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| T1 ________ | **32572** | F1 ________ |
| T2 ________ | | F2 ________ |
| T3 ________ | Problem Chosen | F3 ________ |
| T4 ________ | **A** | F4 ________ |

**2015**
**Mathematical Contest in Modeling (MCM/ICM) Summary Sheet**
(Attach a copy of this page to your solution paper.)

Type a summary of your results on this page. Do not include the name of your school, advisor, or team members on this page.

# Eradicating Ebola by Medication Estimate-Delivery Network


## Summary

Ebola is a severe epidemic with high mortality and killed thousands of people in West Africa and some other countries around the world. To eradicate Ebola, we design a feasible and reliable plan, which is named as "Ebola Medication Estimate -Delivery Network" (EMED-Network in shorthand), to achieve the objective that we can provide and deliver enough amount of the new medication announced by World Medical Association (WMA) to the place in time where the new medication is needed through predicting the number of potential Ebola cases. Our "Ebola Medication Estimate-Delivery Network" is constructed by 2 secondary systems, *the medication estimate system* and *the medication delivery system*. With the two subdivided systems, "Ebola Medication Estimate Delivery Network" can let WMA estimate the daily Ebola cases in a country and its cities and deliver the medication to the cities precisely and feasibly.

To adopt such a synthetic strategy, our objective encompasses the following aspects in orders:

1. Predict the spread of Ebola and the daily amount of the confirmed cases.
2. Determine the daily need of the medication in all Ebola outbreak districts.
3. Choose the best place as the distribution center to send the medication to all districts.

We choose the Republic of Sierra Leone as the case study to construct our "Ebola Medication Estimate-Delivery Network", since Sierra Leone is the most infected country for the moment around the world.

To achieve these objects listed above, we first build *the medication estimate system*, as the first system of EMED-Network, which is used to estimate the daily amount of new confirmed Ebola cases in a country through making Susceptible-Infective model (SI) and Susceptible-Infective-Removed model (SIR). We formulate SI model to find out how the realistic amount of the Ebola cases varies with time in Sierra Leone to determine the infection rate and calculate the removing rate( the recovery rate and the death rate) based on the relevant daily-updated data released by a Sierra Leone's Health Ministry. Then we use SIR model to predict the proportion of patients among the country's population in the present sanitary condition (without new medication). After that, taking the recovery rate of new medication into account, we use SIR model to predict the daily patients amount when the new medication is applied practically and widely in Sierra Leone. With the possible specific recovery rate at 14.5%, the time needed to eradicate Ebola is 89 days. In the end, we estimate *the daily amount of patients, the need of medication per day* and *the speed of manufacturing medication* through this system.

The *medication delivery system* is built up to meet the demand from the Ebola outbreak districts, since we know the daily need of the medication with the previous system. We use the Analytic Hierarchy Process (AHP) to make a feasibility evaluation criterion on the following 5 aspects: *distance of the delivery routes, disease severity, traffic infrastructure, sanitary condition, status of the district.* We apply Floyd–Warshall algorithm of Shortest Path Problem (SPP) to calculate the distance of the delivery routes. After collecting the detailed data related to the 5 aspects and obtaining the index weight through the Pairwise-Comparison Matrix, we define their significance through calculation so that we can measure each Ebola outbreak districts' feasibility, named as "Feasibility Grade", by numbers. Then we rank all these Ebola outbreak districts by the "Feasibility Grade" from high to low. The district at first rank is the distribution center. Still taking Sierra Leone as example, we evaluate all the 13 Ebola outbreak districts in Sierra Leone. Receiving 73.71 feasibility grade, Bo city is set as the distribution center of our *medication delivery system* out of the 13 districts in Sierra Leone. The top 3 feasible districts in Sierra Leone, in order, are Bo(73.71), Port Loko(72.68), Western Area(66.17).

With the real data by monitoring the spread of Ebola, we can adjust the medication estimation system to ensure the EMED network working effect.

Through the whole EMED-Network, we can eradicate Ebola in 89 days by sending the medication from the distribution center (Bo city) to all outbreak districts in Sierra Leone.

We also apply EMED-Network on Liberia and Guinea, which also prove that our program is realistic and feasible.

We conduct sensitivity analysis on the SIR model to find the most feasible algorithm for *the medication estimate system*. It proves the recovery rate does make more difference than the infection rate on the total time. It also gives guidance to find the proper recovery rate of new medication.

We also discuss the strengths and weaknesses of "Ebola Medication Estimate-Delivery Network".

In the end, we write a non-technical letter to World Mediation Association to introduce "Ebola Medication Estimate-Delivery Network" so that WMA can use the non-technical introduction in their announcement.

# 1 Introduction

## 1.1 Problem background and objectives

New medication has been released in the World Medical Association announcement against Ebola virus. Ebola is a lethal epidemic and has resulted in 22522 total cases (13860 laboratory-confirmed cases) and 8994 deaths by 2015 Feb. Our team is faced with a task to build a realistic, sensible, and useful model aiming at the eradication of Ebola by delivering the new medication to the Ebola outbreak places.

Our goals are listed as follows:

- Build mathematical models to estimate spread of Ebola (such as amount of the patients vary with time).
- Analyze the quantity of the medication needed with the number of patients predicted above.
- Set up a feasible delivery system and find the location of delivery.
- Employ a case study on a specific country which, then, can be extended to the world as an example to fight against Ebola.

## 1.2 Previous research and related models

# 2 Major Assumptions, Symbols and Definitions

## 2.1 Major Assumptions

- **There is no incubation period, which means all the confirmed cases have the ability of infection.**

*Base on the reality of Ebola treatment, patients can only be confirmed with some flu symptoms. Patients in this period all have ability to infect others. In our model, we would assume patients become infectious at the moment confirmed as Ebola cases.*

- **Patients who have been cured by the new medication will neither have infectious ability nor be infected again.**

*We assume that the people cured would are quarantined so that they will be removed.*

- **Ebola infection rate is set as constant in our models.**
- **In our model for a specific area, no influx or outflow of the population occur during the whole Ebola outbreak.**

*Due to the Ebola is an epidemic with high mortality, an area is banned of population movement to prevent the widespread and intense transmission.*

- **The infection of Ebola is only considered its average effect, since we assume that the population is large enough.**

*This simplification allows us to convert discrete variable related to days into continuous time by fitting data.*

- **The time factor in our model is measured in days.**
- **The enough transportation can be provided to meet any needed amount of the medication.**

- **The amount of a daily dose for a person is 1 pill or needle.**

*To simplify the calculation of the quantity of the medication needed with the number of patients predicted, but not influence the real results.*

- **The distribution center can deliver the medication to the other outbreak districts in a day.**

*Since our medication delivery system is applied in the country level and the limited time of transportation, it is reasonable to make this assumption.*

