A Decision Making Aid for Organizations during Epidemic Situations

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Abstract—An epidemic is a widespread infection within a population at a particular period. COVID-19 is one such epidemic which is turned into a pandemic by mid-2020. COVID-19 had an enormous impact on people's livelihood, health, economy, and social life. In Sri Lanka, we have faced the dreadful side of the COVID-19 during its second, third, and fourth waves. Some of these waves were propagated by the behavior of individuals in organizations. During this period several intervention strategies have been introduced in order to stop the disease spread globally and as well as locally using. Many different epidemic models built using techniques ranging from statistical prediction to simulation. For this research we used Agent-Based modeling to simulate the spread of a contagious disease in different organizations. Several parameters have been introduced in the development process of these models considering some important aspects of contagious disease spreads. Two common interventions practiced in countries were implemented to evaluate their effectiveness, namely social distancing and face mask. Agent-based simulation models were generated from these computational models and evaluated using parameter sweeping. The effectiveness of the two interventions in mitigation of the spread of the disease were compared. Flattening the curves of the graphs of infection spread can be achieved by timing the interventions early. The simulation clearly shows the impact of parameters these and their importance in the control of disease spreads.

Keywords—Agent based modeling, Epidemic modeling

I. INTRODUCTION

The world has faced several epidemics throughout history. The most recent epidemic[1] that individual countries had to face can be identified as COVID-19. COVID-19 is not just an epidemic anymore, but was officially designated as a pandemic[2] by the WHO in march 2020. In history, there have been several other contagious diseases reaching pandemic proportions owing to deadly diseases such as SARS, HIV, Spanish Flu, H1N1, Ebola virus and Zika. During COVID-19, countries have practiced different levels of lockdown to mitigate the spread.

Lockdown level-1 often refers to a situation where individuals were permitted to wander anywhere. Limiting the number of people in a gathering and being informed to wear a face mask characterized Lockdown level-2. Lockdown level-3 restricted the number of people in a social gathering to a small number. All commercial activities were limited to only essential services in Lockdown level-4. Under lockdown level-5 entire countries were shut down by their borders being closed to others[3]. These lockdown levels were practiced in countries in fairly different ways. Every lockdown level was an attempt to minimize the harm that the virus would cause to human beings.

Predicting the spread of a disease and suggesting control mechanisms is an important aspect of epidemic surveillance. We have seen that many rules and regulations were established in Sri Lanka during COVID-19, specially focusing on organizations. These interventions[4] included, the establishment of a full curfew (equivalent to Level 4 or 5 lockdown), to allowing only essential services to operate, and 1/3 of government workers to report for work (while others being allowed to work from home), and for workers to report to work only 2-3 days a week. However these were introduced in an ad hoc manner as the government didn't have time to understand and respond to the situation adequately.

Studying the spread of a disease in an organization is an important step in tracking the spread of an epidemic, since an organization consists of a dense unit of people occupying single physical space. Individual's mobility will be the key factor when modeling any contagious diseases. The importance and influence of interventions can only be measure by studying such microcosms [5] of the wider society more closely. Simulation is a well-established method for studying such life and death scenarios. The problem domain of this research focuses on this kind of scenario, which could not easily be studied by waiting for physical observation. Simulation also provides the mechanisms necessary to ask what-if questions related to different mitigation strategies.

The lack of possibilities available to compare several interventions practicing during COVID-19 is the main motivation for this research project. The prediction of dynamic behaviors of individuals in an organization is a challenging task to generalize. Due to these individuals' behaviors, the propagation of a disease can't be predicted other than by observing the real situation. Implementing simulated models with very similar environments to the real environment (changing several parameters) would be a solution for this kind of problem. In such a simulated environment, we could fine tune several parameters and come up with a model mimicking a realistic ground situation. This problem field has risen in importance enormously over the past year due to the COVID-19 pandemic. Evaluation of any kind of intervention against the disease in the real environment is difficult because of the life and death issues faced. However a simulated environment, very similar to the real environment, can be used for decision making. Figure 1 illustrates several organization types that we want to consider within scope of this research.

