Modeling Social Distancing Methods and Their Effectiveness in Combating the Spread of Ebola

Rachel Fair, SUNY Geneseo Department of Biology

Abstract

Ebola Virus Disease (EVD) is a rare but severe disease that is transmitted among humans through direct-contact with, and close proximity to, infected bodily fluids. From 2014-16, West Africa experienced the largest Ebola outbreak ever recorded, infecting over 28,000 people, and killing over 11,000. Although the symptoms of EVD are treatable, the disease can be extremely deadly, with an average of 50% EVD cases resulting in fatality. In areas where healthcare is scarce and vaccinations are not readily available, the practices of social distancing and self-quarantining have been shown to be highly effective in combating the spread of EVD. To evaluate the effects of social distancing and quarantining on the spread of EVD through a population, a small-world network-based model was implemented. The model population was evaluated to determine the most beneficial method of quarantine. Our study indicates self-quarantine to be an extremely effective method in combating the spread of EVD, as it greatly reduces the amount of contact between individuals in a population. Through limiting the amount of hospitalizations and resulting EVD deaths, the burden that healthcare systems typically experience due to such outbreaks can be significantly lessened.

Introduction

This study was conducted using a small-world network model. The network (representing a given population) consists of "vertices" (each representing a singular individual) and "edges" (illustrating the contact between individuals). An illustration of a small-network model is shown in Figure 1.

The parameters for this model were determined using data collected from the largest and most recent EVD Outbreak that occurred from 2014-2016 in West Africa. The outbreak was caused by *Zaire ebolavirus,* the most lethal species of Ebola Virus.

- The reproductive number (R_0) of EVD is 2.5-3.5; the R_0 used in this model was 3.
- The mean incubation period of EVD is 6 days. To achieve maximum accuracy within the network model and better model the reality of an EVD outbreak, a distribution of incubation periods of 5000 Ebola patients from Sierra Leone was utilized (Figure 2.).
- The amount of time that an individual is considered infectious (and therefore able to spread the disease to other individuals) is 12 days.

In this model there are 3 initially infectious individuals, with the remainder of the population considered completely susceptible to infection. Upon contact with a neighboring infectious individual, an individual will become infectious themselves, allowing the disease (EVD) to spread. Once an individual becomes infectious, their neighbor will have to wait 1-10 days until they are knowledgeable of the infection and are able to self-quarantine (as manipulated in the model). The population, ranging from 100-1600 individuals, will also be manipulated to determine if the size of a population influences the relative success of self-quarantine in mitigating the spread of EVD.

The goal of this study is to determine if self-quarantining is effective in mitigating EVD, to determine the maximum day after which an individual is deemed infectious that their neighbor can still effectively self-quarantine, and to determine if population size has any influence on the effectiveness of self-quarantining.

Methods

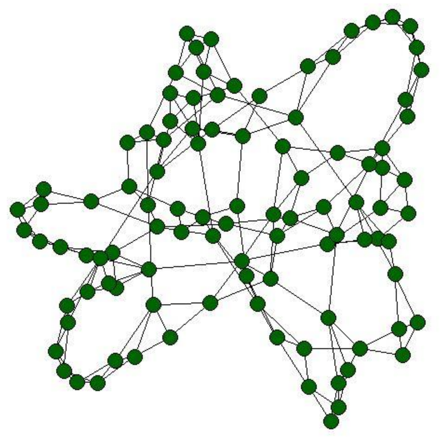

Figure 1. This is a visual representation of the small-world network model that was used to conduct this study. The circles (vertices) represent each individual of the population, and the lines connecting the circles (edges) represent the direct contact that an individual has with another individual. In this illustration there are 100 individuals, with each individual being randomly connected to 4 other individuals in the population.

