Analysis of Eradicating Ebola

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Summary

Current out breaking Ebola Virus Disease (EVD) makes people around the world tremble with fear. Since March 2014, Ebola virus rapidly spread out, mainly in Western Africa, such as Liberia, Sierra Leone, and Guinea. EVD is very well known as one of the terrible disease, because the first time when this virus takes root in human body was in 1976, but there is no official Ebola Treatment Unit (ETU) created yet. Through mathematical modeling, we will assume that there is an official ETU discovered. A company of this ETU is trying to know how many quantity of vaccine is needed to eradicate EVD based on the spread of disease. This quantity of vaccine is influenced by the amount of treatments that each person needs to take. A company also likes to know the most effective delivering system to send their vaccine to countries that are needed as fast as possible with high quality of security. This feasible delivery system with location of delivery is able to arrive at final destination where Ebola management center is in the center of distribution. Lastly, this company likes to know how the speed of manufacturing system influences on Ebola virus cases. Through the mathematical modeling, we found the equation of spread of disease by using a differential equation, quantity of treatments that a company needs to make based on the number of spreading disease that we previously found. To deliver those treatments most effectively, we also found out the best location on center of distribution based on the number of road with latitude and longitude. We also measured the distance between the centers of distribution imagine to have a Ebola management center in the middle of the distance, so that people can use the management center conveniently. Lastly, we found the relationship of speed of manufacturing of the vaccine that how numbers and speed of manufacturing influence on market system. We found out that the increase of demand will conclude the increase of laborer on manufacturing with sigmoid function.

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1. Introduction

The current outbreak in West Africa, EVD killed 4,877 people in the last year of 2014, and this number of death toll is still increasing. EVD has the high fatality rate, but there is no certain vaccine to stop this virus. This virus started in 1976 at Yambuku, small village in northern Democratic Republic of the Congo. The name of the Ebola is from the Ebola River where the 1976 outbreak started. Since then, the virus spread slowly, but from 2014, this speed rapidly increased. There are several ETUs that have been made, such as ZMapp, TKM-Ebola, or Favipiravir, but none of those ETUs officially proved by world medical association, such as WHO (World Health Organization) that these are safe enough to be used in human. However, since thousands of people are dying by this virus, and there is no better solution than these ETUs, WHO accepted the usage of these vaccines.

Base on the basic information on EVD, we will be look forward to find out the number of infected people, quantity of the ETU needed, speed of manufacture these vaccines, and the quick delivery systems at optimal location with many variables as possible. The system that we develop will guide future Ebola virus to eradicate.

2. Spread of The Disease

To eradicate EVD, the first thing that we should be doing is to determine the current number of EVD cases on Earth, and how fast this number does grow. Current number of EVD cases is a constant number that we can easily find out; therefore what we need right now to know is how fast this number grows. To find this number, we decided to use the differential equations. In this way, we are able to describe how the EVD could potentially ravage a population. We will be using SIR model to generate the differential equation of spreading EVD. Before we start, there is one constant number that we need to be aware of; the percent of death among human cases is 73.61 percent.

From the basic SIR model, there are susceptible and infected populations. Yet, in this case, the infected group is divided into two groups, since one moves from susceptible to infected, and the other moves from infected to recovered group. Therefore, we say there is a recover group. Hence, we should think one more about the reduction of infected group. Of course, one way is recovery and another is deceased. Finally, we assume there are four populations, susceptible, infected, recovered and deceased groups. Let’s say that there are rates at which the groups join the other groups in the constant. Then there will be four constants of rate. Then here are the differential equations based on SIR model.

$$\frac{dS(t)}{dt} = -aS(t)I(t) + cR(t)$$

$$\frac{dI(t)}{dt} = aS(t)I(t) - bI(t) - eI(t)$$

$$\frac{dR(t)}{dt} = bI(t) - cR(t)$$

$$\frac{dD(t)}{dt} = eI(t)$$

To summarize the coefficients,
S(t) = the population of susceptibility
I(t) = the population of infected
R(t) = the population of recovery
D(t) = the population of decease
N(t) = S(t)+I(t)+R(t)+D(t) which is the total population
a = the rate of infection
b = the rate of recovery
c = the rate of susceptibility
e = the rate of decease.

Since the model is composed of four separate differential equations, we must use a numerical solver to plot the solution. We used the solver as MS Excel. The first scenario we used the current population of Kalisepll, Montana as the initial susceptible group, this value is 22,000.