### 2.2 Symbols and definitions

| Symbol | Definition |
|---|---|
| **Symbols for SI model and SIR model** | |
| $N$ | total population of area investigated |
| $I$ | proportion of the Infective |
| $S$ | proportion of the Susceptible |
| $k$ | daily infection rate |
| $p$ | daily recovery rate |

| | |
|---|---|
| $q$<br>$h$ | daily death rate<br>daily removing rate |
| **Symbols for medication calculation** | |
| $Q$<br>$SQ$ | daily quantity of medication needed<br>total quantity of medication needed |
| **Symbols for Analytic Hierarchy Process** | |
| $M$<br>$\boldsymbol{\lambda}$<br>$C\,I$<br>$C\,R$<br>$R\,I$<br>$\boldsymbol{W}$<br>$\boldsymbol{g_{ij}}$<br>$\boldsymbol{G}$<br>$\boldsymbol{FG}$ | judging matrix<br>greatest eigenvalue of M<br>indicator of consistency check<br>consistency ratio<br>random consistency index<br>weight vector of criteria level factor<br>the $j^{th}$ grade of $i^{th}$ district<br>matrix of $g_{ij}$<br>Feasible Grade |
| **Symbols for Shortest Path Problem** | |
| $\boldsymbol{p_{ij}}$<br>$\boldsymbol{P_0}$<br>$\boldsymbol{P_k}$<br>$\boldsymbol{D_{ij}}$ | distance between adjacent city *i* and *j*<br>matrix of $p_{ij}$<br>sequence of matrix<br>shortest distance of every paired cities |

**Table 1. Symbols**

### 2.3 Case Study-The Republic of Sierra Leone

Sierra Leone is one of the countries worst hit by West Africa's Ebola outbreak, it has announced a three-day lockdown to try to tackle the disease. The outbreak has killed 2,936 people in Sierra Leone and The World Health Organization (WHO) announced that the Cumulative confirmed cases. [apps.who.int]

The broad information resources allow us to calculate and specify the accuracy of our model which updates by the Ministry of Health and Sanitation, The Republic of Sierra Leone.

## 3 System I: Medication Estimate System

3.1 Susceptible- Infective model (SI model)

Assumption for SI model

- The total people in the area investigated is a constant, meaning that the birth and death, migration are not taken into account.

- When the Infective have effective contact with the Susceptible, the Susceptible are turned into the Infective
- The Infective cannot be cured. Since the outbreak is still in early days, effective measure haven't been taken yet.
- Let the number of latest total cases be the number of total people, that is $\mathrm{I(t)_{max}} = 1$ and $\mathrm{I_0} = 0.00149$[data resource]

According to the assumptions, we have

$$\begin{cases} N\dfrac{dI}{dt} = kNSI \\ S(t) + I(t) = 1 \end{cases} \qquad (1)$$

For the proportion of the initial Infective is $I_0$ , then

$$\frac{dI}{dt} = kI(1-I), \qquad I(0) = I_0 \qquad (2)$$

The solution of the equation (2) (called Logistic model) is

$$I(t) = \frac{1}{1+(\frac{1}{I_0}-1)e^{-kt}} \qquad (3)$$

According to the epidemic data in Sierra Leone from outbreak to now, through the data fitting of Matlab, we have:

$$k = 0.0391$$

And the 95% confidence bound is

$$(0.03871,\ 0.0395)$$

The fitting result is displayed by Figure 1

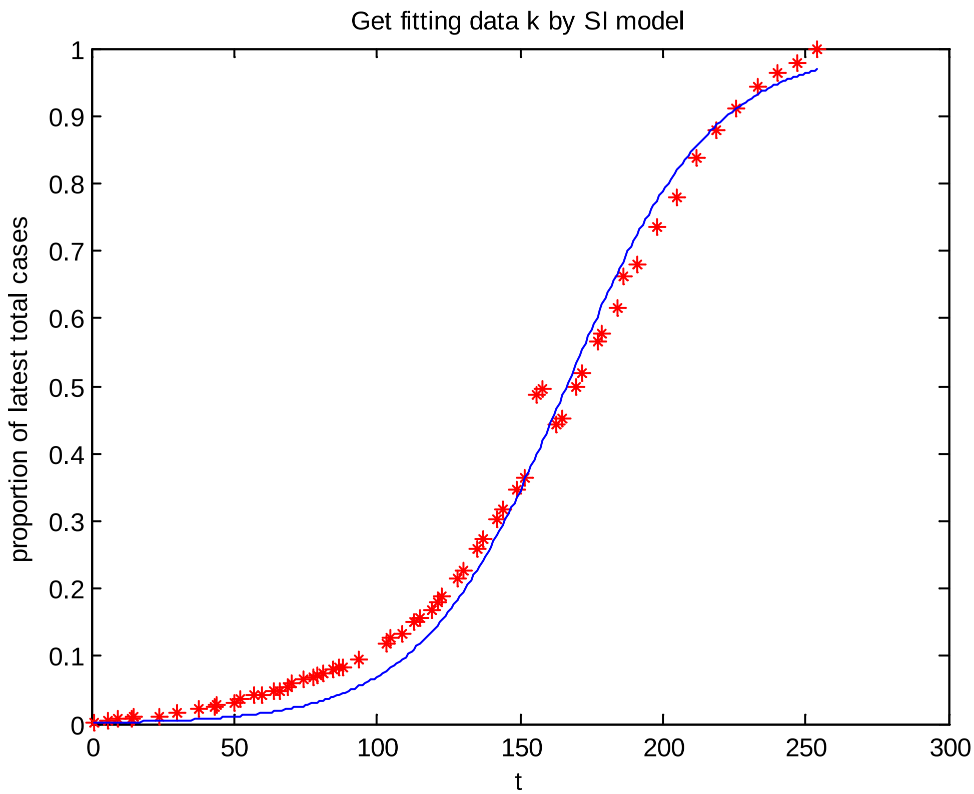


**Figure 1. k of SI model**

## 3.2 Susceptible –Infective-Removed model ( SIR model)

In this model, we take the daily recovery rate $p$ and daily death rate $q$ into account, we define them as:

daily recoverty rate $p$

$$=\frac{\text{the number of recovered people on that day}}{\text{cumulative confirmed cases-the number of recovered people on that day-cumulative death cases}}$$

daily death rate $q$

$$=\frac{\text{the number of dead people on that day}}{\text{cumulative confirmed cases-the number of dead people on that day-cumulative death cases}}$$

**Modeling process**

According to assumptions above,

$$S(t)+I(t)+R(t)=1 \qquad (4)$$

For the Removed recovered and immune

$$N\frac{dR}{dt}=hNI \qquad (5)$$

And the equation of SIR model can be written as

$$\begin{cases} \dfrac{dI}{dt} = kIS - hI, & I(0) = I_0 \\ \dfrac{dS}{dt} = -kIS, & S(0) = S_0 \end{cases} \quad (5)$$

According to the data fitting result of SI model, the daily infection rate $k = 0.0391$.

According to cumulative cases of Ebola virus and the population of Sierra Leone [dataresource], the current proportion of the Infective is

$$I_0 = 0.002$$

and the current proportion of the Susceptible is

$$S_0 = 1 - I_0 = 0.998$$

According to the epidemic data in Sierra Leone recently [dataresource],

$$p = 0.0044, q = 0.0047$$

and we have the daily removing rate:

$h = p + q$=0.0091

For the equation (5) cannot be solved as analytical solution, we can have numerical solution using the data above ($I_0 = 0.002$, $S_0 = 0.998$, $k = 0.0391$, $h = 0.0091$ ). The result is showed in Table 2, Figure 2 and Figure 3.