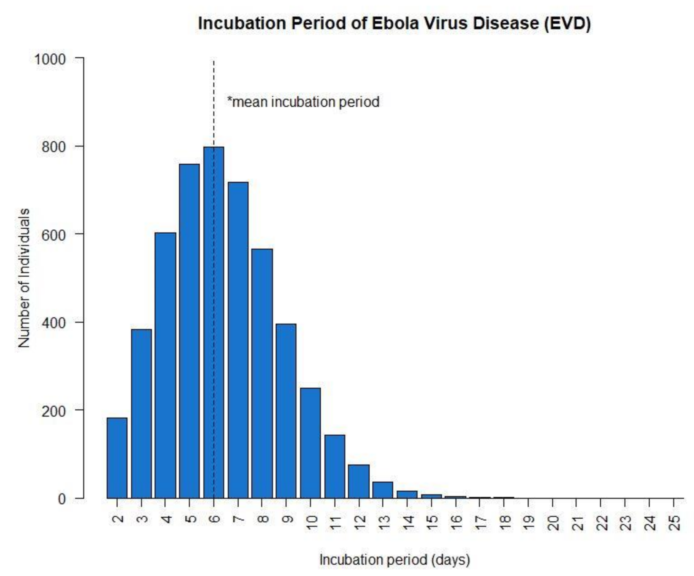

Figure 2. This graph illustrates a Poisson distribution of the EVD incubation periods collected from a total of 5000 Ebola patients from Sierra Leone (2014-16 outbreak). The vertical dotted-line represents the mean incubation period of EVD (6 days). Since the incubation period among individuals can vary widely between 2 and 21 days, an incubation period from this distribution was randomly assigned to every individual of the population at the start of each model replicate.

Results

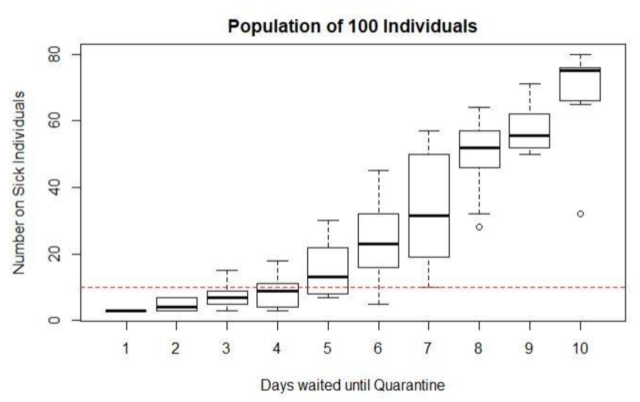

Figure 3. The number of individuals who become sick (infectious) in a population of 100 increases gradually as more days are waited until self-quarantine. Each box represents the compiled data of 10 model replications, the red dotted line represents a 10% threshold of the population.

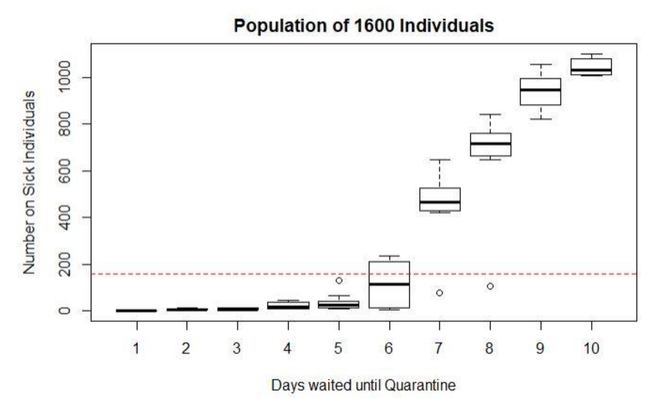

Figure 4. The number of individuals who become sick (infectious) in a population of 1600 increases sharply after more than 6 days are waited until self-quarantine. Each box represents the compiled data of 10 model replications, the red dotted line represents a 10% threshold of the population.

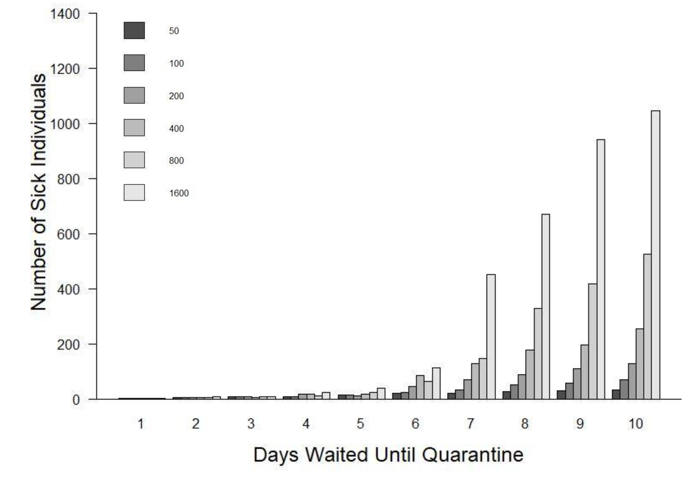

Figure 5. This plot illustrates a complete compilation of all data that was collected. The model was run at populations: 50, 100, 200, 400, 800, and 1600, with 10 replicates completed for each day (1:10).

