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Research Paper

Calculation of the urgency of emergency medical supplies needs under public health events

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ABSTRACT: *In this paper, SEIRD model is used to predict the infection of public health events, so as to predict the demand for emergency medical materials, calculate the demand for prevention and control ability of public health events at a certain demand point, and then determine the urgency of public health events at a certain time. It is of great significance to quantify the demand urgency of a certain demand point, and the calculation of the demand urgency is helpful to the transportation and storage of emergency medical materials and the prevention and control of public health events at the demand point.*
KEYWORDS: *Public health events; emergency medical supplies; SEIRD model; Demand Urgency Calculation*

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I. INTRODUCTION

Since the beginning of this century, major events have occurred frequently in the field of public health. For example, the outbreak of SARS in 2003 and Severe Acute Respiratory Syndrome (SARS); The outbreak of influenza a (H1N1) virus in April 2009 has caused great losses to people all over the world. Since December 2019, the COVID-19 epidemic has appeared and started to break out on a global scale, seriously affecting the lives, health and lives of people all over the world; In 2023, influenza A virus broke out again recently [1]. These public health events have not only seriously affected the health of people all over the world, but also caused negative economic impacts on all walks of life [2]. The level of emergency management of public health emergencies is related to the happiness and safety of the people. For example, the ongoing Covid-19 epidemic is one of the most serious and difficult public health events to prevent and control. It has the characteristics of suddenness, urgency, uncertainty, multidisciplinary and sociality [3][4][5]. The World Health Organization named it COVID-19 (COVID-19) [6]. In January 2020, the World Health Organization (WHO) declared the Covid-19 outbreak a public health emergency of international concern, and it has been three years since then. On May 5, 2023, the World Health Organization announced that the Covid-19 epidemic no longer constitutes a "public health emergency of international concern" [7], which marked an important victory for human society to join hands in fighting the virus. However, the Covid-19 virus still spreads all over the world, and even those who have recovered from illness are still at risk of getting sick again.

Emergency material support is the basic work of emergency management, and the timeliness and effectiveness of support have a direct impact on the emergency support effect of public health emergencies. The ability to respond, deal with and prevent public health events in a region is also the top priority. The demand for emergency materials and the ability to prevent and control public health events in a region cross-reflect the urgency of the needs in the region.

II. THE PREDICTION MODEL

2.1PREDICTION OF INFECTION

SEIR (Susceptible, Exposed, Infectious, Recovered) model is the most basic system dynamics model of infectious diseases [8], which studies the dynamic mechanism of infectious diseases in the process of transmission and provides theoretical basis for the prevention and treatment of infectious diseases. SEIR epidemic model can effectively simulate public health events. Basic public health event models of infectious diseases include SI, SIR, SIRS and SEIR, etc. In order to solve the models, ordinary differential equations, partial differential equations and network dynamics are studied.

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S stands for Susceptible, which refers to people who have not yet got sick but are easily infected by viruses and become the Infiltrator, that is, people who have not been infected with viruses;

E stands for the Infiltrator, which refers to a person who has been in contact with an infected person but is temporarily unable to infect others. He carries a virus and has a certain incubation period and will become a susceptible person;

I stands for Infectious, which refers to people who have been infected with viruses and can transmit viruses to susceptible people and turn them into Class E or Class I members;

R stands for Recovered, who is isolated from the system or has recovered and will not be infected again.

Based on SEIR model and considering the new characteristics of modern public health events, this paper assumes that the new identity D stands for Dead, which refers to the person who has died in the event and can no longer become other types of identity.

And make the following assumptions:

1、Contact between susceptible persons and the Infiltrator has no possibility of infection, that is, the Infiltrator will not infect susceptible persons.

2、Susceptible people have the possibility of infection after contact with susceptible people.

3、The recovered patients have lifelong immunity and will not be infected again as long as they are cured.

4、The death population is not infectious.

5、The total population remains unchanged during public health events.

6、Only the communication between people is considered, and the environmental communication is not considered.

7、At the beginning of public health events, the number of recovered persons and the number of dead persons were 0.

