Financial Engineering and Risk Management (2022)
Clausius Scientific Press, Canada

DOI: 10.23977/ferm.2022.050304
ISSN 2523-2576 Vol. 5 Num. 3

Use the Analytic Hierarchy Process to Comprehensively Evaluate the Control Effects of Major Countries on the Epidemic

Hui Wang[1,*], Rui Huang[2], Fengmei Xin[1], Linhui Liu[1], Xin Li[1]

[1]*School of Morden Manufacturing Engineering, Heilongjiang University of Technology, Harbin, Heilongjiang, China*

[2]*School of Electrical & Information Engineering, Heilongjiang University of Technology, Harbin,* Heilongjiang, *China*

**corresponding author*

Keywords: Cluster analysis, AHP, Logistic model, SEIR model

Abstract: Understanding the characteristics and laws of the development of the new coronavirus epidemic has become a global focus. This paper firstly uses the analytic hierarchy process to comprehensively evaluate the control effects of major countries on the epidemic. Secondly, the relevant data are analyzed and correlation research is carried out to analyze the characteristics of the epidemic development and the situation of fighting the epidemic; finally, through the cluster analysis method, the relevant model is established, and the nine selected countries are reasonably classified by SPSS software. Through the establishment of appropriate models, the global epidemic situation is analyzed according to the model results, and the subsequent epidemic spread is predicted, and reasonable epidemic prevention suggestions and prospects for the future development of the epidemic are put forward.

1. Introduction

The novel coronavirus (COVID-2019) has now become a world epidemic infectious disease [1], which has caused a huge impact on the economy, people's life, life and property of various countries. However, due to the different economic conditions and systems of various countries in the world, the difference in people's attention to the epidemic, and the insufficiency of testing equipment and personal protective equipment in many countries, there are different ways to fight the epidemic. Some countries have already seen dawn, some countries still have a long way to go. To understand the characteristics and laws of the development of the new coronavirus epidemic, we can have a clear understanding of the development of the epidemic around the world.

Establish a mathematical model based on real-time monitoring data [2] to solve the following problems: 1. According to the time series data related to the development of the epidemic, analyze the characteristics of the epidemic development and the situation of fighting the epidemic in major countries around the world, and make a reasonable classification; 2. Select reasonable indicators, build a mathematical model, and conduct a comprehensive evaluation of the control effects of major countries around the world on the epidemic; 3. Build models to predict the development trend of the epidemic in major countries around the world, and test the models.

2. Model Building and Solving

2.1. Analyze the Characteristics of the Development of the Epidemic in Major Countries around the World and the Situation of Fighting the Epidemic

In order to have a clearer and more accurate understanding of the new crown pneumonia epidemic that is currently threatening the world, this paper selects nine major countries among the many countries affected by the new crown virus by analyzing the international situation, international influence, economic development and other aspects. Nine countries are located in Europe, Asia, North America, and South America, which are far apart and widely spread. The characteristics of the epidemic development and the fight against the epidemic in these nine countries are analyzed. Use Python to make a Nightingale rose diagram of cumulative diagnoses, cumulative cures, and cumulative deaths in nine countries [3] (Figure 1-Figure 3).

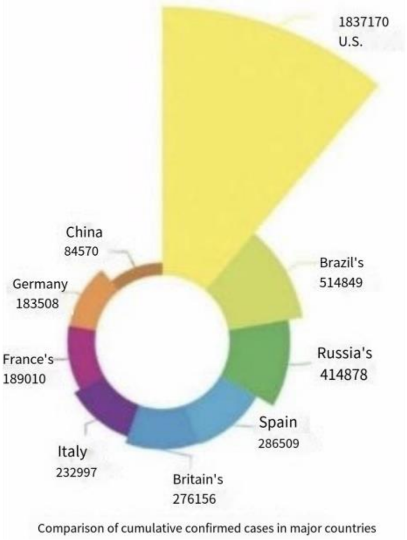

Figure 1: Comparison chart of cumulative confirmed cases in major countries.

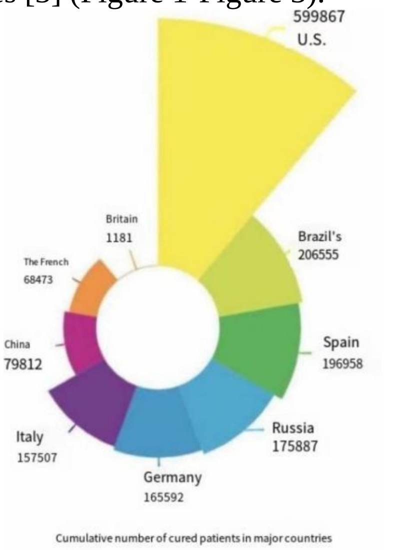

Figure 2: Comparison chart of the cumulative number of cured people in major countries.

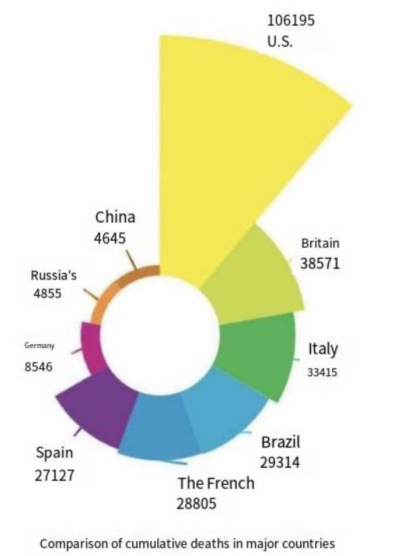

Figure 3: Comparison chart of cumulative death toll in major countries.

From the data comparison, it is not difficult to see that the United States is "topping the list". The cumulative number of deaths and the cumulative number of cured patients in the United States are 2.7 times and 2.9 times that of the second UK and Brazil, respectively, accounting for 1/3 of the total number of deaths in the world; and the cumulative number of confirmed cases is 3.6 times that of Brazil. The first case in Brazil was on February 26. It was a late outbreak among the nine countries, but it has grown rapidly, and the number of confirmed cases is now second only to the United States. Using Python to crawl the daily real-time update of the cumulative diagnosis, cumulative cure, cumulative death, and the number of people diagnosed in a single day in nine countries from Tencent Information Network,and make a data map for analysis.