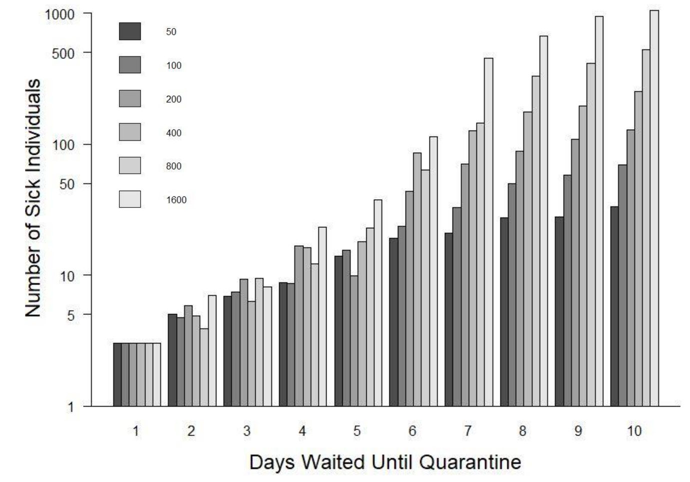

Figure 6. This plot is a semi-log plot of Figure 5. Here, the difference in the total number of sick individuals relative to each population size can be better visualized.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
N	5	6991970	1398394	582.5	<0.001
QD	9	9211557	1023506	426.3	<0.001
N:QD	45	10876194	241693	100.7	<0.001
Residuals	540	1296441	2401		

Figure 7. An ANOVA analysis of the complete compiled data set. N is the population size, QD is the quarantine date, and N:QD is the interaction effect between N and QD.

Conclusion and Discussion

The results of this study suggest that the practice of self-quarantine is most effective if it is implemented within 6 days of a given individual's neighbor becoming infectious with EVD - in this model, a "neighbor" is categorized as someone with whom an individual may have direct contact. As illustrated in Figure 4 and 5, the total amount of individuals that become infectious steeply increases after more than 6 days are waited to self-quarantine, with approximately 500 individuals presenting as infectious on day 7, and more than 1000 individuals presenting as infectious on day 10. Comparatively, <10% of the 1600 population presents infection when self-quarantining is implemented within 6 days, suggesting that day 6 acts as a critical point in mitigating the spread of EVD.

When comparing the total number of infectious individuals in Figure 3 and 4 (relative to each population; 100 and 1600), it appears that self-quarantine is most effective in large populations. In a population of 1600 the infectious population remains <10% until after day 6 , in contrast to a population of 100 , where the infectious population remains <10% until only day 4. However, upon conducting an ANOVA analysis (Figure 7.) on a compilation of all data that was collected, it can be noted that the size of a population does not increase the effect of quarantine efforts. The Sum of Squares(SS) calculation of Q is greater than N, suggesting that the quarantine day has a greater effect on the total number of infectious individuals than the size of the population where the quarantining is taking place. In addition, the SS of N:QD is greater than the SS of QD, further suggesting that although the effect of quarantine may be enhanced by a greater population size but the effectiveness of self-quarantining is not directly related to population size.

In remote areas where access to healthcare and vaccines may be limited, the use of self-quarantine provides significant assistance in mitigating a disease, such as Ebola Virus Disease. As this method of quarantine has been concluded to be equally effective regardless of the population size in which it is being implemented, self-quarantine can be concluded to serve as a reasonable alternative to tradition vaccination methods in any sized population, big or small.

Acknowledgements

I would like to thank Dr. Gregg Hartvigsen, Dr. Christopher Leary, and my peers of the Biomathematical Innovation Group for their continual knowledge, support, and encouragement! It is not without them that this research study would have been possible. I would also like to thank my friends and family for their overwhelming support throughout my time at SUNY Geneseo that has allowed me to flourish.

I would like to extend my gratitude and very sincerest thank you to Patty Hamilton-Rodgers and her entire team for working tirelessly to make Virtual GREAT Day possible despite the many obstacles that they faced.

References

"Appendix: Additional Results and Technical Notes for the EbolaResponse Modeling Tool." *Centers for Disease Control and Prevention*, Centers for Disease Control and Prevention, 23 Sept. 2014, www.cdc.gov/mmwr/preview/mmwrhtml/su63e0923a2.htm#tab1.

"Regional Confirmed and Probable Cases." *World Health Organization*, World Health Organization, 29 Oct. 2014, www.who.int/csr/disease/ebola/maps-2014/en/.

Qureshi, Adnan I et al. "High survival rates and associated factors among ebola virus disease patients hospitalized at donka national hospital, conakry, Guinea." *Journal of vascular and interventional neurology* vol. 8,1.5 (2015): S4-S11.