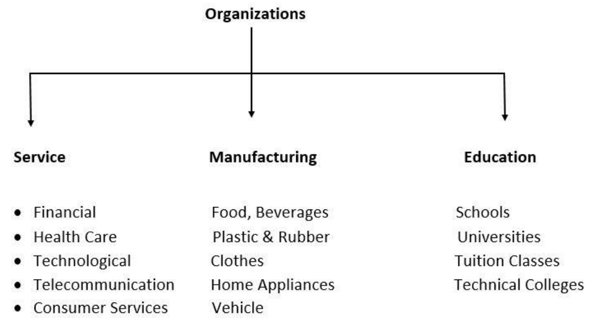

Fig. 1. Basic Organization Types Considered

Service, Manufacturing and Education organizations may have several differences from their behaviors. These sectors differ from each other in the nature of their environment and operations. These will influence the behaviors of their employees, which are the main cause for the propagation of a disease. Hence identifying these variations and generalizing them is a key aspect in this research.

The main focus of this research is to build computational models[6] simulating epidemic spread in different organizations such as service, manufacturing and educational. In Agent Based Modeling, we model the interactions of individuals separately without modeling an average behavior. We then model the effect of interventions currently practiced within these organizations, so that we can compare each of them and find the most suitable interventions for a particular organization. We can also suggest new interventions and evaluate them using these models. The main deliverables are the conceptual disease model, the simulated data considering different organizations and the disease intervention regimes put in place by them. These organizational disease models are implemented using the popular simulation language NetLogo[7].

To identify the scope of this research following research questions are addressed in this study;

- **How does organizational behavior affect the spread of contagious diseases?**
- **What interventions are most effective in organizations to control the spread of diseases?**
- **How does the type of the organization affect the intervention regimes proposed?**

From these research questions we would be able to address the importance of the organizational behaviors in epidemic modeling as well as the interventions commonly practiced within these organizations. The suggested conceptual and actual disease models focus on the organizations in the Sri Lankan context, though they can be generalized to other countries and contexts. These organizational disease models may include several different interventions. By simulating several different intervention regimes, their effect could be compared and the most effective ones could be recommended for their situation since the likely outcomes of these interventions have been adequately evaluated.

II. Literature Review

Epidemic is a widespread infection of a contagious disease with in a population. Several models have been proposed for studying various epidemics. These models try to predict how the disease spreads, the total number infected, the duration of an epidemic, by estimating various epidemiological parameters such as the reproductive number.

A. *Mathematical Epidemic Models*

The most widely used mathematical epidemiological model is the SIR model. 'S' stands for the susceptible (currently healthy) individuals, 'I' stands for infected individuals and 'R' stands for removed individuals (those who recovered or dead). Khrapov et al. [8], is an example of this model being applied to the COVID-19 epidemic in China.

The distinction between diagnosed and non-diagnosed individuals is important in the mitigation of the spread of diseases. Giordano et al. [9], considered eight stages of infection: susceptible (S), infected (I), diagnosed (D), ailing (A), recognized (R), threatened (T), healed (H) and extinct (E), collectively termed SIDARTHE which was an extension to the traditional SIR model. In the developed model some possible counter measures were implemented and their effects compared.

Khan et al. [10] formulated the model for hepatitis B virus transmission with saturated incidence rate using the idea of classic SIR model. They used the basic reproductive number R0 and then discussed the backward bifurcation for the proposed problem. Introduced the threshold quantity and equilibria for the proposed epidemic problem using this study.

B. *Computational Epidemic Models(Macro Models)*

Computational epidemic models can be implemented using two methodologies, namely, very detailed agent-base models and large-scale spatial meta-population models.

Balcan et al. [11] proposed a meta-population model of worldwide scale. The Global Epidemic and Mobility (GLEaM) model structured a meta-population integrating the stochastic modeling of the disease dynamics by considering the demographic and human mobility patterns at a global scale. In this model, subpopulations were introduced using a Voronoi decomposition of the world surface according to the major transportation hubs.