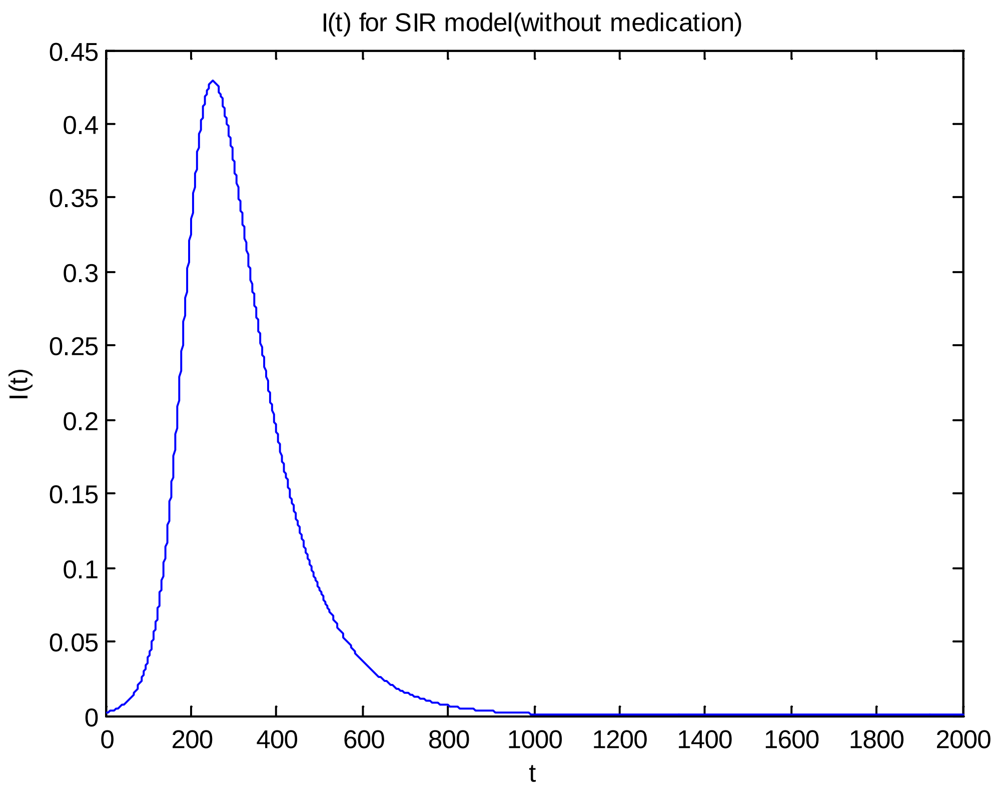


**Figure 2. I(t) of SIR model(without medication)**

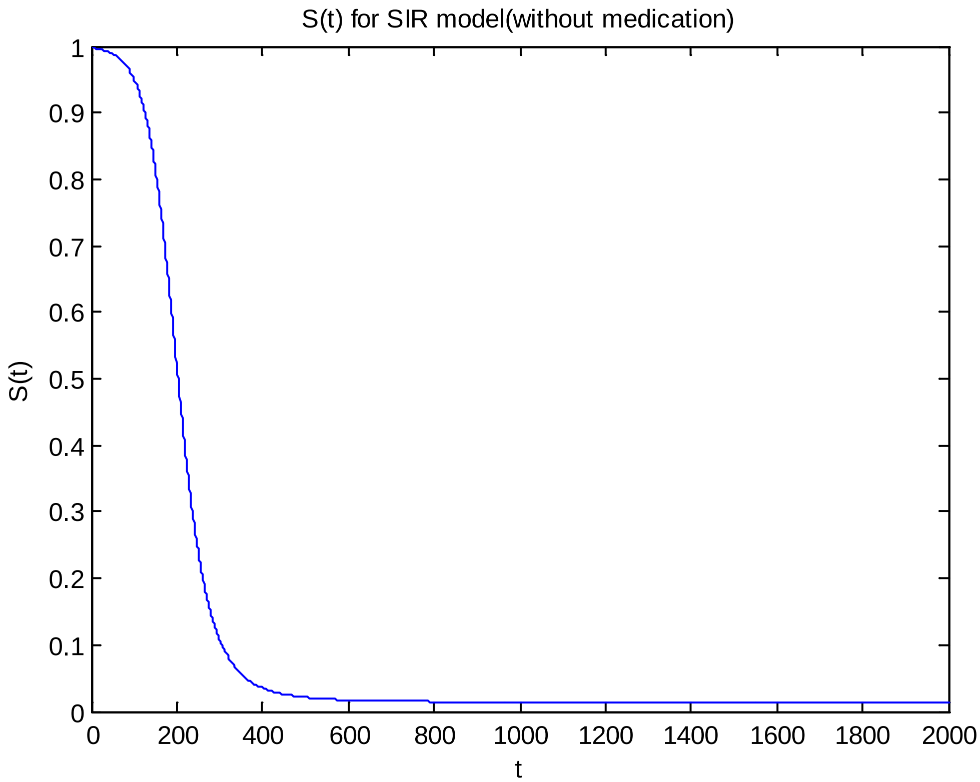


**Figure 3. S(t) of SIR model(without medication)**

| t | I(t) | S(t) | t | I(t) | S(t) | t | I(t) | S(t) |
|---|---|---|---|---|---|---|---|---|
| **0** | 0.0020 | 0.9980 | **240** | 0.4239 | 0.2831 | **1370** | 0.0001 | 0.0143 |
| **1** | 0.0021 | 0.9979 | **241** | 0.4248 | 0.2785 | **1371** | 0.0001 | 0.0143 |
| **2** | 0.0021 | 0.9978 | **242** | 0.4255 | 0.2739 | **1372** | 0.0001 | 0.0143 |
| **3** | 0.0022 | 0.9978 | **243** | 0.4261 | 0.2693 | **1373** | 0.0001 | 0.0143 |
| **4** | 0.0023 | 0.9977 | **244** | 0.4267 | 0.2649 | **1374** | 0.0001 | 0.0143 |
| **5** | 0.0023 | 0.9976 | **245** | 0.4272 | 0.2605 | **1375** | 0.0001 | 0.0143 |
| **6** | 0.0024 | 0.9975 | **246** | 0.4277 | 0.2562 | **1376** | 0.0000 | 0.0143 |
| **7** | 0.0025 | 0.9974 | **247** | 0.4280 | 0.2519 | **1377** | 0.0000 | 0.0143 |
| **8** | 0.0025 | 0.9973 | **248** | 0.4283 | 0.2477 | **1378** | 0.0000 | 0.0143 |
| **9** | 0.0026 | 0.9972 | **249** | 0.4285 | 0.2436 | **1379** | 0.0000 | 0.0143 |
| **10** | 0.0027 | 0.9971 | **250** | 0.4287 | 0.2396 | **1380** | 0.0000 | 0.0143 |
| **11** | 0.0028 | 0.9970 | **251** | 0.4287 | 0.2356 | **1381** | 0.0000 | 0.0143 |
| **12** | 0.0029 | 0.9969 | **252** | 0.4287 | 0.2317 | **1382** | 0.0000 | 0.0143 |
| **13** | 0.0030 | 0.9968 | **253** | 0.4287 | 0.2279 | **1383** | 0.0000 | 0.0143 |
| **14** | 0.0030 | 0.9966 | **254** | 0.4286 | 0.2241 | **1384** | 0.0000 | 0.0143 |
| **15** | 0.0031 | 0.9965 | **255** | 0.4284 | 0.2204 | **1385** | 0.0000 | 0.0143 |
| **16** | 0.0032 | 0.9964 | **256** | 0.4281 | 0.2167 | **1386** | 0.0000 | 0.0143 |
| **17** | 0.0033 | 0.9963 | **257** | 0.4278 | 0.2131 | **1387** | 0.0000 | 0.0143 |
| **18** | 0.0034 | 0.9961 | **258** | 0.4275 | 0.2096 | **1388** | 0.0000 | 0.0143 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **19** | 0.0035 | 0.9960 | **259** | 0.4271 | 0.2061 | **1389** | 0.0000 | 0.0143 |
| **20** | 0.0036 | 0.9959 | **260** | 0.4266 | 0.2027 | **1390** | 0.0000 | 0.0143 |

**Table 2. I(t) and S(t) of SIR model(without medication)**

## Conclusion:

$I(t)$ reaches the $I(t)_{max}$ when $t = 250$, and $I(t)_{max} \approx 0.4287$, then decreases. When $t \to \infty, I(t) \to 0$ . But $S(t)$ decreases , when $t \to \infty, S(t) \to 0.0143$.
That is $S_\infty = 0.0143$ and $I_\infty = 0$.

