The Strategy of Eradicating Ebola

Weilin Qu, Nan Geng, Yidi Xu

Beijing University of Posts and Telecommunications, Beijing, 100876, China
85617320qwl@sina.com

***Abstract*—This paper constructs three models to predict the medicine needed in Guinea, Sierra Leone and Liberia, and creates an optimal transport strategy of eradicating Ebola. GM model is the basic prediction model. By applying the reproductive rate model (Re Model), this paper predicts the vaccines needed with different goal reproductive rate. The medicine transport plan is based on the minimum spanning tree algorithm (MST) combining airports and urgent epidemic areas factors. The weight of other three important factors is determined by AHP model.**

Keywords-Ebola control; Medicine prediction; GM; Re Model; MST;AHP

I. INTRODUCTION

WHO reported that people infected by Ebola had been over seventeen thousand by 2014. Infections have exceeded ten thousand while the rising trend of death is slowing. This paper offers an effective plan in which we can ease the Ebola epidemic to a certain extent. There are many factors concerning the spread of Ebola such as the medicine needed per month, the transport line, the proper production project and others. Our goal is to eradicate Ebola to the minimum degree.

This paper consists of four parts. In the first part, we build the prediction model to obtain the rough trend of Ebola. The second part evaluates the amount of medicine needed per month to control Ebola to some degree. In the third part, we build an optimal medicine transport scheme. The final part is based on AHP analysis theory to assess the weight of other important factors to eradicate Ebola.

II. PREDICTION OF EBOLA

Ebola broke out in 2014. Guinea, Sierra Leone and Liberia are the countries suffering most in the world. In order to eradicate Ebola effectively, this section constructs a mathematical model to predict the number of patients and deaths per month after January 2015 in three countries mentioned above. We assume that no effective medicine for curing Ebola will emerge in the near future. To simplify the model, we make assumptions that patients infected in future are not included in the official statistics.

A. Modeling Process

We apply grey theory to our model and build model GM (1,1). We use $x^{(0)}$ to represent months from Mar.2014 to Dec.2014

$$x^{(0)} = (x^{(0)}(1), x^{(0)}(2), ..., x^{(0)}(10))$$

Use $x^{(1)}$ to make Mean Generating:

$$z^{(1)}(k) = 0.5x^{(1)}(k) + 0.5x^{(1)}(k-1), k = 2,3,...,n$$

$$x^{(0)}(k) + az^{(1)}(k) = b, k = 2,3,...,n$$

Build array：

$$\boldsymbol{Y} = \left[x^{(0)}(2), x^{(0)}(3), ..., x^{(0)}(n)\right]^T, \boldsymbol{B} = \begin{bmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(3) & 1 \\ : & : \\ -z^{(1)}(n) & 1 \end{bmatrix}$$

$$\boldsymbol{J}(\boldsymbol{u}) = (\boldsymbol{Y} - \boldsymbol{B}\boldsymbol{u})^T(\boldsymbol{Y} - \boldsymbol{B}\boldsymbol{u})$$

We use The Least Square Method to get the minimum, and the estimated value of u is:

$$\hat{\boldsymbol{u}} = \left[\hat{a}, \hat{b}\right]^T = (\boldsymbol{B}^T\boldsymbol{B})^{-1}\boldsymbol{B}^T\boldsymbol{Y}$$

Then we can assign values in and get the equation below

$$\hat{x}^{(1)}(k+1) = (x^{(0)}(1) - \frac{\hat{b}}{\hat{a}})e^{-\hat{a}k} + \frac{\hat{b}}{\hat{a}}, k = 0,1,...,n-1,...$$

B. Result

We obtain the data of infected people and the death all over the world from WHO's official website and obtain the increase number of infected people and deaths per month by processing original data. Then we use grey theory to obtain the fitted value and the predicted value.

Table 1. The cases added per month

2014								
Month	05	06	07	08	09	10	11	12
Patients (original)	121	405	681	2267	3785	5155	4498	3061
Patients (prediction)	1336	1658	2056	2551	3165	3926	4870	6042

2015			
Month	01	02	03
Patients (prediction)	7496	9298	11534

Table 2. The death added per month

2014								
Month	05	06	07	08	09	10	11	12
Deaths (original)	55	259	359	1022	1591	1648	983	1835
Deaths (prediction)	468	586	735	920	1153	1445	1811	2269

978-1-4673-7143-8/15 $31.00 © 2015 IEEE
DOI 10.1109/ICMTMA.2015.315

2015			
Month	01	02	03
Deaths (prediction)	55	259	359

The result indicates that the number of the infected people and the death per month will increase continuously in three months. So effective medicine should be used to optimize the Ebola's current strain. Then this paper builds a model to predict the dose of medicine needed.

