wider range.

In recent years, the optimal supply and allocation of medical supplies in the outbreak of the epidemic has attracted increasing attention of the scientific community [8–11]. Regarding the equitable allocation of emergency supplies, Balcik et al. [12] constructed a mixed integer programming model to determine delivery schedules for vehicles and equitably allocated resources, considering supply, vehicle capacity, and delivery time constraints, with the objectives of minimizing transportation costs and maximizing benefits to aid recipients. Huang et al. [13] compared equity measures regarding delivery quantity, arrival times, and deprivation time in different locations in emergency distribution. To study the fairness of distribution for emergency supplies after an earthquake, Xiong et al. [14] used a multilevel location-routing problem (LRP) to effectively realize the supply of emergency supplies within a specified time after an earthquake. Cao et al. [15] formulated a fuzzy triobjective bilevel integer programming model to achieve the unmet demand rate, potential environmental risks, and emergency costs of the optimal target.

With respect to synergic optimization of emergency supplies distribution, Lei et al. [16] considered that coordination of medical teams and medical supplies to the rescue point should be accomplished with a minimum of total tardiness so as to minimize the spoilage of medical supplies. Zhu et al. [17] established an emergency logistics network optimization model under crowded conditions using Bayesian decision theory and verified the effectiveness of the model under congested conditions through empirical studies, aiming at the total loss of emergency materials transportation units. Shi et al. [18] innovatively studied the distribution optimization of medical supplies after natural disasters from the perspective of disturbance management. A disturbance management model of medical supplies distribution is established from two dimensions of time and cost. Sun et al. [19] proposed a biobjective robust optimization model for strategic and operational response to decide the facility location, emergency resource allocation, and casualty transportation plans in a three-level rescue chain.

In terms of the location of emergency supplies supply points, Han et al. [20] proposed a Lagrangian relaxation framework to solve the supply location selection and routing problem of emergency material supplies with regard to delivery deadline and route capacity. Caunhye et al. [21] established a two-stage location-routing model in disaster

situations where there are uncertainties in demand and the state of the infrastructure. Based on the constraints on-demand period, collection time, and capacity limit of hub nodes, Huang [22] established a multiobjective programming model for earthquake emergency to solve the optimal decision problem of the multihub emergency materials collection network with constrained demand period and collection time. Mohamadi et al. [23] established a biobjective stochastic optimization model for the location of the medical supplies distribution centers. Wang et al. [24] proposed a mixed integer programming (MIP) model based on time cost under uncertainty, which is helpful to solve the emergency warehouse location and distribution problem.

Some researchers have conducted in-depth studies from the perspective of emergency material logistics and transportation methods. Feizollahi et al. [25] performed an empirical study on the distribution and management of emergency logistics emergency preparedness for staff of government, health and treatment, Red Crescent Society, electricity, water and sewage, transportation, and other departments of the central province of Ilam in the west part of Iran. Garrido et al. [26] proposed a flood emergency logistics auxiliary decision-making model. This model was attempted to optimize inventory levels for emergency supplies and the availability of vehicles to meet demands under a given probability. Ruan et al. [27] presented a clustering-based intermodal route optimization model considering helicopter travel time, transfer time, and vehicle delivery time. Dalal et al. [28] developed a robust optimization model to determine centralized supply locations and supply quantities for different transportation modes in a five-tier network.

Existing literature has made fruitful achievements in the research on multicycle collaborative optimization of emergency supplies and allocation model of emergency supplies. However, most of the existing achievements are based on the establishment of optimization models for the medical supplies allocation at epidemic points. First, to the best of the authors' knowledge, little attention has been paid to how to coordinate multiple transportation modes and optimize different loading combinations of various transportation modes according to the analysis of rescue points. Second, some of the assumptions of the models do not appear to be consistent with the demand for medical supplies in the early stage of the epidemic. In particular, they fail to fully consider the impact of traffic control in the early stage of the epidemic on the time when emergency supplies can be put into use. Third, the characteristics of the dynamic change of the demand for medical supplies in the early stage of the epidemic with the progress of the epidemic seem to be overlooked. Last, the models and algorithms used in some studies are relatively complex, which affects the practicability of the models.

Based on the characteristics of the initial period of COVID-19 and the possible traffic control situation during this period, this study establishes an optimal stowage model of emergency medical supplies at the rescue points to ensure that the rescue points can timely provide sufficient medical supplies to the epidemic points within the specified period. The basic steps of the study are as follows:

Step 1 : hypotheses were put forward in terms of transportation mode, capacity limit, loading scheme, traffic control, demand for medical supplies, and inventory of medical supplies.

Step 2 : the SEIR model with uncertain incubation period was used to predict the demand for medical supplies in different periods at the epidemic point.

Step 3 : analyze the influence of traffic control on travel time. Set up the road impedance function to analyze its impact on the travel cost and calculate the cycle number of the medical supplies transported from the rescue point to be used.

Step 4 : an integer programming optimization model was established. The constraint conditions of the model included meeting the supply limit, demand limit, and transport capacity limit of medical materials, and the objective function was to minimize the total cost. The basic idea of the model is shown in Figure 1.

This study chooses to use integer programming to build an optimization model for two reasons. First, emergency medical supplies are generally arranged in full containers during stowage, so using integer programming to build an optimal stowage model is not only in line with the actual situation of transportation but also conducive to improving transportation efficiency. Second, as a common optimization model, integer programming has the advantages of clear model mechanism and convenient solution, and it is easy to popularize and apply the optimization stowage model constructed by integer programming.

The remainder of the article is structured as follows. Section 2 introduces the optimal stowage model of emergency medical supplies; Section 3 analyzes the calculation examples and describes and the results; Section 4 discusses the results. Finally, our conclusions are presented in Section 5.

2. Materials and Methods

2.1. Problem Description.
In this article, the period immediately after the outbreak is referred to as the initial period of the epidemic, which represents the period when the epidemic begins to appear and is mainly spread in a region. In aiming to meet the demand for medical materials in time, this article studies how to coordinate multiple transportation modes and optimize the loading scheme at the rescue point during the initial outbreak of the epidemic.

The initial stage of the epidemic generally has the following characteristics:

(1) The epidemic area is relatively concentrated, mainly in one area, which is called epidemic point.

(2) There are areas that can provide medical aid materials, which are known as rescue points.

(3) The outbreak of the epidemic suddenly occurred, and the reserve materials of the epidemic sites were relatively

insufficient, and emergency medical supplies needed to be provided through the rescue sites. In the meantime, the number of infected people has not yet reached a significant level, and the medical supplies at the rescue sites can meet the needs of the epidemic sites.

(4) The epidemic point has a variety of demands for medical materials, such as reagents, life-support machines, surgical masks, and protective suits.

