Modeling Vaccine Efficacy for Tuberculosis in a Prison Population

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Abstract

Tuberculosis is a highly contagious disease caused by bacteria called *Mycobacterium tuberculosis* and is particularly problematic in confined communities such as prisons. I simulated how Tuberculosis moves through a prison population and tested how much vaccination effort is needed to control its spread. To explore this, I used the program *R* to test adding ever increasing numbers of randomly placed edges in a network and determined the size of the largest component. Afterwards, I removed edges in the model using two different methods, one illustrating if the edges were removed randomly and the other starting with prisoners that had the most connections, to simulate the effect of vaccination.

Introduction

- Incarceration rates are at an all time high (*figure 1*), with United States prisons ranking the highest in the world.
- Although TB rates are decreasing, the level of TB in prisons has been reported to be up to 100 times higher than that of the civilian population.
- Late diagnosis, inadequate treatment, overcrowding, poor ventilation and repeated prison transfers encourage the transmission of TB infection.
- With an R0 of 10, active TB is transmitted through airborne and other droplet particles with an incubation period anywhere from 2-12 weeks. Symptoms include a weak immune system, high grade fever, lingering cough, vomiting blood in extreme cases.
- The goal of this study is to observe the most effective tactics of vaccinating within a network prison population to reduce future chances of outbreak.

Figure 1. In 2017, the number of people incarcerated in the United States was 1,439,808 with the U.S. having the highest rate in the world.

Methods

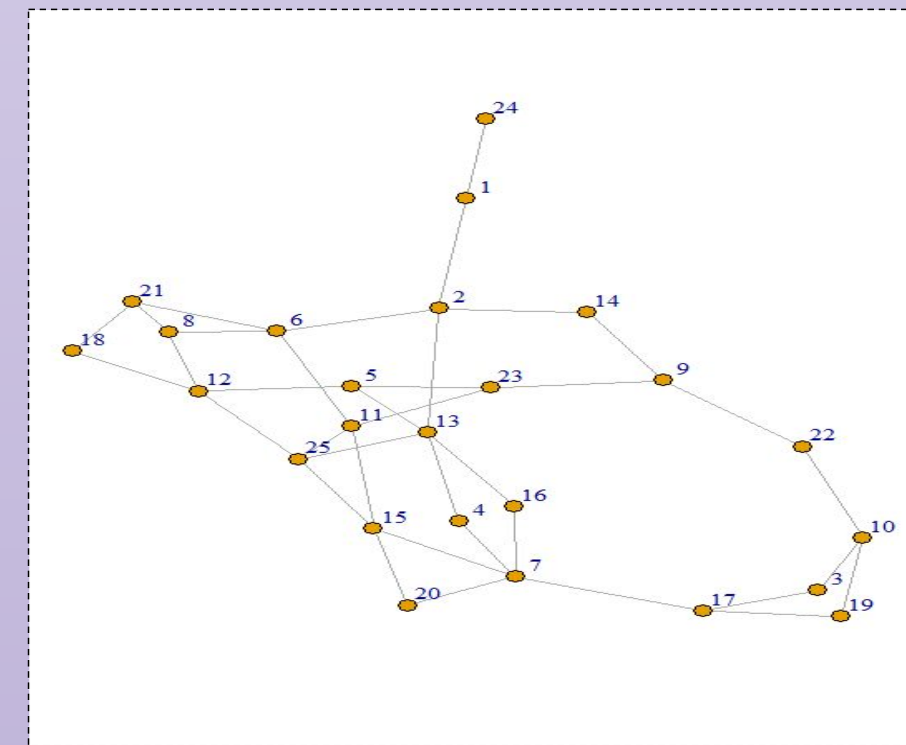

Figure 2. Each vertex represents an individual while each line represents an edge, or a linkage. For example, this means that individual 24 and individual 1 have made a connection which is a possible route of infection causing people to contract a disease, or in this case, Tuberculosis. This figure shows a random graph with 25 vertices and a probability of an edge = 0.1.

- Both methods of stimulating vaccination of the host had parameters that remained constant in the program *R*. The number of vertices in the giant component were 5000, the rewiring parameter was 0.05 which represents disconnecting an edge from a prisoner and randomly attaching it to another, the vaccination effort increases from no vaccinations to 90% of the vertices vaccinated, and they both use a Watts- Strogatz network implemented in a for loop.
- Method 1 involved removing edges from the prison population randomly. This was achieved with a delete edges function that was then plotted on a graph comparing vaccination effort to the size of the giant component (*figure 4).*
- Method 2 involved removing edges based on degree. This was completed by finding the vertices with the most edges, in descending order and then deleting the edges of those vertices. This was then plotted on a graph *(figure 5)*.

Acknowledgements

I would like to thank the SUNY Geneseo Department of Biology and Math for the support in this research. Thank you to Dr. Hartvigsen. Dr. Leary, and my peers in the biomathematics innovation group for help in statistical analysis as well as overall encouragement. Finally, I would like to thank Patty Hamilton-Rodgers for all of her hard work in putting together an amazing Virtual GREAT Day.