III. THE NEEDED MEDICINE MODEL

A. *Reproductive Rate Model*

In this section, R_0 (basic reproductive rate) is used to determine whether or not an infectious disease can spread through a population. When $R_0 < 1$,the infection will die out in the long run. But if $R_0 > 1$, the infection will spread in a population. Generally, the larger the value of R_0, the harder it is to control the epidemic. By applying the reproductive rate model, we predict the medicine needed accurately.

1) We assume that the time that vaccines take effects is the beginning of February 2015. Then we can set the goal *Re'* at the end of April.

2) We consider January 6th, 2014 as the time origin (t=0) and 15 days as time interval. Furthermore, maximum likelihood estimates for R_0 and d were 1.79 (95% CI 1.78-1.81) and 0.00922 (95% CI 0.00879-0.00966) respectively. Then we can calculate *Re* without the apply of the vaccines by employing the formula:

$$\mathrm{Re} = R_0(1+d)^{1-2t}$$

3) W Then based on *Re* and the goal *Re'*, we can obtain *V* which denotes the injection rate of the three most serious Ebola countries (Guinea, Sierra Leone, Liberia). We set the cure rate *E* as 100%:

$$\mathrm{Re}' = \mathrm{Re}(1-VE)$$

4) We use *M* to denote the whole people of the three most serious Ebola countries. Because we assume the time we use vaccines is the beginning of February 2015. So before the beginning of February 2015, *V* equals to 0. Thus, we can calculate the vaccines needed *N* during the three months' time:

$$N = V \cdot M$$

B. *Result*

We can see vaccines needed in three months changes with the value of the goal *Re'* at the end of April. If we want to decline *Re'* to 0.8, we need to produce 5.7 million vaccines in three months. If we want to decline *Re'* to 0.5, we need to produce 11.8 million vaccines in three months.

Table 3. Vaccine needed in 3 months

Re'	0.8	0.7	0.6	0.5
Vaccine needed (million doses)	5.7	7.74	9.78	11.81

IV. THE OPTIMAL TRANSPORT SCHEME

A. *Locations of delivery*

In this section, this paper adopts Minimum Spanning Tree Algorithm to distribute medicine. We regard Guinea, Sierra Leone and Liberia as a whole, and select 8 most severe districts based on confirmed cases (A) and airports (B), which are showed in Table 1. To estimate the minimum distance, this paper assumes that medicine transported by straight airlines.

Table 4. Eight most severe districts selected

Confirmed Cases		Airports	
Number	Districts	Number	Districts
A1	Western Rural	B1	Western Rural
A2	Freetown	B2	Freetown
A3	Conakry	B3	Conakry
A4	Kambia	B4	Kabala
A5	Lunsar	B5	Bo
A6	Kenema	B6	Kenema
A7	Monrovia	B7	Monrovia
A8	Koidu	B8	Kankal

B. *Modeling Process and results*

A minimum spanning tree is a spanning tree of minimum weight among all spanning trees. This paper refers to Google map and gets the straight distances between each district. Then, we find the MST by Prim Algorithms. The best airline to distribute medicine is showed in Figure 3.

Figure 1. Distribution based on Minimum Spanning Tree

The distribution map indicates that most of the severe districts are near the sea. The Transport System based on MST is approximately 1037km. Because of the geographical conditions, deviation might be between (-70, 70) km.

V. OTHER FACTORS

Based on the research above, this paper draw that medicine, isolation and safe burial can directly influence the Ebola epidemic. In this section, this paper will take three other indirect factors including international fund contribution, medical staff and ETC (Ebola Treatment Center) into consideration. To evaluate the weight of each direct and indirect factor to the ease of Ebola, this paper adopt Analytic Hierarchy Process to calculate the weight.

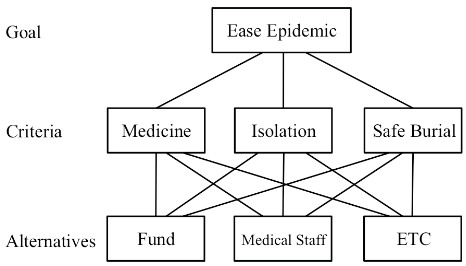

Figure 2. The AHP Hierarchy Diagram

A. Modeling Process

1) By comparing every two metrics in the same hierarchy, we construct the metrics paired-comparative matrix *B* with Saaty's Rule. The elements of b_{ij} it indicate the difference.

