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Forest Fires Model and SIR Model Used in Spread of Ebola Virus in Prediction and Prevention

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ABSTRACT

Ebola has been repeatedly ravaged Earth. Since the end of 2013, Ebola swept West Africa, has caused tens of thousands of people infected or death. Based on this, it is an effective way to establish an effective, workable, practical significance of the mathematical model for health care workers and researchers to help in the fight against the Ebola epidemic. We base on assumptions of population stability in West Africa, the epidemic is no longer continue to expand, the drug can effectively reaches the hands of the patient once it put in; By SIR model, the most classic model in infectious disease, and published data, we realize the epidemic prediction. And base on them, by using forest fires model of cellular automata and two-compartment model of pharmacokinetic, we analyze and forecast three aspects for Vaccine/drug Efficacy, Epidemic Area, Vaccine/drug Production and R&D Speed. We propose drug distribution points in West Africa should be in accordance with changes by the strength of the Epidemic area, and drug development should begin at the growth of the epidemic stage 1/3, and 1/2 of the growth of the epidemic stage clinical trials in order to achieve the best results. Although limited ability, we analyze factors with a single control and then propose solution. But we built the best model out.

Keywords: *Ebola Virus Disease, Eradicating Ebola Epidemic, SIR Model, Forest-Fire Model, Two-Compartment Model, Epidemic Prevention*

I. INTRODUCTION

Ebola Virus Disease (EVD) is a human disease, which is caused by the Ebola Virus (EBOV). EVD first appeared in Central Africa Zaire (which is Democratic Republic of Congo now) and South Sudan in 1976. After that, EBOV has outbreak around 24 times in Central Africa, all of these happened in remote areas away from the local city. Ebola mortality rate of 90%, the incubation period of infection ranging from 2 to 21 days. In the early stages of the disease, Ebola virus may not be highly contagious, so people don't be infected even they touch patient in this period. As the disease progresses, the body fluid from the patient will be excluded with a high degree of biological risk. Also, Ebola Virus is usually transmitted through blood and other body fluids. Fortunately, there is no confirmation that it can spread by air to anyone. [1, 2, 3, 4]

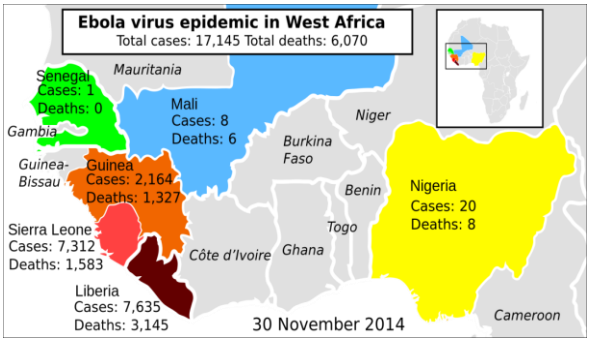

Figure 1: Ebola virus epidemic in West Africa (Since 30 Nov 2014) [6]

The spread of Ebola virus is an infectious disease problem. In the field of mathematical modelling has been a lot of research about it. The SIR model is more complete one. SIR model by establishing a set of differential equations, as a general propagation mechanism establish a centralized model. We will select the number of confirmed cases which published by the World Health Organization (WHO) for the

establishment of SIR model. We choose West Africa as the main research district of Ebola virus infection. It is well known cases of Ebola virus infection in Liberia, Sierra Leone and Guinea, such as the three countries are becoming the focus of attention. [1, 2, 5, 6, 8]

In addition, we choose Forest Fires model to research about any of possible factors which can affect the Ebola outbreak. By using Forest Fires model of Cellular Automata, we can analogy the patient to the ignition point. And effective cure meaning Firemen extinguishing, and the optimal solution is what we want.

First of all, we need to conduct a diagnostic population in Ebola epidemic area, determine the epidemic stricken area and the epidemic situation by SIR model. Then, we discuss the theory on three aspects of Vaccine/Drug Efficacy, Epidemic Area, Vaccine/Drug Production and R&D Speed. Finally, through the establishment of Forest Fires model to put forward a reasonable and effective solution for Ebola epidemic.

II. ASSUMPTIONS

- For an effective cure model, we require if a district spent 42 days and found no new cases, we can declare the end of Ebola virus outbreak, which is an effective cure program. Here, 42 days showing the twice than Ebola maximum incubation period (21 days). And this 42 days period from anyone in the country with confirmed or probable cases of Ebola appeared last contact date since the beginning.
- For Ebola epidemic control has many factors, here, we select the greatest impact in three factors: Vaccine/Drug Efficacy, Epidemic Area, Vaccine/Drug Production and R&D Speed, as considerations for the relevant modeling and design.
- Cure patients have immunity, after that no longer suffer Ebola anymore.
- The incubation period is obtained from virus infection to the onset of symptoms in the time interval, it lasts 2 to 21 days. When the patient began showing symptoms, he/she is contagious.
- In each model, is not considered drug loss during transport.
- Because Ebola epidemic has been controlled effectively, so we will not discuss uncontrolled, no latency infection model.