(5) If the initial period is subdivided into several cycles such as days, with the development of the epidemic, the demand for various kinds of medical supplies in different cycles in the initial period generally shows an obvious upward trend.

2.2. Symbolic Description.
First of all, we used Q and G to represent the epidemic point and rescue point, respectively, where Q represents the local area where the epidemic occurred during the initial stage of the epidemic and G indicates the area that can provide medical aid materials to the epidemic point during the initial stage of the epidemic.

For the convenience of analysis, the initial period of the epidemic was divided into R (with $i = 1, 2, \ldots, R$) cycles in accordance with the characteristics and development of the epidemic. It is assumed that there are K (with $k = 1, 2, \ldots, K$) types of medical supplies required by the epidemic point Q and the number of medical supplies k required by the epidemic point Q in period i is recorded as D_{ik}. In addition, S_{ik} represents the number of medical supplies k that can be provided by rescue point G in period i.

There are three modes of transportation: air, railway, and highway. The means of transportation are, respectively, airplanes, trains, and trucks. The transport mode q is denoted as Y_q, and aviation $q = 1$, railway $q = 2$, and highway $q = 3$. In addition, assuming that airplanes, trains, and trucks all have capacity limits, where the capacity limit of aviation is M_{i1}, the capacity limit of railway is M_{i2}, and that of highway is M_{i3} in period i for $i = 1, 2, \ldots, R$.

Each shift of each mode of transportation (e.g., one flight, or a train carriage, or a truck) adopts one feasible loading scheme. Each loading scheme is relatively efficient and selected and consists of a combination of different types and quantities of medical supplies. The loading scheme set Y_1, Y_2, and Y_3 can be expressed as follows:

$$F(Y_1) = \{f_{l_1}(Y_1)\}, \quad l_1 = 1, 2, \ldots, L_1,$$
$$F(Y_2) = \{f_{l_2}(Y_2)\}, \quad l_2 = 1, 2, \ldots, L_2, \qquad (1)$$
$$F(Y_3) = \{f_{l_3}(Y_3)\}, \quad l_3 = 1, 2, \ldots, L_3,$$

where L_1, L_2, L_3 are the number of feasible loading schemes of the three transportation modes, respectively. In $f_{l_1}(Y_1), f_{l_2}(Y_2)$, and $f_{l_3}(Y_3)$, the quantities of various medical supplies contained are, respectively, $\{l_1(1), l_1(2), \ldots, l_1(K)\}$, $\{l_2(1), l_2(2), \ldots, l_2(K)\}$, and $\{l_3(1), l_3(2), \ldots, l_3(K)\}$.

The travel time of one-way transportation by aircraft is $T(Y_1)$, that by train is $T(Y_2)$, and that by truck is $T(Y_3)$, where $T(Y_1)$ and $T(Y_2)$ are relatively fixed, while $T(Y_3)$
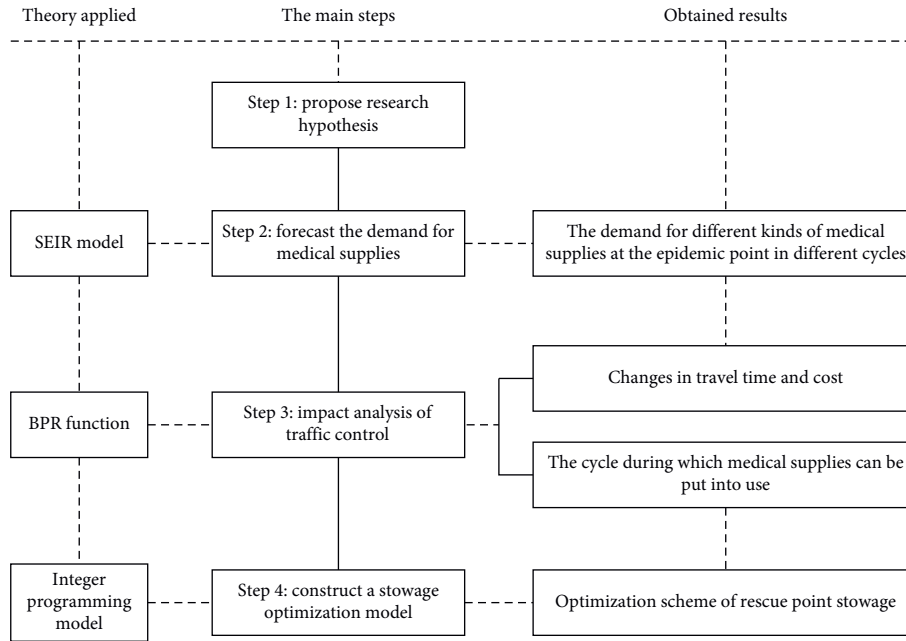
Figure 1: The basic idea of constructing the model.

changes dynamically with the development of the epidemic under the influence of traffic control.

Travel cost is defined as the cost of medical supplies every time transported by each mode of transportation. $C_d(Y_1)$, $C_d(Y_2)$, and $C_d(Y_3)$ represent the travel costs of one-way transport by plane, train, and truck, respectively, where $C_d(Y_1)$ and $C_d(Y_2)$ are relatively fixed, whereas $C_d(Y_3)$ changes dynamically with the development of the epidemic and the change of transportation time.

In this article, inventory costs only indicate the costs incurred during the storage of emergency medical supplies at the epidemic point, where $V_i(k)$ is the inventory quantity of medical supplies k at the beginning of period i and $C_s(k)$ is the unit inventory cost of medical supplies k.

2.3. Research Hypothesis.
In response to the research questions, combined with the characteristics of the initial stage of the COVID-19 epidemic, the basic assumptions of the research are proposed as follows.

Assumption 1. Rescue points can use aviation, railway, road, and other transportation methods to urgently supplement medical supplies. These three modes of transportation all have certain capacity limitations.

Assumption 2. There are several loading schemes for each mode of transportation. Taking road transportation as an example, a large truck can form different stowage schemes of medical supplies by combining different quantities of medical supplies, provided that the rated load and loading volume are satisfied.

Assumption 3. During the initial period of the epidemic, air and railway operations are generally not regulated, but some road transportation may be under control. Besides, the spread of the epidemic will make the implementation of traffic control on the roads more stringent. In the process of strengthening the traffic control of road transportation, the transportation impedance will gradually increase and be translated into the increase of transportation time and transportation cost.

Assumption 4. Because the demand for medical materials is relatively limited, to ensure the control of the epidemic, the shortage of medical materials is not allowed.

Assumption 5. Medical materials are allowed to be in stock, but there may be certain inventory costs for specific medical materials.

Assumption 6. There is no transportation loss and other transportation risks.