Skvortsov et al. [12] developed a model called CROWD which is a civilian population model that takes census data and combines this with city planning information to build an urban population that has homes, families and places of work. This model was an agent-based simulation model using SIR model. This model was capable on outputting data allowing the creation of a map of where infections occur within a virtual town.

Human mobility is the key to the spread of epidemics within a population. Therefore, considering these mobility patterns could potentially be the turning point in modeling epidemics. The results of a model by Meloni et al. [13], found the important influence of self-initiated behavioral changes in the mobility patterns of individuals for spreading of a disease in a meta-population.

Above three epidemic models built considering macro level and they are mostly about 10years old models.

C. *Computational Epidemic Models(Micro Models)*

Epidemic modeling at the micro level could be more effective in epidemic surveillance than considering the 'whole world'. These models are more practical than the macro models.

Arslan et al. [14], developed a spatial-temporal, rule based response system with a combination of geographic information and environmental controls. This model was able to predict disease spread throughout any region by showing the interactions between the agents/individuals. In this simulation model, several rule sets were defined emphasizing how an agent will be infected based on the basic SIR model.

Bin et al. [15] proposed a model called SLIRDS based on cellular automata in order to study the main factors that affect the spread process of infectious diseases. In the simulation experiment, the influence of population density, sex ratio, and age structure on infectious disease spread was analyzed by comparing the results with those from the actual spread process of pandemic influenza A (H1N1), and the accuracy of the SLIRDS model was confirmed. But in this model couldn't be reflect every individual's and their neighbors' randomness using cellular automata.

D. Models which Forecast some Intervention Strategies

Epidemiological models developed so far, have been able to forecast the total number of infected cases, as well as to inform intervention strategies.

Thompson and Brooks-Pollock et al. [16], proposed a unified approach involving mathematical epidemiologists focused on pathogens of humans, animals and plants. This study discussed how epidemiological modelling can be used in real-time prediction during an outbreak.

Comparing the strategies that have been taken in order to prevent infectious disease spread is also as important as modeling the epidemic in a computer based environment. Sanchez et al. [17] proposed an agent-based model developed by simple heuristic rules using the science of complexity approach. This model evaluated two strategies of spreading the propagation of infectious diseases, namely, the avoidance of close contacts and, the detection and timely isolation of newly infected people. This model points to the strategy of detection and timely isolation being the better strategy in the containment of the disease from among the above two strategies.

Another study was done by Roy et al. [18], which suggest an algebraic structure to predict the prevention of the spread of COVID-19 in India. This mathematical tool is designed to help make better predictions of the spread of the disease. According to the created model, asymptomatic carriers play a major role in transmitting the disease. The effect of interventions such as the imposition of lockdowns have been demonstrated clearly in this model.

Throughout the history there were several epidemiological disease models built but most of them considered globally. They built up considering main transportation hubs (Air transportations and land) or population densities of a place. But these models lack interactions of people which is a key factor of epidemic spreads. Few micro models built considering small populations. Some of them used basic SIR models which is very old in epidemiology. New technologies have been evolved so far. Therefore we can adopt these technologies for epidemiological analysis. Literally these micro models lack of possible counter measures which can be taken in order to mitigate the spread of the disease. The main computer science problem which is going to be address by this research project is to fill up that gap in the epidemiological analysis.

III. Methodology

Simulation is the methodology selected for the research. Simulation helps to answer the question 'what if?' Simulation enables study of more complex systems. Agent Base Modeling(ABM) [19] used as the method of implementing these disease models. ABM comes under the complex systems and it is much suitable for this kind of epidemic modeling [20]. Agent in the sense is an autonomous individual element of a computer simulation. These individual elements has their own properties, behaviors and states.