III. SYMBOL DESCRIPTION

In the section, we use some symbols for constructing the model as follows.

Table 1: The Description and Explanation of Symbol in this Paper

Symbol	Description
$S(t)$	Susceptible group people per unit time
$I(t)$	Incidence group people per unit time
$R(t)$	Exit group people per unit time
$E(t)$	Latent group people per unit time
θ	Week Contact Rate Constant
λ	Rescue Rate/ The speed of each ambulance personnel
$f_0(t)$	The rate of administration
λ_1	The speed of production of medicines
M, N	Constant coefficient

Ps: Other symbols instructions will be given in the text.

IV. PREPARED MODEL ABOUT EBOLA OUTBREAK

4.1 Model in Non-considering Latency

4.1.1 Assumption

1) In the period of Ebola Virus spreads, the total number of people within West Africa for N unchanged, Neither consider life and death, nor migration, the crowd divided into four groups: Susceptible S, Incidence I and Exit R (including those who died and recovery). In the time t, These three types of people in the proportion of the total number of people are $S(t), I(t), R(t)$.
2) The growth rate with time of $I(t)$ and $S(t)$ are proportional. The constant of proportionality is θ. The speed of reduce the number of patients is directly proportional to the total number of patients. The constant of proportionality is ν. Cure patients have immunity, after that no longer suffer Ebola anymore.
3) The sum of $S(t), I(t), R(t)$ is a constant 1.

4.1.2 Constitution

Here is the West African Ebola epidemic WHO confirmed the number of cases; we pick up some days in the whole chart:

Table 2: West African Ebola epidemic WHO confirmed the number of cases [2]

DATE	CASES	DEATHS
13-May	245	164
20-May	270	181
27-May	309	200
4-Jun	354	208
11-Jun	438	231
18-Jun	528	337
25-Jun	599	338
2-Jul	759	467
9-Jul	888	539
16-Jul	1048	632
21-Jul	1201	672
28-Jul	1440	826
4-Aug	1711	932
11-Aug	1975	1069
18-Aug	2473	1350
25-Aug	3069	1552
1-Sep	3707	1848
8-Sep	4366	2177
15-Sep	5339	2586
22-Sep	6574	3043
29-Sep	7192	3286
6-Oct	8386	3988

Susceptible people become patient after effective contact with other patient. Set $\theta S(t)$ as the number of susceptible people contact effective to patient per day. The patients with number of $NI(t)$ can make $\theta S(t)NI(t)$ susceptible people become latent virus people. So we can conclusion as:

$$\frac{dS(t)}{dt} = -\theta S(t)I(t) \quad (1)$$

And the change of Exit in unit of time is equal to reducing the incidence as follows:

$$\frac{dR(t)}{dt} = \nu I(t) \quad (2)$$

The change of incidence is equal to the part of susceptible-in, we can express as:

$$\frac{dI(t)}{dt} = \theta S(t)I(t) - \nu I(t) \quad (3)$$

We define the healthy people are S_0 and the patients are R_0 at the start time. And set $R_0 = 0$.

4.1.3 Solution

The equations (1), (2), (3) cannot find out the analytical solution, so we set a new variable σ, which is equal θ / ν.

So, we can solute the equation as follows:

$$i = (s_0 + i_0) - s + \frac{1}{\sigma}\ln\frac{s}{s_0} \quad (4)$$

Now, we are analysis of the change of the $S(t), I(t), R(t)$ as follow:

1) Whatever S_0, R_0, patients will be disappear, its $i_\infty = 0$.
2) The proportion of heathy people who don't be infected at the last time is s_∞, and it's $(s_0 + i_0) - s + \frac{1}{\sigma}\ln\frac{s}{s_0} = 0$ root in $(0, 1/\sigma)$.
3) If $s_0 > 1/\sigma$, then at first beginning: $i(t)$ will be increase first. When $s_0 = 1/\sigma$, $i(t)$ reach the maximum, then $i(t)$ decrease and tends to zero, and $s(t)$ monotone decreasing to s_∞.
4) If $s_0 \le 1/\sigma$, then $i(t)$ monotone decreasing to five, and $s(t)$ monotone decreasing to s_∞.

We found that the people health level is higher, the smaller weekly contact rate gets; and medical level is higher, on the higher cure rate, and the is smaller. So improve the level of health and medical level can prevent infectious diseases from spreading.