2.4. Prediction of the Demand for Medical Supplies in Each Cycle of the Epidemic Point.
In this study, the SEIR epidemic spread model with an uncertain incubation period was used to predict the spread of the epidemic in each cycle after the outbreak of the epidemic [29]. The model divides the population into four categories: susceptible persons, latent persons, infected persons, and rehabilitated persons. Then, the SEIR epidemic spread model was established as follows:

$$\begin{cases} \dfrac{dS}{di} = A - dS(i) - \beta S(i)I(i), \\[2mm] \dfrac{dE}{di} = \beta S(i)I(i) - \beta S(i-\tau)I(i-\tau) - dE(i), \\[2mm] \dfrac{dI}{di} = \beta S(i-\tau)I(i-\tau) - (d+\alpha+\gamma)I(i), \\[2mm] \dfrac{dR}{di} = \gamma I(i) - dR(i). \end{cases} \qquad (2)$$

where $S(i), E(i), I(i), R(i)$ are the numbers of susceptible persons, latent persons, infected persons, and rehabilitated persons at the epidemic point Q in period i, respectively. Parameter A is the constant input rate of the population at the epidemic point Q; d is the natural mortality rate of the population at the epidemic point Q; α is the mortality rate of the infected people at the epidemic point Q due to infectious diseases; γ is the cure rate of the infected people at the epidemic point Q; β is the epidemic transmission coefficient of epidemic point Q; and τ is a random variable whose incubation period obeys a certain distribution. Parameters satisfied $A, d, \beta, \gamma > 0, \alpha \geq 0$.

The demand for different kinds of medical supplies at epidemic point Q mainly depends on the number of patients in the incubation period and infected people. In the forecasting process, the lower limit number, the most probable number, and the upper limit number of the demand for medical supplies k in period i can be predicted, which is expressed as $(f_k(I(i), E(i)) - \Delta_1, f_k(I(i), E(i)), f_k(I(i), E(i)) + \Delta_2)$, where $f_k(I(i), E(i))$ is the function of the demand of medical supplies k and $I(i), E(i)$, representing the most probable number. Δ_2 and Δ_1 are, respectively, the deviation between the lower limit and the upper limit number of the demand for medical supplies k to the most probable number. Using the center of gravity method, the predicted value of the demand for medical supplies k can be determined as follows:

$$\hat{D}_{ik} = f_k(I(i), E(i)) + \dfrac{\Delta_2 - \Delta_1}{3}. \qquad (3)$$

It should be noted that this is an empirical formula, and one-third of the difference between Δ_2 and Δ_1 is taken as the adjustment of the predicted value. In the prediction process, if only the most probable number is predicted, then $\Delta_2 = \Delta_1 = 0$ is set in formula (3).

2.5. Road Impedance Function and Its Effect on Travel.
After the outbreak of the epidemic, for the sake of epidemic prevention and control, traffic control may be carried out on

some roads, thus affecting the traffic on the roads. Based on the BPR function of the Bureau of Public Road [30], this study analyzed the influence of traffic control on road traffic. Its expression is as follows:

$$t^{(1)} = t^{(0)}\left[1 + \eta\left(\dfrac{G}{C}\right)^{\theta}\right], \qquad (4)$$

where $t^{(1)}$ is the driving time of the section under traffic control, $t^{(0)}$ is the free driving time of the section, η and θ are parameters, C is the traffic capacity of the section, and G is the traffic flow under control. Generally, G/C is less than 1, and with the strengthening of traffic control, G/C becomes smaller; η and θ are the parameters, reflecting the influence of traffic control on travel time. Generally, $\eta \in [0.15, 0.5]$, and the larger the value is, the greater the influence of traffic control on travel time will be. In addition, $\theta \in [1.5, 5]$, and the smaller the value is, the greater the influence of traffic control on travel time will be. Furthermore, according to the proportional relationship between travel costs and travel time, with the development of the epidemic, the impact of traffic control on travel costs can be calculated.

Next, we consider that it will take a certain time for medical supplies to be put into use after they arrive at the epidemic point through transportation mode Y_q, from the rescue point G at the beginning of period i. To simplify the analysis, it is assumed that the medical supplies will be transported from 0:00 on the same day. If the medical supplies arrive at the epidemic point before 12 noon on the same day, it is deemed that they can be put into use on the same day. Otherwise, it is regarded as the next day can be put into use.

If medical supplies are transported in transportation mode Y_q at the beginning of period i, and $T(Y_q)$ is measured in hours, it can be expressed using the following formula:

$$j^* = i + \text{int}\left[\dfrac{T(Y_q) + 12}{24}\right], \qquad (5)$$

where j^* is the period serial number of medical supplies that can be put into use and $\text{int}[\cdot]$ is the integral function.

2.6. Optimization Model Construction.
The decision variable $x_i(f_{l_1}(Y_1))$ represents the number of times that medical supplies are transported through air transportation mode Y_1 at the beginning of period i by repeating the loading scheme $f_{l_1}(Y_1)$. $x_i(f_{l_2}(Y_2))$ and $x_i(f_{l_3}(Y_3))$ have a similar meaning as above. In the same way, $x_{j*}(f_{l_1}(Y_1))$ is the number of times that the medical supplies can be put into use by repeated loading scheme $f_{l_1}(Y_1)$ through air transportation mode Y_1 in period i. $x_i(f_{l_2}(Y_2))$ and $x_i(f_{l_3}(Y_3))$ have meanings similar to those just mentioned.

Based on the above analysis, the following optimization model is expressed as follows:

$$\min Z = \left[\sum_{i=1}^{R} \sum_{l_1=1}^{L_1} x_i\big(f_{l_1}(Y_1)\big) \cdot C_d(Y_1) + \sum_{i=1}^{R} \sum_{l_2=1}^{L_2} x_i\big(f_{l_2}(Y_2)\big) \cdot C_d(Y_2) + \sum_{i=1}^{R} \sum_{l_3=1}^{L_3} x_i\big(f_{l_3}(Y_3)\big) \cdot C_d(Y_3) \right]$$

$$+ \sum_{k=1}^{K} \sum_{j^*=1}^{R} v_{j^*}(k) \cdot C_s(k). \tag{6}$$

$$s.t \sum_{i=1}^{p} \left[x_i\big(f_{l_1}(Y_1)\big) \cdot l_1(k) + x_i\big(f_{l_2}(Y_2)\big) \cdot l_2(k) + x_i\big(f_{l_3}(Y_3)\big) \cdot l_3(k) \right]$$

$$\leq \sum_{i=1}^{p} S_{ik}, \quad i = 1, 2, \ldots, R, p = 1, 2, \ldots, R, k = 1, 2, \ldots, K, \tag{7}$$