Simple rules were formed to observe the results of the agents' interactions in ABM. This technique can be used to model and describe a wide variety of processes, phenomena and situations. In this methodology agents/individuals attempts to maximize their fitness functions by interacting with other agents and resources. Simulation is the best suitable approach than mathematical approaches when the behaviors of individuals are dynamic. Observed and identified each of individuals' behaviors within an organization is the first step. By doing this we were able to gather sufficient data to model this disease propagation. Then differentiated their behaviors with others and evaluated the impact on spreading the disease over the population. Mainly considered the distance from infected ones and generated probability function of getting infected. Individuals who are more vulnerable to the infection, identified from the model and nearest individuals of the contacted ones marked as risked individuals.

The propagation of the disease happened when the above rules have been initiated in the model. Then defined different rules and examine which rule may mitigate the spread of the disease. As the first step built a simplified version of the model as considering each individual is equal. Then the model was changed according to the organization environment. Different types of organizations and different types of hierarchies were added to the model by examining them carefully. These organizational models were developed in an iterative process.

Used Netlogo as the modeling tool. Methodology can be explained further in detailed as the following figure. Figure 2 shows the methodology that used for the research in step by step process.

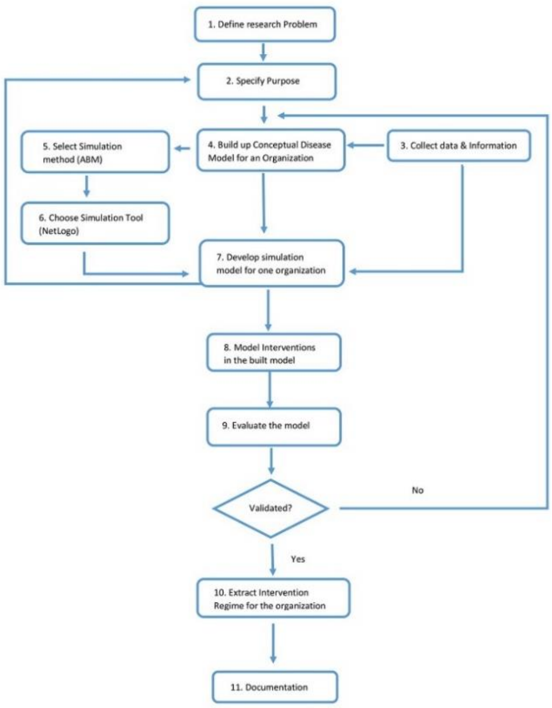

Fig. 2. Methodology

IV. Implementation

Proposed model for the problem analyzed, can be explained using several parameters. Before modeling the epidemic simulations several conceptual models [21] need to be created. The simulation carried out with the following several parameters;

- ✓ Initial Population[0-500]
- ✓ Total Iteration Number[0-500]
- ✓ Infected Number[0%-100%]
- ✓ Infective Period[0-20 ticks]
- ✓ Management Floor Density[3%-50%]

- ✓ Immunity[0%-100%]
- ✓ Links between Agents[On/Off]
- ✓ Wearing Face Mask Strategy[On/Off]
- ✓ Keep the Social Distance Strategy[On/Off]

This conceptual model created considering one basic organization type. When it comes to organizational disease models these parameters can be changed accordingly to generate different organization type.

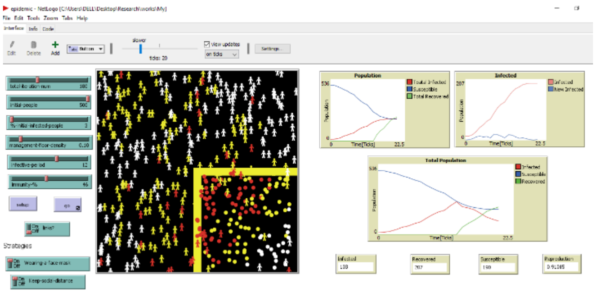

Fig. 3. Simulated Model

Figure 3 shows the simulated interface and the interface can be divided into three main parts as; left – model parameters, center – graphical view of modeled organization environment, right – plots and monitors.