We can combine with the specific situation of West Africa and assumptions analysis as follows:

According to the obtained data to draw a West African Ebola prevalence curves and cure number change curve:

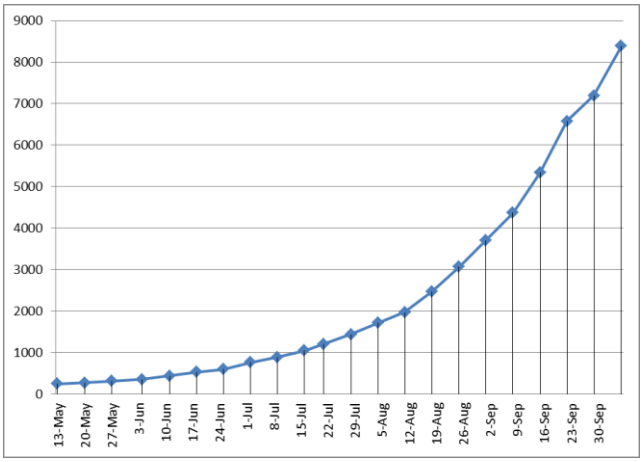

Figure 2: The number of patients change chart

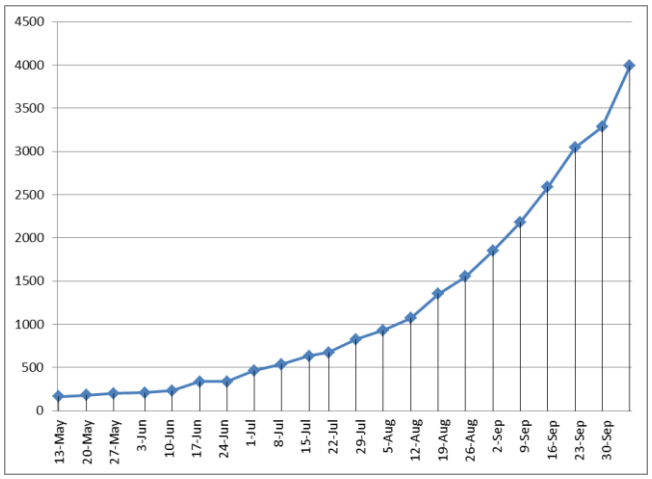

Figure 3: The number of cure (including death) people change chart

According to the figure, Ebola virus shows the form of spread in West Africa, which is now, belongs to the case of $\sigma = \theta / \nu > 1/ s_0$. From the range of assumptions, we can know θ between 1400~1600. Now we take θ =1600, it shows $\nu < \theta / (1/ s_0)$ = 1600. In other words, the average number of West African cure for a maximum is 1600 people per week; this is different from the data released by World Health Organization. If that, the number of cure people in 30-Sep is 1600*23=36,800; this is far away from the actual situation. The reason of this problem has the following several aspects:

Firstly, the average number of each patient's weekly effective contact estimate is smaller. It's not a direct relationship simply; it should be a multiple party relationship, even exponential relationship.

Secondly, West African Ebola epidemic data from WHO has hysteresis.

Thirdly, $s_0 \approx 0$ may not be set up in West Africa. We can put those strong, pay attention to their personal health people are excluded.

4.2 Model in Considering Latency

4.2.1 Assumption

1) In the period of Ebola Virus spreads, the total number of people within West Africa for N unchanged, Neither consider life and death, nor migration, the crowd divided into four groups: Susceptible S, Latent E, Incidence I and Exit R (including those who died and recovery). In the time t, These four types of people in the proportion of the total number of people are $S(t), E(t), I(t), R(t)$.
2) The average number of effective contacts for each patient weekly is θ, we can call Weekly Contact Rate. When infected people and susceptible people make effective contact, the susceptible one will change into the latent group. And the latent crowd converted into patient group later again, patient group be cured.

4.2.2 Constitution

Susceptible contact patients effectively and be incubation. Let $\theta(t)S(t)$ be a weekly average number of effective contact susceptible of each patient. The number of $NI(t)$ patients can make number of $\theta(t)S(t)NI(t)$ susceptible become latent group per week. So we have an equation as follow:

$$N\frac{dS(t)}{dt} = -\theta(t)S(t)NI(t) \qquad (5)$$

The simplification as follow:

$$\frac{dS(t)}{dt} = -\theta(t)S(t)I(t) \qquad (6)$$

The latent group change is equal to the transfer number of susceptible group minus a transfer number of patients. So the equation is

$$\frac{dE(t)}{dt} = \theta(t)S(t)I(t) - \alpha(t)E(t) \quad (7)$$

Among them, $\alpha(t)$ says the latency weekly morbidity, each latent average effective number of patients.

