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Network Analysis of Ebola Virus Control Model Based on Differential Equations

by

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HR EXCELLENCE IN RESEARCH

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Article Used and Motivation

The Ebola Outbreak Control Model Based on the Differential Equation

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Recently, it has been a hot topic in the field of medical and disease how to slow down or control the speed of the spread of Ebola. To solve this problem, we divided the whole stage of Ebola spread into three stages: Free-Spread stage, Isolation-Control stage and Prevent-Treatment stage. Based on these stages, we get the corresponding SEID ordinary differential equations method, SEIQD method and SEIQRD method respectively. And the feasible projects can be worked out at different stages to control Ebola. In further discussion, we study the problem of drug delivery, and delivery method was got in order to make the best use of medicine which includes three steps: 1) finding the best location of transfer station; 2) carrying out the clustering analysis of the affected regions; 3) finding the preliminary delivery systems of any one of affected regions. From the above steps, possible feasible delivery systems can be made from the above steps. Finally, the simulation analyses of the series of methods were made. The numerical results indicate that our method can be used to simulate the Ebola spread.

Figure 1. The Paper used for the modelling of the Ebola virus

Limitation: The exact results of the article could not be reproduced due to the fact that the authors did not present the exact parameters they used. They only stated to have gotten it from WHO database and other articles – a procedure which we also followed but obviously had different parameters.

Motivation: The current spreading virus is the novel coronavirus popularly known as COVID-19. However, the Ebola virus which was declared to have been suppressed was discovered to surface again earlier this year. WHO confirmed four new cases of the Ebola virus disease (EVD) from 29 January to 4 February in the Democratic Republic of the Congo. All four cases were reported in Beni Health Zone, North Kivu Province.

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Article Details Extracted

The exact models of the articles were used. Three models are presented in the article:

- Ebola Virus Model: Free-Spread Stage (figure 2)

- Ebola Virus Model: Isolation-Control Stage (figure 3)

- Ebola Virus Model: Prevention-Treatment Stage (figure 4)

$$
\begin{cases}
\frac{dS(t)}{dt} = -\beta S(t)(1-\gamma)I(t) \\
\frac{dE(t)}{dt} = \beta S(t)(1-\gamma)I(t) - \theta E(t) \\
\frac{dI(t)}{dt} = \theta E(t) - \gamma I(t) \\
\frac{dD(t)}{dt} = \gamma I(t)
\end{cases}
$$

figure 2

$$
\begin{cases}
\frac{dS(t)}{dt} = -\beta S(t)(1-\delta-\gamma)I(t) \\
\frac{dE(t)}{dt} = \beta S(t)(1-\delta-\gamma)I(t) - \theta E(t) \\
\frac{dI(t)}{dt} = \theta E(t) - (\delta+\gamma)I(t) \\
\frac{dQ(t)}{dt} = \delta I(t) - \varepsilon Q(t) \\
\frac{dD(t)}{dt} = \gamma I(t) + \varepsilon Q(t)
\end{cases}
$$

figure 3

$$
\begin{cases}
\frac{dS(t)}{dt} = -\beta(1-\alpha)S(t)(1-\delta-\gamma-\rho)I(t) \\
\frac{dE(t)}{dt} = \beta(1-\alpha)S(t)(1-\delta-\gamma-\rho)I(t) - \theta E(t) \\
\frac{dI(t)}{dt} = \theta E(t) - (\delta+\gamma+\rho)I(t) \\
\frac{dQ(t)}{dt} = \delta I(t) - (\varepsilon+\rho)Q(t) \\
\frac{dR(t)}{dt} = \rho(I(t)+Q(t)) \\
\frac{dD(t)}{dt} = \gamma I(t) + \varepsilon Q(t)
\end{cases}
$$

figure 4

❖ **Parameter Values (from WHO, CDC and published articles):**

α (vaccine working rate) = 0.016

β (effective contact rate) = 0.002,

ε (death rate from quarantine) = 0.5

δ (quarantine rate) = 0.16

θ (exposure rate) = 0.1

γ (lethality rate) = 0.3

ρ (cure rate) = 0.2

❖ **Numerical Approach for Simulation:**

Runge Kutta Methods

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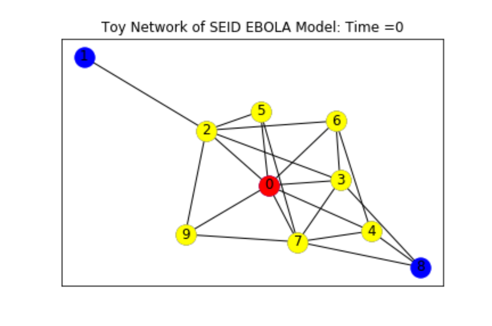
Modification of the Model for Network Analysis

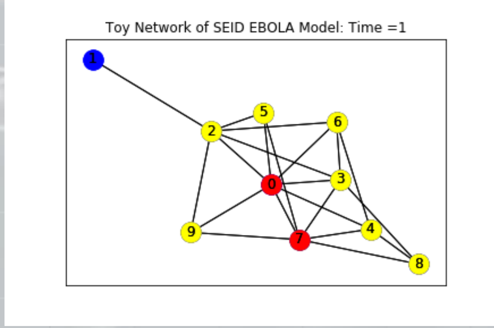
- Developed the same system in a network graph.
- Start with an infected node, all nodes are susceptible.
- Connectivity with an infection node implies exposure in our modification.
- Use ε, θ, δ, γ and ρ as rate to switch in-between compartments.
- Take count of the number of individuals in each compartment at every time point.