$$\sum_{l_1=1}^{L_1} x_i\big(f_{l_1}(Y_1)\big) \leq M_{i1}, \quad i = 1, 2, \ldots, R, \tag{8}$$

$$\sum_{l_2=1}^{L_2} x_i\big(f_{l_2}(Y_2)\big) \leq M_{i2}, \quad i = 1, 2, \ldots, R, \tag{9}$$

$$\sum_{l_3=1}^{L_3} x_i\big(f_{l_3}(Y_3)\big) \leq M_{i3}, \quad i = 1, 2, \ldots, R, \tag{10}$$

$$v_{j^*}(k) + x_{j^*}\big(f_{l_1}(Y_1)\big) \cdot l_1(k) + x_{j^*}\big(f_{l_2}(Y_2)\big) \cdot l_2(k) + x_{j^*}\big(f_{l_3}(Y_3)\big) \cdot l_3(k) \geq D_{j^*k}, \quad j^* = 1, 2, \ldots, R, k = 1, 2, \ldots, K, \tag{11}$$

$$v_{j^*+1}(k) = \left[v_{j^*}(k) + x_{j^*}\big(f_{l_1}(Y_1)\big) \cdot l_1(k) + x_{j^*}\big(f_{l_2}(Y_2)\big) \cdot l_2(k) + x_{j^*}\big(f_{l_3}(Y_3)\big) \cdot l_3(k) \right] - D_{j^*k}, \quad j^* = 1, 2, \ldots, R, k = 1, 2, \ldots, K, \tag{12}$$

$$x_i\big(f_{l_1}(Y_1)\big), x_i\big(f_{l_2}(Y_2)\big), x_i\big(f_{l_3}(Y_3)\big) \geq 0, \text{ and they are all integers}, \quad i = 1, 2, \ldots, R. \tag{13}$$

This model is an integer programming model. In this model, formula (6) is the objective function to minimize the total costs. The objective function consists of two parts: the first part is the total transportation cost and the second part is the total inventory cost. Formulas (7)–(13) are constraints, and formula (7) indicates the limit on the amount of each medical supplies that can be provided at the rescue point G. In this study, the constraint for each medical material is that the total amount of transportation to a certain period does not exceed the total amount of supply. Formulas (8)–(10) are the constraints on the transport capacity of Y_1, Y_2, and Y_3, respectively. Formula (11) is expressed as the demand constraint of epidemic point Q on various medical materials in each period. Formula (12) is the recurrence relationship of inventory. Formula (13) is a nonnegative constraint and integer variable constraint, and the number of times of each loading scheme is guaranteed to be nonnegative and integer. Moreover, the model can be solved by LINGO software.

3. Results

The initial period of the COVID-19 epidemic in Wuhan was mainly from December 10, 2019, to February 6, 2020, lasting for 58 days. During this period, the COVID-19 epidemic mainly occurred in the Wuhan area, so Wuhan was set as the epidemic point.

According to the demand for medical supplies in Wuhan, this study divided the initial period of the COVID-19 epidemic in Wuhan into three periods. The first period is from December 10, 2019, to January 17, 2020. Due to the relatively limited number of infected people, the self-provided medical materials in Wuhan can basically meet the demand, and there is no need for other rescue points to provide medical material assistance. The second period is from January 18, 2020, to January 23, 2020; although the number of infected people in Wuhan has increased, the demand for medical materials is still relatively limited. Medical materials can be provided to Wuhan through Shandong Province in China. The third period is from January 24, 2020, to February 1, 2020; with the development of the epidemic, the medical materials needed in Wuhan showed a rapid growth trend, and many regions in China needed to provide medical materials assistance to Wuhan one after another. It should be noted that this study mainly aims at the second period, namely, January 18, 2020, solstice, 23, to build the optimization model and solve it.

First, we set the epidemic point as Wuhan city and the rescue point as Shandong Province. There are four kinds of medical materials: disinfectant, protective suit, surgical masks, and medical apparatus and instruments. Second, the period is divided into days, including 6 cycles from January 18 to 23, 2020. Thirdly, aircraft, train, and truck are selected as three

modes of transportation, in which there can only be 2 flights to the epidemic point per cycle; that is, $M_{i1} = 2$; only 5 train carriages can be provided per cycle, that is, $M_{i2} = 5$; and 20 trucks can be provided per cycle, which is equal to $M_{i3} = 20$.

Next, through screening, three loading schemes for aircraft (per flight), four loading schemes for train (per carriage), and five loading schemes for the truck (per vehicle) are provided here. Table 2 is used to describe each loading scheme and the number of medical materials carried.

Referring to the relevant reports of authoritative departments on epidemic trend analysis from January 10 to 23, 2020, and the prediction results of Cai Yong's team from the School of Public Health of Shanghai Jiao Tong University and Zhang Xinmin's team from Ruijin Hospital Affiliated to Medical College of Shanghai Jiao Tong University using formula (2), the prediction results of the number of infected persons and patients in incubation period in each cycle are obtained, as shown in Table 3.

The supply of various medical supplies in each cycle provided by the rescue point is shown in Table 4. In formula (3), take $\Delta_2 = \Delta_1 = 0$; the demand for various medical supplies in each cycle can be predicted.

$$f_k(I(i), E(i)) = \varepsilon_k(\Omega \cdot I(i) + E(i)). \tag{14}$$

Let $\Omega = 2, \varepsilon_1 = 0.03$; the demand for disinfectant in each cycle is predicted. Similarly, let $\varepsilon_2 = 0.04, \varepsilon_3 = 0.07, \varepsilon_4 = 0.015$; the demand for the remaining three medical supplies was predicted, as shown in Table 4.

The travel time for one-way transport of medical supplies by plane is 9 hours (including the time of transfer and delivery at the rescue point and the epidemic point, the same below), and it takes 14 hours for the train to complete the one-way transportation of medical materials. Because of the implementation of traffic control, the travel time of truck one-way transportation of medical supplies varies dynamically with the development of the epidemic. Let $\eta = 0.2, \theta = 2$, and the unit of measurement is an hour. Formula (4) is used to calculate the travel time required by the truck to transport medical supplies one way from the transportation time point. Then, for the three modes of transportation, the cycle serial number of medical materials transported in each initial transportation period can be put into use can be calculated according to formula (5), as shown in Table 5. It was observed from Table 5 that medical supplies transported by plane can be put into use during the same period of transportation. Medical supplies transported by train can only be put into use in the next cycle. Moreover, medical supplies transported by truck can be put into use in the next cycle before the fourth cycle, and from the fifth cycle, with an interval of two cycles before they can be put into use.