First parameter in the parameters list is 'total-iteration-num'. It is a one stopping condition. When the ticks count reaches the total number of iterations provided in the slider then the execution of the model will stop. Next parameter is 'initial-people' count. This is to define the total population number. This parameter would be the key to generate several organizational models. Parameter called '%initial-infected-people' will let the user to define infected count in the population as a percentage value. This generated by multiplying the initial population count by the infected percentage. This will vary of 0% to 100%. Another parameter which is essential to define organization models is 'management-floor-density'. Each and every organization would have a factory floor and a management floor. They may not come in the name as it is. But the concept would remain same in every organization type irrespective of the type service, manufacturing or education. The area highlighted with the yellow frame is defined as the management floor. According to the parameter value given by the slider management floor density population setup. Rest of the population reside on the other area called as factory floor. The management floor individuals' mobility is restricted to the area under that yellow frame. Next parameter in that list is 'infective-period'. This indicates the time that normally a particular infection is within in human body according to the medical justifications. For this simulation maximum of the infective period has been set up to 20 ticks (days). Because of this parameter a particular infected person will remain in the same infected state until that infective period is over.

Individuals or the agents of this model would have three different status namely; susceptible (white), infected (red) and recovered (yellow). 'Setup' and 'Go' buttons are used to set the above parameters inside the model and to run the model respectively. Probability of getting infected any individual defined according to the distance calculated from a neighboring infected individual. Model will calculated that distance and generate the probability of getting infected according to the equation as in;

$$P = \frac{1}{2^d} \tag{1}$$

If the individual gets this value grater to the threshold value then the status will change to 'infected'. Infected individuals will have a separate variable to save their infectious period. If that period exceeds the defined infective-period then only that individual will able to change its status to 'recovered'. The connections between these individuals' can be defined using the parameter called 'Links'. When there is a direct link established between infected individual and a susceptible individual it will increase the probability of getting infected. Infection chance would doubles in this simulation environment if there are links exist. In the lowest section of the interface there are two strategies define as; 'Wearing-a-face-mask' and 'Keep-social-distance'. These are like two switches. When each of these are activated several changes can be observed in simulation. The strategy 'Wearing-a-face-mask' is activated the probability of getting infected will reduce by 70%. The strategy 'Keep-social-distance' will increase the distance between infected individual and susceptible ones. In the middle pane simulated the organization model according to the given parameters. When the model start its execution individuals will move within the environment and according to the defined rules.

Left hand side of the interface consists of all the plots and monitors. These data helps for the evaluation process. 'Population graph' is drawn considering the count of total infected, total recovered and the total susceptible count of the population. 'Infected graph' is drawn considering total infected count and the new infected count in a given tick. Time is considered as ticks in this model. Ticks can be defined as days in the real situation. When the profile becomes flat this indicated that the maximum number of people infected due to the spread of the epidemic has been reached to the maximum level. 'Total population graph' is drawn to visualize infected, recovered and susceptible count of the population in a given tick. Monitors which reside in the lowest section of the interface shows Infected, Recovered and Susceptible counts. The other monitor is to show the reproduction number which is used to predict the infected count from a one infected individual in the population.