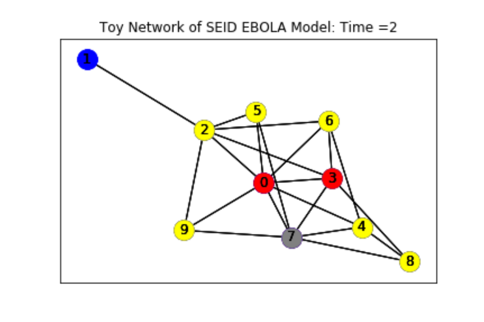
Table 1. Network Specifications

Graph	Random	Watts Strogatz	Barabasi Albert
Parameters	N=100 p=0.02	N=100 k=20 p=0.7	N=100 m=20

Toy Network: Susceptible Exposed Infected Death







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Model Simulation (Numerical Approximation)

Article Simulation

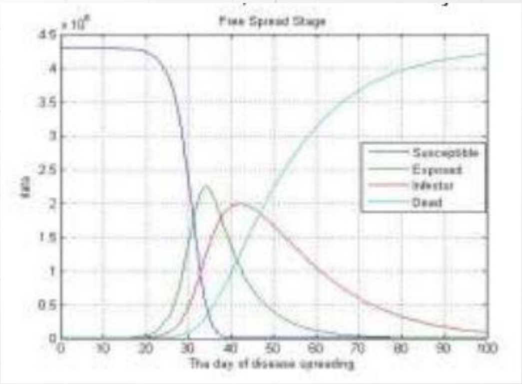


figure 11 (Model 1)

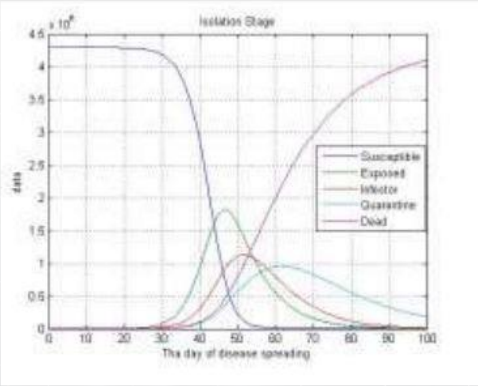


figure 12 (Model 2)

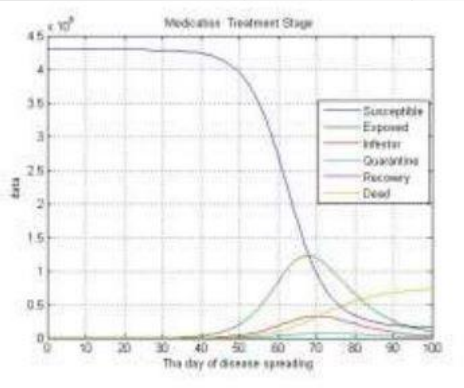


figure 13 (Model 3)

Our Simulation

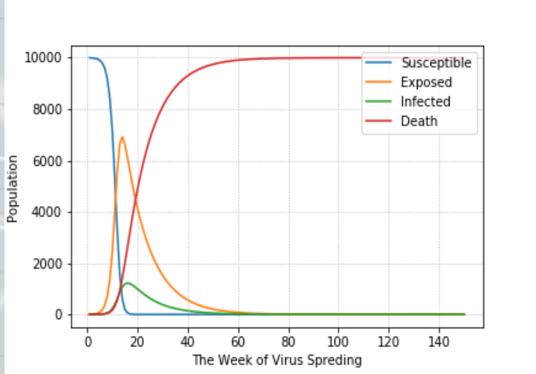


figure 14 (Model 1)

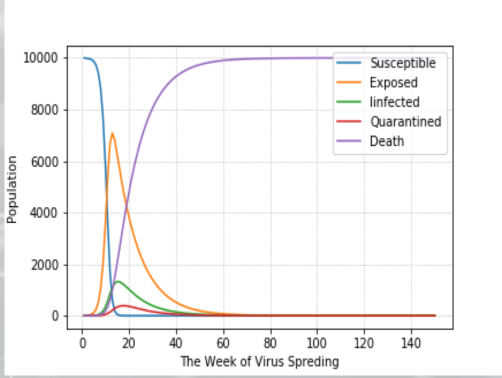


figure 15 (Model 2)