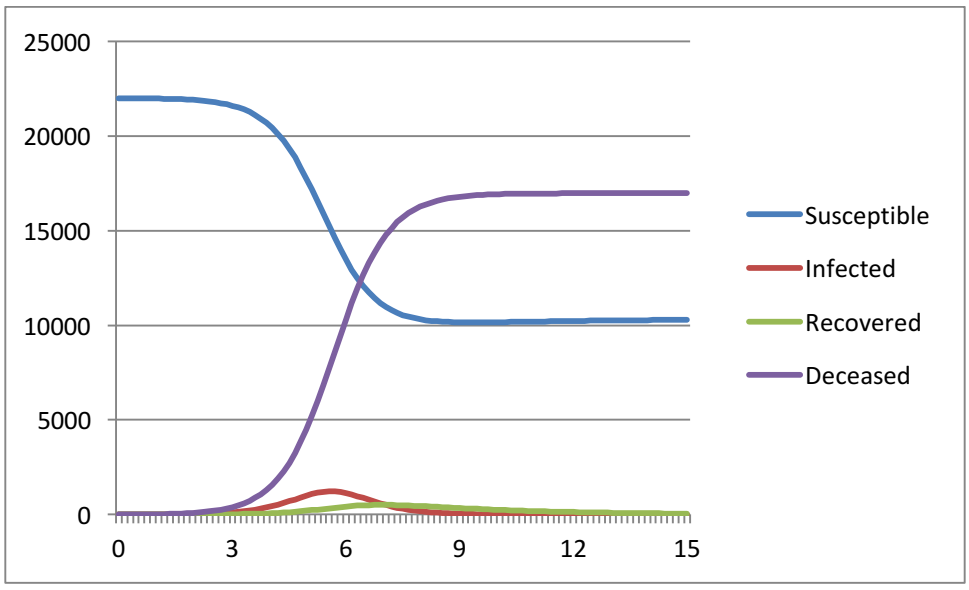
Time	Susceptible	Infected	Recovered	Deceased
0	21998	2	0	0
0.15	21996	2	0	0
0.3	21995	3	0	2
0.45	21992	4	0	4
0.6	21989	5	0	7
0.75	21986	6	1	10
0.9	21982	7	1	14
1.05	21976	9	1	19
1.2	21970	11	1	26
1.35	21962	13	2	33
1.5	21952	16	2	43
1.65	21940	20	3	54

1.8	21925	24	3	69
1.95	21907	30	4	86
2.1	21885	36	5	108
2.25	21858	44	6	134
2.4	21824	55	8	167
2.55	21783	67	10	207
2.7	21733	82	12	255
2.85	21672	100	15	315
3	21597	122	18	388
3.15	21507	148	22	477
3.3	21397	180	27	585
3.45	21265	218	33	717
3.6	21105	263	40	875
3.75	20915	315	49	1067
3.9	20688	376	59	1297
4.05	20421	446	72	1572
4.2	20108	524	86	1897
4.35	19745	611	103	2280
4.5	19331	704	123	2726
4.65	18863	802	146	3240
4.8	18344	900	171	3825
4.95	17778	994	199	4483
5.1	17172	1078	230	5208
5.25	16539	1147	262	5995
5.4	15891	1195	296	6833
5.55	15243	1218	330	7705
5.7	14611	1214	364	8594
5.85	14009	1184	395	9480
6	13448	1129	424	10344
6.15	12936	1056	449	11169
6.3	12479	968	470	11939
6.45	12076	872	487	12646
6.6	11728	774	499	13283
6.75	11431	677	506	13848
6.9	11180	586	509	14342
7.05	10971	501	508	14769
7.2	10798	426	504	15135
7.35	10656	359	497	15446
7.5	10541	301	487	15708
7.65	10448	251	476	15927

7.8	10374	208	463	16110
7.95	10315	172	449	16262
8.1	10269	142	434	16388
8.25	10233	117	419	16492
8.4	10206	97	404	16578
8.55	10185	80	388	16648
8.7	10171	65	373	16706
8.85	10161	54	357	16754
9	10154	44	342	16793
9.15	10150	36	327	16825
9.3	10149	30	313	16852
9.45	10149	24	299	16873
9.6	10151	20	286	16891
9.75	10154	16	273	16906
9.9	10158	13	260	16917
10.05	10162	11	248	16927
10.2	10167	9	237	16935
10.35	10172	7	226	16942
10.5	10177	6	215	16947
10.65	10182	5	205	16952
10.8	10187	4	195	16955
10.95	10193	3	186	16958
11.1	10198	3	177	16961
11.25	10203	2	169	16963
11.4	10208	2	161	16965
11.55	10213	2	153	16966
11.7	10217	1	146	16967
11.85	10222	1	139	16968
12	10226	1	132	16969
12.15	10231	1	126	16969
12.3	10235	1	120	16970
12.45	10239	0	114	16970
12.6	10242	0	108	16971
12.75	10246	0	103	16971
12.9	10250	0	98	16971
13.05	10253	0	93	16971
13.2	10256	0	89	16972
13.35	10259	0	85	16972
13.5	10262	0	81	16972
13.65	10265	0	77	16972

13.8	10267	0	73	16972
13.95	10270	0	69	16972
14.1	10272	0	66	16972
14.25	10274	0	63	16972
14.4	10276	0	60	16972
14.55	10278	0	57	16972
14.7	10280	0	54	16972
14.85	10282	0	52	16972
15	10284	0	49	16972

Total	22000	
Infection Rate	0.000165	
Recovery Rate	0.27	
Susceptible again Rate	0.23	
Decease Rate	0.73	
Initial Infected	2	
Delta time	0.15	
Interaction Rate	1.4	14000