We find that the max of $I(t)$ is 0.4287, that's to say, approximately 40% of the population will be infected by the Ebola virus. That means for the current medical technology and control measures, the recovery rate in Sierra Leone is extremely low, and we can't prevent the Ebola Virus to spread.

According to lemma of SIR model,

If $S_0 > h/k$, $I(t)$ increases to the maximum, then decrease and tend to 0, $S(t)$ monotonely decreases to $S_\infty$.

If $S_0 \leq h/k$, $I(t)$ decreases to 0, $S(t)$ decreases to $S_\infty$.

a conclusion can be reached that, on account of the new medication, when $S_0$ and $k$ is set, once the removing rate h reach a certain value(the recovery rate p reach a certain value), $I(t)$ decreases from the beginning to 0. In this way, we can prevent the spread of Ebola virus. The calculation is below:

$$h \geq S_0 k = 0.0390$$

$$p \geq S_0 k - q = 0.0343$$

therefore the minimum requirement of the recovery rate p is 0.0343 for the prevention of Ebola virus spreading.

And we set up a standard: when $I(t) < \frac{1}{540000} \approx 1 * 10^{-7}$ (according to the population of Sierra Leone), we consider that as the time when we completely cure all the patients in Sierra Leone.

We might as well set the recovery rate p=0.035, then we have a new function of $I(t)$ in Figure 4 , as proved by lemma above.

**Figure 4. I(t) and S(t) of SIR model(without medication)**

Let $t_x$ be the time when $I(t)$ meets the standard, then we can conclude from figure 4 that when $p = 0.035, t_x = 4547$. It's clear that we have to improve the p significantly cut down the days needed. So we increase p, and we get the Figure 5 and Table 3.

| **p** | **0.05** | **0.07** | **0.1** | **0.3** | **0.5** |
|---|---|---|---|---|---|
| **tx** | 600 | 291 | 144 | 39 | 23 |

**Table 3. The influence of p increase**

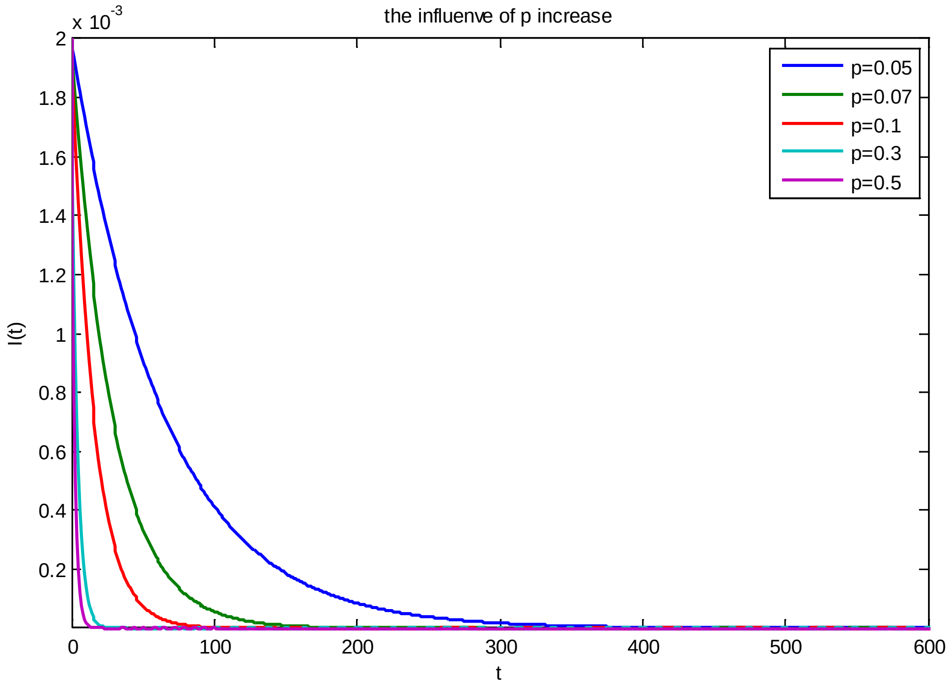


**Figure 5. The influence of p increase**

**Conclusion:**

If p increases, $t_x$ decreases dramatically. So if we require certain $t_x$, we can get a proper the recovery rate p.

We set that $t_x = 89$, which is reasonable. Then we find out the recovery rate p is 0.145, when $t_x = 89$.

**3.3 Medication calculation**

The quantity of medicine needed per person every day is set as 1 unit medication/person, then the everyday medicine needed is

$$Q(t) = NI(t)$$

According to Table 2, we can find the relationship between $Q(t)$ and *t*, as showed in Figure 8.

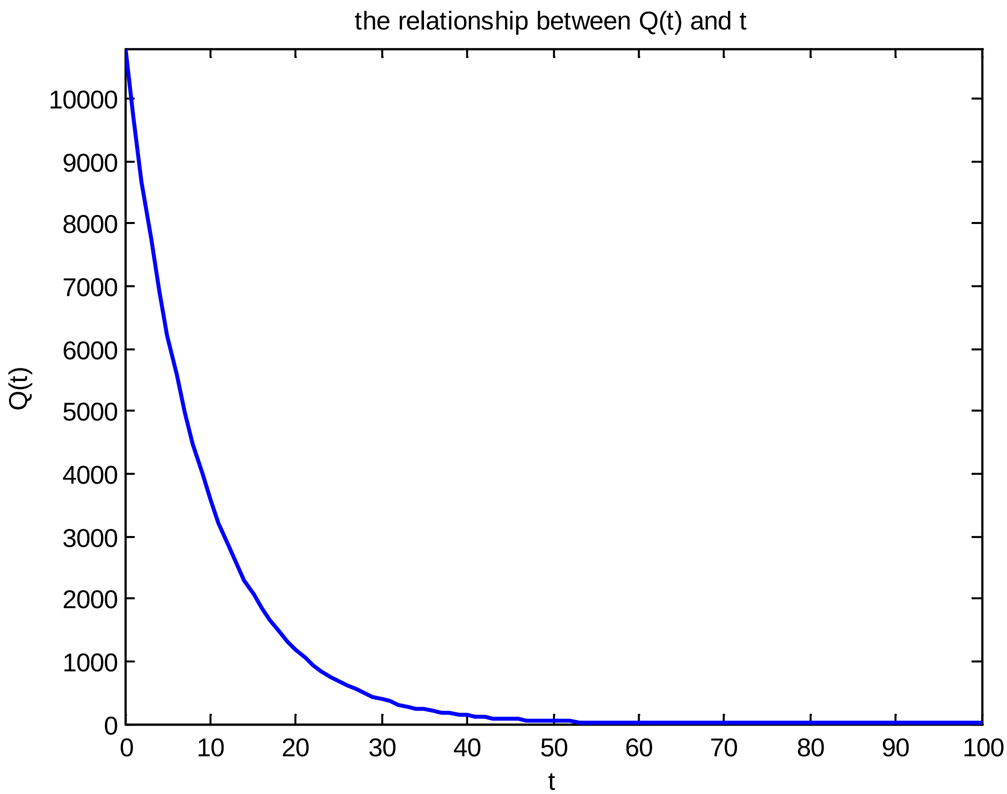


**Figure 8. Relationship of Q(t) and t**

The total quantity of medicine needed is:

$$SQ = \sum Q(t) = 103063 \text{(unit medication)}$$

# 4 System II: Medication Delivery System

## 4.1 Introduction

To simplify this problem, we consider creating a general country-level system and then spread it to other countries making our goal more visible, feasible and effective.