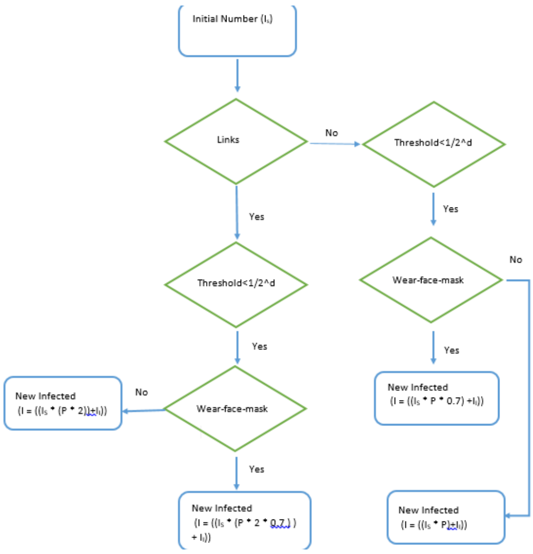

Fig. 4. One of Conceptual model

V. Evaluation and Results

Evaluation process of the simulation models involve two main concepts called model verification and model validation. Model verification concerns on whether the model gives correct and anticipated output for given inputs in a defined scenario. Model validation is checking that the built model is useful for the real world problem solving. Before modeling these epidemic simulations several conceptual models were created. The first evaluation of the built model can be verified with the basic conceptual model. Then the validation takes palace in order to check the built model is actually giving the answers to the real world problem defined the research questions.
Following figure 5 will show that in a graphical way.

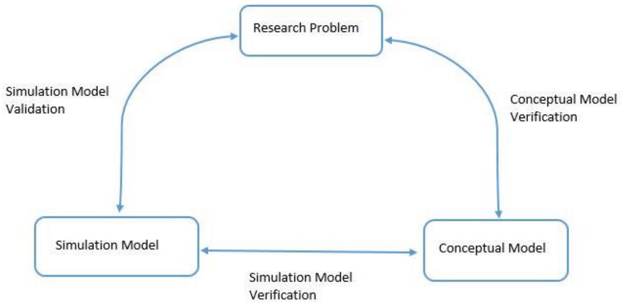

Fig. 5. Evaluation Plan

Since the research methodology is simulation it helps to answer the question 'what if?' After building several interventions in the modeled environment and check 'what if' scenario if we build up those interventions in there. Then start the validation process whether we can see a real life phenomena in there or not. Other than these 'what if' scenarios several emergent behaviors can be extracted from the implemented Netlogo model. Scenarios where getting total infected or total recovered populations can be referred to as emergent behavior in this research project. To get this kind of emergent behaviors, several experiments done in the Netlogo behavior space tool.

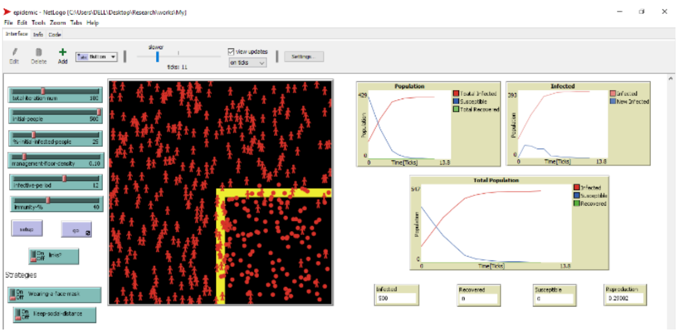

Fig. 6. Total population got infected (Emergent Behavior)

Validation of the built simulation model can be successfully done by generating these emergent behaviors. Different types of organization behaviors can get by changing the number of people and by changing management floor density. Effectiveness of strategies can be considered by changing the parameters declared under the section called strategies (policies). This model lets adjust these pandemic policies and decide what would be the best policy scheme with respect to a one organization type. This evaluation will include values of each parameter contain for a particular behaviors especially in an emergent behavior within this model. This will helpful in getting decisions in an environment which is more likely to this simulated environment in an epidemic situation. Effectiveness of the strategies can be evaluate by setting up the two strategies in four different ways. 1 – No strategy, 2 - Wearing-a-face-mask strategy on, 3 - Keep-social-distance strategy on, 4 – both strategies on.