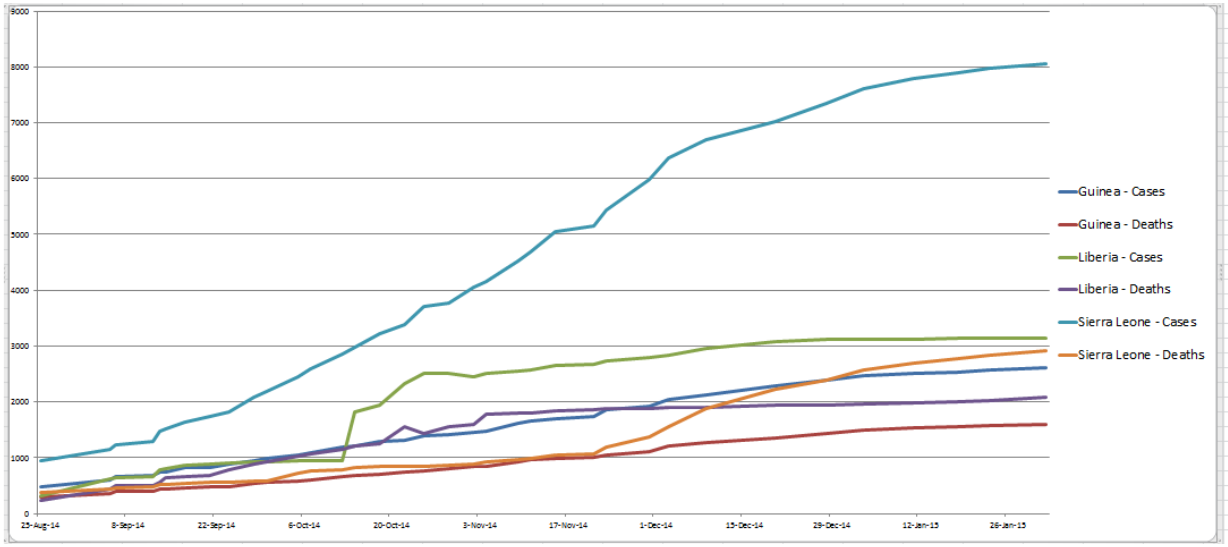


The following data Figure [1] is from WHO based on 3 nations,

Cumulative	Guinea - Cases	Guinea - Deaths	Liberia - Cases	Liberia - Deaths	Sierra Leone - Cases	Sierra Leone - Deaths
25-Aug-14	484	287	322	225	935	380
5-Sep-14	604	362	614	431	1146	443
6-Sep-14	664	400	634	508	1234	461
12-Sep-14	678	403	654	498	1287	478
13-Sep-14	743	429	790	563	1464	514
14-Sep-14	750	435	812	631	1513	517
17-Sep-14	818	465	863	670	1640	545
21-Sep-14	832	468	890	671	1745	552
24-Sep-14	876	481	914	792	1816	557
28-Sep-14	950	535	927	890	2076	574
30-Sep-14	977	562	931	934	2179	575
5-Oct-14	1044	587	941	1018	2455	725
7-Oct-14	1097	598	943	1072	2593	753
12-Oct-14	1184	653	950	1143	2849	776
14-Oct-14	1217	671	1820	1219	2977	819
18-Oct-14	1289	710	1942	1241	3223	836
22-Oct-14	1312	732	2321	1562	3389	839
25-Oct-14	1391	761	2515	1432	3700	845
29-Oct-14	1409	793	2515	1564	3778	862
2-Nov-14	1457	837	2451	1590	4057	893
4-Nov-14	1479	850	2514	1783	4149	921
9-Nov-14	1612	934	2553	1795	4523	960
11-Nov-14	1647	958	2562	1806	4683	978
15-Nov-14	1698	982	2643	1834	5056	1041
21-Nov-14	1745	998	2669	1854	5152	1058
23-Nov-14	1850	1050	2727	1877	5441	1189
30-Nov-14	1929	1117	2801	1882	5978	1374
3-Dec-14	2051	1207	2830	1902	6375	1559
9-Dec-14	2127	1262	2949	1908	6702	1876
20-Dec-14	2284	1344	3085	1933	7017	2216
28-Dec-14	2397	1433	3110	1943	7354	2392
3-Jan-15	2471	1499	3118	1964	7602	2577
11-Jan-15	2514	1530	3127	1982	7786	2696
18-Jan-15	2539	1557	3135	2003	7903	2779
23-Jan-15	2569	1578	3138	2015	7968	2833
1-Feb-15	2608	1597	3143	2075	8059	2910