The change for Exit group in unit time is equal to patients decrease. The equation is

$$\frac{dR(t)}{dt} = \nu(t)I(t) \quad (8)$$

Wherein $\nu(t)$ represent Week Withdrawal Rate, the number of average effective condition of each patient recover or death.

Changes in incidence of people are equal to the number of people into the latent. The equation is

$$\frac{dI(t)}{dt} = \alpha(t)E(t) - \nu(t)I(t) \quad (9)$$

And

$$S(t) + I(t) + R(t) = 1 \quad (10)$$

The initial time susceptible group, infected group and recover immune group are $s_0(s_0 > 0), i_0(i_0 > 0), r_0 = 0$.

4.2.3 Solution

The incubation period is obtained from virus infection to the onset of symptoms in the time interval; it lasts 2 to 21 days. When the patient began showing symptoms, he/she is contagious. Because the incubation period of group cannot be determined, so they can be regarded as part of a susceptible group. Therefore, the solving process is same as non-considering latency.

V. MODEL BASED ON FACTORS & PREPARED MODEL AS ABOVE

5.1 Vaccine/Drug Efficacy

5.1.1 Assumption

For the efficacy of the drug in the human body, we will be distributed in the human body which to build a two-compartment model. Use differential equation model describing the dynamic characteristics. In order to further simplify the problem, to obtain linear equations with constant coefficients, the following assumptions are:

1) The body is divided into the central compartment (Compartment I) and peripheral compartment (Compartment II), the volume of the two chambers (i.e. blood volume or volume of drug distribution) remains unchanged in the process.
2) Drugs transfer rate from a compartment to another and vitro rate to the exclusion, is proportional to the plasma concentration of the chamber.
3) Only the central compartment exchange drug with vitro that is drug from the vitro into the central , and finally excreted from the central compartment. Compared with the number of metastatic and exclusion, absorption of the drug can be ignored.

5.1.2 Constitution

According to the model assumptions, and make a schematic diagram of a two-compartment model:

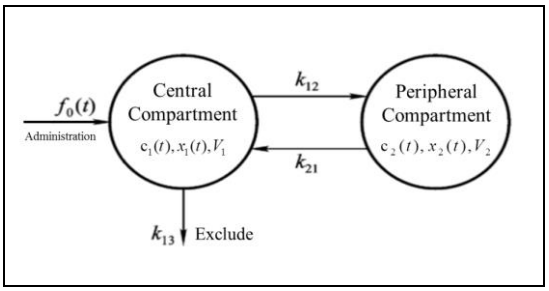

Figure 4: A schematic diagram of a two-compartment model

Where $c_i(t), x_i(t), V_i(t)$ denote compartment of i ($i = 1, 2$) plasma concentration, dose and volume. k_{12} and k_{21} is the rate coefficient of drug transfer between the two compartments. k_{13} is the excluded rate coefficient of the drug from the Compartment I to the vitro. $f_0(t)$ is the rate of administration.

According to the assumptions and Figure 4 can write the dosage volume of two compartments $x_1(t), x_2(t)$. $x_1(t)$ satisfies the differential equation of the rate of change is combine with transfer Compartment I to II $-k_{12}x_1$,

Compartment I exclude to vitro $-k_{13}x_1$, transfer Compartment II to I $k_{21}x_2$ and Administration $f_0(t)$. $x_2(t)$ satisfies the differential equation of the rate of change is combine with transfer Compartment I to II $k_{12}x_1$ and transfer Compartment II to I $-k_{21}x_2$. So here we give equations as follow:

$$\begin{aligned} x_1(t) &= -k_{12}x_1 - k_{13}x_1 + k_{21}x_2 + f_0(t) \\ x_2(t) &= k_{12}x_1 - k_{21}x_2 \end{aligned} \quad (11)$$

$x_i(t)$ and plasma concentration $c_i(t)$, is clearly the relationship between the atrioventricular volume $V_i(t)$. So, here is the equation:

$$x_i(t) = V_i c_i(t), i = 1,2 \quad (12)$$

Equation (12) assignment equation (11) can be given:

$$\begin{aligned} c_1(t) &= -(k_{12} + k_{13})c_1 + \frac{V_2}{V_1}k_{21}c_2 + \frac{f_0(t)}{V_1} \\ c_2(t) &= \frac{V_1}{V_2}k_{12}c_1 - k_{21}c_2 \end{aligned} \quad (13)$$

We can get the general solutions as follow:

$$\begin{aligned} \overline{c_1(t)} &= M_1 e^{-\alpha t} + \mathrm{N}_1 \mathrm{e}^{-\beta t} \\ \overline{c_2(t)} &= M_2 e^{-\alpha t} + \mathrm{N}_2 \mathrm{e}^{-\beta t} \end{aligned} \quad (14)$$