In order to more clearly see the situation of each country's fight against the epidemic, this paper uses formula (1) and formula (2) to calculate the cure rate P_1 and mortality rate P_2 of each country respectively.

$$P_1 = \frac{C}{D} \tag{1}$$

$$P_2 = \frac{M}{D} \tag{2}$$

Available:

Table 1: China's outstanding performance in this epidemic

Nation	Cure rateP_1	Mortality rateP_2
China	94.373891%	5.492491%
U.S.	29.460156%	5.809987%
Brazil	40.304149%	5.784849%
Russia	42.352092%	1.156358%
Spain	68.792349%	9.474063%
U.K.	0.429830%	13.967106%
Italy	66.891741%	14.329677%
France	36.230609%	15.244342%
Germany	90.162513%	4.656705%
Average	52.110814%	8.435064%

Through Table 1, we can clearly analyze China's outstanding performance in this epidemic. China's cure rate is as high as 94.373891%, ranking first, and the mortality rate is second only to Germany, ranking second (the lower the mortality rate, the higher the ranking). Looking at the entire table, the cure rate in the UK is only 0.429830%, completely deviating from the average level of normal European countries.

2.2. Classification of Major Countries [4]

Through analysis, it was decided to classify the nine countries according to the six determinants of cumulative diagnosis, cumulative cure, cumulative death, confirmed rate, cure rate, and mortality rate in each country, as shown in Table 2 The tabular data is imported into SPSS, the Wald method is used as the classification standard, and the squared Euclidean distance [5] is used to calculate the similarity, and the final classification result is shown in Figure 4-Figure 5.

Table 2: The six determinants of major countries

Nation	Cumulative diagnosis	Cumulative cure	Cumulative death	Diagnosis rate	Cure rate	Mortality rate
China	84570	79812	4645	0.006040%	94.373891%	5.492491%
U.S.	1816820	535238	105557	0.550552%	29.460156%	5.809987%
Brazil	498440	200892	28834	0.237352%	40.304149%	5.784849%
Russia	405843	171883	4693	0.277975%	42.352092%	1.156358%
Spain	286308	196958	27125	0.612686%	68.792349%	9.474063%
U.K.	276156	1187	38571	0.415341%	0.429830%	13.967106%
Italy	232664	155633	33340	0.385006%	66.891741%	14.329677%
France	188752	68386	28774	0.281773%	36.230609%	15.244342%
Germany	183370	165331	8539	0.221120%	90.162513%	4.656705%

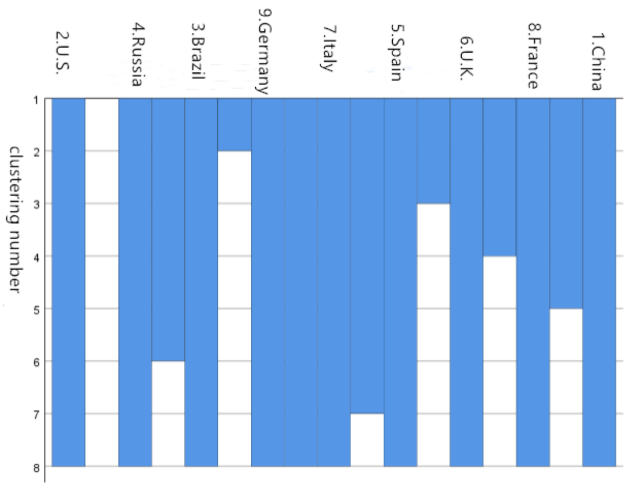

Figure 4: Clustering number.

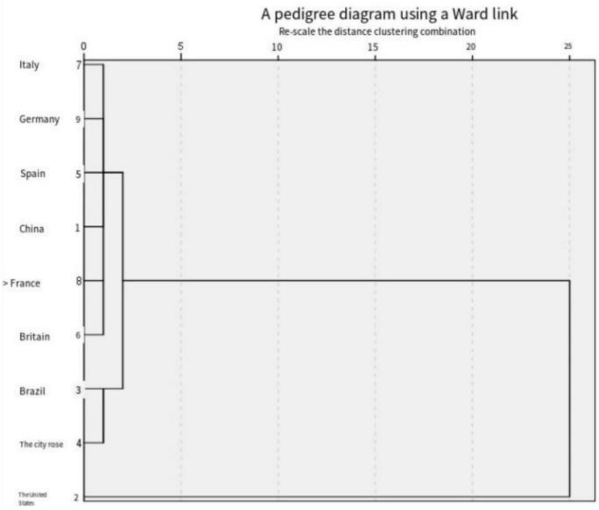

Figure 5: A pedigree diagram.

The nine countries were divided into three groups based on the resulting icicle and genealogy diagrams, and the results are as follows:

Category 1: China, Germany, France, Great Britain, Germany, Spain.

The second category: Brazil, Russia.

The third category: the United States.

In order to comprehensively evaluate the effect of epidemic control of major national teams around the world, the AHP [6] model was used in this question to introduce the daily mask production and Data on the time from the first outbreak to the implementation of control measures by countries are compared and analyzed.

First, a hierarchical structure model is established, and on the basis of in-depth analysis of actual problems, the relevant factors are decomposed into three layers from top to bottom according to different attributes. The first layer is the target layer: evaluating the effect of epidemic control in each country. The second layer is the criterion layer: judging the indicators of each country (specific data are shown in Table 3), including the diagnosis rate, cure rate, mortality rate, daily mask output of each country and the time from the first outbreak to the implementation of control measures in each country (hereinafter referred to as the control time). The third layer is the object layer: the nine major countries judged by the first question, including China, the United States, Brazil, Russia, Spain, the United Kingdom, Italy, France, and Germany.

Table 3: Specific data

Nation	Diagnosis rate	Cure rate	Mortality rate	Daily output of masks (in 10,000 units)	Control time (unit day)
U.S.	0.550552%	29.460156%	5.809987%	5000	4
China	0.006040%	94.373891%	5.492491%	20000	24
U.K.	0.415341%	0.429830%	13.967106%	150	53
France	0.281773%	36.230609%	15.244342%	133	24
Germany	0.221120%	90.162513%	4.656705%	285	49
Brazil	0.237352%	40.304149%	5.784849%	50	24
Russia	0.277975%	42.352092%	1.156358%	160	46
Italy	0.385006%	66.891741%	14.329677%	70	1

Second, a pairwise comparison matrix is constructed, and the scoring criteria are shown in Table 4.