First, We define some terms and phrases:

- **Outbreak place:** cities with confirmed cases of Ebola in a specific country which needs medicine.
- **distribution center:** served as the most optimal center of delivery system among all Outbreak place. The drugs for the country should be sent to the destination countries' distribution center, then the center hand out them to the other outbreak places.
- **delivery station :**all outbreak places except the place chosen as distribution center.

**Medication delivery procedure**

Step 1.The pharmaceutical factory batches the medicine needed for a country and deliver the medicine to the distribution center.

Step 2.The distribution centers send the medicine to the delivery stations to cover all outbreak places.

Step 3.The monitoring system sends the real data to evaluate and adjust the medication estimation system in time.

FIGURE 流程图

Considering the Realistic local social and environmental conditions of many aspects discussed below ,

Instead of sent the drugs separated to the outbreak places, By this way, we can Groupe small freights into large ones ensuring achievement of the goal and lower the cost per unit of weight in transportation.

**4.2 Feasibility Evaluation Criterion**

In order to choose the distribution center, we design a model for ranking the feasibility among all outbreak cities. We specify the indicators in Feasibility Evaluation criterion and applied Analytic Hierarchy Process (AHP) to combine the weighting coefficients of all.

**4.2.1 Background of Analytic Hierarchy Process (AHP)**

The pairwise comparison method was developed by Saaty in the context of the Analytical Hierarchy Process (AHP) in 1980. The AHP is a mathematical method used to determine the priorities of different decision alternatives via pair wise comparisons of decision elements with respect to a common criterion. The pairwise comparison approach coupled with a ratio scaling method has been used to uncover the relative importance among all decision criteria in multi-attribute decision-making environments. [Wikipedia]

Based on the advantages and characteristics mentioned above, we think AHP is a feasible way to be applied in our Feasibility Evaluation criterion.

After using the first *medication estimate system* to forecast the quantity of medication needed， we build *medication delivery system* to balances the drugs consumption needs of the current, and the necessity of creating a long-term plan that can continue to meet the demand of medication well into the future .

**2.1.2 Decomposition**

The Feasibility Evaluation criterion encompasses the following 5 manageable aspects that count: Distance of the delivery routes, disease severity, Traffic infrastructure, Sanitary condition, Status of the city, which is shown in the figure below.

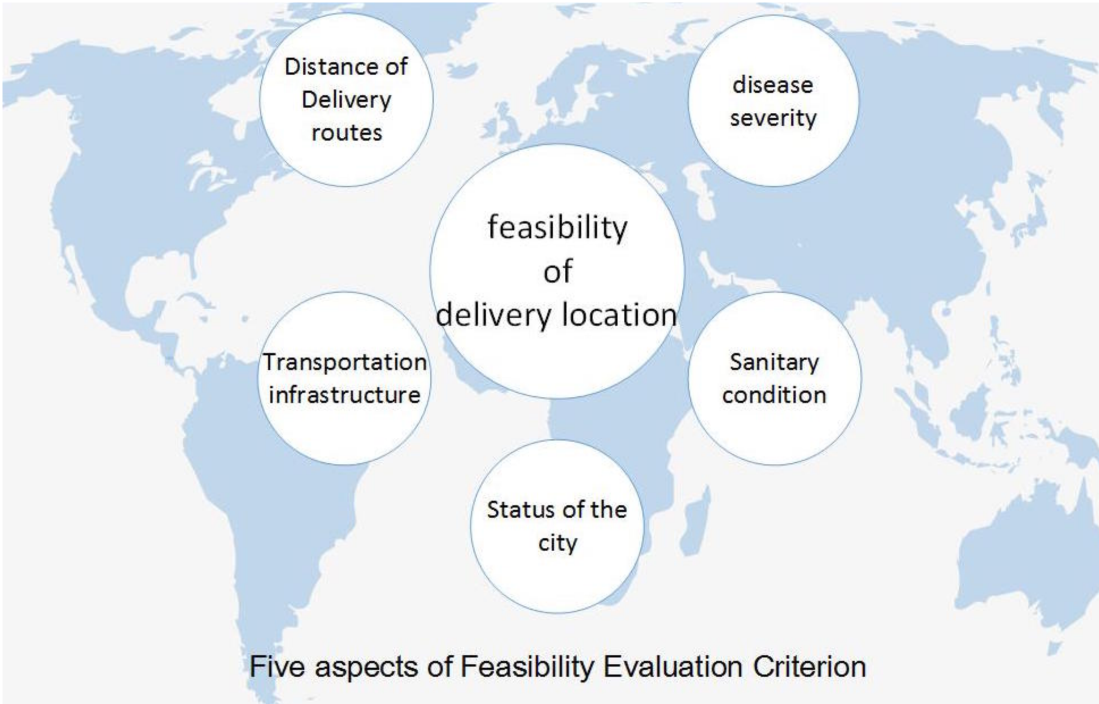


**Figure 9. First level evaluation criterion**

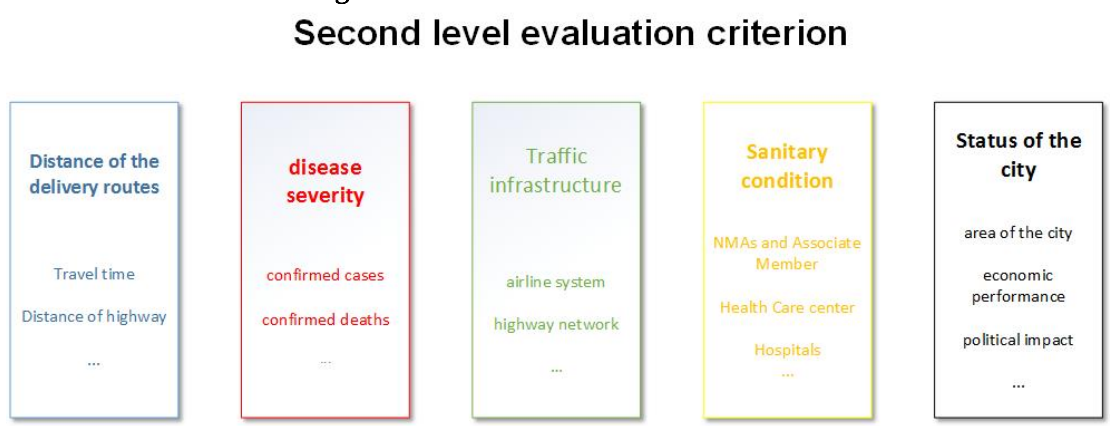


**Figure 10. Second level evaluation criterion**

**Evaluate the hierarchy**:

- **Distance of the delivery routes**

  Considering minimizing time of delivering the drugs, we apply Floyd–Warshall algorithm of Shortest Path Problem (SPP) to calculate the possible shortest distance of the delivery routes. So we define and calculate the sum of shortest distances from one site to reach the other sites as SD.