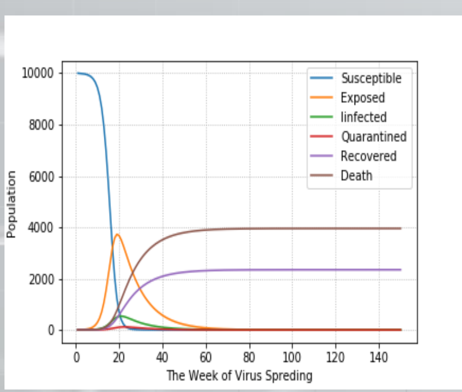
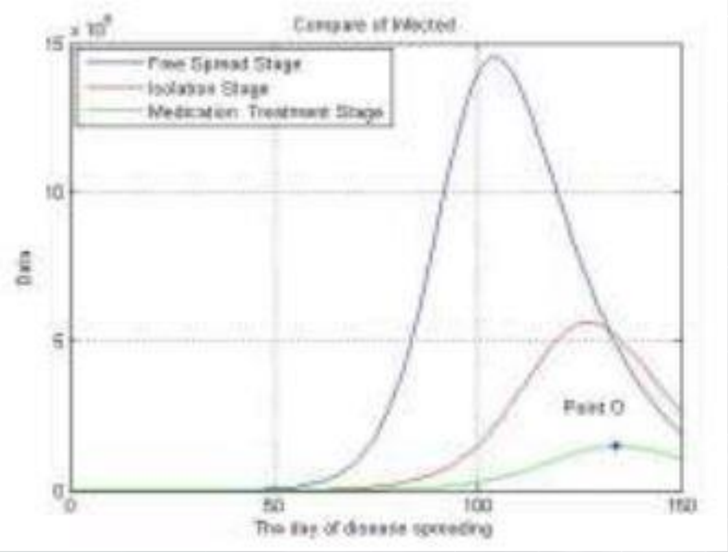
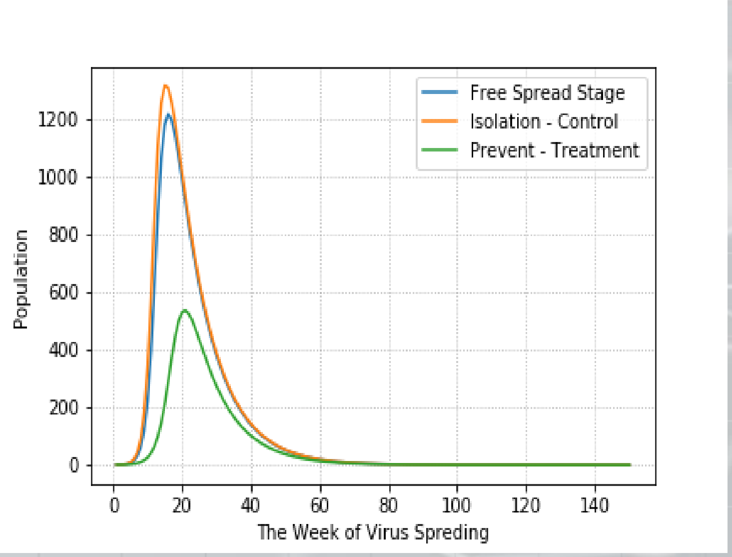


figure 16 (Model 3)

Infection Spread (Numerical Approximation)





The impact of the additional compartment and rate of transmission was observed from this diagram. Due to the selection of our parameter, it is easy to know that to achieve the goal of eradicating the Ebola, we need to identify the parameter's values of the specific areas (For example, the transmission rates in different regions are different). This will make the model more accurate and completely.