Table 4: The scoring criteria

Scaling	Meaning
1	Comparison of two factors, equally important / equally good performance
3	Comparing two factors, one is slightly more important/excellent than the other
5	Comparing two factors, one is significantly more important/excellent than the other
7	Comparing two factors, one is strongly important/excellent than the other
9	Comparing two factors, one is extremely important/excellent than the other
2, 4, 6, 8	Suspension of the above two adjacent judgments
Reciprocal	Factor i and j comparison a_{ij}, then the judgment of comparison of factor j and i $a_{ij} = 1/a_{ij}$

For tedious data, it is necessary to construct a comparison matrix for calculation, calculate weights and perform consistency check. Although the pairwise comparison matrix is obtained by comparing the real data, in order to make the result more accurate, it must pass the consistency test, so as to eliminate the inconsistency caused by the error as much as possible.

Consistency test generally uses the consistency index CI to test. When CI<0.01, the calculated weights are considered acceptable. CI can be calculated by the following formulas (3)~(7) m is the number of sub-objectives of the level to be inspected).

$$CI = \frac{\lambda_{max} - m}{m - 1} \tag{3}$$

$$\lambda_{max} = \sum_{i=1}^{m} \frac{\lambda_i}{m} \tag{4}$$

$$\lambda_i = \sum_{i=1}^{m} \frac{a_{ij} w_j}{w_i} \tag{5}$$

$$w_i = \frac{w_i'}{\sum_{i=1}^{m} w_i'} \tag{6}$$

$$w_i' = \sqrt[m]{a_{i1} a_{i2} \cdots a_{im}} \tag{7}$$

In order to further determine the consistency, the random consistency ratio CR can be calculated. When CR<0.1, it can be judged that the matrix satisfies the consistency, where:

$$CR = \frac{CI}{RI} \tag{8}$$

$RI = [0\ 0\ 0.52\ 0.89\ 1.12\ 1.26\ 1.36\ 1.4\ \ 1.4\ \ 1.49\ 1.52\ 1.52\ 1.56\ 1.58\ 1.59]$

The above calculations can be calculated by importing the corresponding data into MATLAB, and the detailed procedures are shown in Appendix II. After the consistency check is successful, the weight calculation results of each matrix are shown in Table 6 and Table 7.

The pairwise comparison matrix weights of the criterion layer are shown in Table 5.

Table 5: The pairwise comparison matrix weights of the criterion layer

Guidelines	Diagnosis rate	cure rate	mortality rate	Daily mask production	Measures implementation time
Weights	0.2636	0.4758	0.0538	0.0981	0.1087

The weight of each country under the relevant criteria is shown in Table 6.

Table 6: The weight of each country under the relevant criteria

Nation	Diagnosis rate weight	Cure rate weight	Mortality weight	Daily mask production weight	Measure implementation time weight
U.S.	0.0295	0.0229	0.1116	0.2417	0.2671
China	0.2519	0.3208	0.1558	0.4521	0.0835
U.K.	0.0556	0.0158	0.0185	0.0484	0.0158
France	0.1031	0.0352	0.0151	0.0357	0.1018
Germany	0.1925	0.2361	0.1427	0.1098	0.0208
Brazil	0.1741	0.049	0.1116	0.013	0.1018
Russia	0.1163	0.0606	0.3247	0.0637	0.0266
Italy	0.0586	0.1185	0.0199	0.0206	0.3457
Spain	0.0183	0.1412	0.1001	0.0149	0.0371

Finally, by calculating the weights of each country to the overall target, the epidemic control effect of each country can be judged. The weight of each country to the overall target is the sum of the weight of each country under the relevant criteria multiplied by the weight of the relevant criteria. The results are shown in Table 7.

Table 7: The weight of each country to the overall target

Nation	Country weights on overall goals
U.S.	0.077
China	0.281
U.K.	0.030
France	0.059
Germany	0.184
Brazil	0.088
Russia	0.086
Italy	0.112
Spain	0.083

The epidemic control effect of each country can be obtained:

China>Germany>Italy>Brazil>Russia>Spain>France>US>UK

Advantages of the model:

1. Analytic hierarchy process takes the research object as a system, and the results are simple and clear.

2. The multi-objective, multi-criteria and difficult to quantify problems are transformed into multi-level single-objective problems, which are easy to calculate.

Disadvantages of the model:

1. There are few quantitative data and many qualitative components.

In order to predict the development trend of the epidemic in major countries around the world, Ontology uses the Logistic model to make a general prediction of the epidemic development in each country.

For the logistic model, first understand that the logistic curve is usually divided into five periods, as shown in Table 8.

Table 8: The logistic curve.

Start period	Slow growth, also known as the incubation period
Accelerated period	Growth accelerates
Turning point	The current number of infected individuals reaches half of the saturation density, and the density increases the fastest at this time
Deceleration period	The current number of infected individuals exceeds half of the saturation density, and the density growth slows down at this time
Saturation period	The current number of infected individuals has reached saturation

Next, determine the logistic model formula (where K is the maximum capacity of the environment, P_0 is the initial capacity, r is the growth rate, and the larger the r, the faster the growth rate).

$$P_t = \frac{KP_0e^{rt}}{K + P_0(e^{rt} - 1)} \tag{9}$$

Finally, use Python to write a program, substitute formula (9) and the confirmed data of each major country crawled in Question 1 (see Appendix 3 for the specific procedures), and obtain the following prediction results (Figure 6-Figure 14):