Among them, the equations are established as follow:

$$\begin{aligned} \alpha + \beta &= k_{12} + k_{21} + k_{13} \\ \alpha\beta &= k_{21}k_{13} \end{aligned} \quad (15)$$

5.1.3 Solution

Taking into account the Ebola virus infection commonly used method of administration; here we give two methods as the following:

1) Rapid intravenous injection

Setting the rate of administration $f_0(t)$, in this condition, we can make the model simply at t = 0, the instantaneous drug dose D_0 input central compartment, immediately rose to D_0V_1. So we can get equations:

$$f_0(t) = 0, c_1(0) = \frac{D_0}{V_1}, c_2(0) = 0 \quad (16)$$

Solution of equations (13) (16) can be obtained:

$$\begin{aligned} c_1(t) &= Me^{-\alpha t} + Ne^{-\beta t}, M = \frac{D_0(k_{21} - \alpha)}{V_1(\beta - \alpha)}, N = \frac{D_0(\beta - k_{21})}{V_1(\beta - \alpha)} \\ c_2(t) &= \frac{D_0 k_{12}}{V_2(\beta - \alpha)}(e^{-\alpha t} - e^{-\beta t}) \end{aligned} \quad (17)$$

So, as above, we can conclude:

Equation shows a rapid intravenous injection model. While in clinical trials, the people who infected with Ebola virus immune responses were damaged. And currently developed drugs for human use, either ZMapp, TKM-Ebola or JK-05, requires repeated dosing in order to maintain effective plasma concentrations during treatment. Based on this, we fixed a dosing interval, an interval of every treatment administered, modeling impulsive differential equations. But this is beyond our ability, and then we will fight with Ebola by other modeling tools.

2) Constant rate infusion

When intravenous infusion at a rate of constant k_0, set dosing rate $f_0(t)$, the initial condition is

$$f_0(t) = k_0, c_1(0) = 0, c_2(0) = 0 \quad (18)$$

Solution of equations (13) (18) can be obtained:

$$\begin{aligned} &c_1(t) = M_1 e^{-\alpha t} + N_1 e^{-\beta t} + \frac{k_0}{k_{13}V_1}, c_2(t) = M_2 e^{-\alpha t} + N_2 e^{-\beta t} + \frac{k_{12}k_0}{k_{21}k_{13}V_2} \\ &M_2 = \frac{V_1(k_{12} + k_{13} - \alpha)}{k_{21}V_2}M_1, N_2 = \frac{V_1(k_{12} + k_{13} - \beta)}{k_{21}V_2}N_1 \end{aligned} \quad (19)$$

So, as above, we can conclude:

When t is large enough, $c_1(t), c_2(t)$ will tend to 3rd of equations (19), the right side represents a constant value. In fact, after the infusion is stopped if $t = T$ (T is the time when stopping injection or infusion), then $c_1(t), c_2(t)$ exponentially decays to zero after $t > T$.

Derived from human infections EBOV valid data obtained, was acquired immunity in fatal and non-fatal cases, significantly different. This implies that the acquired immunity in EBOV infection important role. Study of survivors showed the body to produce specific IgM antibody was 2 days after the attack, after 5 ~ 8 days to produce specific IgG antibodies. In contrast, in fatal cases, only 30% of patients were detected low levels of specific IgM, and specific IgG is not detected. In the early days after the onset of symptoms appearing acquired immune response can have a major impact on patient survival; survivor after EBOV infection occurs early inflammatory response supported this conclusion.[10,11,12]

5.2 Epidemic Area

5.2.1 Analysis

Rescue progress generally proportional to the range of the virus infection, but the infection scope of the outbreak of Ebola virus, and treatment time are required to cure, and treatment time depends on the number and speed of drug delivery, the drug in the shortest possible time delivery of more treatment sooner. Rescue costs and the number of delivery of both drug-related, but also with the duration of drug delivery related. Setting time $t=0$ for Ebola outbreak start, begin rescue work time for $t=t_1$, the rescue is completed in time for $t=t_2$. Set time t with affected by the Ebola virus area range is $B(t_1)$, After the affected areas by Ebola is $B(t_2)$. To do rough statistics for the area affected by the Ebola virus:

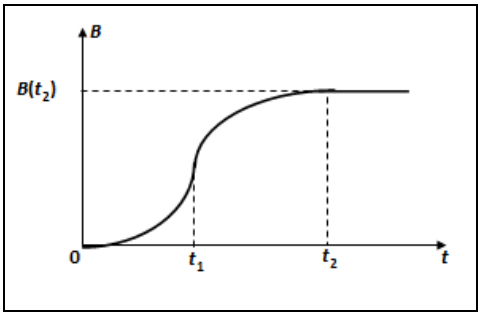

Figure 5: Rough statistics for the area affected by the Ebola virus [6]