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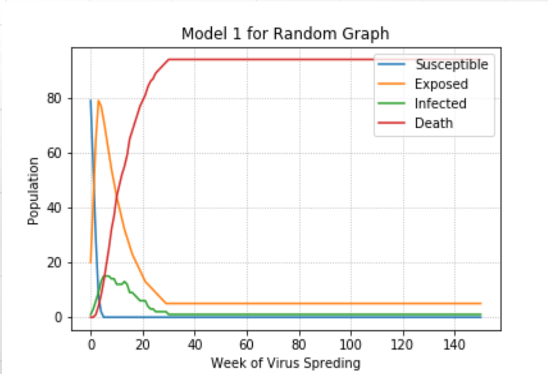
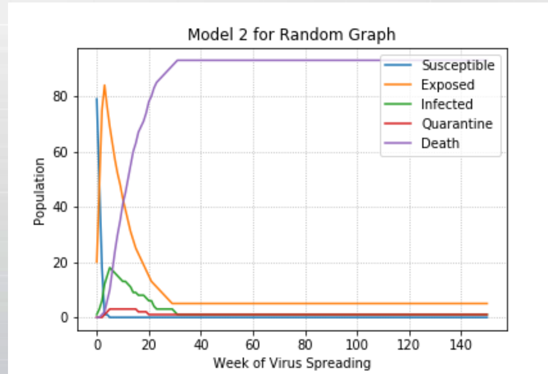
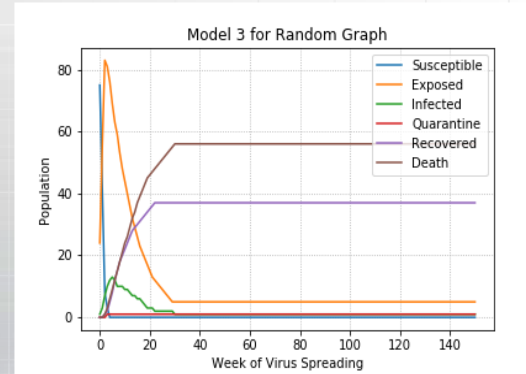
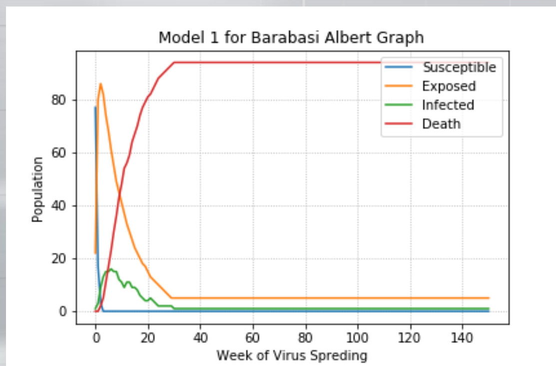
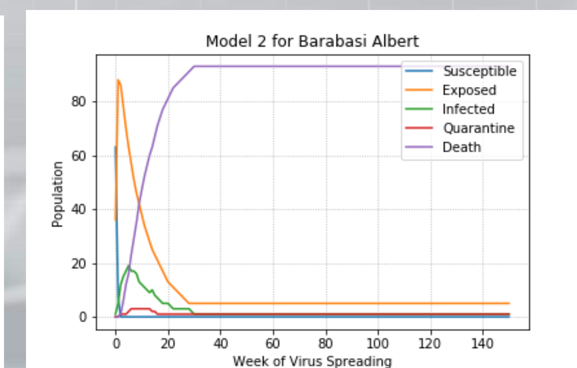
Model Result on Network