The cost of a trip for the transport of medical supplies by plane and train is 180,000 yuan and 20,000 yuan (RMB, the same below), respectively, while the travel cost of the truck to complete the transportation of medical supplies is dynamic with the development of the epidemic, and its change is directly proportional to the travel time. The comprehensive costs are calculated as 150 yuan per hour. There is no inventory cost for disinfectant, protective suit, and surgical masks, and the inventory cost of medical apparatus and instruments is 80 yuan per day per box.

According to formulas (6)–(13), the model is constructed and solved by LINGO software (see Appendix). The optimal scheme of three modes of transportation at the rescue point in each cycle is obtained, as shown in Table 6.

The above stowage scheme shows that, for the mode of aircraft transport, due to the high transport cost and capacity limits, only two flights are arranged in the first cycle. For the train transportation mode, except for the third cycle, medical supplies from the first to the fifth cycle are basically in the state of full load transportation. As for the truck transportation mode, since medical supplies can only be put into use after two cycles starting from the fifth cycle, so medical supplies are only arranged to be transported from the first to the fourth cycle within the set six cycles, and these four cycles are basically in a state of full load transportation. The total cost of the optimal stowage scheme is RMB 1.0882 million.

The optimization model constructed in this study is an integer programming model, and its solution algorithm is branch and bound method. In the branching process, this algorithm can ensure that all integer solutions are retained and continually optimize by gradually reducing the upper bound and increasing the lower bound, ensuring the global optimal stowage scheme.

4. Discussion

4.1. Changes in Inventory. According to the stowing scheme shown in Table 6, the inventory of disinfectant in each cycle was calculated and compared with the newly available amount and demand in each cycle, as shown in Figure 2(a). Similarly, the comparative analysis diagrams of protective suits, surgical masks, and medical apparatus and instruments were drawn, as shown in Figures 2(b)–2(d).

As can be seen from Figures 2(a)–2(c), since there is no inventory cost for the three medical supplies of disinfectant, protective suit, and surgical masks, there is a considerable difference in the cargo transportation volume in the early and late stages. That is, the number of new medical supplies available in the former three cycles is significantly higher than that in the later three cycles. It also results in a large inventory in the second, third, fourth, and fifth cycles, which is necessary for sufficient medical supplies during the initial period of the epidemic. However, due to the inventory of medical apparatus and instruments, certain inventory costs are incurred. The newly available amount of medical apparatus and instruments in each cycle of the optimized stowage plan is basically in a synchronous state of change relative to the demand, resulting in a relatively low inventory.

4.2. Changes of Stowage Plan with the Intensity of Traffic Control. According to the previous setting, the travel time of airplanes and trains is relatively fixed, and the transportation cost

TABLE 2: The feasible loading schemes for the three modes of transportation and the number of medical supplies carried.

Type of medical supplies	Airplane			Train				Truck				
	$f_1(Y_1)$	$f_2(Y_1)$	$f_3(Y_1)$	$f_1(Y_2)$	$f_2(Y_2)$	$f_3(Y_2)$	$f_4(Y_2)$	$f_1(Y_3)$	$f_2(Y_3)$	$f_3(Y_3)$	$f_4(Y_3)$	$f_5(Y_3)$
Disinfectant	0	9	36	0	3	6	15	0	1	1	2	4
Protective suit	27	54	18	3	12	0	6	0	0	8	6	0
Surgical mask	36	9	36	12	3	0	15	8	4	1	2	4
Medical apparatus and instrument	18	18	9	9	9	15	0	1	3	1	1	2

TABLE 3: The predicted value of the number of infected people in each cycle and patients in the incubation period.

	The number of infected people $I(i)$						The number of patients in the incubation period $E(i)$					
Period	1	2	3	4	5	6	1	2	3	4	5	6
Predicted value (persons)	94	170	245	303	389	441	500	600	800	1200	1600	2000

Note: to use the model to determine the optimal plan of medical supplies stowing at the beginning point of the second period, the number of infected people and patients in the incubation period should be predicted.

TABLE 4: Supplies of various medical supplies at rescue points and demands at epidemic points in each cycle.

Type of medical supplies	Supplies of rescue point in each period						Demands of epidemic points in each period					
	1	2	3	4	5	6	1	2	3	4	5	6
Disinfectant	160	160	160	160	160	160	21	29	39	55	70	87
Protective suit	130	130	130	130	130	130	28	38	52	60	73	116
Surgical mask	200	200	200	200	200	200	49	66	91	131	163	202
Medical apparatus and instrument	60	60	60	60	60	60	14	19	26	37	47	58

TABLE 5: One-way transportation travel time corresponding to each initial transportation cycle of the three transportation modes and the cycle serial number when medical materials can be put into use.

Modes of transportation	Initial transport cycle 1		Initial transport cycle 2		Initial transport cycle 3		Initial transport cycle 4		Initial transport cycle 5		Initial transport cycle 6	
	Travel time (hours)	Cycle number when put into service	Travel time (hours)	Cycle number when put into service	Travel time (hours)	Cycle number when put into service	Travel time (hours)	Cycle number when put into service	Travel time (hours)	Cycle number when put into service	Travel time (hours)	Cycle number when put into service
Airplane	9	1	9	2	9	3	9	4	9	5	9	6
Train	14	2	14	3	14	4	14	5	14	6	14	7
Truck	24	2	26	3	29	4	32	5	36	7	40	8

is relatively fixed as well. However, because of the implementation of traffic control, the travel time of truck transportation is dynamically changing, likewise the transportation cost. If the demand for medical supplies remains the same and the traffic control is further strengthened, the truck transportation time will be changed, which causes the transportation cost to increase by 10%. This article obtained a new transportation and stowage plan through recalculation. In view of the space limitation, only the newly available amount was provided, and the inventory changes of the four kinds of medical supplies in each cycle were drawn, as shown in Figures 3(a)–3(d).

The results show that trains will become the main mode of transportation on account of the increase in truck transportation costs. It should be noted that the transportation cost of the train is fixed. As the trains are in full load in the third cycle, the newly available medical supplies in the fourth and fifth cycles increase significantly. At the same time, as the impact of inventory costs on the objective function compared with the transportation costs has gradually weakened, there was a marked increase in the inventory of medical devices in the second, third, and fourth cycles.