  Specific algorithm of SD described as below:

  we calculate shortest distance $D_{ij}$ of every city to the other cities (if accessible) by Floyd algorithm：

1. generate a sequence of matrix$\mathrm{P_1, P_2, \cdots, P_k, \cdots P_n}$ by recurrence, where $\mathrm{P_k(i,j)}$ denotes the length of shortest path from $\mathrm{v_i}$ to $\mathrm{v_j}$ where the vertex number is

less than k.

2. calculate with the iterative formula $\mathrm{P_k}(i,j) = \min\left(\mathrm{P_{k-1}}(i,j), P_k(i,k) + P_{k+1}(k,j)\right)$, and k is the iterations $\mathrm{i,j,k} = 1,2,\cdots,\mathrm{n}$
3. at last, when k=n, is the distance of shortest path between each vertex, then $\mathrm{P_n}$ is $D_{ij}$
4. Calculate the sum of $\mathrm{D_{ij}}(1 \le \mathrm{j} \le \mathrm{n})$ to be the $\mathrm{SD_i}$

Taking the Cumulative confirmed cases and location data from [Government of Sierra Leone Ministry of Health and Sanitation], [health.gov.sl], [Wikipedia. Sierra Leone], [EBOLA OUTBREAK UPDATES---February 4, 2015], we apply this algorithm to the 12 most cities—with the smallest having just over 4,000 people—generating the pipeline network depicted in Figure 7.

- **Disease severity**

  Disease severity is evaluated by the number of the Cumulative confirmed cases (CCC). Since it also means the quantity of the medicine we needed, we think the city with the most amount of medicine needed as the most optimal distribution center because of the convenience and fewer costs in the future delivery procedure.

- **Traffic infrastructure**
  - ✧ Airline system: approaching degree of the airport (whether it have or near the airport) for the convenient degree of receiving medicine from the factory.
  - ✧ Highway network: the development degree of local highway network.

- **Sanitary condition**

  To ensure the quality of drugs, we manage the cleanliness, tidiness, and some tech methods to ensure storage conditions, regard of security and safety of the medicine.

  We calculate this element by the number of local sanitary organizations such as NMAs and Associate Members (for NMAs and Associate Members can make use of the WMA's products and services.[who.int/]),primary health care center, hospitals, training and laboratory services center ,etc.

- **Status of the city**

  We evaluate the Significance of city into five parts:

  - ✧ The area of the city
  - ✧ The scale of the local tourism: influence the spread of the disease.
  - ✧ The economic performance
  - ✧ The political impact
  - ✧ The environmental condition

We assign points for each aspect above:

0 for poor, 1 for mediocre,2 for good, then add the 5 kinds of points up to form the final grade(the full mark is 10).

$$S=\sum Si\ (i=1,2,3,4,5)$$

The three-level decomposition of our feasibility evaluation criterion is shown in table 6.

| Goal | Elements | criterion |
|---|---|---|
| **The Feasibility of delivery location** | Distance of the delivery routes | Travel time |
| | | Distance of highway |
| | | … |
| | disease severity | Cumulative confirmed cases |
| | | Cumulative confirmed deaths |
| | Traffic infrastructure | Airline system |
| | | Highway network |
| | | … |
| | Sanitary condition | Number of Sanitary organizations |
| | Status of the city | Population of the city |
| | | Political impact |

**Table 6. The three-level decomposition of our feasibility evaluation criterion**

### 4.1.3 Prioritization

Priorities are numbers associated with the nodes of an AHP hierarchy. They represent the relative weights of the nodes in any group.The AHP carries out comparisons of the elements involved in a decision in an appropriate manner to derive their scales of priorities.

**Specific methods to Obtain the index weight**

1. Determine the judging matrix

We use the pair wise comparison method and 1-9 method to construct judging matrix $M = (m_{ij})$.

$$m_{ik} * m_{kj} = m_{ij} \qquad (6).$$

Where $a_{ij}$ is set according to the 1-9 method

2. Calculate the eigenvalues and eigenvectors

The greatest eigenvalue of matrix A is $\lambda$, and the corresponding eigenvector is $x = (x_{1,} x_{2,} x_{3,} \dots x_n)^T$. Then we normalize the x:

$$w_i = \frac{x_i}{\sum_{i=0}^{n} x_j} \qquad (7)$$

3. Do the consistency check

The indicator of consistency check formula:

$$\mathrm{CI} = \frac{\lambda_{max} - n}{n - 1} \qquad (8)$$

Where n denotes the exponent number of matrix.

The consistency ratio:

$$\mathrm{CR} = \frac{CI}{RI} \qquad (9)$$

Since we have obtained the weight of all the factors in the evaluation system, now we quantify the feasibility of cities.

Let $\mathrm{W}$ denotes the weight vector of criteria level factor, and $\mathrm{g_{ij}}$ is the $j^{th}$ grade of $\mathrm{i}^{th}$ city, matrix $\mathrm{G} = \mathrm{g_{ij}}$.

We define Feasible Grade FG as:

$$\mathrm{FG} = \mathrm{W} \times \mathrm{G} \qquad (10)$$

## Collect data:


**Figure 11. The Ebola outbreak districts in Sierra Leone**

We use Sierra Leone's 13 districts with ebola confirmed cases(Kailahun, Kenema, Kono, Bombali, Kambia, Koinadugu, Port Loko, Tonkolili, Bo, Bonthe, Moyamba, Pujehun, Western Area)[National Ebola Response Centre (NERC)] that will be utilized our models discussion as an example, and collect relative data from the Internet. Using the parameters of The Republic of Sierra Leone, we test our model by running a number of simulations.

**Five Articulate Metrics:**

- Distance of the delivery routes (SD)

We measured the distance of highway between any two adjacent cities by Google Map, and we create a highway net of Sierra Leone, as showed in Figure.

Then we build the model of SPP (shortest path problem). Let $\square_{\square\square}$ denote the distance between adjacent City i and j, and we have the $12 \times 12$ matrix:

$$\begin{pmatrix}
0 & \infty & \infty & 179 & \infty & 102 & \infty & 110 & \infty & \infty & \infty & \infty \\
\infty & 0 & \infty & \infty & \infty & \infty & \infty & \infty & \infty & 115 & 128 & \infty \\
\infty & \infty & 0 & \infty & \infty & \infty & \infty & \infty & \infty & \infty & 50.1 & \infty \\
179 & \infty & \infty & 0 & \infty & 153 & 143 & \infty & \infty & \infty & \infty & \infty \\
\infty & \infty & \infty & \infty & 0 & \infty & 152 & \infty & 167 & \infty & \infty & \infty \\
102 & \infty & \infty & 153 & \infty & 0 & 107 & 68.7 & \infty & \infty & \infty & \infty \\
\infty & \infty & \infty & 143 & 152 & 107 & 0 & \infty & \infty & 48.5 & \infty & \infty \\
110 & \infty & \infty & \infty & \infty & 68.7 & \infty & 0 & 112 & \infty & \infty & \infty \\
\infty & \infty & \infty & \infty & 167 & \infty & \infty & 112 & 0 & \infty & \infty & \infty \\
\infty & 115 & \infty & \infty & \infty & \infty & 48.5 & \infty & \infty & 0 & 98.9 & 156 \\
\infty & 128 & 50.1 & \infty & \infty & \infty & \infty & \infty & \infty & 98.9 & 0 & 89.8 \\
\infty & \infty & \infty & \infty & \infty & \infty & \infty & \infty & \infty & 156 & 89.8 & 0
\end{pmatrix}$$

Here we calculate shortest distance $D_{ij}$ of every city to the other cities (if accessible) by Floyd algorithm. Let $\mathrm{SD_i}$ be the sum of $\mathrm{D_{ij}}(1 \le j \le 12)$, and the $\mathrm{SD_i}$ of each city is showed in Table 7.

| rank | district | SD |
|---|---|---|
| **1** | PUJEHUN | 2049.9 |
| **2** | KOINADUGU | 2921.8 |
| **3** | KAMBIA | 2809.5 |
| **4** | MOYAMBA | 1889.9 |
| **5** | KONO | 3026.4 |
| **6** | BO | 2074.7 |
| **7** | TONKOLILI | 1809.8 |
| **8** | KENEMA | 2402.5 |
| **9** | KAILAHUN | 3298.5 |
| **10** | BOMBALI（MAKENI） | 1771.8 |
| **11** | PORT LOKO | 2308.5 |
| **12** | WATERLOO | 2253.7 |

**Table 7. The $\mathrm{SD_i}$ of each city**

As we can see, MAKENI has the smallest SD.