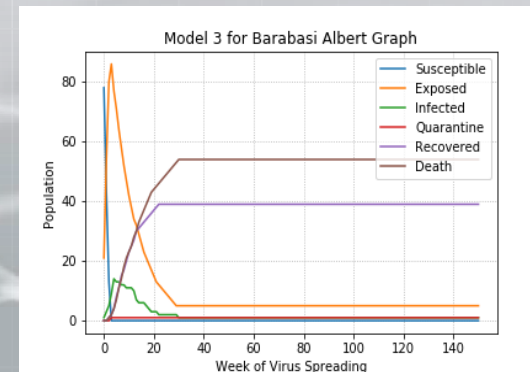


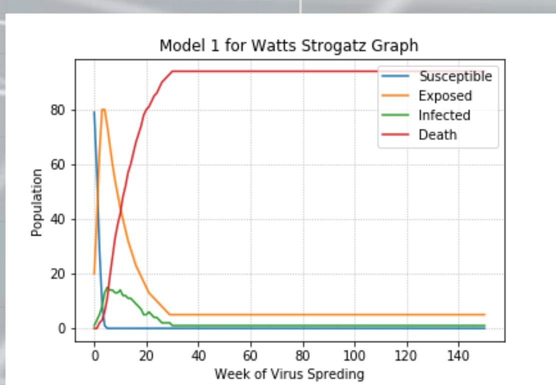


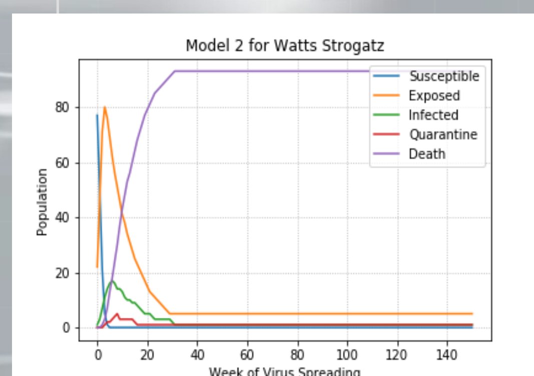


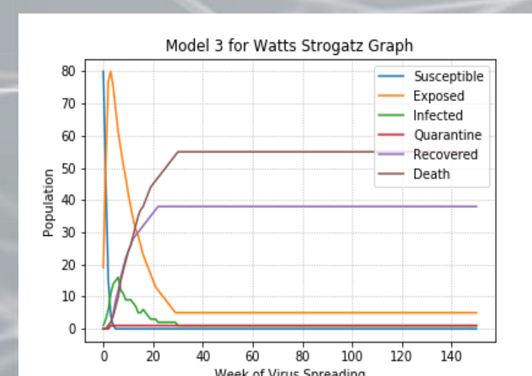




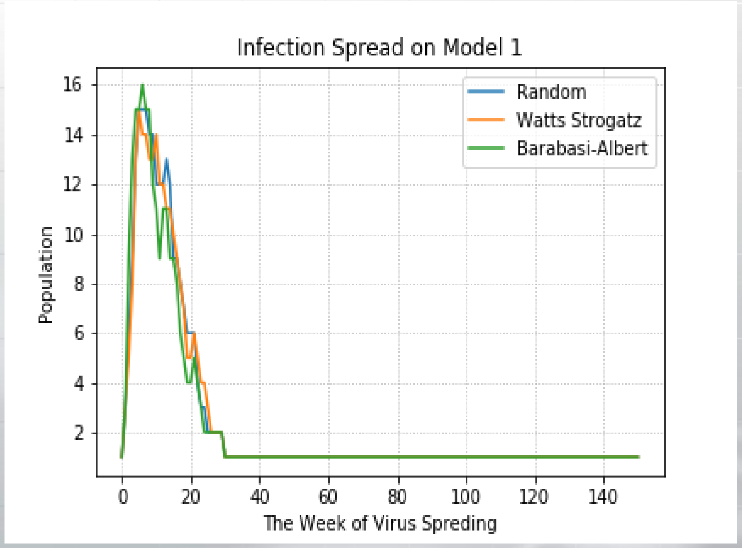


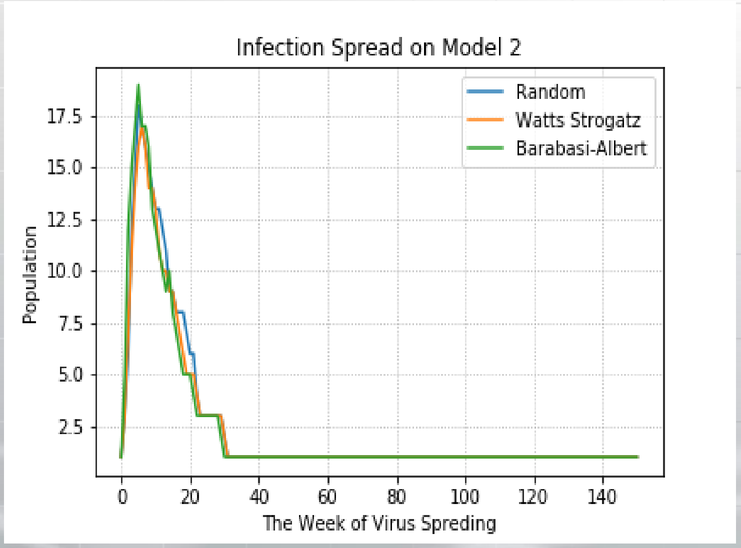


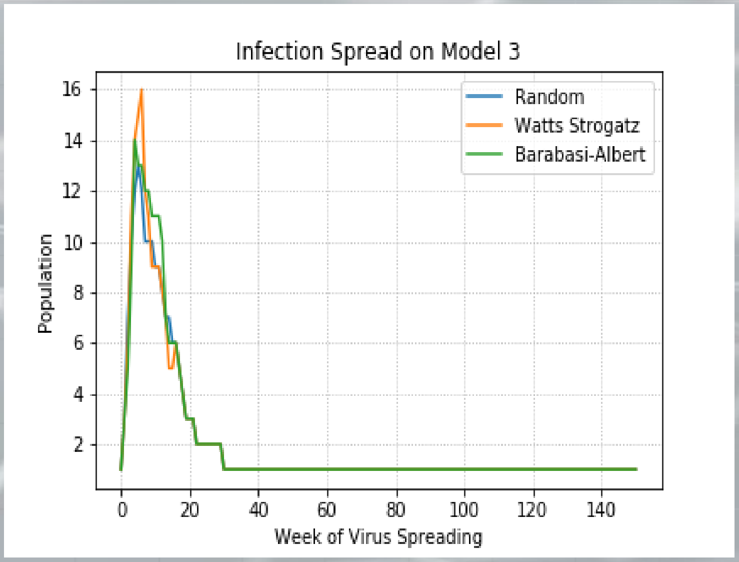




Infection Spread on Network







Some slight shifts in the infection spread for each graph compared to the other can be traced to the connectedness of the graph and flow rate of infection from exposure to the virus.

Conclusion

- We observed the spread of the Ebola Virus based on the Model Proposed by Li et al.(2015)
- We simulated the spread of the virus using the Runge-Kutta Methods
- The Parameters for the model were obtained from credible sources such as WHO, CDC and published articles.
- We modified the model in a network system based on the parameters of the virus spread.
- We observed and present the result from the network analysis.
- The movie for the infection spread in the model and the role of each group member is presented after this section.