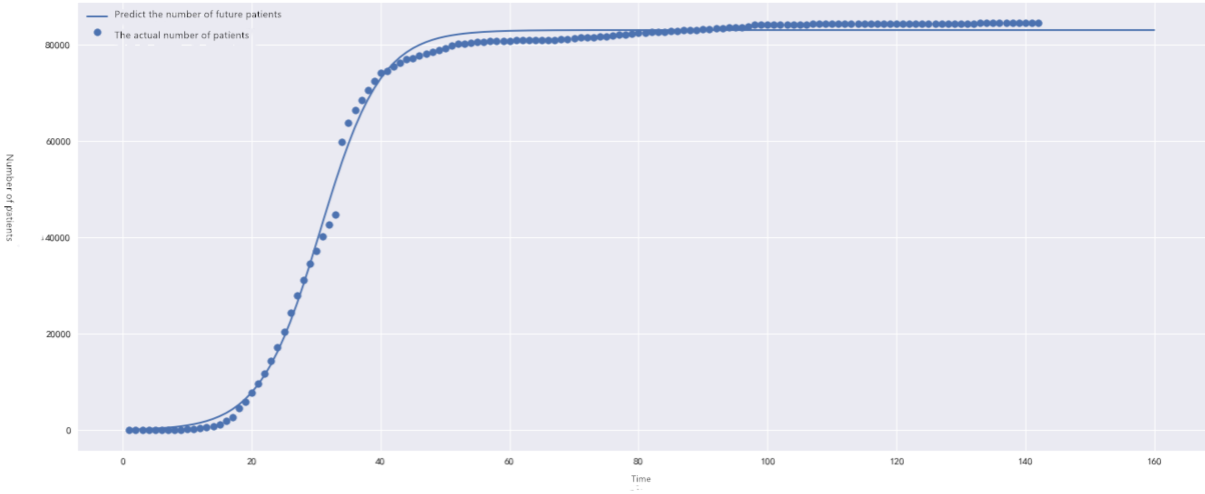

Figure 6: The prediction of China's data

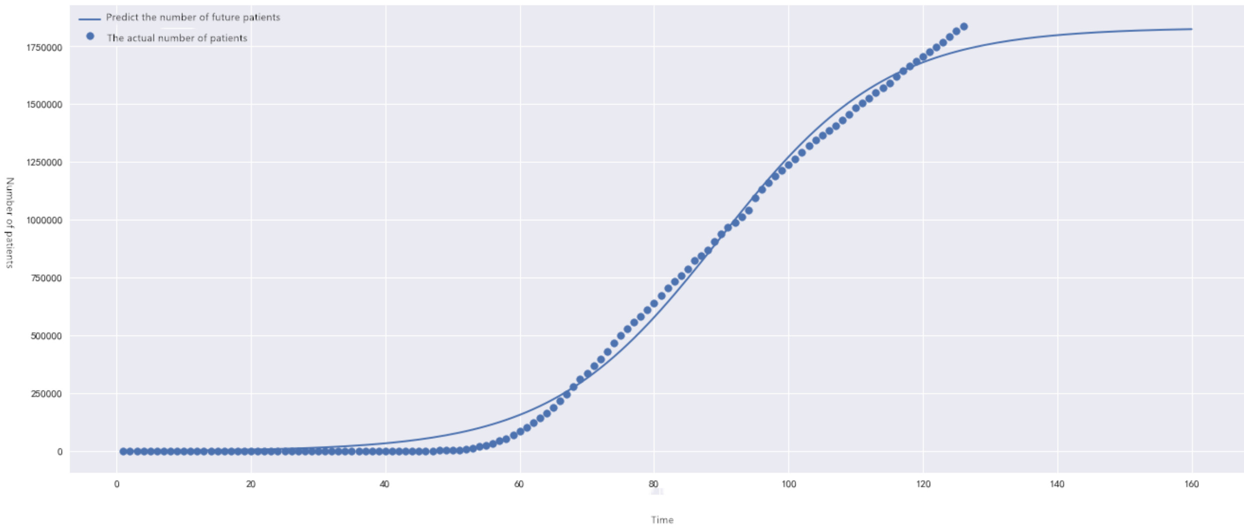

Figure 7: The prediction of American's data

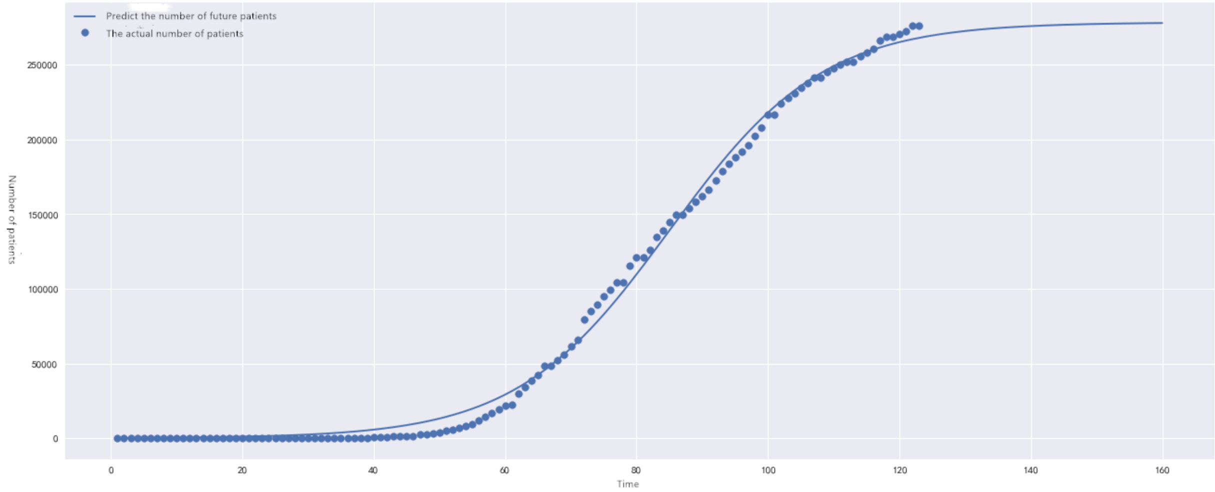

Figure 8: The prediction of U.K.'s data

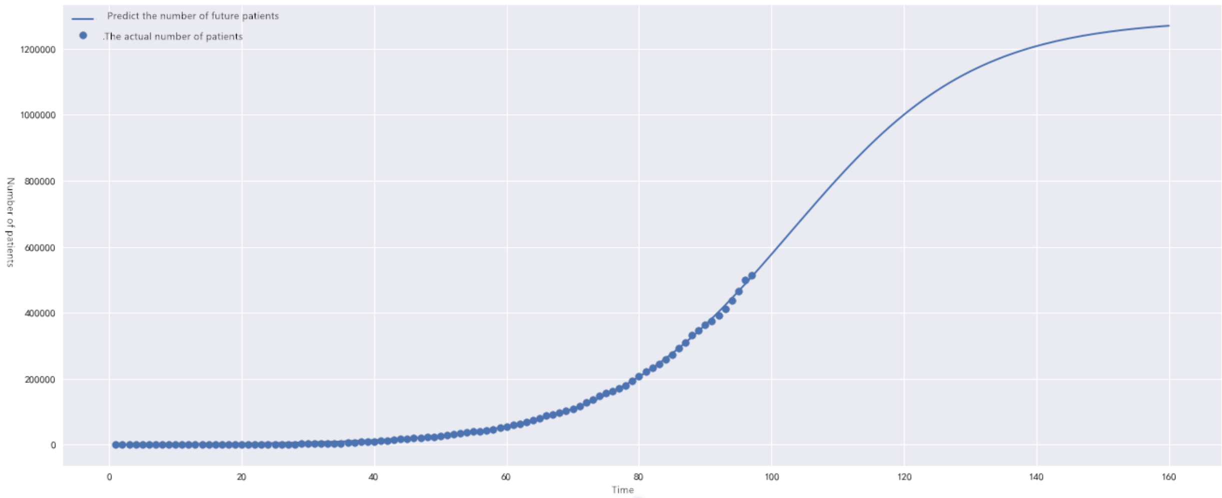

Figure 9: The prediction of Brazil's data

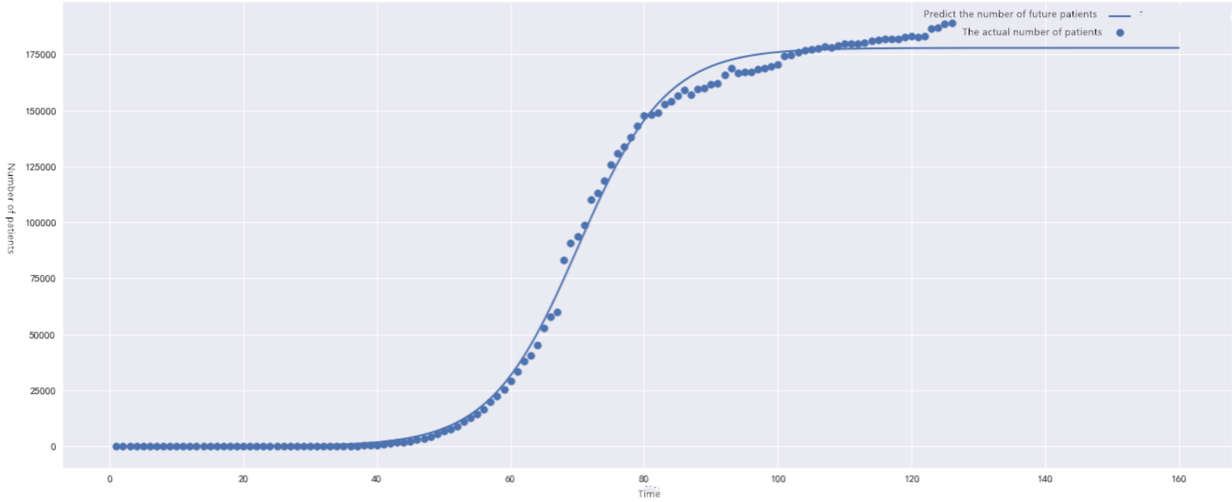

Figure 10: The prediction of France's data

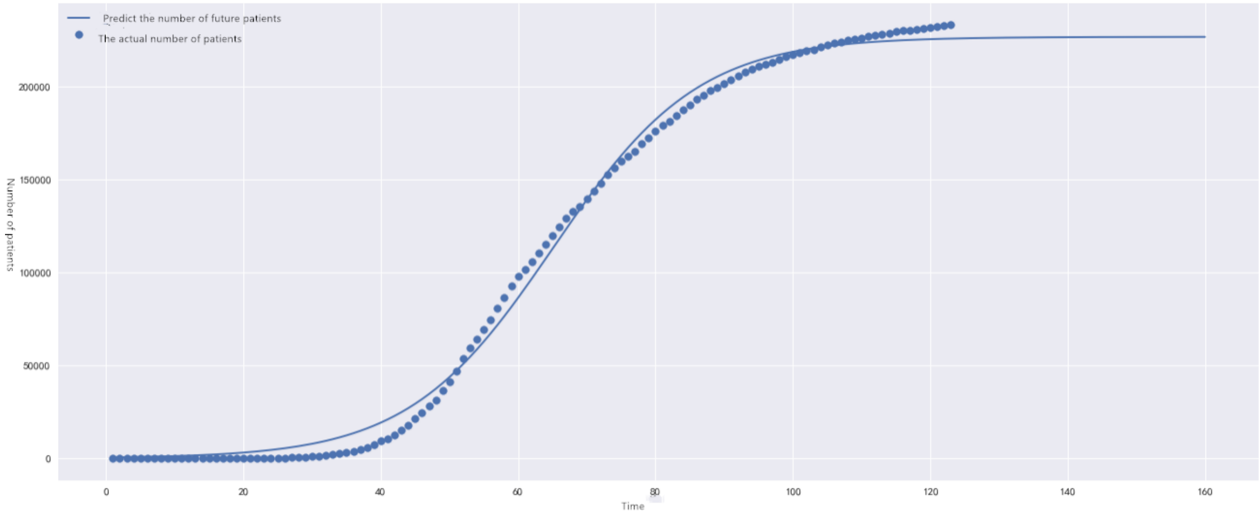

Figure 11: The prediction of Italy’s data

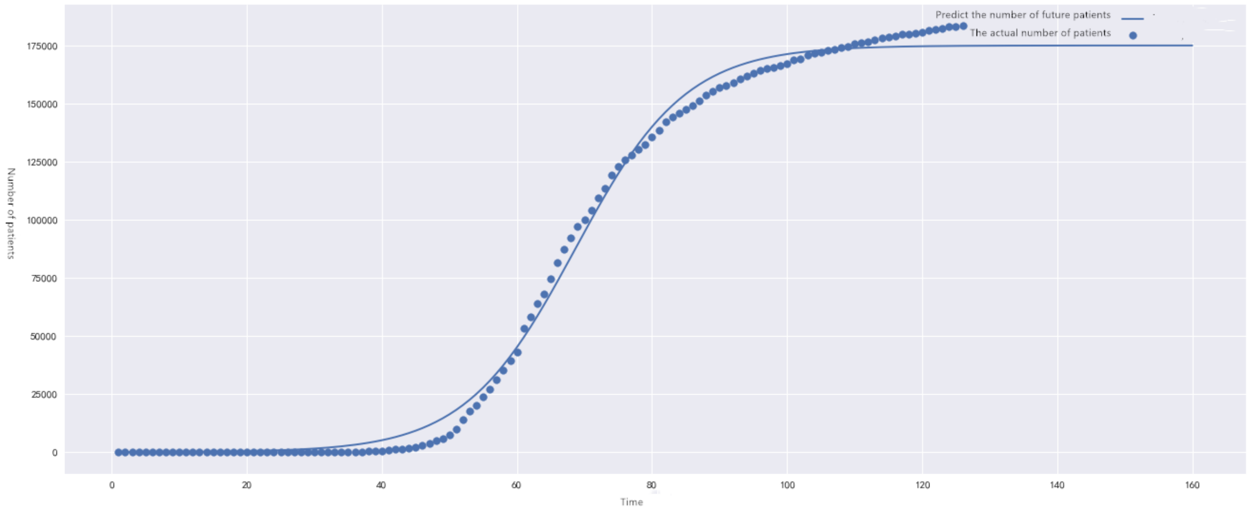

Figure 12: The prediction of Germany’s data

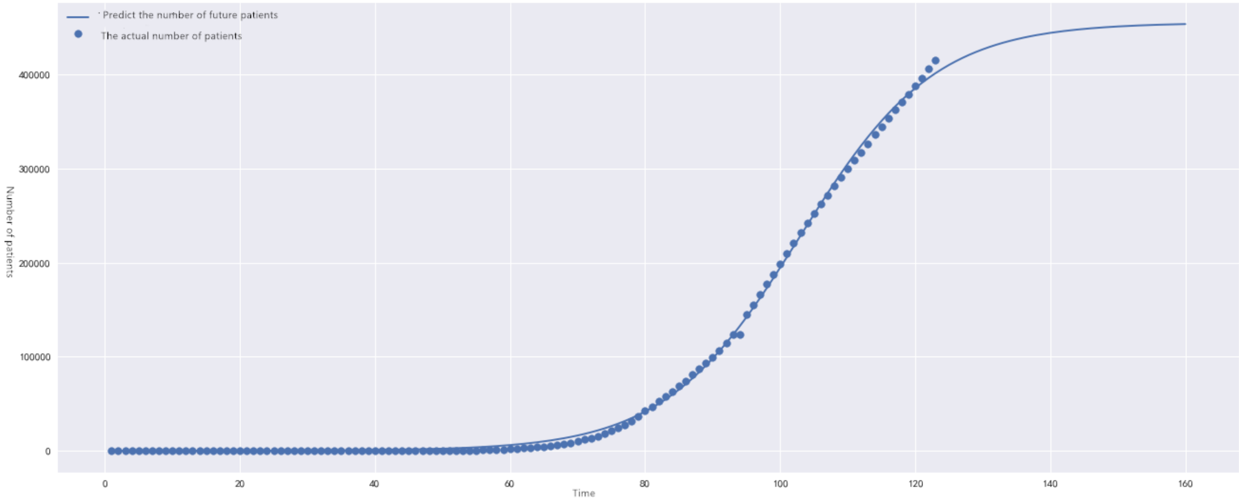

Figure 13: The prediction of Russia’s data

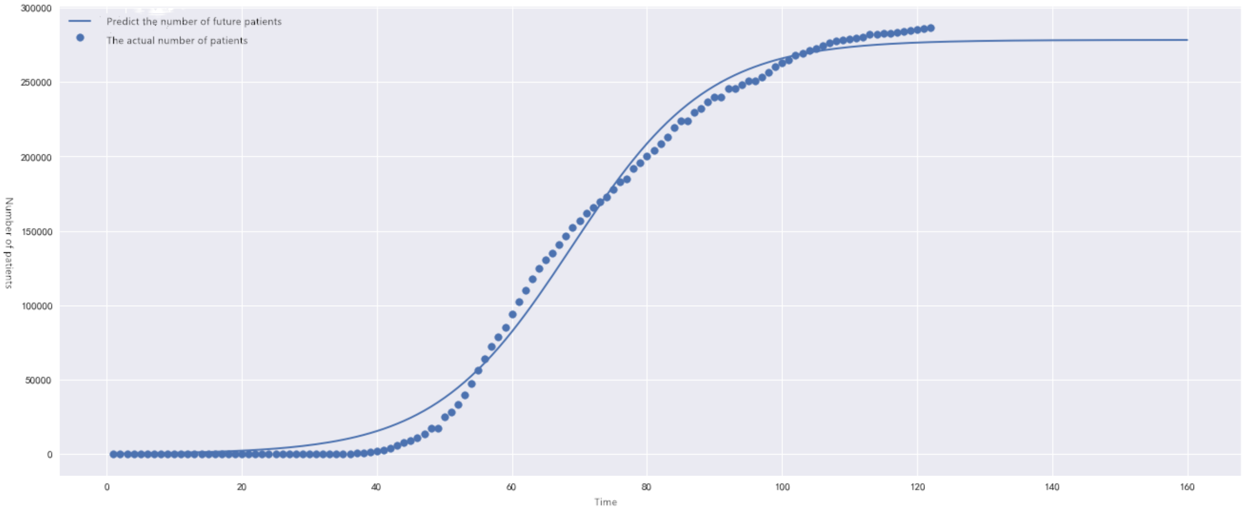

Figure 14: The prediction of Spain's data

