Masking Strategies in a Network Based Epidemic Simulations

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***Abstract*—Explores the effectiveness of masking in reducing the spread of infectious diseases. A stochastic model of disease transmission in a susceptible population was constructed, incorporating masking as a factor affecting transmission. Variations of the simulation were ran to gauge the impact of various masking strategies on the overall outcomes of the epidemic, with primary concerns being total eventual case counts and peak case counts. The implementation is based on an agent-based simulation, allowing fine control of who in the population is masked and when they are masked. The research builds upon existing studies on the efficacy of masks and aims to provide better insights into masking at large scales.**

I. Introduction

The outbreak of infectious diseases poses a significant threat to global public health. As such, it is critical to understand their transmission dynamics and evaluate the effectiveness of interventions. Infectious diseases can be studied a real-world setting, but such research raises concerns of resources, ethics, and time. One alternative is the use of simulations. To varying degrees of complexity, a susceptible population and the spread of an infection can be modeled mathematically. These models can then be simulated at large scales computationally. This is a field of immense historic and active research, with even greater effort being expended due to the impact of the global Covid-19 pandemic.

One area of interest is the effectiveness of masking as a response to an outbreak. During the Covid-19 pandemic, shortages of surgical grade masks lead to widespread adoption of cloth masks. There was much dissent over the effectiveness of either and public health measures relating to masking varied widely across jurisdictions. It is important, therefore, that the impact of masks be better understood, so public health guidelines can be well informed. Simulations of infectious diseases can help meet these ends.

Building upon existing research, we constructed a stochastic model of disease spreading amongst a susceptible population, with capacity for an individual to be masked, affecting transmission. Running many variations of the simulation, we gauged the impact of various masking strategies on the overall outcomes of the epidemic. Of primary concern were total eventual case counts and peak case counts.

II. Background

Epidemics are typically simulated compartmentally, with fractions of the population separated into different groups. (The simplest of which is the **SIR** model, where individuals are either **S**usceptible, **I**nfected or **R**ecovered.) Two types of simulations exist to model the movement of individuals between these groups. Deterministic models use differential equations to govern the change group sizes over time. The equations often have analytic solutions, or solutions determined numerically, that characterize the epidemic over time. These types of simulations are computationally inexpensive but lack granularity representing the infection spread at the individual level. The second type are stochastic, network based models which represent individuals as nodes and transmission routes as edges. The infection then spreads through the network probabilistically.

Real world experiments have been conducted on the efficacy of masks (MacIntyre et al 2015) (van der Sande et al 2008), but this kind of research is limited by scale. Such studies can adequetly characterize the effectiveness of a mask on an individual scale, but provide little insight into the masking of large populations. However, these results can be attained by incorporating the empirical effectiveness of a single mask into large scale simulations.

The question of masking has already been examined in deterministic epidemic simulations (Eikenberry et al 2020) (Tracht et al 2010). While insightful, these types of simulations, in general, do a poor job simulating the finer structures of a population. At the lowest level, individuals behave differently and come in to contact with different amounts of people. These factors can impact the effectiveness of masking, and as such, better simulation options exist.

Of interest are stochastic simulations that that include every individual as an agent in the simulation (Maheshwari et al 2020) (Kuzdeuov et al 2020). The tradeoff of this type of simulation is it is significantly more computationally expensive. This model would allow for very fine control of who in the population is masked and when they are masked. Any masking strategy could be deployed and evaluated.

III. Implementation

Our implementation is based heavily on the work of (Maheshwari et al 2020). They constructed an agent based simulation to investigate the impact of lockdown measures on the outcome of a pandemic. They're published implementation was an excellent starting point for our alternative question of masking strategies.

The network is constructed with each node representing an individual and each edge representing a chance of disease transmission. First, edges representing familial relationships are added to the network, clustering the nodes into groups of 1-4. A scale-free network of edges is added to represent workplace relationships and random edges are added for social relationships.

A number of nodes are randomly selected as the initial infection and the rest are considered susceptible. The compartments used in this model, and how individuals can move between compartments is included.

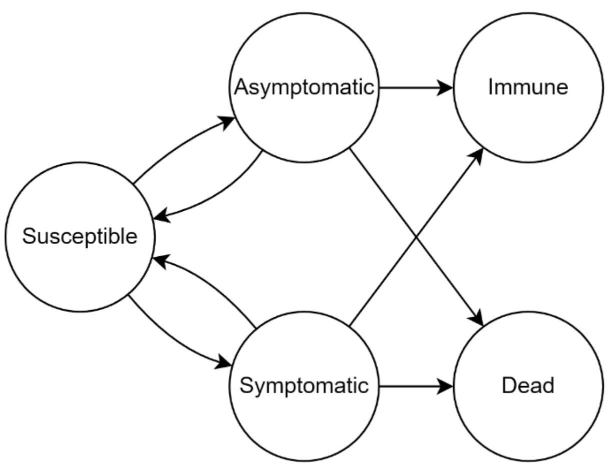

Fig. 1. Model Compartments.