Difference	Guinea - Cases	Guinea - Deaths	Liberia - Cases	Liberia - Deaths	Sierra Leone - Cases	Sierra Leone - Deaths
25-Aug-14	484	287	322	225	935	380
5-Sep-14	120	75	292	206	211	63
6-Sep-14	60	38	20	77	88	18
12-Sep-14	14	3	20	-10	53	17
13-Sep-14	65	26	136	65	177	36
14-Sep-14	7	6	22	68	49	3
17-Sep-14	68	30	51	39	127	28
21-Sep-14	14	3	27	1	105	7
26-Sep-14	44	13	24	121	71	5
28-Sep-14	74	54	13	98	260	17
30-Sep-14	27	27	4	44	103	1
5-Oct-14	67	25	10	84	276	150
7-Oct-14	53	11	2	54	138	28
12-Oct-14	87	55	7	71	256	23
14-Oct-14	33	18	870	76	128	43
18-Oct-14	72	39	122	22	246	17
22-Oct-14	23	22	379	321	166	3
25-Oct-14	79	29	194	-130	311	6
29-Oct-14	18	32	0	132	78	17
2-Nov-14	48	44	-64	26	279	31
4-Nov-14	22	13	63	193	92	28
9-Nov-14	133	84	39	12	374	39
11-Nov-14	35	24	9	11	160	18
15-Nov-14	51	24	81	28	373	63
21-Nov-14	47	16	26	20	96	17
23-Nov-14	105	52	58	23	289	131
30-Nov-14	79	67	74	5	537	185
3-Dec-14	122	90	29	20	397	185
9-Dec-14	76	55	119	6	327	317
20-Dec-14	157	82	136	25	315	340
28-Dec-14	113	89	25	10	337	176
3-Jan-15	74	66	8	21	248	185
11-Jan-15	43	31	9	18	184	119
18-Jan-15	25	27	8	21	117	83
23-Jan-15	30	21	3	12	65	54
1-Feb-15	39	19	5	60	91	77

Following is the graph Figure[2] on cummulative of spread of disease,



3. Quantity of Treatment Needed

The quantity of ETU needed straight forwardly relevant with the number of infected people and the number of ETU(s) prescript per person. Since we are looking forward to find the

Quantity of vaccine needed Q_n

Let's say the current number people infected by Ebola virus N

Simply, we can calculate the quantity of ETUs needed by

$$Q_n = N * number\ of\ ETU(s)\ prescript\ per\ person$$

However, there is one big variable in the number of infected people N .

The number of infected people is not constant; in fact the number is increasing in certain speed every year. To find the number of infected people, we are able to use the date from previous section. To find the general equation on N, we can use the Figure [2] of graph, draw a temporary linear function to estimate slope of the graph. Yet, we are focusing on 3 nations right now; therefore we will bring the cumulated number of N from Figure [1]. Guinea had 2,608 cases of EVD, Liberia had 3,143 and Sierra Leone had 8,059.

Before we use this $\boldsymbol{Q_n}$function with number of ETU(s) prescript per person, we would like to give general ideas about what kinds of ETUs had been discovered, and how those vaccines are used differently as in the quantity of usage. These are the three main ETUs that had been discovered. None of these are officially proved that it is safe on human body, but since these are the best solutions on EVDs, WHO allows these companies to create treatment and prescript on human.

- ZMapp
  ZMapp discovered by Mapp Biopharmaceutical Co. San Diego, United States of America. Each person needs to take 50mg of liquid type vaccine for 3 times. A company makes an average of 70 treatments per month that is 840 treatments per year. Since a person takes 3 treatments to cure, which give us that, a company saves 280 people per year.
- TKM-Ebola
  TKM-Ebola discovered by Tekmira pharmaceutical Co. Vancouver, Canada. Each person needs to take 2.4mg of liquid type vaccine for 3 times. A company makes average of 900 treatments per year. Since a person takes 3 treatments to cure, which give us that a company saves 158 people per year.
- Favipiravir
  Favipiravir discovered by Toyama Chemical Co. Tokyo, Japan. Each person needs to take 150mg of tablet twice a day for 14days. That means each person takes 4200mg of treatment by having 28 tablets. A company makes average of 20,000 tablets per year. Since a person takes 28 tablets to cure, which give us that a company saves 188 people per year.

Likewise, each ETU has different amount of treatment allowed us to take. Among previous Q_n solution with certain number of treatments prescript and the previous spread of disease equation, we are able to find out the quantity of treatments needed based on differences of treatments type. According to Figure [1], Guinea had 2,608 cases of EVD, Liberia had 3,143 and Sierra Leone had 8,059 with number of treatments prescript. Following chart is the quantity of treatments that each company needs to make,

	Zmapp	TKM-Ebola	Favipiravir
Guinea	7,824	7,824	73,024
Liberia	9,429	9,429	88,004
Sierra Leone	225,652	225,652	225,652

4. Feasible Delivery System / Location of Delivery

Out breaking of fatal disease, such as EVD is a serious warning on people all over the world. Since March 2014, the number of cases on EVD rapidly increased, and it still is. In condition that

pharmaceutical companies are making enough ETUs, the next step that we need to have is feasible delivery system. As companies make vaccines, we need an effective delivering system to move this ETU to the area in need of aid. To have a general idea on this delivery system, we got a lot of helps from Coca-Cola Company's Project Last Mile. Project Last Mile Company is the system that the Coca-Cola Company partnership with U.S. Agency for International Development fund to fight AIDS or Malaria. Through this Project Last Mile project, Coca-Cola Company is delivering medicines to many countries in Africa. As Coca-Cola Company does, now we are trying to figure out the ability on delivery system step-by-step.