4.3. The Stowage Plan Changes with the Demand. We further analyzed the impact of the medical supplies demand changes in each cycle on the stowage plan. After trial calculations, it is found that once the demand increases by more than 3%, the solution of the optimization model will become an infeasible solution. Therefore, this study assumed that the demand was increased by 3% and carried on the analysis, and the newly available number and inventory of different medical supplies in each cycle are shown in Figures 4(a)–4(d).
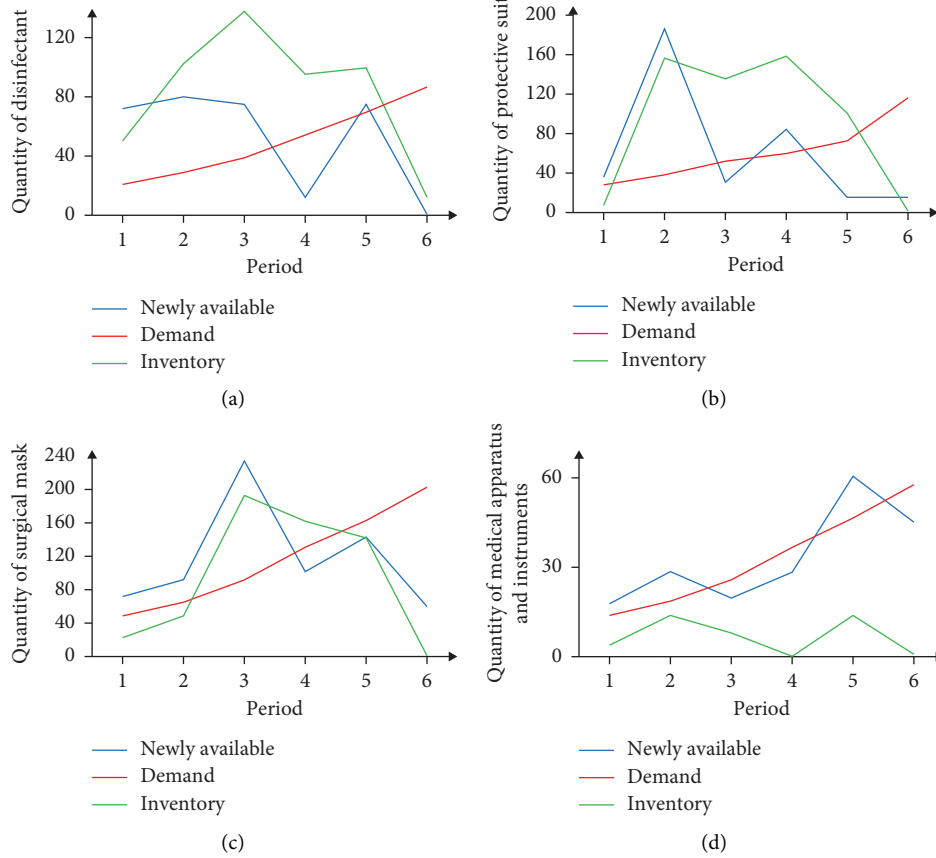
(a)

(b)

(c)

(d)

FIGURE 2: (a) Changes in the inventory of disinfectants in each cycle. (b) Changes in the inventory of protective suits in each cycle. (c) Changes in the inventory of surgical masks in each cycle. (d) Changes in the inventory of medical apparatus and instruments in each cycle.

TABLE 6: Stowage scheme of three transport modes at the rescue point in each cycle.

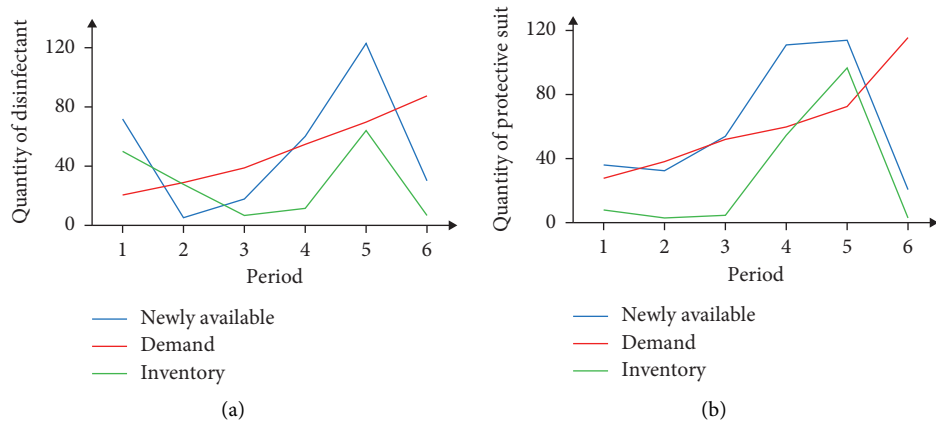| Modes of transportation | Stowage scheme adopted in each initial transportation cycle | | | | | |
	1	2	3	4	5	6
Airplane	$x_1(f_3(Y_1)) = 2$					
Train	$x_1(f_1(Y_2)) = 1$ $x_1(f_4(Y_2)) = 4$	$x_2(f_4(Y_2)) = 5$	$x_3(f_2(Y_2)) = 1$	$x_4(f_1(Y_2)) = 3$ $x_4(f_4(Y_2)) = 1$	$x_5(f_1(Y_2)) = 5$	
Truck	$x_1(f_3(Y_3)) = 20$	$x_2(f_1(Y_3)) = 20$	$x_3(f_1(Y_3)) = 11$ $x_3(f_3(Y_3)) = 9$	$x_4(f_1(Y_3)) = 4$ $x_4(f_5(Y_3)) = 15$		

(a)
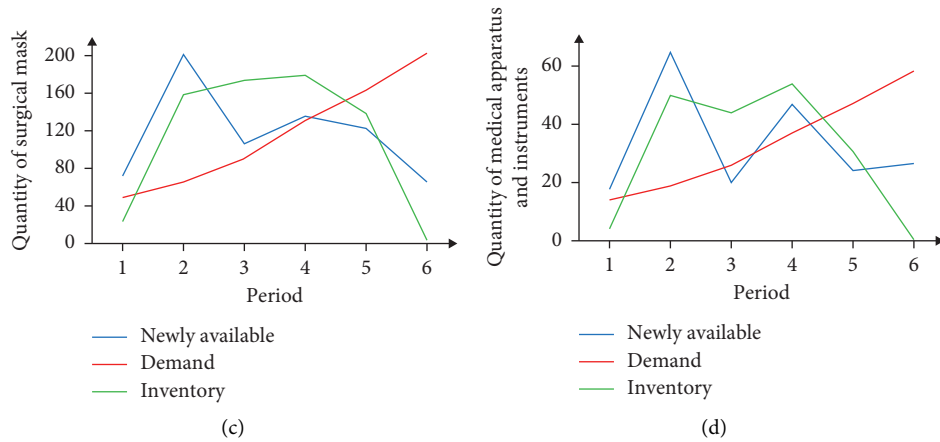

(b)

FIGURE 3: Continued.

