Models of Eradicating Virus

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Abstract：

To eradicate Ebola, we build models from 5 aspects.

Firstly, we build *disease transmission model* with the example of Uganda, one of the countries which have Ebola infection. This model aims to analyze the relationship between the spread of Ebola and the measures of controlling disease. According to the relationship within people in different period of disease, we establish differential equations, and obtain the spread forecasting of Ebola. By comparing the results of different control measures, we find that it is important to isolate patients in time and strengthen the health awareness of the public.

Secondly, to determine the quantity of the medicine needed and the frequency of drug supply, we use the method of fitting curve and ANOVA. According to the infection rate, we find that the need of drugs is urgent and the supply of new drugs must be completed in 4 years. In addition, we calculate the supply of drugs is 2.2 million every 4 years.

Thirdly, to provide financial support to Uganda with drugs needed, we want to know the cost of drugs. To solve this problem, we use the method of *linear interpolation* to get the coherent cases data from 2000 to 2014, then we use *grey prediction method* to estimate the number of people at risk of infection from 2015 to 2025. Finally, we assess the spending of drugs according to the cost of the different stages of pharmaceuticals available in the Reference [1]. The cost of drugs shows an upward trend year by year, and in this year, drug investment of $2054.66million is still needed.

In addition, to reduce drug price and compress the drug sales, we devise a scheme to provide financial support for pharmaceutical companies on the drug manufacture with the method of *nonlinear programming*. The best of the programming result for pharmaceutical companies is to provide them with $208 million's government budget and $207.3432 million's public health benefits in drug development stage, $200.6 million's government budget and $143.23 million' public health benefits in drug sales stage.

Finally, we design an evaluation model to establish cooperation among companies to reduce the cost and risk according to the different advantages of pharmaceutical companies.

Likewise, other African countries affected by Ebola, such as Guinea, Liberia and Sierra Leone, can be analyzed with the same models above to determine the spread of the disease, the quantity of the medicine needed, the cost and the investment of drugs.

KEYWORDS: Ebola; Disease transmission model

1. Introduction

1.1 Background

The deadly hemorrhagic fever Ebola was first discovered in 1976, and it has haunted the public imagination for twenty year. Since December 2013, an ongoing outbreak of Ebola in West Africa has infected at least 567 people in Guinea, Sierra Leone and Liberia, including 350 who died, according to the World Health Organization. The outbreak appears to be the largest in history.

In spite of the world medical association announcing that their new medication could stop Ebola and cure patients whose disease is not advanced, Eradicating Ebola thoroughly has been an arduous journey.

Nowadays, the main obstacles to eradicate Ebola are shown as follows:

1. It is difficult to forecast the spread of the disease accurately;

2. The lack of new effective drugs;

3. Because of economic backwardness, countries in

West Africa do not have a complete public health benefits system, nor enough government budgets for medicine and drugs.

4. The period of new drugs coming into market is too long.

Our models aim at solving the problem above and providing some positive suggestions to the government, associations and pharmaceutical companies.

1.2 Assumptions

1. Assume all the cured patients getting out of the infection system;

2. Effective contact with disease sources inevitably leads to infection;

3. People have no infection ability in the incubation period.

4. Do not consider cross-impact caused by virus mutates or other virus;

5. Assume unit output as the average dosage of curing a patient.

6. Supply-demand relationship does not affect the change of drug price: decline of price will not lead to higher demand for drugs;

7. The governmental health budget is completely put into the drug research and development;

8. Output is equal to the sales, there is no stock;

2. Model Design

2.1 The spread of the disease

This model mainly analyzes the relationship between the spread of Ebola and the measures of controlling disease, and gives some positive suggestions to government and health department.

2.1.1 Problem assumption

1. Assume all the cured patients getting out of the infection system;

2. Effective contact with disease sources inevitably leads to infection;

3. People have no infection ability in the incubation period.

2.1.2 Establishing of the model

The model divides people who are in the infection system into three categories:

Category S: the susceptible, people who are not getting ill, but have contacted with infected person and at a high risk in infection.

Category I: the infected, people who have been infected with Ebola.

Category R: the removed, people who are isolated due to infection. They are not susceptible people, nor infected people; in fact they have removed from the infection system.

We establish differential equations according to the relationship within three kind's people above:

$$\begin{cases} \dfrac{dS}{dt} = -kIS \\ \dfrac{dI}{dt} = kIS - hI \\ \dfrac{dR}{dt} = hI \\ S + I + R = N \end{cases}$$

Variables and symbols:

k : Infectious rate: the average number of people that each infected person effectively contacts with in one day.

h : Removed rate: the percentage that the number of the cured and the dead account for the number of the infected per unit time.