The first step that we can think is from a company to the airport. The three main pharmaceutical companies that we used in previous section were,

- ZMapp, by Mapp Biopharmaceutical Co. San Diego, United States of America
- TKM-Ebola, by Tekmira Pharmaceutical Co. Vancouver, Canada
- Favipiravir, by Toyama Chemical Co. Tokyo, Japan

Other than these examples, countries that are putting effort to make vaccination are mostly advanced countries, because the country must be able to afford financially to researchers to work on their research. And most of advanced countries have fairly convenient transportation, so there is no worry about transportation from one company to the airport. Here, we are assuming, also highly recommending using airplane, because we are delivering large amount of treatments and these treatments have to be deliver as fast as possible, so that we decided that airplane is the best solution to use. While using the airplane, there are few things that we need to be aware. Since we are trying to deliver large amount of treatments without spoil it, it is important to keeping the certain level of temperature with high level of protection. These are the recommended conditions to keep these treatments safely. These conditions can be change by types of treatments,

- No more than 60% relative humidity
- Some treatments need to be stay away from exposure of sunlight
- Frozen storage needs to stay at -20°C
- Room temperature storage needs to stay 15°-25°C

For high level of protection, we are highly recommended to have 4-6 managers during this level of transportation, but this number can be flexibly change by amount of treatments or by types of treatments.

When treatments arrive to the airport, next step is to move to the other country's airport where treatments are needed. At this point, we will consider having a one airport per a country. As we mentioned above, it is very important to move those treatments safely, so it requires at least 4 people to guide treatments for safe travel. The airport that we land can be either international or domestic. Since this is an emergency delivery of treatments, we are able to use any airports that

are efficient. In our case, regardless whether it is an international or not, we will use an airport that has the most convenient distribution for the next transportation. More mathematically, we will decide the location of the airport which is adjacent to the center of distribution. By calculating the mean of coordinate (latitude and longitude) with the number of truck roads in each city, we set the center of distribution. We used the number of expressway and local road as the number of truck road.

$$\overline{\mathrm{X}} = \sum_{i=1}^{n} \frac{r_i * x_i}{R}, \qquad \overline{\mathrm{Y}} = \sum_{i=1}^{n} \frac{r_i * y_i}{R}$$

$$for\ i = number\ of\ cities, r_i = number\ of\ roads, x_i = latitude, y_i = longitude, R = \sum_{i=1}^{n} r_i$$

From the airport we land, we will now distribute these treatments into $n = 10$ big cities, therefore we would set i as 1 through n. In this assumption, we set $n = 10$, but this number can be various.

Now, we got the distance between the center of distribution and the coordinates of each airports in the nation. To find the shortest path between the airports and the center of distribution,

$$d_j = \sqrt{\left(\bar{X} - a_j\right)^2 - \left(\bar{Y} - b_j\right)^2}$$

$$for\ j = the\ number\ of\ airports, a_j = latitude\ of\ airport, b_j = longtitude\ of\ airport$$

We will rank the length of d_js to find the shortest path.

From the airport we found, now we need to send those treatments to each city's Ebola management center. On the way to each center, again, it is important to keep high level of security with certain amount of temperature. The location of Ebola management center is next to a big hospital for example of ELWA 3 Ebola Management Center, Monrovia, Liberia. At management center, as soon as they get the treatments they store it at the storage building with high security. Figure [3] is the example of Ebola Management Center, Monrovia, Liberia.