The specific relationship is shown in figure 1:

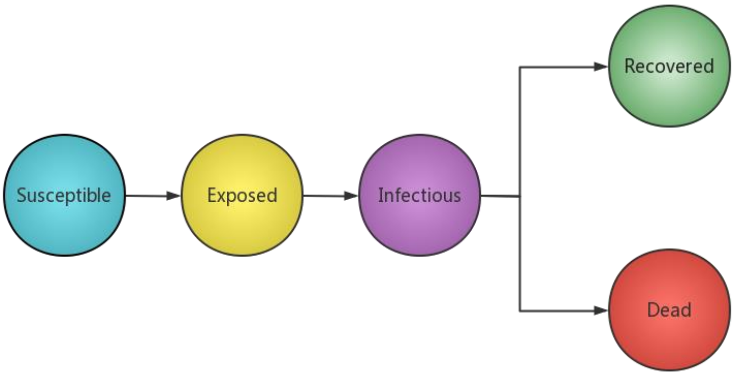

Figure 1: SEIRD model

According to the relationship between SEIRD model and its variables, the following differential equations are constructed:

$$\left.\begin{aligned} \frac{dS}{dt} &= -\frac{\beta * I(t) * S(t)}{N} \\ \frac{dE}{dt} &= -\zeta * E(t) + \frac{\beta * I(t) * S(t)}{N} \\ \frac{dI}{dt} &= \zeta * E(t) - \gamma * I(t-\tau_r) - \mu * I(t-\tau_d) \\ \frac{dR}{dt} &= \gamma * I(t-\tau_r) \\ \frac{dD}{dt} &= \mu * I(t-\tau_d) \end{aligned}\right\} \rightarrow (1)$$

Among them:

S refers to susceptible persons, E refers to the lurker, I refers to infected persons, R refers to recovered persons, D refers to dead persons, and N refers to the total number;

t represents the current time;

β indicates the probability that susceptible people will be converted into the lurker after contacting infected people per unit time;

$1/\zeta$ indicates the average latent period, and people with $\zeta * E(T)$ per unit time change from the lurker to infected people;

γ Indicates the cure rate, and $\gamma * I(t-\tau_r)$ people change from infected people to recovered people in unit time t;

μ Indicates the mortality rate, and $\mu * I(t-\tau_d)$ people change from infected people to dead people in unit time t;

Time delay τ_r and τ_d are used for rehabilitation (cure) and death respectively. Usually, because the epidemic time is very short, it is assumed that the net impact of birth and natural death is zero. Without considering various factors such as birth, natural death, immigration and emigration, it is assumed that the total number of people N remains unchanged, and the number of people of various types at T time is recorded as S (T), E (T), I (T), R (T) and D (T) respectively, then N = S (T) + E (T) + I (T) + R (T) + D (T).

In this paper, the unit time is set as day (D). In order to solve the differential equations, it is necessary to estimate the parameters of the equations. In the process of solving the SEIRD model, the statistical data of cases in a certain period of time in various regions are mainly used, including the existing diagnosis data, the lurker data, the cure data and the death data. Through the transformation of the model formula, five kinds of population data, such as SEIRD, are obtained, thus establishing the SEIRD nonlinear differential equations. Calculate according to the scientific parameter values given by relevant data and adjust according to the actual situation, and determine the parameter values as shown in Table 1:

Table 1: SEIRD Model Parameter Settings

parameter	value	Description
β	0.06026785	Infection rate
$1/\zeta$	6.4	Latent time
γ	0.0011236	Healing rate
μ	0.00000041855658	Death rate

Since not all people are susceptible people, according to the relevant public information, Wu Zunyou, chief epidemiologist of the Chinese Center for Disease Control and Prevention, pointed out that the proportion of COVID-19 infection was 10% to 30% at the annual financial meeting on December 17, 2022. Therefore, the susceptible population is set at 20% of China's total population, which is about 280 million people.

The differential equation is fitted by MATLAB. The simulation diagram is shown in Figure 2.