- Disease severity (DIS)

Calculated by the cumulative confirmed cases (CCC).[Ebola Virus Disease Update][health.gov.sl]

- Traffic infrastructure(TI)
  - ✧ Airline system: whether it has or near an airport (yes for 6,no for 0)
  - ✧ Highway network: the number of local highway.
- Sanitary condition (SA)
  Calculated by the number of implement partners
- Status of the city (ST)
  - ✧ The area of the city
  - ✧ Political impact: calculated by the number of Chiefdom (POL).

Searching from the health.gov.sl, a website that can provide specific data about Sierra Leone, we can find relative data for our specific evaluation criterion. Combining those data with the statistics we search from the Wikipedia, we finally conclude the relative statistics of those 13 districts and list them in a form.
Here we give statistics of 12 districts.

In the following table, “*SD*, “*DIS*”, “*TI*”, “*SA*”, “*ST*” refer to “Distance of the delivery routes”, “Disease severity”, “Traffic infrastructure”, “Sanitary condition”, and “Status of the city”, respectively.

| Name of district | SD | DIS | TI | SA | ST | Feasible grade | RANK |
|---|---|---|---|---|---|---|---|
| **BO** | 82.90 | 9.90 | 100.00 | 88.89 | 68.40 | 73.71 | 1 |
| **PORT LOKO** | 69.71 | 42.48 | 100.00 | 59.26 | 57.97 | 72.68 | 2 |
| **WESTERN_AREA** | 72.80 | 100.00 | 70.00 | 0.00 | 0.00 | 66.17 | 3 |
| **BOMBALI** | 100.00 | 31.26 | 40.00 | 100.00 | 73.19 | 65.00 | 4 |
| **MOYAMBA** | 93.33 | 6.49 | 40.00 | 66.67 | 72.22 | 55.42 | 5 |
| **KENEMA** | 64.40 | 15.82 | 50.00 | 88.89 | 74.97 | 52.91 | 6 |
| **KOINADUGU** | 35.09 | 3.28 | 90.00 | 51.85 | 84.38 | 51.90 | 7 |
| **PUJEHUN** | 84.30 | 0.98 | 30.00 | 48.15 | 54.43 | 45.38 | 8 |
| **TONKOLILI** | 97.86 | 14.15 | 0.00 | 48.15 | 63.26 | 43.21 | 9 |
| **KAMBIA** | 41.43 | 5.07 | 30.00 | 48.15 | 34.70 | 30.64 | 10 |
| **KAILAHUN** | 13.83 | 17.81 | 30.00 | 92.59 | 59.67 | 29.30 | 11 |
| **BONTHE** | 0.00 | 0.16 | 60.00 | 51.85 | 48.68 | 27.27 | 12 |
| **KONO** | 29.19 | 7.78 | 0.00 | 66.67 | 67.02 | 21.16 | 13 |

**Table 8. The feasible grade of each district**

We use the Analytic Hierarchy Process (AHP) to determine the weight of each metric on a location's evaluation in terms of being the best delivery station of the country.

## 5 Extension of the EMED-Network

As a general model for the world, "Ebola Medication Estimate Delivery System" can be applied in any countries to fight against Ebola. Thus, we use EMED-Network in Liberia and Guinea. After our analysis, we estimate the days and the location to eradicate the Ebola in these two countries. Results are listed below:

| | Days | Location |
|---|---|---|
| Liberia | 41 | Harbel |
| Guinea | 36 | Kindia |

The results of the two countries proves "Ebola Medication Estimate Delivery System" to be feasible and useful to eradicate Ebola, so that we can conclude that EMED-Network will fit the countries generally around the world.

## 6 Sensitivity Analysis

Since the sensitivity analysis on p is listed above, we test the sensitivity analysis on the infection rate k.

We analyze how $I(t)$ changes with varying the k for SIR before the medication is introduced and SIR after the medication is introduced(set the recovery rate p=0.145).

- **Sensitivity analysis of SIR model without medication**

| **k** | 0.02 | 0.03 | 0.0391 | 0.05 | 0.07 |
|---|---|---|---|---|---|
| **I(t)max** | 0.1882 | 0.3357 | 0.4287 | 0.5085 | 0.6052 |
| **tx** | 3185 | 2431 | 2064 | 1932 | 1911 |

**Table 4. Sensitivity analysis of SIR model without medication**

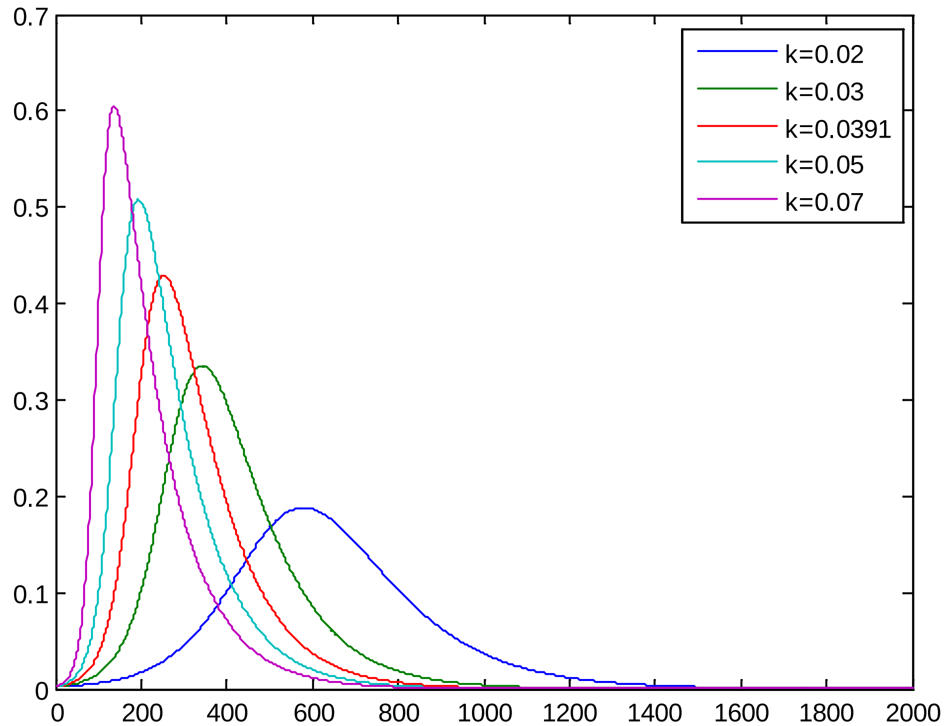


**Figure 6. Sensitivity analysis of SIR model without medication**

As shown in Table 4 and Figure 6 , with k increasing, $I(t)_{max}$ increases, and $t_x$ decreases, which is reasonable.