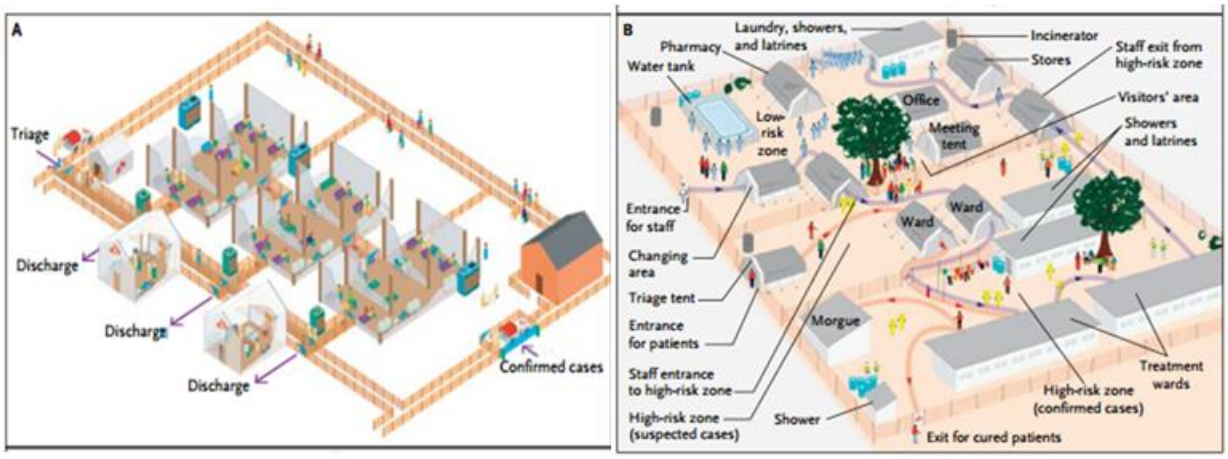
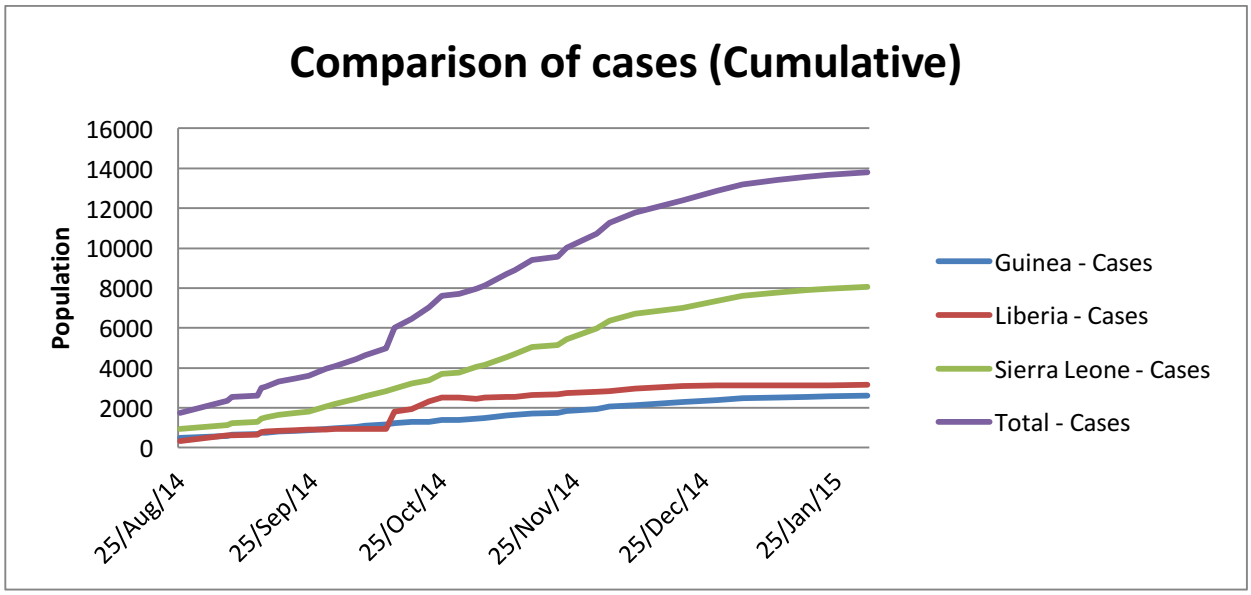


Figure [3] Ebola Management Center, Monrovia, Liberia
Panel A shows the high-risk zone
Panel B shows the complete center

So far we got the basic formula of feasible delivery systems and location of delivery. Based on this information, we are able to find out the optimal condition of delivering system to bring the ETU. One thing that we need to add on those formulas would be the spread of disease that we previously presented. According to the spread of disease tells the concentration of Ebola cases, and the distance between the airport will show us the best location of management center.

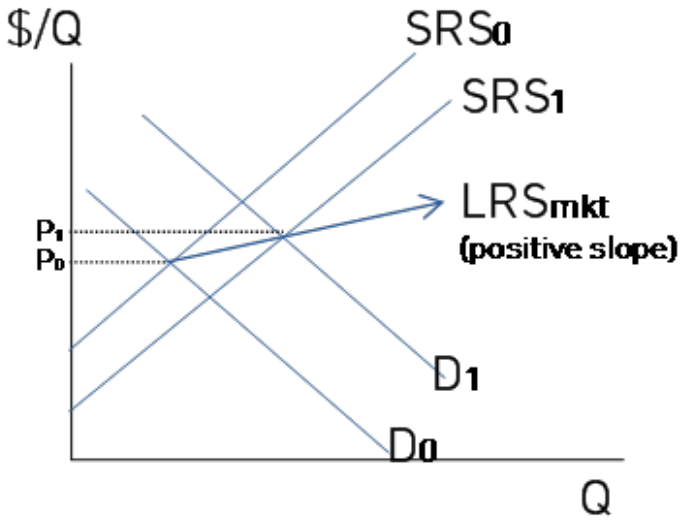
5. Speed of Manufacturing of The Vaccine

Before we find the speed of manufacturing the vaccine, let's assume that anyone who is infected wants to get the vaccine to cure and a health association cost the vaccine at the market price. The Following graph, Figure [4], shows the comparison of cases among three nations and the total.

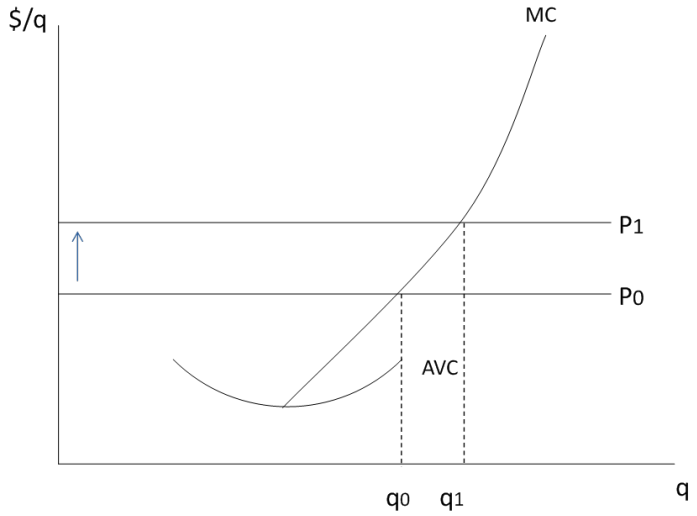


As we see, the cases are escalating and downward shape. Also, the graph is extracted from Figure [2].