The focus of the previous research (Maheshwari et al 2020) was gauging the effectiveness of lockdowns. They simulated this by removing edges representing nonessential interactions from the graph and allowing the simulation to continue. Noting the differences.

Our implementation left all relationships intact over the course of the simulation, but implemented functionality for a node to become masked. Using numbers determined experimentally, (van der Sande et al 2008), a node having masked status would have a reduced probability of becoming infected, or infecting others.

The other significant change, though not affecting the results of these simulations, was refactoring the code base to execute simulations in parallel using multi threading. This lead to an effective 10x increase in simulation speed, allowing us to run much larger simulations.

IV. Results

For each test case, 10 simulations were executed on a population of 1000 and the results were averaged. Included are the results for the case of an unfettered outbreak, with no masking to stem the tide of the infection.

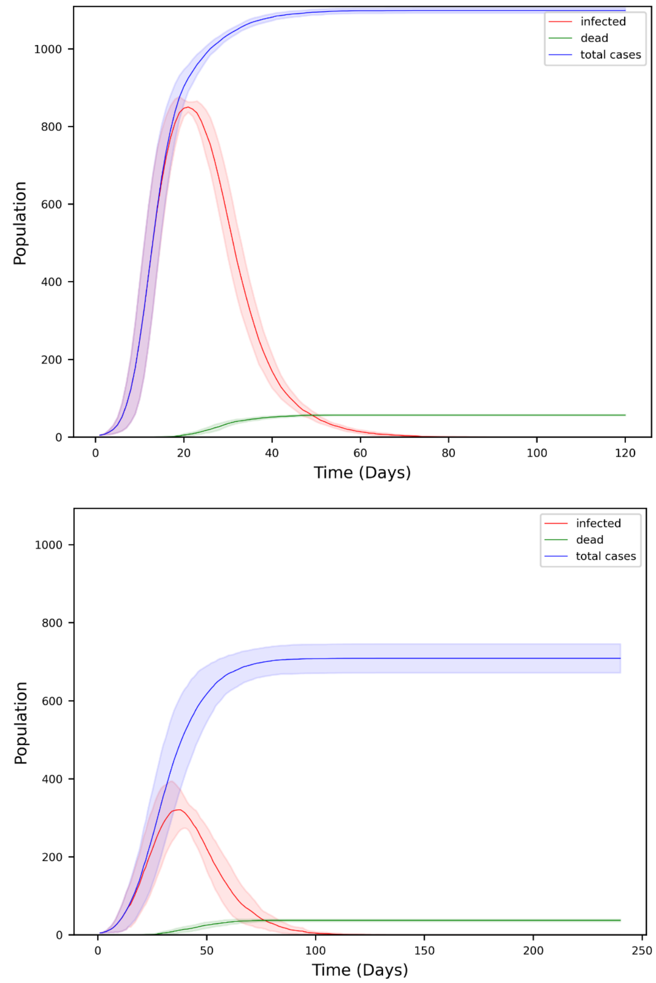

Fig. 2. Unfettered outbreak in population of 1000 alongside simulation with 50% adoption of surgical masks. Shaded areas indicate standard deviation of simulation results across 10 iterations.

Our first investigation concerned the percentage the population that was masked during an outbreak, and with what type of mask. Simulations were executed using homemade masks and the surgical type, each with corresponding inwards and outwards infection probability reductions (van der Sande et al 2008). For each, simulations were executed for a range 0-100% mask adoption.

One observes the expected result that more of the population adopting masks results in lower final case counts. Universal adoption of surgical grade face masks prevents the epidemic from taking root all together. However, such a strategy might not be realistic. The Covid-19 pandemic saw a worldwide shortage of medical grade masks, leading the the widespread usage of homemade cloth type masks. Simulation results

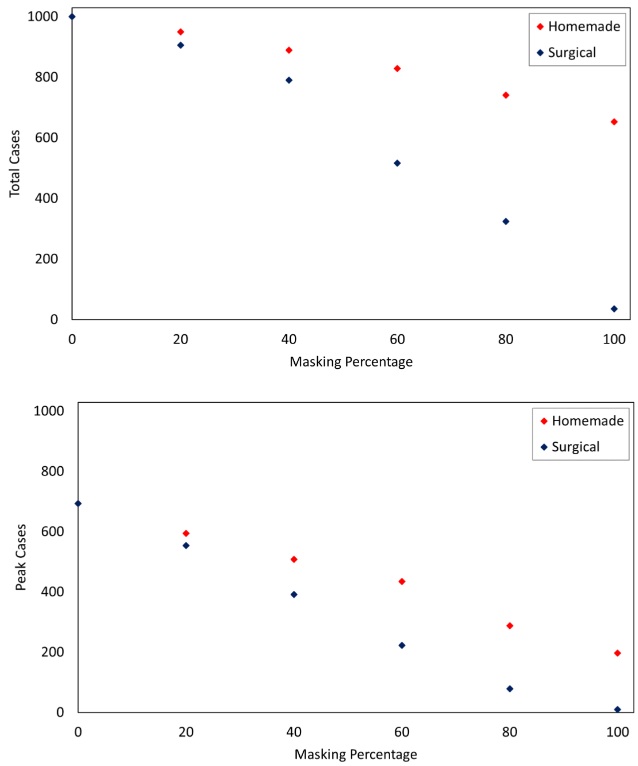

Fig. 3. Final total case counts and peak case count resulting from different thresholds of mask adoption, for both homemade and surgical type masks.

indicate that this type of mask, even when universally adopted, is mostly unsuccessful at preventing infections.