The scatter plot represents the actual number of confirmed cases, the starting date is the date when the first case occurred in each country, and the end date is May 31.

2.3. Test of the Model

In order to test the results predicted by the Logistic model, one is to use the SEIR model [7] to predict the development trend of the epidemic in major countries,and compare the prediction results of the two models; the other is to use real data to test.

In the SEIR model, S stands for susceptible persons, referring to those who are not sick; E stands for exposed persons, referring to those who have been exposed to infected persons and are in the incubation period; I stands for infected persons; R stands for recovered persons; D stands for the number of deaths, of which the total Population N=S+E+I+R+D. At this point there are:

For susceptible persons: $S(t) = S(t-1) - r \times B \times S(t-1) \times I(t-1)/N(1)$

About Lurkers: $E(t) = E(t-1) + r \times B \times S(t-1) \times \frac{I(t-1)}{N(1)} - a \times E(t-1)$

Regarding the sick: $I(t) = I(t-1) + a \times E(t-1) - y \times I(t-1)$

Regarding the recovered: $R(t) = R(t-1) + y \times I(t-1)$

(where B is the infection rate, and this question is set to 0.6; y is the coefficient of recovery, which refers to the reciprocal of the total recovery time of an infected person, and this question is set to 0.1; a is the probability of latent transformation into an infected person, and this question is set to 0.1; r is The average number of infected people in daily contact, the model data is set to 5)

We are using Matlab to write a program and obtain the following results in Figure 15-Figure 23:

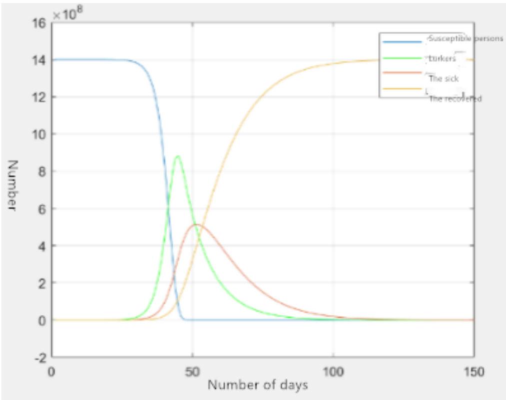

Figure 15: The SEIR model of China

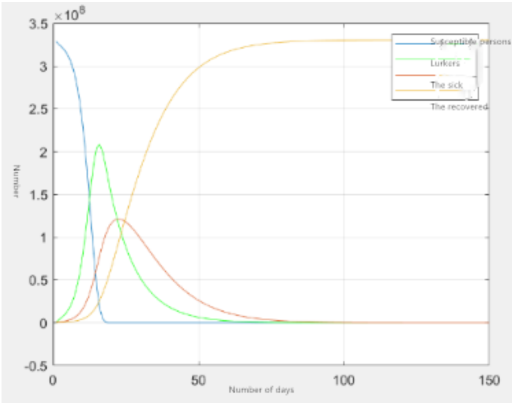

Figure 16: The SEIR model of U.S

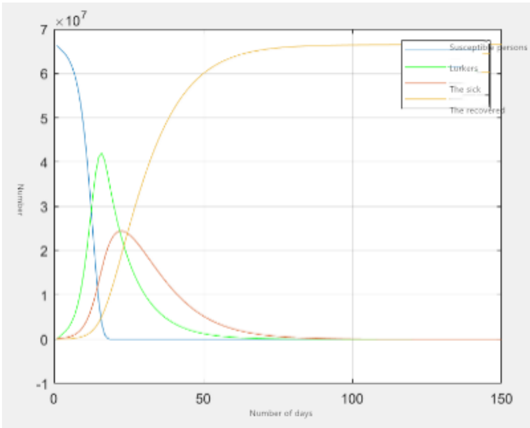

Figure 17: The SEIR model of U.K

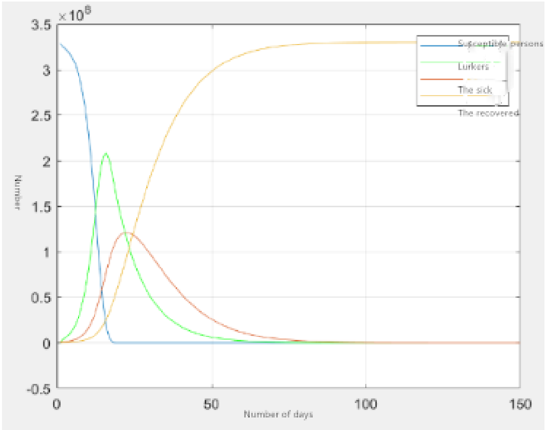

Figure 18: The SEIR model of Brazil

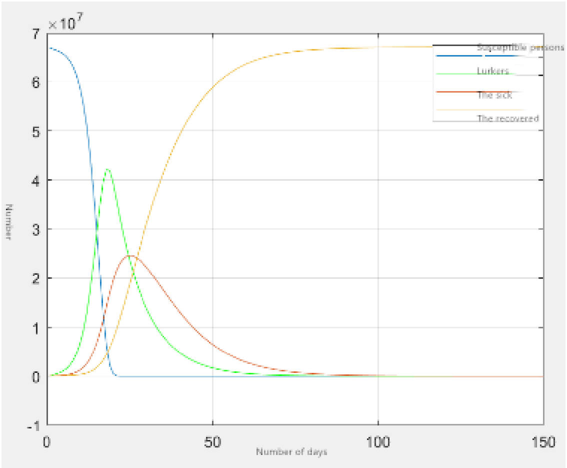

Figure 19: The SEIR model of France

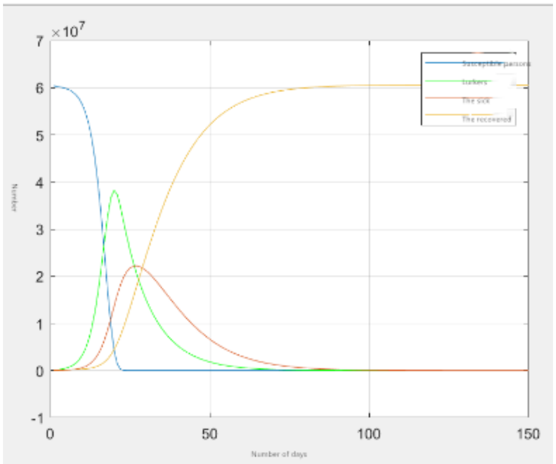

Figure 20: The SEIR model of Italy

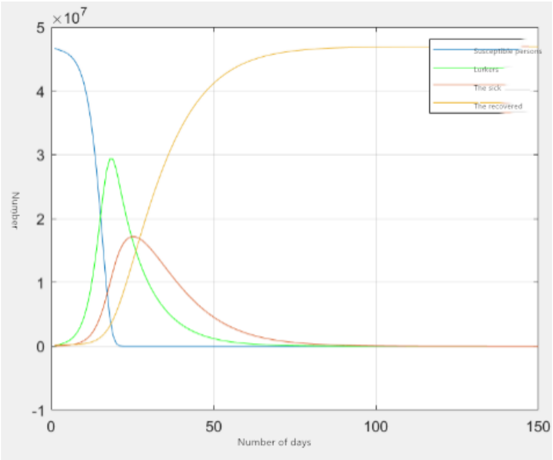

Figure 21: The SEIR model of Germany

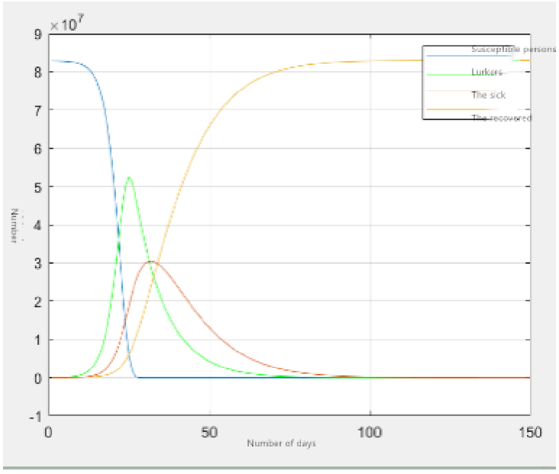

Figure 22: The SEIR model of Russia

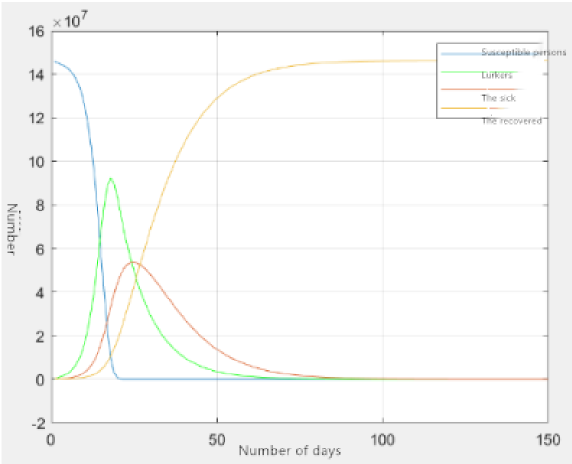

Figure 23: The SEIR model of Spain

According to the comparison between the SEIR model and the Logistic model, the roughly predicted trend is consistent. In order to more accurately verify the validity and reliability of the model, the model uses the actual diagnosis data from June 1 to June 7 to compare the results predicted by the Logistic model. The results are shown in Table 9 to Table 17:

Table 9: The comparison of China's data

Date	06.01	06.02	06.03	06.04	06.05	06.06	06.07
Forecast data	83382	83382	83382	83382	83382	83382	83382
Real data	84597	84602	84603	84614	84620	84629	84634
Error/%	1.44	1.44	1.44	1.46	1.46	1.47	1.48

Table 10: The comparison of U.S.'s data

Date	06.01	06.02	06.03	06.04	06.05	06.06	06.07
Forecast data	1757900	1766040	1770160	1782520	1790400	1793760	1803120
Real data	1737170	1759323	1781205	1801783	1834051	1865708	1891544
Error/%	1.19	0.38	0.62	1.07	2.38	3.86	4.67

Table 11: The comparison of U.K.'s data

Date	06.01	06.02	06.03	06.04	06.05	06.06	06.07
Forecast data	269075	270945	271569	272816	273439	273439	273439
Real data	276156	277738	279392	281270	284730	286292	287621
Error/%	2.56	2.45	2.80	3.01	3.97	4.49	4.93

Table 12: The comparison of France's data

Date	06.01	06.02	06.03	06.04	06.05	06.06	06.07
Forecast data	179148	179148	179148	179148	179148	179148	179148
Real data	179010	181348	182450	183802	184569	186180	188059
Error/%	0.08	1.21	1.81	2.53	2.94	3.78	4.74

Table 13: The comparison of Brazil's data

Date	06.01	06.02	06.03	06.04	06.05	06.06	06.07
Forecast data	531509	540052	571379	591313	599857	631183	659662
Real data	514849	526447	555383	584016	614941	646006	673587
Error/%	3.24	2.58	2.88	1.25	2.45	2.29	2.07

Table 14: The comparison of Germany's data

Date	06.01	06.02	06.03	06.04	06.05	06.06	06.07
Forecast data	175580	175580	175580	175580	175580	175580	175580
Real data	173508	178879	179879	180472	182924	183416	184745
Error/%	1.19	1.84	2.39	2.71	4.01	4.27	4.96

Table 15: The comparison of Italy's data

Date	06.01	06.02	06.03	06.04	06.05	06.06	06.07
Forecast data	226588	226588	226588	226588	226588	226588	226588
Real data	232997	233197	233515	233836	234013	234531	234801
Error/%	2.75	2.83	2.97	3.10	3.17	3.39	3.50

Table 16: The comparison of Russia's data

Date	06.01	06.02	06.03	06.04	06.05	06.06	06.07
Forecast data	407547	411616	415685	419754	420771	423822	428909