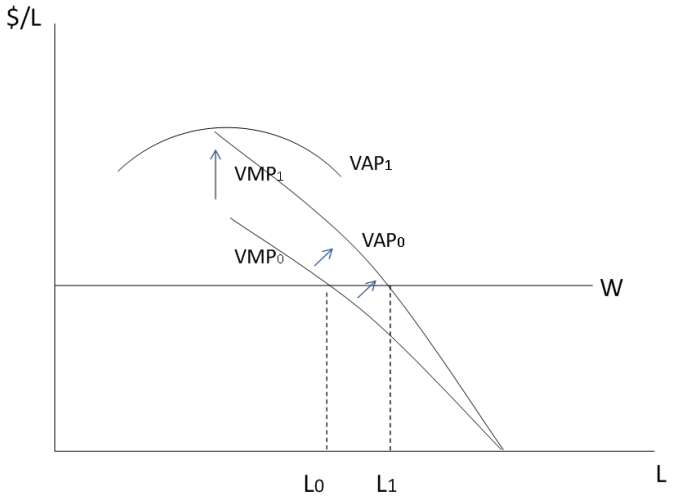
To find the speed of manufacturing, we adjust Increasing-cost Industry-entry/expansion from the text book Microeconomics: Theory & Applications by Edgar Browning and Mark Zupan, 11th edition. Here is the graph.



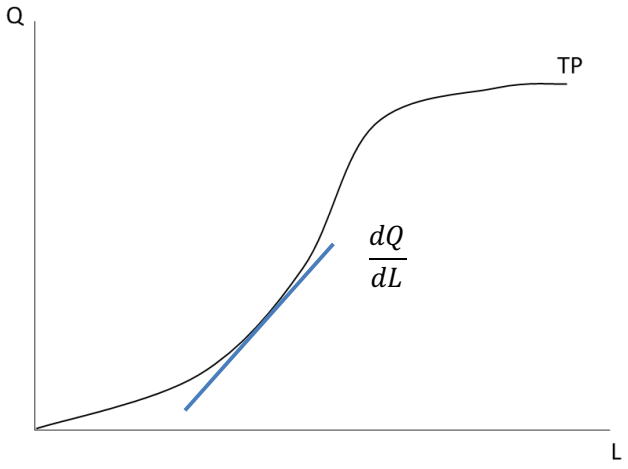
As the infected increase, the demand of the vaccine increases and then the price of the vaccine increase. Then the original manufacturing industry expands or a new manufacturing industry enters. But here we assume that there is no any new manufacturing industry. The result is that the supply increases and the market price reduces to P_1.



Since the price increases, the quantity of vaccine increases when the marginal cost and average variable cost are constant.



As the demand and the price increase, VMP and VAP shift upward and the wage is constant. Therefore, the labor increases from L_0 to L_1.



From the above graphs, we can notice that the labor and quantity increase and the total production graph shows like above. Since we set the time as a long-term period, the labor is proportional to the time until certain limit. Thus, the labor and the time is linear relationship. The slope of the total production is the speed of manufacturing of the vaccine. As the labor increase, the speed of manufacturing rapidly increases. From a point that the slope is vertical, the increase of speed reduces. As we see, the total production converges to some point of the quantity. That's because the quantity depends on the population and the population becomes constant because the society makes boundary.

6. Letter to Medical Association

Dear Organization,

Hi, we are the 2015 Mathematical Contest of Modeling participants. Through the contest, we've got the two choices of mathematical modeling problems, and we decided to work on the topic of Ebola Virus Disease (EVD). While solving the problem on EVD, we learned a lot of general information on Ebola virus and we furthermore modeled several mathematical equations. We would like to present our models to your organization. We hope our modeling is useful for your organization to plan the future expectations.

First, we started with the number of EVD cases. To find the EVD cases that has been happened, we started with constant number of current EVD cases with additional equation of spreading diseases.

$$\frac{dD(t)}{dt} = eI(t)$$

D(t) = the population of decease
e = the rate of decease.
I(t) = the population of infected

Based on the current EVD cases, and the additional number of spread of diseases, we can determine the cumulated number of EVD cases. With cumulated number, we can also find the quantity of treatments that each company needs to make by multiplying the cumulated number of EVD cases with number of treatment(s) that each person needs to take to cure. For the cumulated number of EVD cases, we chose the 3 main nations; Guinea, Liberia, and Sierra Leone. Along with that, we also chose 3 examples of Ebola vaccines; ZMapp, TKM-Ebola and Favipiravir.

	EVD Cases Cumulated
Guinea	2,608
Liberia	3,143
Sierra Leone	8,059

	ZMapp	TKM-Ebola	Favipiravir
Guinea	7,824	7,824	73,024
Liberia	9,429	9,429	88,004
Sierra Leone	225,652	225,652	225,652

Now we know how many treatments do companies need to produce to eradicate Ebola. As we figured out the quantity of treatments needed, the next step that we need to be concerned is the delivering system from a country where the companies are located to the country where people need them. During the delivery, the most important condition that we need to maintain is to keep high level of security with certain level of temperature, so that those treatments will not be spoiled.