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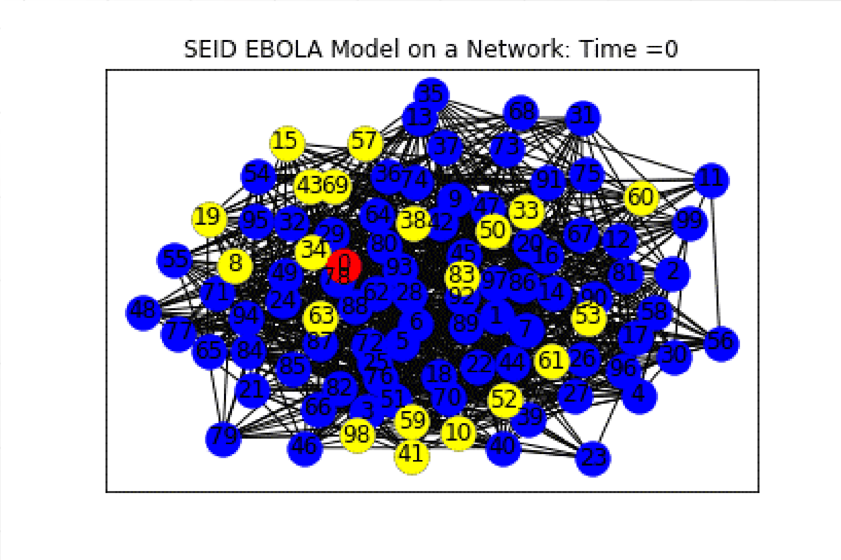
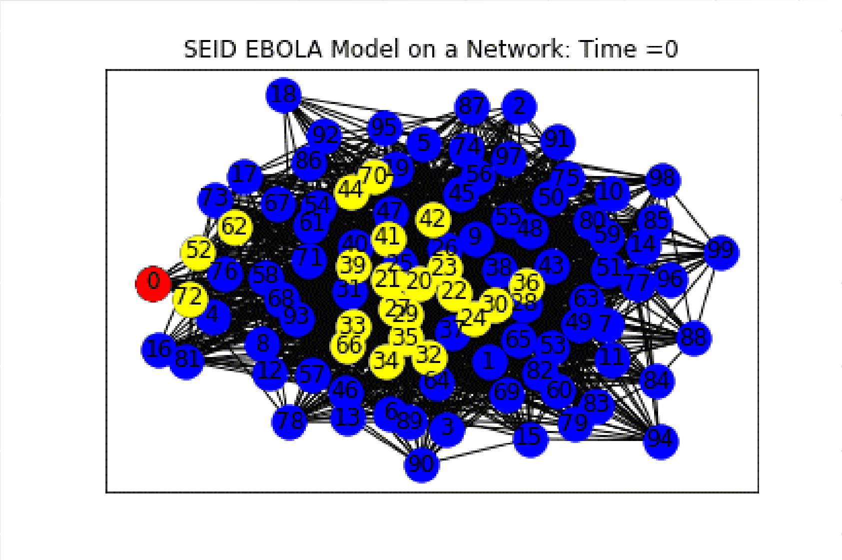
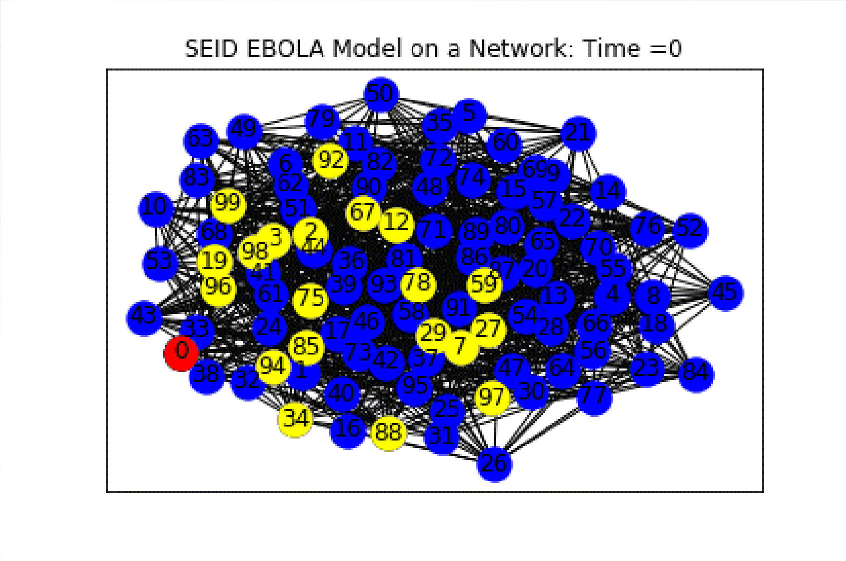
Ebola Virus Disease (Free Spread) on Network