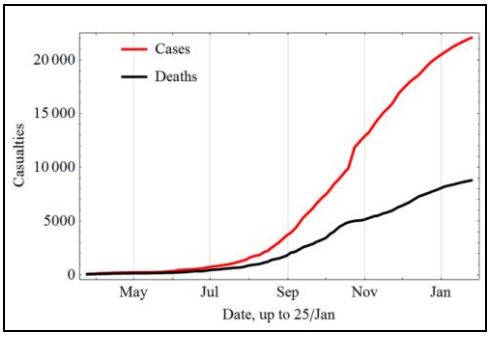

Figure 6: Ebola outbreak in 2014 and the cumulative infections and deaths has evolved [6]
(It is easy to see that it's similar with the first half of the evolution trend of our model)

Because analysis of x is more difficult, we explore, the spread of the Ebola virus in the region per unit time $\frac{dB}{dt}$, represents the propagation velocity of Ebola virus. In the ambulance before that $0\le t\le t_1$, expand the scope of the Ebola virus is growing, that $\frac{dB}{dt}$ increases with increasing t; when begin a large-scale rescue work, that $t_1\le t\le t_2$. If the rescue work fully enough, the Ebola virus will be contained, that $\frac{dB}{dt}$ should be reduced, and when the equation is zero when $t=t_2$.

5.2.2 Assumption

We need make assumptions about form of degree $\frac{dB}{dt}$ of the transport rescue in speed and spread of fire:

1) Ebola virus outbreak in the original point as the center, spread evenly rounded to four weeks, the radius r is proportional to t.
2) The number of people infected with Ebola virus is proportional to the area of spreading Ebola virus is $B(t_2)$, scale factor c_1 is the number of rescue medicines for unit area.
3) From the outbreak of the Ebola virus to begin rescue operations $0\le t\le t_1$, Ebola virus degree of diffusion is directly proportional to the time t, scale factor β (Ebola virus from spreading rate).
4) Ambulance personnel were dispatched x, after start of rescue work ($t\ge t_1$), Ebola virus from spreading rate dropped $\beta-\lambda x$, Where λ can be regarded as the speed of each ambulance personnel. Obviously $\beta<\lambda x$.
5) Each rescue ambulance unit time required for the number of drug c_2, so every ambulance crew rescue medication is $c2(t2-t1)$, and the total number of drug required for each patient is c_3.

5.2.3 Constitution

According to 3) 4) of assumptions as above, the extent of the spread of the Ebola virus $\frac{dB}{dt}$, increased linearly at $0\le t\le t_1$, decreases linearly at $t_1\le t\le t_2$. $\frac{dB}{dt}\sim t$ pattern as shown in **Figure 6**.

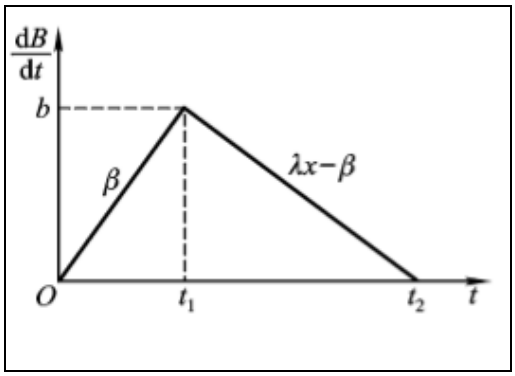

Figure 7: $\frac{dB}{dt} \sim t$ linear graph

Set $t = t_1$, and then $\frac{dB}{dt} = b$. The number of Ebola virus infection $B(t_2) = \int_0^{t_2} \frac{dB}{dt} dt$ is precisely the area of the triangle diagram, clearly $B(t_2) = \frac{1}{2} b t_2$.

And t_2 satisfy:

$$t_2 - t_1 = \frac{b}{\lambda x - \beta} = \frac{\beta t_1}{\lambda x - \beta} \quad (20)$$

So

$$B(t_2) = \frac{\beta t_1^{\,2}}{2} + \frac{\beta^2 t_1^{\,2}}{2(\lambda x - \beta)} \quad (21)$$

5.2.4 Solution

According to 2) 5) of assumptions, the number of assumptions for Ebola virus is $c_1 B(t_2)$, rescue medication need $c_2 x(t_2 - t_1) + c_3 x$. Substituting into equation (20), (21), to obtain the desired drug to total relief is

$$C(x) = \frac{c_1 \beta t_1^{\,2}}{2} + \frac{c_1 \beta^2 t_1^{\,2}}{2(\lambda x - \beta)} + \frac{c_2 \beta t_1 x}{\lambda x - \beta} + c_3 x \quad (22)$$

For the sake of x, so that $C(x)$ to a minimum, we can get the number of rescue workers should be sent is

$$x = \frac{\beta}{\lambda} + \beta \frac{c_1 \lambda t_1^{\,2} + 2 c_2 t_1}{2 c_3 \lambda^2} \quad (23)$$

Based on this, we propose we should set drug distribution points in West Africa should be in accordance with changes by the strength of the Epidemic area. Based on this model of computing and serious epidemic situation, each radiation locale should set 2 to 5 points. At the same time, we want to deploy second "mobile lab" in guinea and mali border line at the midpoint, in order to carry out the epidemic diagnosis faster and medical issuance.