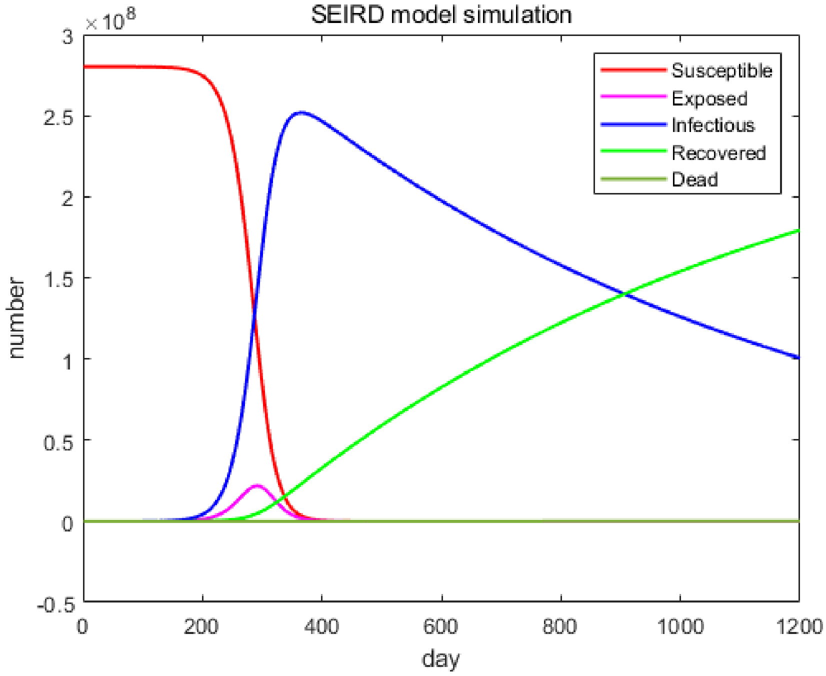

Figure 2: SEIRD model simulation

According to the fitting results in Figure 2, it can be seen that the number of susceptible persons fitted by SEIRD model will gradually decrease, while the number of the Infiltrator will first decrease and then increase, and the number of patients will produce a peak, while the number of recovered persons and dead persons will always increase. Due to China's excellent medical care and policies, the vast majority of people will become patients first, then recover by patients, and a small number of people will die. The fitting effect is very consistent with the development of the epidemic situation. According to the report of China CDC, as of December 2022, 82.4% of the people have suffered from COVID-19, and more than 82% of the population has been infected within two months. Most people will experience a 4-7-day illness cycle, and the virus toxicity will weaken, and most people will recover slowly.

Due to China's precise prevention and control and adherence to the policy of dynamic clearing, the number of infected people and latent people have been controlled, and the first aid measures are very timely, which greatly reduces the number of people who died due to the epidemic in China. At the same time, the epidemic condition is concealed, and some people are sick and do not report it. Therefore, the fitted data has a small deviation from the actual data, but it is in line with the actual development of the epidemic, so the fitting effect is good.

2.2DEMAND FORECAST OF EMERGENCY MEDICAL MATERIALS

In order to predict the demand for emergency medical materials, it is necessary to predict the number of people based on Section 2.1, combined with the urgent needs of various groups of people for consumable medical materials at the initial stage of the epidemic. Due to the lack of uniform and effective personnel classification methods and standards, there are many problems in large-scale population evacuation. Considering the complexity of the volume of emergency materials needed by different people in a single day in SEIRD model, we set the model by directly defining the emergency medical materials group θ. In view of the ambiguity of the actual observation of susceptible population (S) and latent population (E), we classify these two groups as susceptible population (S), and draw the conclusion that S= (N-I-R-D). Therefore, the hypothesis is set as shown in Table 2 below.

Table 2: Assumption Table of Emergency Medical Material Demand

Crowd Category	Number of people	Demand	Total demand
Susceptible (S)	N-I-R-D	2θ	2θ(N-I-R-D)
Infected person (I)	I	3θ	3θI
Recovered (R)	R	θ	θR
Dead person (D)	D	0	0

According to the epidemic experience, the daily demand of each infected person is 3 θ I; The daily demand of each susceptible person is 2θ(N-I-R-D); The demand of each healer in a single day is θ R. At the same time, the daily consumption index and the proportion of daily demand for different infection types were formulated. Through calculation, the daily consumption of various items is obtained: in a single day, the demand for medical surgical masks weighing about 18 grams by the cured population is 2; The number of disposable gloves with a weight of about 4 grams is three sets; 75 grams of goggles are required every day; The demand for disinfection products weighing about 27 grams is 30ml (containing alcohol and antibacterial hand gel). Disposable gloves and goggles are mainly used to isolate patients and infected persons during the epidemic, while alcohol and disinfectant are used to treat or care for patients, which are the most commonly used drugs in hospitals. The total weight is 150g, and the daily emergency medical supplies required by a single person in kilograms are 0.15, that is, the set θ = 0.15, so the daily total demand of susceptible people is 0.3 (N-I-R-D), the daily total demand of infected people is 0.45 i, and the daily total demand of cured people is 0.15 r.