$S(t)$: The total number of susceptible people.

$I(t)$: The total number of infected people.

$R(t)$: The total number of removed people.

N : The population of infection area.

The accumulative number of infection is far less than the total population, so the infected people and the removed people have little influence in the total number of the susceptible people. The total number of susceptible people I is a constant:

$$\begin{cases} \dfrac{dI}{dt} = kIN - hI \\ \dfrac{dR}{dt} = hI \end{cases}$$

We do not take the removed people into account, so the equations above are actually an ordinary differential equation:

$$\frac{dI}{dt} = kNI - hI = \lambda I$$

In this equation: $\lambda = kN - h$

It is easy to get:

$$I(t) = I_0 e^{-\lambda t}$$

And I_0 is initial value.

Based of analysis above, we find out when numbers of patients is far less than total population, the number of patients will increase in index. To solve this problem, we improve the model.

We divide people in infection system into five categories:

Free Carrier $f(t)$: the number of people who carry the virus (they have no infection ability in the incubation period).

Daily patient $x(t)$: the number of people who are isolated per day.

Isolated People $y(t)$: the number of people who are suspected of carrying the Ebola for having contacted with the free carriers.

Effective Contact $z_1(t)$: the number of people who have contacted with the free carriers and been infected with the virus.

Ineffective Contact $z_2(t)$: the number of people who have contacted with the free carriers but been not infected with the virus.

The spread of infected individual is shown in figure 1. Free carriers have a incubation period of 8 ~ 10 days and have no infection ability; 10 days later, free carriers are sick and effectively contact with k_1 people every day; after 2 days (the 12th day), they are isolated and ineffectively contact with k_2 people per day before the isolation. People who have contacted with carriers and can be controlled (account for β in the total contacts) are regarded as suspect patients 3 days later. Effective contacts in suspect patients are regarded as daily patients in the 12th day, and other people in effective contacts are still regarded as free carriers.

Use mathematical model to describe the relationship within variables:

$$\begin{cases} z_1[i+5] = k_1 f[i] \\ z_1[i+6] = k_1 f[i] \\ z_2[i+j] = k_2 f[i] (j = 0,1,2,\cdots 6) \\ f[i] = (1-\beta) z_1[i] \\ x[i] = f[i-6] + \beta z_1[i-6] \end{cases}$$

k_1: Effective contact rate, the number of people that a free carrier effectively contacts with per day.

k_2: Ineffective contact rate, the number of people that a free carrier ineffectively contacts with per day.

3. Conclusions

To eradicate Ebola , we build models from 5 aspects, and reach the following conclusion:

1. By analyzing the relationship between the spread of Ebola and the measures of controlling disease, we know that strengthening the power of isolation control can significantly reduce the period of infection and strengthening the awareness of the public can significantly reduce the total number of infection. So we suggest government and health department isolating patients in time and strengthening the health awareness of the public.

2. The maximum period of the new drugs supply is 4 years, and the approximate need of drugs is 2.2 million every 4 years.

3. The cost of drugs shows an upward trend year by year, and in this year, drug investment of $2054.66million is

still needed.

4. To reduce drug price and compress the drug sales, we devise a scheme to provide financial support for

including $208 million of government departments, $207.3432 million of public health departments, and the investment in drug sales stage being $343.8 million, including $200.6 million of government departments, $143.23 million of public health departments.

In the other hand, those poorer countries in Africa like Uganda can get financial help and learn more measures about budget distribution for drugs from the US.

5. Eradicating Ebola needs the cooperation of big pharmaceutical companies and associations from all over the world. $y_1, y_2, y_3, \ldots, y_n$ represent respectively n company's nearly three years' average annual production quantity of drug, when ρ' (the growth of speed) $\leq \eta'$ (a threshold value), choosing a combinations of $y_1, y_2, y_3 \cdots y_i$ to comprehensively manufacture medicine. For more details, see **2.5**.

Likewise, other Africa countries affected by Ebola, such as Guinea, Liberia and Sierra Leone, can be analyzed with the same models above to determine the spread of the disease, the quantity of the medicine needed, the cost and pharmaceutical companies on the drug manufacture. The US budget distribution is a good example with the investment in drug development stage being $415.2 million, the investment of drugs. Only through the joint efforts of the whole world, can we conquer Ebola and build a more beautiful world.

References

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[3] http://apps.who.int/gho/data/view.ebola-sitrep.ebola-summary-20141119?lang=en

[4] http://www.fda.gov/Drugs/default.htm

[5] http://www.nsf.gov/statistics/