- SIR model with medication (daily recovery rate *p*=0.145)

| **k=** | **0.02** | **0.03** | **0.0391** | **0.05** | **0.06** |
|---|---|---|---|---|---|
| **tx** | 77 | 82 | 91 | 97 | 107 |

**Table 5. Sensitivity analysis of SIR model with medication**

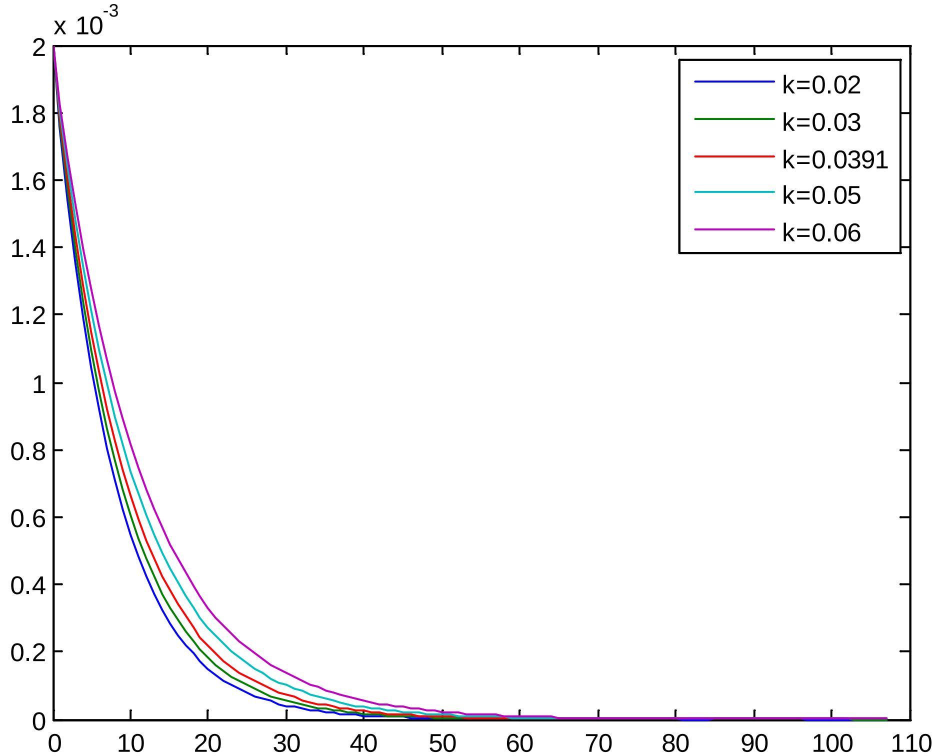


**Figure 7. Sensitivity analysis of SIR model without medication**

As showed in Table 5 and Figure 7, with k increasing, $t_x$ decreases, which is reasonable.

# 7 Strength and Weakness

### 7.1 Medication Estimate System

- Strength

1. Our assumption of the SI and SIR model is based on the actual situation of Ebola, which is relatively fair.
2. We set some parameters by the real data from the government of Sierra Leone
3. We display the law of spread perfectly by varying different parameters.

- Weaknesses

1. We adopt the SI model and SIR model to predict the infective people in the future, but there are some important factors that we don't take into account in the real world
2. We think that the daily quantity of medication that will be manufactured is exactly the demand. However, the real production cannot be like this.

### 7.2 Medication Delivery System

- Strength

1. We take all the important factors into account when selecting the most feasible city to be the distribution center
2. We find out much useful and real data to make our evaluation reasonable
3. Our model can be applied to all the strategy of selecting the location of delivery

- Weaknesses

1. We only use the distance of highway at A level to calculate the shortest distance, neglecting the other transportation between cities.
2. We idealized the transportation system, making it is inappropriate for the real distribution problem.

# 8 References

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[6] http://health.gov.sl/

# 9 Non-technical letter to WMA

To whom it may concern,

The 2014 Ebola Virus Disease outbreak continues to evolve in alarming ways, with the severely affected countries, Guinea, Liberia, and Sierra Leone, struggling to control the escalating outbreak against a backdrop of severely compromised health systems, significant deficits in capacity, and rampant fear.

To eradicate Ebola as soon as possible, our team has launched a program called "Ebola Medication Estimate Delivery Network "(EMED-Network) for World Medical Association to deliver its new medication to the patients who need it. We would like to submit a non-technical introduction of EMED-Network to your association so that you can use it in your announcement to the public.

EMED-Network consists of 2 secondary system, *medication estimate system* and *medication delivery system*. With this two secondary systems, our EMED-Network, every day, can estimate the number of new confirmed Ebola cases in different cities precisely within a country and deliver the medication to the destinations at a proper time and cost. Due to the background of our program is settled in an arbitrary country, as a general example and a feasible strategy, "Ebola Medication Estimate Delivery Network" can be applied in any countries suffering from Ebola epidemic around the world.

The *medication estimate system*, as the first system of EMED-Network, is used to estimate the daily amount of new confirmed Ebola cases in a country. In this system, we first find out how the realistic amount of the Ebola cases varies with time to determine the recovery rate and calculate the remove rate basing on the relevant daily-updated data released by the country's Health Ministry. Then we predict the proportion of patients among the country's population in the present sanitary condition, in another word, that the new medication is not used in eradicating Ebola in the country. After that, we calculate the recovery rate and take it account into our prediction of the daily patients amount when the new medication is applied practically and widely in the country. In the end, we estimate the daily amount of patients, the speed of manufacturing medication, and the need of medication per day through this system.

The *medication delivery system* is built up in the country to supply the demand from the Ebola outbreak cities, since we know the daily need of the medication. What's more, with the previous system, we can estimate the precise patients amount of each Ebola outbreak cities. We list all the Ebola outbreak cities in a country and rate them to find out the best location of delivery. Thus, we make a city evaluation criterion on the following 5 aspects: *distance of the delivery routes, the severity of Ebola, transportation infrastructure, sanitary condition and status of the city.* After collecting and calculating the detailed data related to the aspects, we define their significance by number so that we can measure each cities' ability of these 5 aspects. The cities are given a score, "Feasibility Grade", by the results. Then we rank all these Ebola outbreak cities by the "Feasibility Grade" from high to low. The city at first rank is the delivery location.

With the 2 secondary systems, "Ebola Medication Estimate-Delivery Network " makes the whole process of eradicating Ebola become measurable, visible and feasible. Each day Ebola outbreak cities would receive the medication whose amount is based on the estimation of the patients amount's variation from the delivery station (location of delivery). The whole process could be monitored by World Medical Association. Here is the framework of our Ebola Medication Estimate-Delivery Network:

We take Sierra Leone as a case study to construct our "Ebola Medication Estimate-Delivery Network " because it has the most Ebola cases for the moment. The *medication estimate system* predicts that there would be 10740 at the highest point and the need of the medication would be 103063 units. The *medication delivery system* confirmed the Bo city is the location point. With our EMED-Network, we can finally deliver the medication to the outbreak cities and will eradicate Ebola in Sierra Leone for 89 days.

We also apply EMED-Network on Liberia and Guinea, which also prove that our program is realistic and feasible. Relevant data and results are listed below:

We believe that “Ebola Medication Estimate Delivery Network ” will aid World Medical Association to do more contribution in the fight against the Ebola epidemic. EMED-Network can be applied in countries with Ebola outbreaks and will achieve the goal of eradicating Ebola as soon as possible.