Random Graph



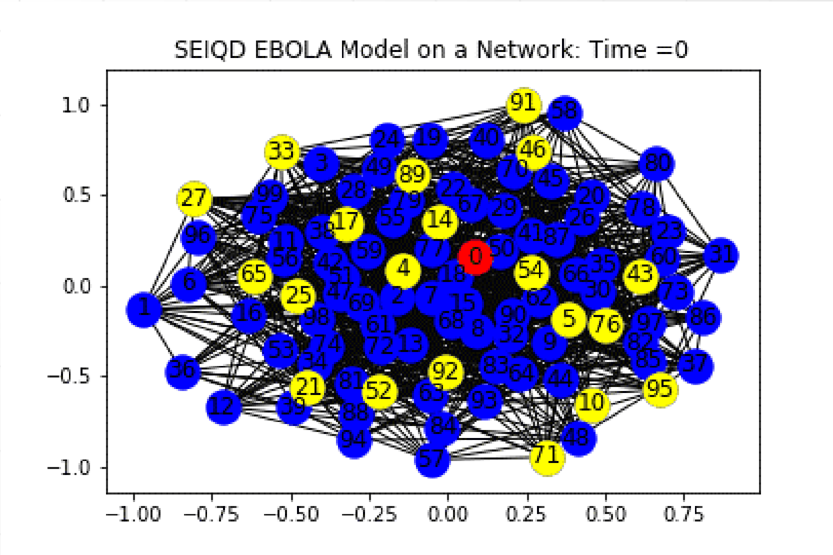
Barabasi Albert Graph



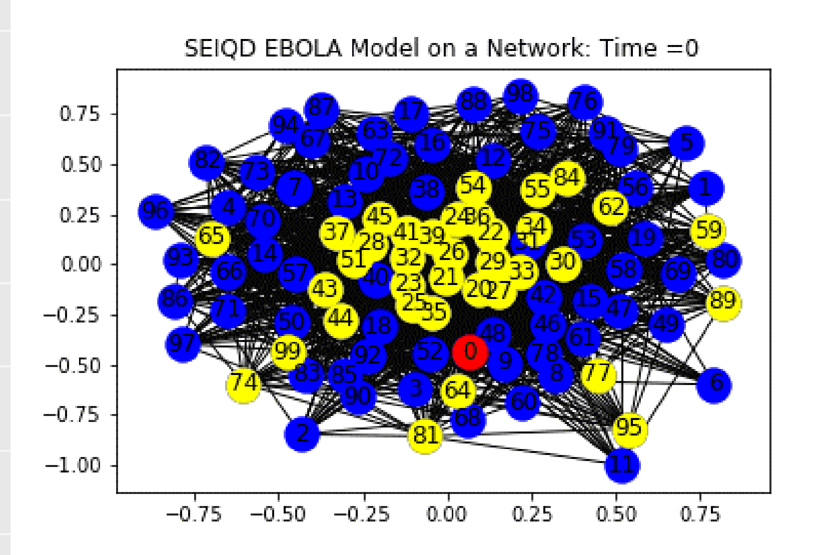
Watts Strogatz Graph

- Susceptible
- Exposed
- Infected
- Death

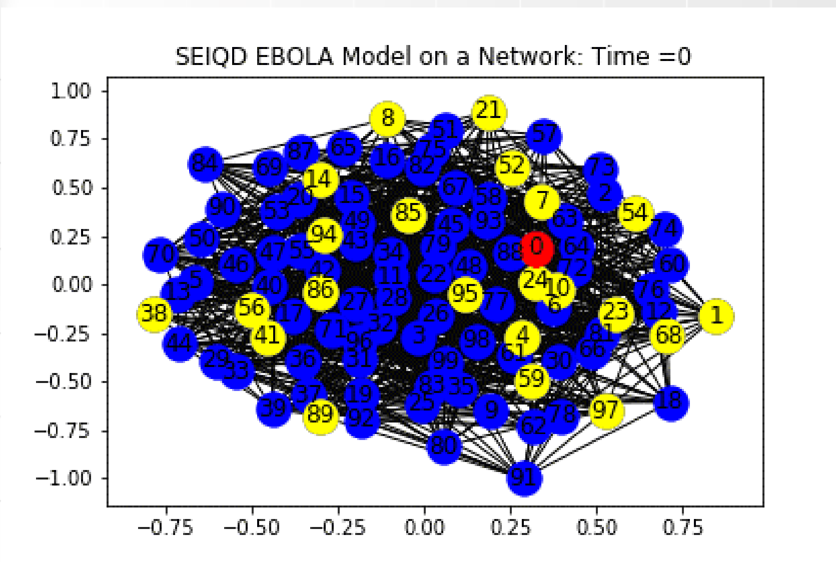
Ebola Virus Disease (Isolation - Control) on Network