FIGURE 3: (a) Changes in the inventory of disinfectants in each cycle. (b) Changes in the inventory of protective suits in each cycle. (c) Changes in the inventory of surgical masks in each cycle. (d) Changes in the inventory of medical apparatus and instruments in each cycle.
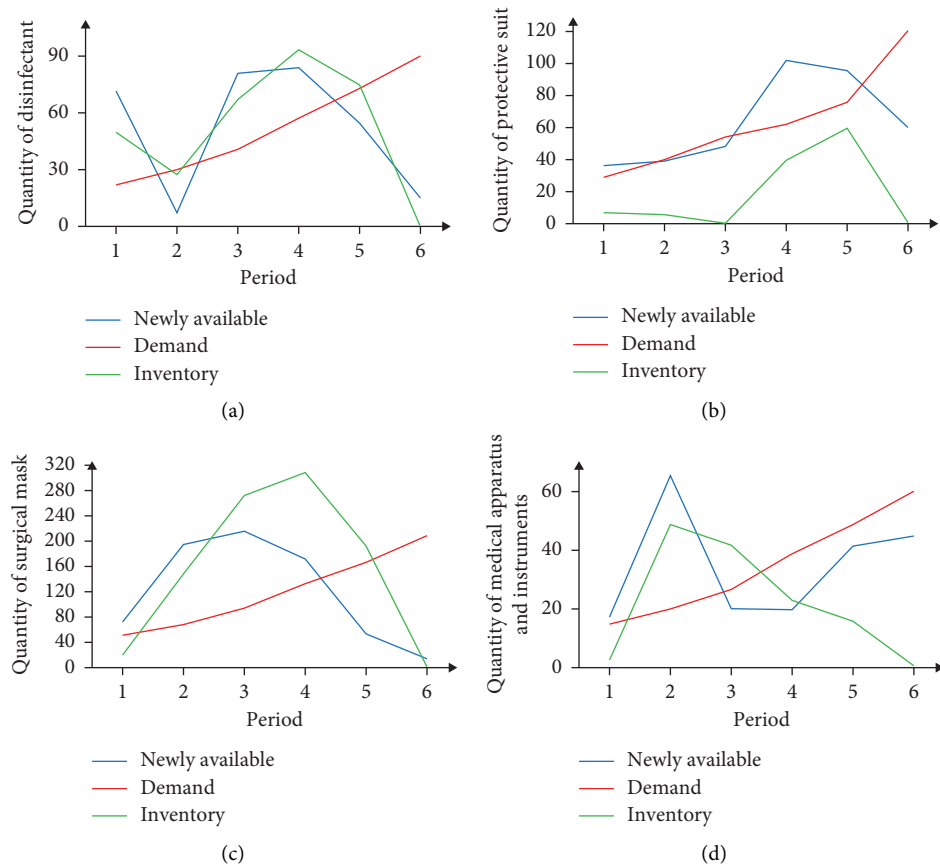

FIGURE 4: (a) Changes in the inventory of disinfectants in each cycle. (b) Changes in the inventory of protective suits in each cycle. (c) Changes in the inventory of surgical masks in each cycle. (d) Changes in the inventory of medical apparatus and instruments in each cycle.

The results showed that the increase of demand also drove trains and trucks to become the main mode of transportation and made the new available number of medical supplies fluctuate to a certain extent in each cycle, but the inventory in the sixth cycle tended to decrease.

4.4. Cost Sensitivity Analysis. Based on the above measurement results, the objective function value of the model is analyzed, i.e., the sensitivity of the total cost with the model parameters changes, as shown in Table 7.

It was observed from Table 7 that every percentage point increase in truck travel cost will lead to an increase of 3,282

TABLE 7: The sensitivity of cost to model parameters.

Parameters and their changes		Total transportation cost (RMB 10,000)
Parameters remain unchanged	Cost value (RMB 10,000)	108.8200
Truck travel costs increased by 10%	Cost value (RMB 10,000)	112.1020
	Sensitivity condition	The total transportation cost will increase by 3,282 RMB for every 1% increase of truck travel cost
Demand for medical supplies increased by 3%	Cost value (RMB 10,000)	111.3000
	Sensitivity condition	The total transportation cost will increase 4,800 RMB when the demand for medical materials increases by 1 percentage point

TABLE 8: The innovative contribution of this paper.

Focus of the study	Gaps in previous literature	Innovative contribution of this study
Stage of the epidemic	The assumptions of the model were not consistent with the demand for medical supplies in the early stage of the epidemic, and the dynamic characteristics of the demand for medical materials at the initial stage of the epidemic were not fully considered	In this study, the optimal model of medical supplies stowage is constructed by integer programming, aiming at the characteristics of a relatively concentrated epidemic area, relative lack of medical supplies at the epidemic point, and obvious rising trend of demand for all kinds of medical supplies
Traffic control	They failed to fully consider the impact of traffic control in the early stage of the epidemic on the time when emergency supplies can be put into use	Based on the BPR function, the impact of traffic control on road traffic was analyzed, and then the impact of traffic control on travel costs with the development of the epidemic was calculated. According to the road impedance function, the specific cycle in which medical supplies can be put into use is analyzed
Stowage optimization object	The existing literature mainly studies the optimal allocation scheme of medical supplies that have been delivered to epidemic sites among different users	The demand for different kinds of medical supplies at the epidemic point was predicted, and the optimal loading model of emergency medical supplies for the rescue point was established

RMB in total cost. In the meantime, every 1% increase in the demand for medical supplies leads to an increase of RMB 4,800 in the total transportation cost, indicating that, from the perspective of the total transportation cost, the change of truck travel cost is more sensitive than the change of the demand for medical supplies.

5. Conclusions

In a pandemic, transport accessibility has proved to be the main vehicle of contagion, allowing the virus to spread among the citizens concerned [31]. During the initial period of the epidemic, road transportation may therefore be under traffic control, and as the epidemic develops, traffic control will become more stringent. Combined with the characteristics of COVID-19 and the above traffic situation at the initial stage of the epidemic, this article studied the optimization of the stowage of emergency medical supplies.

In this article, the constructed optimization model is an integer programming model. The objective function of the model is the least total cost, including total transportation cost and total inventory cost. The constraints include the supply limit of each of the medical supplies that the rescue point can provide, the transportation capacity limit of the transportation mode, and the demand and inventory constraints in each cycle of the epidemic point, nonnegative constraints, and integer variable constraints. The model can

be solved using LINGO software. Combining the development of the epidemic situation in Wuhan from January 18 to 23, 2020, through constructing a model for example analysis, the optimal combination of different periods, different transportation methods, and different stowage plans was obtained during the period, which further verified the feasibility and practicality of the model.

The comparison between this study and previous literature work and its innovative contributions are shown in Table 8.

The limitations of this study are mainly reflected in two aspects. First, in the process of constructing the model, this study puts forward a number of assumptions based on the characteristics of the COVID-19 epidemic. If the reality is that some of the conditions cannot be met, then the model should be appropriately adjusted and optimized according to the real conditions. Nonetheless, the idea of constructing the model is basically similar. Second, in the application process of the model, it is necessary to predict the demand for medical supplies and analyze the influence of road impedance function on the travel time and transportation cost. The accuracy of the prediction and analysis of the above two points may affect the rationality of the stowage optimization scheme.