References

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Walmsley, R. (2019). World Prison Brief. London: Institute for Criminal Policy Research. Available online: http://www.prisonstudies.org/world-prison-brief

Results

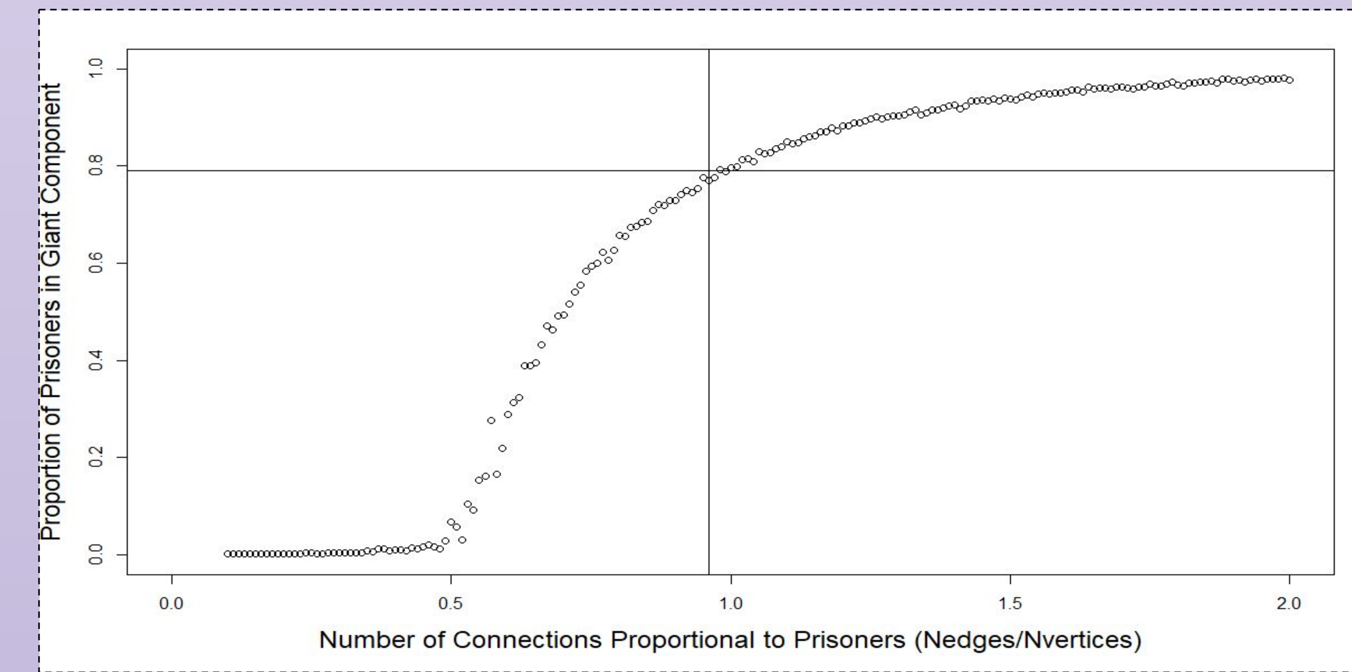

Figure 3. The size of the giant component increases as you add more edges resulting in the complete network where every prisoner has an edge to every other prisoner.

