Inhibit the Spread of Ebola

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Abstract - Nowadays, Ebola epidemic situation is more and more severe and out of control. Taking Sierra Leone as an example, we build a reliable and extensive model to control or at least inhibit the spread of Ebola. We select 16 cities that are affected by Ebola according to the news reports. Taking advantage of the conclusions above, we calculate the daily amount of medicines needed for each cities when considering about the demand for vaccines and drugs. Then, we turn the problem into the Location-Allocation Model skillfully when synthesizing the daily amount of medicines and geographic location, so that we get the five optimal distribution centers. We develop the feasible delivery system by the Immune Optimal Algorithm, and finally obtain the daily quantity of medicines of each distribution center and the bell's trend curve of daily new cases. At last, we analyze the convergence of the immune algorithm, the resultant curve trends toward the optimal fitness curve, which proves the stability and practicality of our model.

Index Terms - Ebola virus, Immune Optimization Algorithm, Convergence Analysis

1. Introduction

People pay more and more attention to the Ebola virus diseases (EVD) in West Africa, since the outbreak of the EVD, there have been 22500 reported confirmed, probable and suspected cases of EVD in Guinea, Liberia and Sierra Leone. The whole world people have been closely stirring their concern about the situation of Ebola.

We develop the Immune Optimization Algorithm to Decide the Locations of Delivery. Taking the numbers of infected areas and the demand for vaccines and drugs of Ebola into account, we use the Immune Optimization Algorithm to search for the optimal locations of delivery. Here, the locations of delivery have at least two definitions:

The location is used only to deliver the vaccines and drugs.

The location is used not only to deliver the vaccines and drugs but also others goods and materials.

We focus exclusively on the second notion.

At last, we hold convergence analysis to test our model.

2. The Immune Optimization Algorithm to Location-Allocation Model

A. *Notation for the Location-Allocation Model*

The location-allocation model has NP-hard complexity, which is hard to deal with, therefore, we use the Immune Optimization Algorithm to solve the problem.

B. *The theory of the Immune Optimization Algorithm*[1]

The Immune optimization Algorithm is one of the intelligence algorithms, which simulates the biology immunity systems. The biology immunity system is a highly evolutionary system, which is highly adaptive, highly distributed and self-organizing, it has strong ability of learning, identifying and remembering. The biology immunity system has the following characteristics:

The ability of manufacturing diverse antibodies. Through the cells' proliferation and differentiation, the immunity system can produce lots of antibodies to fight for the various antigens.

Self-adjusted organization. The immunity system has organization to maintain the immune balance, through inhibiting and promoting the antibodies, the immunity system can create right quantity of necessary antibodies by self-adjusted organization.

The immune memory function. Part of the cells produced antibodies will be retained, when homologous antigens intrude our bodies in future, corresponding memory cells will be stimulates quickly and produce lots of antibodies.

The following is the flowchart of the immune algorithm.

TABLE 1 Notion for the location-allocation model

Symbol	Meaning
N	Set of serial numbers for demand points
S	The upper limit for distance between the new distribution center and the its served demand point
M_i	Set of alternative distribution center when the distance of the demand point i is smaller than s($i \in N, M_i \subseteq N$)
w_i	Quantity demanded for demand point i
d_{ij}	The distance from the demand i to its nearest distribution center
Z_{ij}	0-1 variable
p	The number of distribution center
h_j	0-1 variable

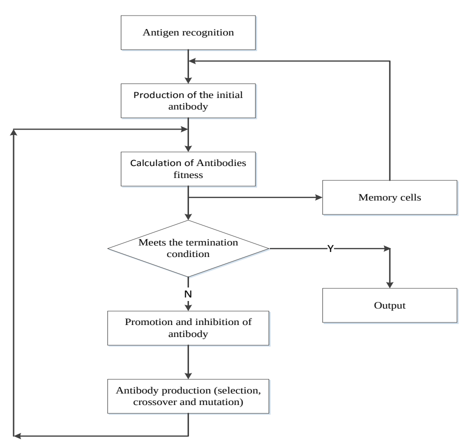

Fig. 1 The flowchart of the immune algorithm

The immunity algorithm takes advantages of the diversity and the maintenance mechanism of the immunity system to maintain the diversity of the colony, get the global optimal solution at last.

The immune algorithm and the genetic algorithm all adopt the group search strategy, and emphasize on the exchange of information between individuals in groups, therefore, they have many similarities, they all experience the cyclical process that "Generate initial population, Compute evaluation standard, Exchange information between individuals in groups, Generate new population", finally, we get the optimal results with a high probability.

The immunity algorithm evaluates individuals by computing affinity, the selection of individuals is also based on the affinity. The affinity of individuals includes the match level between antibodies and antigens and affinity among antibodies, it reflect the diversity of the immunity system, thus the immunity algorithm can fully evaluate individuals and select the individuals more reasonably.