Random Graph



Barabasi Albert Graph



Watts Strogatz Graph

Susceptible

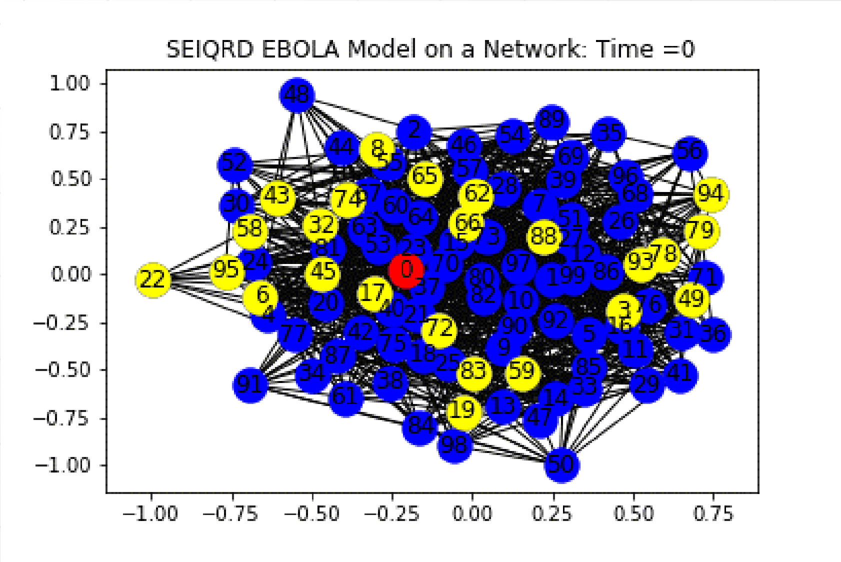
Exposed

Infected

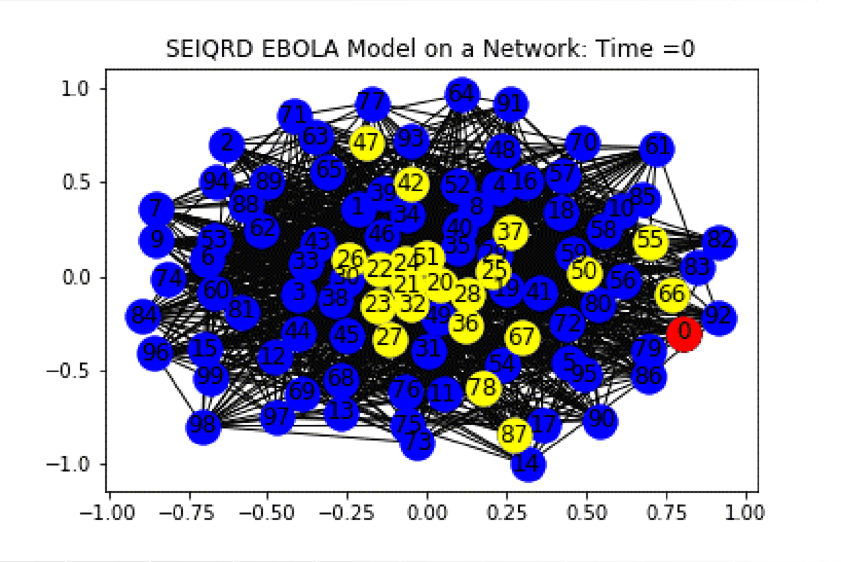
Quarantine

Death

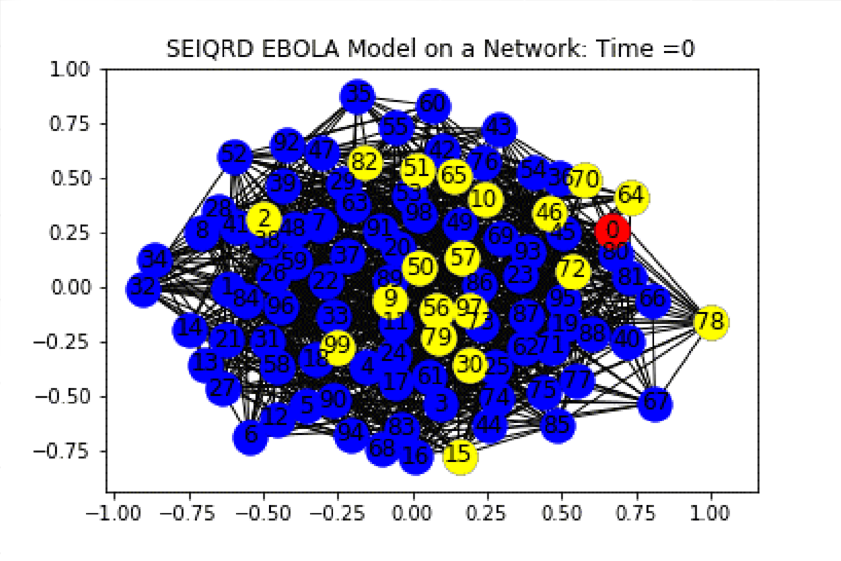
Ebola Virus Disease (Prevent - Treatment) on Network



Random Graph



Barabasi Albert Graph



Watts Strogatz Graph

Susceptible

Exposed

Infected

Quarantine

Recovered

Death

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Role of the Group Members

All Members

- Research
- Simulations

Segun Light Jegede

- Programming
- Presentation

Dare Osilaja

- Slides

Isaac Akoji Paul

- Proof Reading

Thank You