5.3 Vaccine/Drug Production and R&D Speed

5.3.1 Assumption

We assume that the speed and degree of development of vaccine production is analogous to the infection distance and disaster area. So we can still use the Forest-Fire model to building a specifically, intuitive, and effective model to solve the problem. So, the assumptions as above section will be reuse. So, the assumptions are rewritten as follows:

1) The number of people infected with Ebola virus is proportional to the area of spreading Ebola virus is $B(t_2)$, scale factor d_1 is the number of production of drugs for unit area.
2) From the outbreak of the Ebola virus to end of the first drug production operations $0 \le t \le t_1$, Ebola virus degree of diffusion is directly proportional to the time t, scale factor β (Ebola virus from spreading rate).
3) The number of each production for drug x, after production of drug ($t \ge t_1$), Ebola virus from spreading rate dropped $\beta - \lambda_1 x$, Where λ_1 can be regarded as the speed of production of medicines. Obviously $\beta < \lambda_1 x$.
4) In order to ensure efficient use of time speed, the speed of the production of drugs and transportation of drugs should be the same. That is $\lambda_1 = \lambda$.

5.3.2 Constitution & Solution

As the above section mentioned, we can deduce $b = \beta t_1, t_2 - t_1 = \frac{b}{\lambda_1 x - \beta}$, in other words, $t_2 = t_1 + \frac{\beta t_1}{\lambda_1 x - \beta}$.

So, the number of Ebola virus infection is $B(t_2) = \int_0^{t_2} \frac{dB}{dt} dt$, and the total number of drugs needed to cure is

$$C(x) = \frac{c_1 \beta t_1^{\,2}}{2} + \frac{c_1 \beta^2 t_1^{\,2}}{2(\lambda_1 x - \beta)} + \frac{c_2 \beta t_1 x}{\lambda_1 x - \beta} + c_3 x \quad (24)$$

According to equation solving, Ebola virus from spreading area is

$$B(t_2) = \int_0^{t_2} \frac{dB}{dt} dt = \frac{b t_2}{2} = \frac{\beta t_1^{\,2}}{2} + \frac{\beta_2 t_1^{\,2}}{2(\lambda_1 x - \beta)} \quad (25)$$

Find x so that $C(x)$ minimum: $\frac{dC}{dx}=0$, the result is

$$x=\frac{\beta}{\lambda_1}+\beta\sqrt{\frac{c_1\lambda_1 t_1^{\ 2}+2c_2 t_1}{2c_3\lambda_1^{\ 2}}} \qquad (26)$$

Based on this, we propose drug development should begin at the growth of the epidemic stage 1/3, and 1/2 of the growth of the epidemic stage clinical trials in order to achieve the best results. Now the main reason for the slow progress in Ebola drug development is the outbreak stabilizes. But we still want to the company which is in the development as soon as possible to develop drugs or vaccines to deal with Ebola outbreak.

VI. MODEL RESULTS AND CONCLUSION

Advantage and improve:

How to determine the Week Contact Rate value of θ. How to determine the week contact rate can be improved, according to the epidemic cure rate before this Ebola outbreak, we can calculate the weighted average value, rather than simply a proportional relationship. The spread of the virus in the crowd is stage with a burst phase at first, Week Contact Rate of θ will be greatly at this period; we can set it to an impulse variable.

For Epidemic Area of Forest-Fire model, this model assumes that the Ebola virus outbreak in the original for the center, a radial spread around, the actual situation may be due to the terrain, lifestyle and other reasons for the differences. For the treatment of patients with an average speed of rescue workers λ, may be related to the rescue start time t. As t grows, the rescue rate λ is also growing.

Disadvantage:

For Vaccine/Drug Production and R&D Speed of Forest-Fire model, because the trial drug itself has some limitations and latency, total drug production scheme of arrangement exist error. And we choose the averaging method to use in the drugs used at the treatment of the amount recovered; such simple treatment will affect the calculation of the total demand for drugs.

Overall, for the Eradicating Ebola, we should be a comprehensive analysis of a model by normalized all of models as above, the results will be an optimal solution. But limited ability, we did not do so. But we have the optimal solution for a single model was a good deal. So the result of us compare with the integrated optimal solution will not be much apart.