C. The Location-Allocation Model[1]

When satisfying the upper and lower bound of distance, we should find the distribution center among the n demand points and distribute goods and materials to each demand center. The objective function is to minimize the product of demanded quantity between each distribution center and the demand point, and the distance. That is,

$$\min\ F = \sum_{i\in N}\sum_{j\in M_i} w_i d_{ij} Z_{ij}$$

The constraints are as follows:

$$\sum_{j\in M_i} Z_{ij} = 1, i\in N \tag{1}$$

$$Z_{ij} \le h_j, i\in N, j\in M_i, \tag{2}$$

$$\sum_{j\in M_i} h_j = p \tag{3}$$

$$Z_{ij}, h_j \in \{0,1\}, i\in N, j\in M_i \tag{4}$$

$$d_{ij} \le s \tag{5}$$

When $Z_{ij} = 1$, distribution center j supplies for the demand point i, if not, $Z_{ij} = 0$. When $h_j = 1$, we select the point j as the distribution center. The constraint (1) ensures that each demand point can be served only by one distribution center; The constraint (2) ensures that the quantity of the demand point can only be applied by the distribution center, that is, there doesn't exist any customer without distribution center; The constraint (3) stipulates the number of distribution center is p; The constraint (4) stipulates Z_{ij} and h_j are all 0-1 variables; The constraint (5) ensures that the demand points within the scope of delivery.

D. The Immune Optimization Algorithm to solve the Location-Allocation model

We consider about the infectious areas, here, we set the treatment center to be the infection areas, get the relative location to describe the relationships, and taking the quantity of vaccines and drugs demanded for each areas, we use the immune optimal algorithm to solve the location-allocation model and finally get the optimal delivery locations. In the location-allocation model, we set the initial value of the immune algorithm in the following table, the distribution center and corresponding supply relationship is showed in the following figure.

TABLE 2 The initial value for the immune algorithm

parameter	Population size	Memory database	Iterations	Crossover probability
value	20	10	20	0.5
parameter	Mutation probability	Diversity evaluation parameters	Numbers of the distribution center	Upper and lower bound
value	0.4	0.95	5	10000

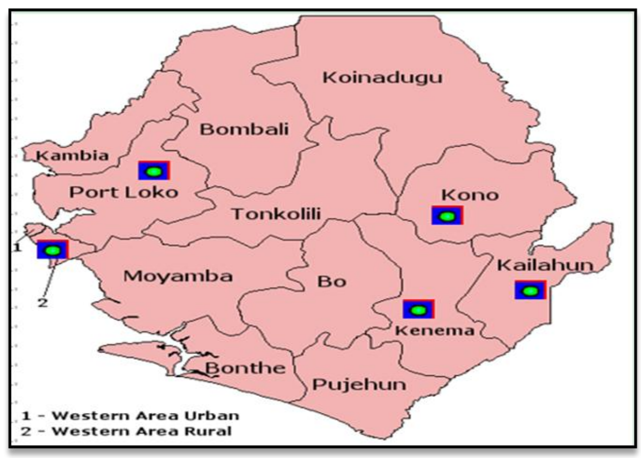

Fig. 2 The locations of delivery, the geographic location in Sierra Leone

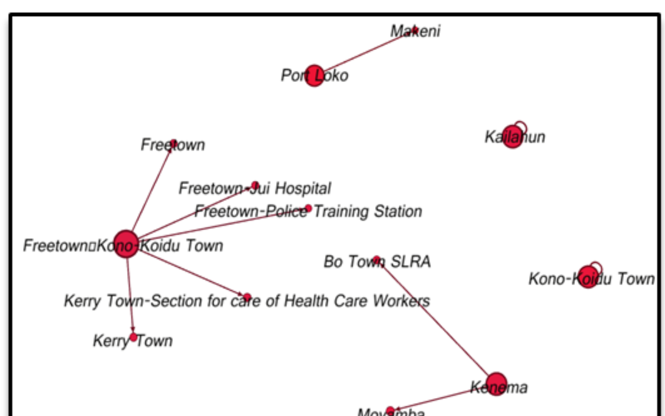

Fig. 3 The locations of delivery, corresponding supply relationships

In the Fig 2 and 3, the bigger red points represents the distribution center, and smaller red points represents the demand points. From the Figure 5, we know that the Freetown Kono-Koidu Town, Port Loko, Kailahun, Kono-Koiu Town, Kenema are the optimal locations of delivery, others are the demand points. The location of Freetown Kono-Koidu Town should supply for the Freetown, Freetown-Jui Hospital, Freetown-Police Training Station, Kerry Town-Section for care of Health Care Workers and Kerry Town; The location of Port Loko should supply for the Makeni; The location of Kailahun and Kono-Koiu Town should supply for themselves; The location of Kenema should supply for the Bo Town SLRA and Moyamba. In addition, all locations of delivery should also supply for themselves.