The model constructed in this study can be used as a reference for relevant departments to propose optimal decision-making schemes for emergency medical supplies at the initial stage of the epidemic. At the same time, this study mainly constructs the optimization model for the initial

period of the epidemic. Once the epidemic enters the growth or outbreak period, there may be multiple epidemic points and multiple rescue points. Some of the basic assumptions of the model constructed in this article will no longer be satisfied. For example, in the context of multiple epidemic points, the demand for medical supplies is relatively large and there may be a shortage of medical supplies. At the same time, due to the existence of multiple epidemic points, the transportation cost and inventory cost in the objective function should be adjusted accordingly, and the demand constraints and inventory constraints of multiple epidemic points should be added to the constraint conditions. The model is modified according to the above boundary conditions, which is also the direction of further research in the future.

Appendix

The running code of LINGO software

```
model:
sets:
plane1/1..3/:x1; plane2/1..6/:x2,a,b; plane3(plane2,-
plane1):plane; train1/1..4/:x3,c,d,e,f,g,h; train2/1..5/:x4;
train3(train2,train1):train; car1(train1,train2):car; u/
1..7/:x5; v/1..12/:x6; coo(plane1,train1):m; fac(train1,-
train1):n; pla(train2,train1):k;
endsets
data:
c = 21,28,49,14;    d = 29,38,66,19;    e = 39,52,91,26;
f = 55,60,131,37;  g = 70,73,163,47;  h = 87,116,202,58;
m = 0,27,36,18,   9,54,9,18,   36,18,36,9;   n = 0,3,12,9,
3,12,3,9, 6,0,0,15, 15,6,15,0; k = 0,0,8,1, 1,0,4,3, 1,8,1,1,
2,6,2,1, 4,0,4,2; enddata
min = 18 * @sum(plane3(i, j):plane(i, j)) + 2 * @sum(-
train3(i, j):train(i, j)) + 0.36 * @sum(car1(i, j)|i#eq#1:
car(i,    j)) + 0.39 * @sum(car1(i,    j)|i#eq#2:car(i,
j)) + 0.435 * @sum(car1(i, j)|i#eq#3:car(i, j)) + 0.48 * @
sum(car1(i, j)|i#eq#4:car(i, j));
@for(plane2(i):@sum(plane1(j):plane(i, j)) <= 2);
@for(train2(i):@sum(train1(j):train(i, j)) <= 5);
@for(train1(i):@sum(train2(j):car(i, j)) <= 20);
@for(train1(j):@sum(plane1(i):m(i,   j) * plane(1,   i))
>= c(j));
@for(train1(j):   (@sum(plane1(i):m(i,    j) * plane(2,
i)) + @sum(train1(i):n(i,    j) * train(1,    i)) + @sum(-
train2(i):k(i, j) * car(1, i)))
+@sum(plane1(i):m(i, j) * plane(1, i)) >= d(j) + c(j));
@for(train1(j):(@sum(plane1(i):m(i,         j) * plane(3,
i)) + @sum(train1(i):n(i,   j) * train(2,   i))+@sum(-
train2(i):k(i, j) * car(2, i)))
+(@sum(plane1(i):m(i,   j) * plane(2,   i)) + @sum(-
train1(i):n(i, j) * train(1, i))+@sum(train2(i):k(i, j) *
car(1, i)))
+(@sum(plane1(i):m(i,         j) * plane(1,        i)))
> =e(j) + d(j) + c(j));
```

```
@for(train1(j):   (@sum(plane1(i):m(i,    j) * plane(4,
i)) + @sum(train1(i):n(i,    j) * train(3,    i)) + @sum(-
train2(i):k(i, j) * car(3, i)))
+(@sum(plane1(i):m(i,    j) * plane(3,    i)) + @sum(-
train1(i):n(i, j) * train(2, i)) + @sum(train2(i):k(i, j) *
car(2,i)))
+(@sum(plane1(i):m(i,    j) * plane(2,    i)) + @sum(-
train1(i):n(i, j) * train(1, i)) + @sum(train2(i):k(i, j) *
car(1, i)))
+(@sum(plane1(i):m(i,         j) * plane(1,         i)))
>= f(j) + e(j) + d(j) + c(j));
@for(train1(j):(@sum(plane1(i):m(i,         j) * plane(5,
i)) + @sum(train1(i):n(i,    j) * train(4,    i)) + @sum(-
train2(i):k(i, j) * car(4, i)))
+(@sum(plane1(i):m(i,    j) * plane(4,    i)) + @sum(-
train1(i):n(i, j) * train(3, i)) + @sum(train2(i):k(i, j) *
car(3, i)))
+(@sum(plane1(i):m(i,    j) * plane(3,    i)) + @sum(-
train1(i):n(i, j) * train(2, i)) + @sum(train2(i):k(i, j) *
car(2, i)))
+(@sum(plane1(i):m(i,    j) * plane(2,    i)) + @sum(-
train1(i):n(i, j) * train(1, i)) + @sum(train2(i):k(i, j) *
car(1, i)))
+(@sum(plane1(i):m(i,         j) * plane(1,         i)))
>= h(j) + g(j) + f(j) + e(j) + d(j) + c(j));
@for(train1(j):(@sum(plane1(i):m(i,         j) * plane(6,
i)) + @sum(train1(i):n(i, j) * train(5, i)))
+(@sum(plane1(i):m(i,    j) * plane(5,    i)) + @sum(-
train1(i):n(i, j) * train(4, i)) + @sum(train2(i):k(i, j) *
car(4, i)))
+(@sum(plane1(i):m(i,    j) * plane(4,    i)) + @sum(-
train1(i):n(i, j) * train(3, i)) + @sum(train2(i):k(i, j) *
car(3, i)))
+(@sum(plane1(i):m(i,    j) * plane(3,    i)) + @sum(-
train1(i):n(i, j) * train(2, i)) + @sum(train2(i):k(i, j) *
car(2, i)))
+(@sum(plane1(i):m(i,    j) * plane(2,    i)) + @sum(-
train1(i):n(i, j) * train(1, i))+@sum(train2(i):k(i, j) *
car(1, i)))
+(@sum(plane1(i):m(i,         j) * plane(1,         i)))
>= h(j) + g(j) + f(j) + e(j) + d(j) + c(j));
@for(plane3(i, j):@gin(plane)); @for(train3(i, j):@
gin(train)); @for(car1(i, j):@gin(car));
end
```

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest or personal relationships that could have appeared to influence the work reported in this study.

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