III. DEMAND URGENCY CALCULATION

National and local governments have invested a lot of manpower and material resources in emergency rescue of public health incidents [9]. Emergency medical materials play a decisive role in the prevention and control of public health events, and their irreplaceability, timeliness and lag make them an important guarantee for treating patients and slowing down the spread of public health events. In this case, determining the urgency of emergency medical materials and regional prevention and control, and rationally distributing materials based on the severity of public health events in various regions are the key to prevention and control. The urgency of needs can quantify the degree to which a region seeks help for public health events.

3.1ESTABLISHMENT OF EVALUATION INDICATORS

According to the requirements of China's National Emergency Plan for Public Health Emergencies, Law of the People's Republic of China on the Prevention and Control of Infectious Diseases, Law of the People's Republic of China on Emergency Response, and Novel Coronavirus Diagnosis and Treatment Plan, combined with the actual situation of countries around the world in dealing with SARS-COV-2, in order to facilitate the reference of data and refer to the data format of statistical yearbook, the corresponding evaluation index system is put forward, as shown in Table 3.

Table 3: Evaluation Index System

Target layer	Guideline layer	Indicator layer
Public health event prevention and control capabilities	Dissemination channels	X1 Population density (people/km^2)
		X2 Strictness of prevention and control policy
		X3 Receives inbound tourists
	Population susceptibility	X4 Enrollment rate of institutions of higher learning (%)
		X5 median age
		X6 vaccination rate (%)
	Responsiveness	X7 Number of beds for thousands of people (sheets/thousands of people)
		X8 GDP per capita (US $10,000)
		X9 Health expenditure as a percentage of GDP (%)
		X10 Consumer Spending as a Percentage of GDP (%)
		X11 UHC Coverage Index

Principal component analysis (PCA), also known as principal component analysis, mainly uses the principle of dimension reduction to transform the original complex variables into a few comprehensive variables (i.e. Principal components). Each principal component represents most of the information of the original variables, and the information contained in it will not be repeated. This multivariate statistical method can get results simply and effectively [10].

According to the principal component analysis method, the data reports released by the United Nations and the World Health Organization, and the statistical data of COVID-19 epidemic released by Johns Hopkins University and Oxford University [11], the principal component analysis is carried out to obtain the correlation matrix, as shown in Table 4.

Table 4: Correlation Matrix

Correlation	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11
X1	1										
X2	0.446	1									
X3	0.309	0.114	1								
X4	0.195	0.157	0.238	1							
X5	0.163	0.108	0.416	0.156	1						
X6	0.453	0.484	0.358	0.335	0.004	1					
X7	0.327	0.107	0.451	0.354	0.014	0.284	1				
X8	0.055	0.447	0.101	0.33	0.026	0.007	0.439	1			
X9	0.168	0.457	0.021	0.417	0.077	0.009	0.291	0.009	1		
X10	-0.794	0.373	0.413	0.065	0.079	0.338	0.266	0.097	0.143	1	
X11	0.155	0.415	0.139	0.174	0.042	0.024	0.483	0.026	0.058	0.094	1

It can be seen that the correlation between variables is moderate, and the selected indicators have a suitable level for explaining the demand degree of COVID-19. At the same time, $p=0.004 < 0.01$, indicating that the data released by the United Nations and the World Health Organization can effectively reflect the situation of COVID-19, and the data are valid.

Table 5: Principal Component Contribution Table

Composition	Total variance explained					
	Initial Eigenvalue			Extracting the sum of squares of loads		
	Total	Variance percentage	Cumulative/%	Total	Variance percentage	Cumulative/%
1	3.793	34.482	34.482	3.793	34.482	34.482
2	2.348	21.342	55.823	2.348	21.342	55.823
3	1.628	14.801	70.624	1.628	14.801	70.624
4	1.316	11.963	82.587	1.316	11.963	82.587
5	0.729	6.627	89.214			
6	0.412	3.747	92.962			
7	0.324	2.947	95.909			
8	0.264	2.404	98.312			
9	0.133	1.213	99.525			
10	0.042	0.384	99.91			
11	0.01	0.09	100			

Table 6: Composition Matrix Table

Indicators	Composition		
	1	2	3
X1 Population density	0.402	-0.751	0.064
X2 Strictness of prevention and control policy	-0.171	-0.2	0.746
X3 Receives inbound tourists	0.334	0.564	0.046
X4 Enrollment rate of institutions of higher learning	0.306	-0.525	0.131
X5 median age	0.761	0.233	0.099
X6 vaccination rate	0.304	0.058	-0.778
X7 Number of beds for thousands of people	0.896	0.059	0.274
X8 GDP per capita	0.598	0.708	0.17
X9 Health expenditure as a percentage of GDP	-0.492	0.764	0.144
X10 Consumer Spending as a Percentage of GDP	0.814	-0.05	-0.432
X11 UHC Coverage Index	0.813	-0.018	0.348