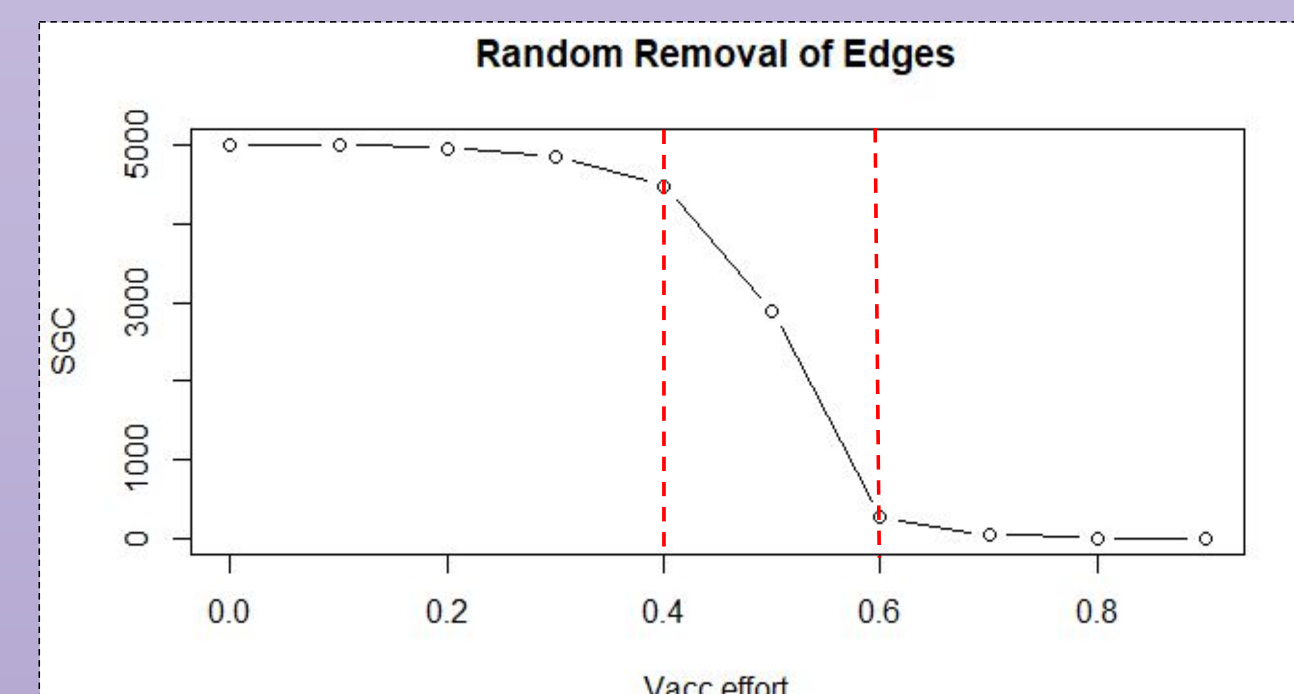

Figure 4.

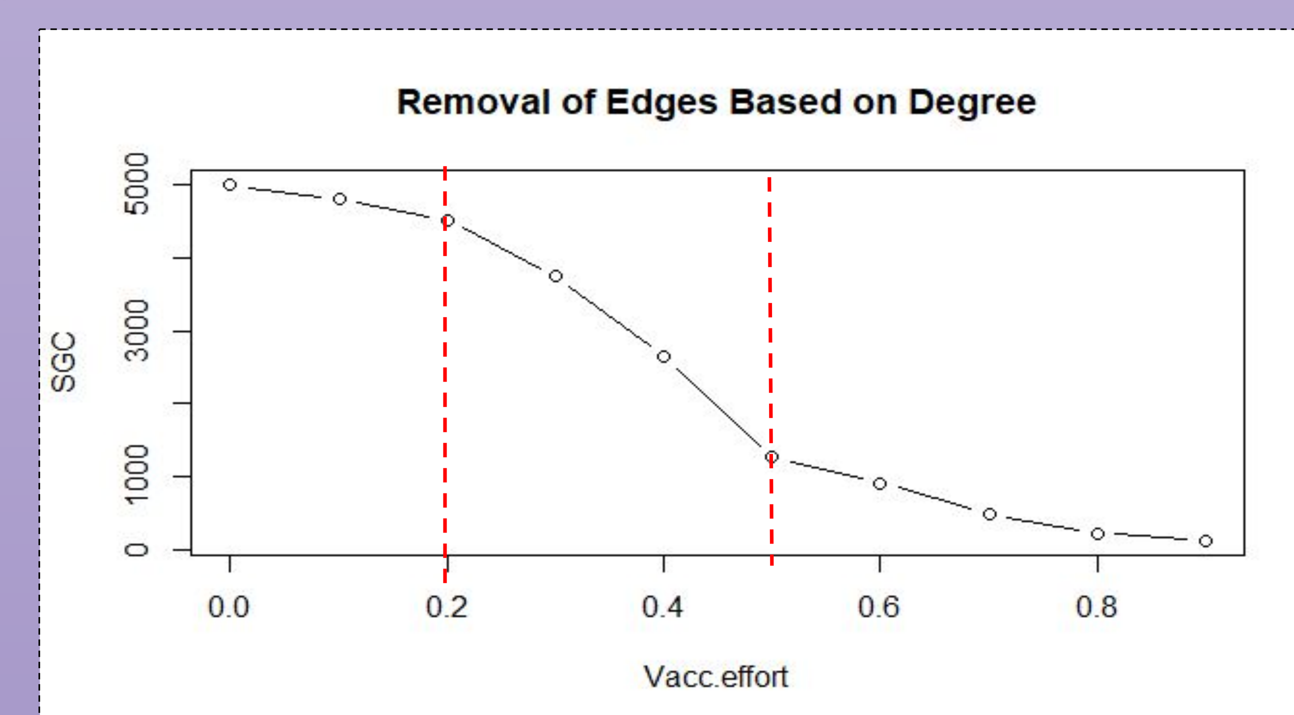

Figure 5.

These results show that the relationship between vaccination effort and the size of the giant component is indirect. *Figure 4* depicts that vaccinating 40-60% of vertices would drop the size of the giant component significantly while *figure 5* indicates one would only need 20-50%.

Discussion/Conclusion

My results conclude that as edges are taken off, or as individuals practice social distancing, the size of the giant component decreases. It also demonstrates that one does not have to vaccinate all the prisoners in the population the greatly reduce the size of the epidemic. If focused on those with the highest degree, less of an effort can be given, saving resources for other patients.This research could aid prison administrators reduce the likelihood of prisoners contracting diseases and can also benefit scientists when they're scrambling to develop a vaccine in a short time frame in order to know how much effort they need to reduce an epidemic.