Another key result is the impact of masking on peak infections. While even widespread adoption of masks may not prevent most people from becoming infected eventually, masking proved very successful at ”flattening the curve”. That is, spreading those infections out over a longer period of time. This can be critical when healthcare resources for the infected are limited. Even low quality homemade masks, at 100% adoption, were enough to reduce the peak infected by about 70%.

In practicality, it’s unlikely any agency would enact a perpetual masking mandate to curb potential epidemics, so we additionally wanted to investigate the effect of delayed adoption of masking. With an aggressive 100% masking rate, simulations were executed with a masking delay of between 0 and 20 days.

The results show a longer delay in masking adoption does lead to higher final case counts, however, the overall effect only diminishes slightly. Late adoption can still be effective at reducing total case, even after 20 days, when the peak infection count has already been reached. Peak case counts are where the most significant changes lie. In order to keep the number of concurrent infections low, mask adoption should be as early as possible.

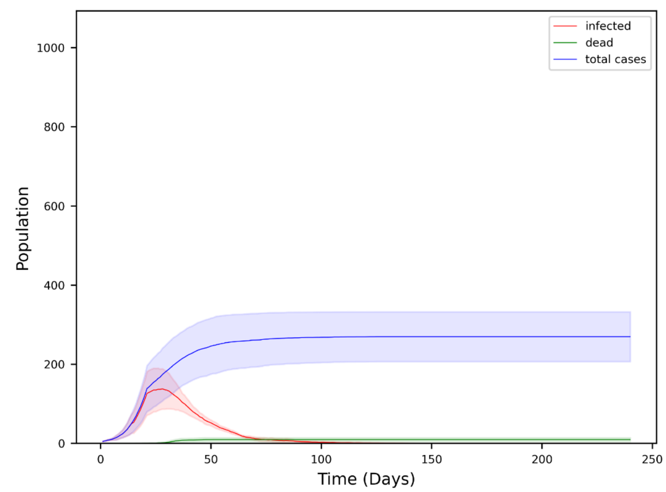

Fig. 4. 100% adoption of surgical grade masks after a delay of 20 days.

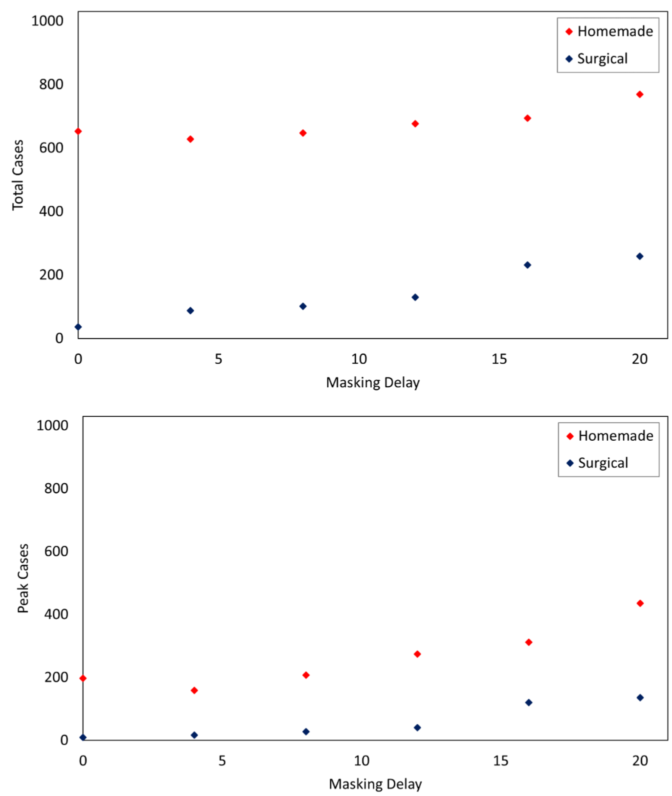

Fig. 5. Final total case counts and peak case count resulting from different thresholds of mask adoption, for both homemade and surgical type masks.

V. Conclusion

Research concerned the impact of mask adoption on the eventual outcomes of an epidemic in a small population. Simulations were run using homemade and surgical masks with varying adoption rates. The results showed that universal adoption of high quality masks was necessary to significantly impact case counts, but masks of any type were successful in reducing the peak number of infections. Research also found that delaying mask adoption minorly impacted final case counts but majorly impacted peak cases. These outcomes could provide insight when policy makers are formulating public health guidelines.

References

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