At the same time, according to Table 5, the contribution rates of the first, second, third and fourth principal components are 34.482%, 21.342%, 14.801% and 11.963% respectively, and the total contribution rate is as high as 82.587%. According to the general principle of eigenvalue selection, only the first four principal components can be selected to retain the information of the original index, and it is simplified into four new comprehensive indexes, thus achieving excellent dimension reduction effect, and the cumulative contribution rate is as high as 70% ~ 95%. Because the first three indicators have reached 70% of the contribution rate, the fourth principal component contribution is low, so only the first three principal components are studied.

According to Table 6 of Component Matrix, through the analysis results of principal components, it can be seen that the number of beds per thousand people, health expenditure to GDP, population density, vaccination rate and epidemic prevention policy control degree have the most important influence on the ability of epidemic prevention and control, so the above indicators are called effective indicators for adjusting the ability of epidemic prevention and control. From Component 1 in Table 6, it can be seen that the coefficients corresponding to the number of beds per thousand people, the percentage of consumption expenditure to GDP, UHC coverage index and median age are 0.896, 0.814, 0.813 and 0.761 respectively. These indicators objectively reflect the resilience of the country in the face of pneumonia in COVID-19, so they are named "resilience"; From component 2, it can be seen that the coefficients corresponding to the percentage of health expenditure to GDP, population density and per capita GDP are 0.764,-0.751 and 0.708, respectively. These indicators objectively reflect the country's ability to fight against pneumonia in COVID-19, so they are named "fighting ability"; According to component 3, the coefficients corresponding to vaccination rate and epidemic prevention policy control degree is-0.778 and 0.746, respectively. These indicators reflect the emergency response ability in the face of pneumonia epidemic in COVID-19, so they are named as "emergency response ability". Set the proportion of principal components as a, and normalize it for convenience of calculation, then resilience a_1=48.825%, resistance a_2=30.219%, and emergency response a_3=20.956%. Set the proportion of indicators as b, b_{11}=0. 402, b_{12}=-0.751, and so on b_{ij}.

3.2 DEMAND URGENCY FUNCTION

According to the weight of classification index, the demand urgency function of epidemic prevention and control is designed. If the urgency of epidemic prevention and control demand in a certain area is y_1 (t), the formula of urgency of epidemic prevention and control demand in a certain area is obtained:

$$y_1(t) = \sum_{i=1}^{3} a_i \sum_{j=1}^{11} x_i(t) * b_{ij} \rightarrow (2)$$

Finally, normalized treatment is carried out, and Y_{1K} represents the urgency of epidemic prevention and control needs in the k-th region among n regions.

$$Y_{1k} = \frac{y_{1k}}{\sum_{i=1}^{n} y_{1i}} \rightarrow (3)$$

According to the development of epidemic situation and the need of emergency medical materials, the urgency function of emergency medical materials demand is designed. If the emergency medical material demand urgency degree in a certain area is y_2 (t), the formula of emergency medical material demand urgency degree in a certain area is obtained:

$$y_2(t) = 0.3N + 0.15I - 0.15R - 0.3D \rightarrow (4)$$

Finally, normalized processing is carried out, and Y_{2K} represents the urgency of emergency medical materials demand in the k-th region among n regions.

$$Y_{2k} = \frac{y_{2k}}{\sum_{i=1}^{n} y_{2i}} \rightarrow (5)$$

Because the higher the urgency of epidemic prevention and control demand, the better the epidemic prevention and control situation in the city, that is, the higher Y_1 proves that the demand for epidemic prevention and control is low; The higher the urgency of emergency medical materials demand, the worse the demand of emergency medical materials in the city, that is, the higher Y_2 proves the high demand of emergency medical materials. Mathematical processing is performed to design the total demand urgency function Y as follows:

$$Y_k = -\varphi_1 * Y_{1k} + \varphi_2 * Y_{2k} \rightarrow (6)$$

Where φ_1 is the weight of epidemic prevention and control demand urgency function, and φ_2 is the weight of emergency medical materials demand urgency function.

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