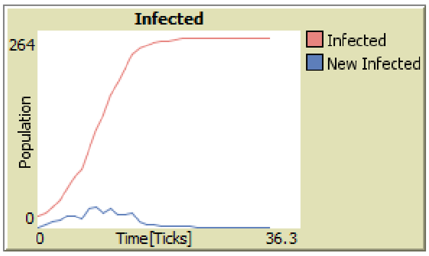

Fig. 7. No Strategies enabled

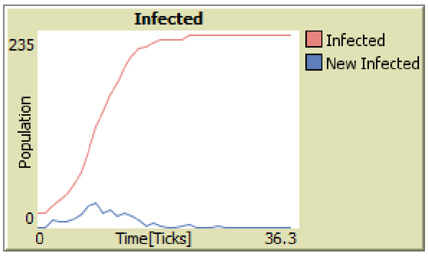

Fig. 8. Keep-social-distance strategy enabled

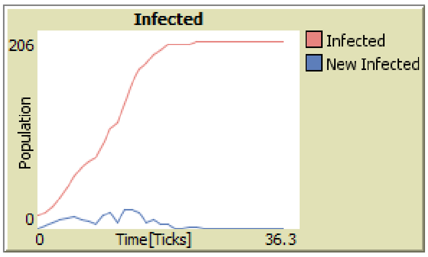

Fig. 9. Wearing-a-face-mask strategy enabled

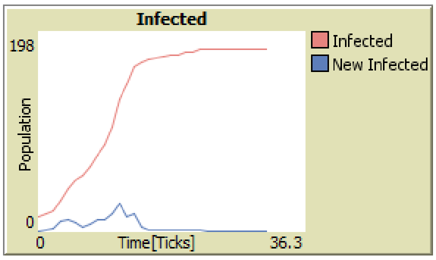

Fig. 10. Both strategies enabled

Figure 7, 8, 9, 10 show the effectiveness of these strategies in deciding the maximum number of infected individuals in the population. It shows the continuous reduction in the number of infected count. Another approach taken in the evaluation process is to get the emergent behaviors whether the total population got infected or total population recovered. Using this model can be able to predict the infected, recovered and susceptible counts in the population by changing several parameters. Also can be evaluated the built two strategies in different populations.

Organization types can be differentiate according to the total population in the modeling environment. When that number is increased, the probability of infection is clearly seen to increase. Some of the emergent behaviors generated in the simulation model shows that the whole population in an organization will get infected when the number of the total population exceeds a threshold. Social connections between individuals also has an effect of increasing disease propagation in the model. Another main parameter which is directly affecting the disease propagation is the management floor and the factory floor densities. Several points where whole population get infected can be generated by gradually increasing the initial people count. Such points can be observed, when the initial infected percentage is set to at least 50%. The management floor population gets infected as the ‘management floor density’ increases. Increment of the infective period let more time to spread the disease for a given infective person. Parameter called 'Links' let the entire population being infected with lesser number of people in the population because it establishes direct relationship between the agents in the population. Emergent behavior generation can be reduced by enabling the two strategies. They also have negative impact on the disease propagation. I have observed that the emergent behavior which is whole population getting recovered can be generated by changing the infective period in 12-15 range.

VI. Conclusions and Future Works

Two emergent behaviors observed in this study are the entire population in an organization being infected and the entire population recovering completely. Parameters such as population count, initial infected count and infective period positively correlate with the infection probability while parameters such as management floor population density and immune probability parameters negatively affect the whole population becoming infected. In addition, infection probability increases when the agent model takes into account the social connections between agents to account for the higher frequency of exposure posed by friends and colleagues at work. We conclude from these that in real environments where population counts are high or where there are more infected people in close proximity with direct connections with each other, whole populations would be infected more easily beyond a lower tipping point. Another evaluation done in this simulation was to predict the effectiveness of the two most common strategies proposed during the pandemic, namely, mask-wearing and distance-keeping. Our simulations show a continuous reduction in the number of infected in scenarios in the following sequence; no strategies enabled, keeping social distance strategy, wearing a face mask strategy and keeping social distance with mask wearing strategy. Among these two strategies, we conclude that mask wearing is more effective than social distancing.

This research was primarily focused on epidemic spreads in different organizations and to compare the effectiveness of the two interventions namely; Wearing-a-face-mask and Keep-social-distance. Still the approach followed in this research can be extensible to cater other requirements in epidemic modeling. There we can consider the death rates and calculate the death count in the population. Can be done major enhancement to the model by adding vaccination details. So the future works are opened in this research such as; adding new parameters to the existing model, calculating death count in the model, and identifying new interventions to the model.

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