VII. REFERENCES

[1] World Health Organization. World health statistics 2014[J]. 2014.

[2] Jiang QY, Xie JX, Ye J. The Mathematical Model [M]. 4th Edition. Beijing: Higher Education Press, 2011.

[3] WHO. Ebola data and statistics[G/OL]. [2015-2-7]. http://apps.who.int/gho/

[4] data/node.ebola-sitrep.quick-downloads?lang=en.

[5] Zhou HP, Cai SH. A spreading model of the SIRS virus based on a two-dimensional regular lattice [J]. Journal of Shandong University (Natural Science),2007,11:94-97+100.

[6] Wikipedia. Ebola virus epidemic in West Africa[G/OL]. [2015-2-7]. http://en.wikipedia.org/wiki/Ebola_virus_epidemic_in_West_Africa.

[7] Wikipedia. Forest-fire model[G/OL]. [2015-2-7]. http://en.wikipedia.org/

[8] wiki/Forest-fire_model.

[9] Wikipedia. Pharmacokinetics[G/OL]. [2015-2-7]. http://en.wikipedia.org/

[10] wiki/Pharmacokinetics.

[11] Basler C F. New Hope in the Search for Ebola Virus Treatments[J]. Immunity, 2014, 41(4): 515-517.

[12] Geisbert T W, Young H A, Jahrling P B, et al. Pathogenesis of Ebola hemorrhagic fever in primate models: evidence that hemorrhage is not a direct effect of virus-induced cytolysis of endothelial cells[J]. The American journal of pathology, 2003, 163(6): 2371-2382.

[13] Tosh P K, Sampathkumar P. What clinicians should know about the 2014 Ebola outbreak[C]//Mayo Clinic Proceedings. Elsevier, 2014, 89(12): 1710-1717.

[14] Tseng C P, Chan Y J. Overview of Ebola virus disease in 2014[J]. Journal of the Chinese Medical Association, 2015, 78(1): 51-55.

[15] Borchert M, Mutyaba I, Van Kerkhove M D, et al. Ebola haemorrhagic fever outbreak in Masindi District, Uganda: outbreak description and lessons learned[J]. BMC infectious diseases, 2011, 11(1): 357.
[16] Kinsman J. A time of fear": local, national, and international responses to a large Ebola outbreak in Uganda[J]. Global Health, 2012, 8: 15.
[17] Rebaudet S, Moore S, Piarroux R. Ebola virus disease in West Africa--the first 9 months[J]. The New England journal of medicine, 2015, 372(2): 188-188.
[18] Sayburn A. WHO gives go ahead for experimental treatments to be used in Ebola outbreak[J]. BMJ, 2014, 349: g5161.
[19] Qiu X, Wong G, Audet J, et al. Reversion of advanced Ebola virus disease in nonhuman primates with ZMapp[J]. Nature, 2014.
[20] Martin-Moreno J M, Llinás G, Hernández J M. Is respiratory protection appropriate in the Ebola response?[J]. The Lancet, 2014, 384(9946): 856.
[21] McCarthy M. US signs contract with ZMapp maker to accelerate development of the Ebola drug[J]. BMJ, 2014, 349: g5488.
[22] Okware S I. Three ebola outbreaks in Uganda 2000-2011[J]. 2015.
[23] Yu YL. Ebola virus/Ebola virus disease out broke in 2014 [J]. Prog in Microbiol lmmunol,2014,06:1-7.
[24] Li C, Yang M, Mu D, Sui HT, Zhao J, Meng YJ, Tu WX. Epidemiology of Ebola virus disease outbreak in West Africa, 2013-2014 [J].DISEASE SURVEILLANCE,2014,11:925-928.
[25] Deng HP. Preliminary Analysis of the Relationship between Physical Geography Factors and Diseases [J]. Journal of Capital Normal University (Natural Science Edition),1995,03:88-92.
[26] Meng XM, Dong P, Lu HZ. Progress in the treatment of and new drug research on Ebola virus disease [J]. Shanghai Pharmaceutical,2014,21:1-5.
[27] Drossel B, Schwabl F. Self-organized critical forest-fire model[J]. Physical review letters, 1992, 69(11): 1629.
[28] Bak P, Chen K, Tang C. A forest-fire model and some thoughts on turbulence[J]. Physics letters A, 1990, 147(5): 297-300.
[29] Chen K, Bak P, Jensen M H. A deterministic critical forest fire model[J]. Physics Letters A, 1990, 149(4): 207-210.
[30] Ritschel W A. Handbook of basic pharmacokinetics[J]. 1976.
[31] China National Knowledge Infrastructure. CNKI[G/OL]. [2015-2-7]. http://www.cnki.net/.