Real data	414878	423186	423186	430538	439256	442102	447073
Error/%	1.77	2.73	1.77	2.50	4.21	4.13	4.06

Table 17: The comparison of Spain's data

Date	06.01	06.02	06.03	06.04	06.05	06.06	06.07
Forecast data	277986	277986	277986	277986	277986	277986	277986
Real data	286509	286718	287012	287406	287740	288058	288390
Error/%	2.97	3.05	3.14	3.28	3.39	3.50	3.61

After comparing with the real data, it is found that the maximum error of the result predicted by the logistic model is 4.96%, and the prediction accuracy of the model meets the requirements. Since the SEIR model considers many parameters, the calculation error is slightly larger than that of the Logistic model.

3. Summary

The logistic model can only predict the approximate inflection point date and the maximum number of sick people,but cannot predict the complete process of the epidemic. For individuals, strengthen exercise, learn about hygiene, disease and other related knowledge, and enhance hygiene and health awareness; avoid going out and gathering less, this new coronary pneumonia is extremely infectious, and through the establishment and solution of the SEIR model in Question 3, it is not difficult to see the isolation. The importance of isolation measures can greatly reduce the infection rate; do not panic, do not spread rumors, and follow the instructions and arrangements of the CDC or relevant departments. To establish a sense of community, the epidemic data of various countries must be transparent and open, and the prevention and treatment experience must be shared with each other. Epidemic prevention work cannot be copied and copied. It should learn from the epidemic prevention experience of other countries and make adjustments according to the actual situation of their own countries; eliminate misunderstandings, let go of prejudice, strengthen confidence, deal with unity, fight against viruses, and jointly research countermeasures, vaccines, medicines, etc.

Acknowledgements

Heilongjiang Education Science Planning Project (GJB1422470); Heilongjiang Higher Education Teaching Reform Project (SJGY20210770); Basic Scientific Research Business Fee Project of Heilongjiang Province (2021-KYYWF-1187).

References

[1] Bai Fumei. Infectious disease model. Journal of Taiyuan Normal University (Natural Science Edition), 2012,11(01):53-56.
[2] Excellent course of Northwestern Polytechnical University (Mathematical Modeling).
[3] Tigan G , Lazureanu C , Munteanu F , et al. Bifurcation diagrams in a class of Kolmogorov systems. Nonlinear Analysis Real World Applications, 2020, 56:103154.
[4] Introduction to Cluster Analysis. China Statistical Network. 2012-12-09.
[5] Tao Changqi. Econometrics. Dongbei University of Finance and Economics. 2011: 212-216.

[6] Xu Shubai. Practical Decision-Making Methods: The Principles of Analytic Hierarchy Process. Tianjin University Press, 1988.
[7] Li Jianquan, Ma Zhien. Analysis of two types of SEIR infectious disease models with definite incubation period. Systems Science and Mathematics, 2006(02): 228-236.