Before companies ship their vaccines, they should consider the center of distribution. As they land at the center of distribution, it is easier for people to visit their management center, and easier for them to spread more if necessary. Following equation is used to find out the center of distribution center,

$$\overline{\mathrm{X}} = \sum_{i=1}^{n} \frac{r_i * x_i}{R}, \qquad \overline{\mathrm{Y}} = \sum_{i=1}^{n} \frac{r_i * y_i}{R}$$

$$for\ i = number\ of\ cities, r_i = number\ of\ roads, x_i = latitude, y_i = longitude, R = \sum_{i=1}^{n} r_i$$

Based on the distribution center, now we need to find the distance between the distribution centers to the every airport in that country. Following is the equation to find the distance between distribution centers to the every airport in that country.

$$d_j = \sqrt{\left(\bar{X} - a_j\right)^2 - \left(\bar{Y} - b_j\right)^2}$$

$$for\ j = the\ number\ of\ airports, a_j = latitude\ of\ airport, b_j = longtitude\ of\ airport$$

By using this equation, we were able to rank airports from the shortest distance to the longest.

We also researched how the speed of treatment manufacturing is influenced. Through this section, we found the relationship of manufacturing with market system. We realized that as the EVD increased, more people would like to buy a vaccine, and therefore the demand of the vaccine increase. As demand goes up, a company would raise the price, so the price will go up, and at the same time they would expand their manufacturing, and therefore the number of supply will also move up. As they expand their manufacturing, the quantity of the treatments will also move up, and to make more treatments, a company will hire more laborers to work in their company.

We also realized as we graph the function between quantity and the labor, it creates a sigmoid function. As the number of laborer increase, quantity of treatments expands faster and faster, but at one point the quantity will become a constant number.

These are the information that we modeled based on the current issue of EVD. Hope it makes sense, and hope these are useful to eradicate EVD.

Very respectfully,

Team # 41735

7. Conclusion

Among with the constant number of current EVD cases, we found the equation on the spread of disease,

$$\frac{dD(t)}{dt} = eI(t)$$

D(t) = the population of decease
e = the rate of decease.
I(t) = the population of infected

Based on this spread of disease equation, we are able to find the quantity of treatments that each company needs to make. Also, to deliver those treatments to the destination as quickly as possible with high level of safety, we found the best location in the center of distribution by the mathematical equation of,

$$\overline{\mathrm{X}} = \sum_{i=1}^{n} \frac{r_i * x_i}{R}, \qquad \overline{\mathrm{Y}} = \sum_{i=1}^{n} \frac{r_i * y_i}{R}$$

$$for\ i = number\ of\ cities, r_i = number\ of\ roads, x_i = latitude, y_i = longitude, R = \sum_{i=1}^{n} r_i$$

Also, to find the distance between these centers of distribution to the airport, to build the management center, we used the equation of,

$$d_j = \sqrt{\left(\bar{X} - a_j\right)^2 - \left(\bar{Y} - b_j\right)^2}$$

$$for\ j = the\ number\ of\ airports, a_j = latitude\ of\ airport, b_j = longtitude\ of\ airport$$

Finally, we also researched how the speed of manufacturing effects on market system. In conclusion, we found out that the increase of demand will result in the increase of laborer on manufacturing with sigmoid function.

8. Strengths & Weaknesses

- Spread of The Disease
  - Strengths
    Since we added the population and the rate of the deceased, our SIR model is more precise than the original SIR model which includes the susceptible, the infected and the recovered.
  - Weaknesses
    Did not include the variables on fertility rate and mortality rate
    Figure [2] Liberia-cases has an error at 10 October -14 that number of death is over the number of cases.
    The data from WHO has little error to compute exact conclusion. So it was hard to make adequate inferences.
- Quantity of The Medicine Needed
  - Strengths
    Quantity of the medicine needed is the information based on the spread of the disease, and since our spread of the disease information is highly reliable, the quantity of the medicine needed must be also highly accurate.
  - Weaknesses
    We assumed the relationship between quantity of medicine and people is proportional, since there is no information given in current situation. We were not able to find the detailed information, because it was restricted by company.
- Feasible Delivery Systems / Location of Delivery
  - Strengths
    Based on the exact coordinate of cities and airport, we adopted a supply chain system from the business.
    We considered every step from manufacturing industries to the Ebola management center as if we are the supply chain mangers.
    We tried the every possible airport in country.
  - Weaknesses
    We could not consider the native infrastructure system since domestic incidence linking with the infrastructure such as expressway or local road.
    We only considered truck road as expressway or local road because we do not know the specific road system in each city: we only used the Google Map.
- Speed of Manufacturing of The Vaccine
  - Strengths
    We adapted the concept of microeconomics such as the relation among demand, supply, market-price, labor, and total production.
    To understand easily, we drew the graphs of each situation and explained according to the graphs.

- Weaknesses
  We assumed the labor increased as much as the time passed since the nation which has the Ebola treatments does not produce as many as needed by the infected people. Thus we cannot get any of relation data between time and labor.

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