E. The Quantity of Medicine Needed for Sierra Leone

We give health people vaccines and infected people drugs, according to the assumption that the producing difficulty of the drugs is 30 times more difficult than the vaccines. Based on the mathematics ratio relation, we get the number of medicines demanded for the Sierra Leone, here, the medicines include both drugs and vaccines, we get the results of all demand points considered above.

TABLE3 The demand medicine for Sierra Leone

Demand point	1	2	3	4
Demand for medicines(dose)	493480	283013	278258.5	278259.5
Demand point	5	6	7	8
Demand for medicines(dose)	278258.5	285249	396839	278258.5
Demand point	9	10	11	12
Demand for medicines(dose)	278258.5	119438	289041	607790
Demand point	13	14	15	16
Demand for medicines(dose)	462780	283013	278258.5	119438

The number of 1-16 respectively represent Makeni, Port Lokko, Freetown(1), Freetown(2), Goderich(near Freetown), Moyamba, Kono-Koidu Town, Lakka, Freetown-Jui Hospital, Kerry Town, Bo Town SLRA, Rural Kenema Field Hospital, Kailahun, Port Lokko, Lunsar, Freetown-Police Training Station, Kerry Town-Section for care of Health Care Workers.

The total number of medicines for Sierra Leone is about 5009633 doses. according to the location-allocation model, we the demand of medicines for each distribution center. The following is the result of the five distribution center.

TABLE 4 The demand of medicines for the five distribution centers

Distribution center	2	5	7	12	13
Demand points served	1,2,14	3,4,5,8,9,10, 15,16	7	12,6,11	13
Demand for medicines(doses)	1059506	1908428	396839	1182080	462780

If the five distribution centers can supply corresponding medicines for their served demand points, the spread of Ebola can be under control.

3. Convergence Analysis

The Convergence Analysis is used for the Immune Optimal Algorithm, in order to verify the convergence of our result. The following is the convergence curve of the immune optimal algorithm.

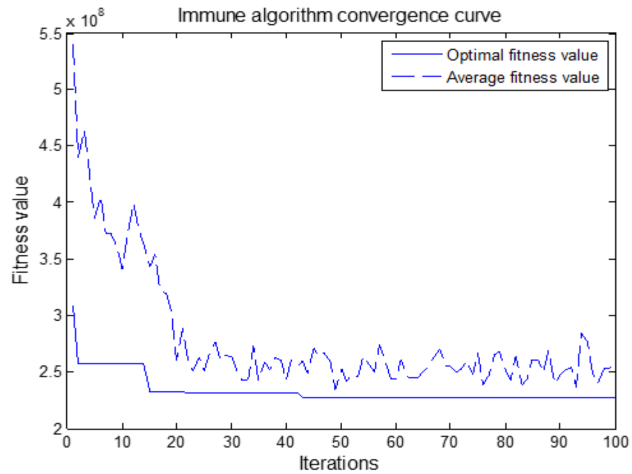

Fig. 4 The convergence curve of the immune optimal algorithm

The fitness value of the average fitness value trends towards the optimal fitness value, therefore, the results of the location-allocation model is convergent.

4. Strengths and Weaknesses

A. Strengths

We take transportation, the requirement of the drugs and vaccines and the spread of Ebola virus into consideration, and convert the question into a problem, which is used to select the location of the distribution centers, at last, we can optimally control the spread of Ebola virus.

The Ebola virus can be controlled within the next 6 to 9 months in our model.

We take Sierra Leone as an example which is one of the countries where the Patients' conditions are most serious, therefore, once the spread of Sierra Leone can be controlled, not only the workload can be reduced, but also the problem can be dealt with.

We develop the location-allocation model in place of the distribution model and the location model, which simplifies the problems.

B. Weaknesses

In the previous assumptions, we assume that the money is enough, if the realities don't satisfy the assumption, we may miss the optimal control time.

In our model, we don't consider the influence of the deaths to the popularity, so our model may have errors.

In our model, we don't consider the variation of Ebola, once that there exists variation in Ebola virus, the quantity of drugs and vaccines must run short in our model.

References

[1] Feng Shi, Hui Wang, Lei Yu, Fei Hu. 30 Cases Analysis of Intelligence Algorithm in MATLAB. Beijing: Beijing University Press, 2011.

[2] http://world.haiwainet.cn/n/2014/0928/c345805-21148977.html.

[3] http://en.wikipedia.org/wiki/Sierra_Leone.