Table 5. Table degree method diagram

Implication	The value of b_{ij}
u_i and u_j are equally important	1
u_i is slightly important than u_j	3
u_i is more important than u_j	5
u_i is strongly important than u_j	7
u_i is strongly important than u_j	9

2) Let the largest eigenvalues of the matrix be λ_{max}. The corresponding eigenvectors is $u=(u_1, u_2, u_{3...} u_n)^T$. Normalize the eigenvectors u to get

$$x_i = \frac{u_i}{\sum_{i=1}^{n} u_i}$$

At the same time, we can get the weight vector.

3) The consistency index is $CI=(\lambda_{max}-n)/(n-1)$ (n=3). The consistency ratio is $CR=CI/RI$. When $CR<0.10$, the consistency of judgment matrix *B* can be accepted, otherwise, the judgment matrix should make some suitable amendments.

Saaty had given the value of *RI*

Table 6. Average random consistency index RI

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Based on the theory of AHP, we can construct the judgment matrix. The judgment matrix *B* of the target layer and the judgment C_1, C_2, C_3 of the Criteria layer are:

$$B = \begin{bmatrix} 1 & 3 & 5 \\ 1/3 & 1 & 5 \\ 1/7 & 1/5 & 1 \end{bmatrix} C_1 = \begin{bmatrix} 1 & 2 & 3 \\ 1/2 & 1 & 2 \\ 1/3 & 1/2 & 1 \end{bmatrix}$$

$$C_2 = \begin{bmatrix} 1 & 1/2 & 1/5 \\ 2 & 1 & 1/3 \\ 5 & 3 & 1 \end{bmatrix} C_3 = \begin{bmatrix} 1 & 1/7 & 1/2 \\ 7 & 1 & 5 \\ 2 & 1/5 & 1 \end{bmatrix}$$

We acquire the largest eigenvalues of the matrix by MATLAB.

$\lambda_B = 3.0649$; $\lambda_{C1} = 3.0092$; $\lambda_{C2} = 3.0037$; $\lambda_{C3} = 3.0142$

At the same time, we obtain the weight vector:

$$W_B = (0.6434, 0.2828, 0.0738)^T, W_{C1} = (0.5390, 0.2973, 0.1638)^T$$

$$W_{C2} = (0.1222, 0.2299, 0.6479)^T, W_{C3} = (0.0944, 0.7380, 0.1676)^T$$

The results of the matrix's Consistency test are showed as follows.

Table 7. The results of Consistency test

	B	C_1	C_2	C_3
CI	0.0324	0.0046	0.0018	0.0071
CR	0.0559	0.0079	0.0032	0.0122
Satisfy the consistency	Y	Y	Y	Y

The final weight of the Analytic Hierarchy Process

$$\boldsymbol{W}_{final} = (\boldsymbol{W}_{C_1}, \boldsymbol{W}_{C_2}, \boldsymbol{W}_{C_3}) \cdot \boldsymbol{W}_B$$

$$\boldsymbol{W}_{final} = (0.3883, 0.3107, 0.3010)^T$$

B. Result

Based on the W_{final} above, we can draw the conclusion that the indirect factors including international fund, medical staff and ETC have different significance to the ease of Ebola infection. Obviously, international fund makes the greatest significance, medical staff ranks second and ETC is the least important factor.

VI. CONCLUSIONS

The prediction of Ebola indicates that Ebola will be more and more serious in the near future. Based on Re Model, we can assess the medicine needed in three months. By employing applying MST algorithm, the optimal transport scheme can be obtained. Finally, we find other important factors using AHP to judge their different contributions to Ebola control.

REFERENCES

[1] Dang L, Sifeng L, Management D Y (O E A, et al. The Optimization of Grey Model GM (1,1)[J]. Engineering Science, 2003. (in Chinese)

[2] DN F. An IDEA for Short Term Outbreak Projection: Nearcasting Using the Basic Reproduction Number [J]. Plos One, 2013, 8(12): e83622.

[3] Qiyuan Jiang. Mathematical experiment and Modeling [J]. The practice and knowledge of mathematics, 2001, 31(5): 613-617. DOI: 10.3969/j.issn.1000-0984.2001.05.022.(in Chinese)

[4] Giordano F, Weir M, Fox W P, et al. First Course in Mathematical Modeling, International Edition [J]. Cengage Learning Emea, 2008.