Agent Based Modeling within an hospital setting

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Summary

Developing a model for a hospital wing during the Covid-19 pandemic which has swept across the world in 2020. This model would consider doctor and nurse pathways, personal protective equipment usage, and number of patients, nurses, doctors and visitors.

Problem Statement

Understanding human behavior in order to model the spread of the COVID-19 virus within varied settings.
The goal that we had stated at the beginning of the semester was to develop an accurate model with varying parameters that depict the spread of the Covid-19 virus. At the time we had not decided which setting to develop this model in and which parameters to utilize. After research we were able to develop a true plan. The challenges we foresaw were parameter reliability and learning a modeling software.

Methodology

To develop a working model tracking the spread of COVID-19, we first began with a thorough research analysis to better understand all factors necessary for consideration. There are many resources already made available to track past viral spreads, and we wanted to tabulate as much initial data as possible. After attaining a general understanding of viral spread (not necessarily about COVID-19), we began a period of specified research about the factors we'd like to analyze in our model. This inquiry includes, but is not limited to, hospital layouts, visitation policies, rates of transmission, and professional testimonials. The next steps were to begin building the model. To create an accurate model, a detailed floor plan was designed so that the agents can move freely within. For the agents to be realistic, each type had systematic movement and directions to match their human behavior. Finally, all the data was fed into NetLogo's program and compiled into a working model capable of tracking spread and communicating insights.

Research

In order to begin a model, it is important to quantify the variables that will be involved in it. Research was conducted regarding typical visitor policies, patient to nurse ratio, patient to physician ratio as well as the transmission rates of the disease and personal protection for these groups of people. The first step was devising which groups of people to include in this model for a hospital. Based on preliminary research and personal experiences it seemed ideal to have four personnel groups: doctors, nurses, patients, visitors. Upon further inspection of visitor policies in the area, specifically Emory hospital, it became clear that for Covid-19 patients visitors were not allowed unless it became an end-of-life situation. In terms of the other groups, Emory hospital usually has a 4:1 patient to nurse ratio and a much higher patient to physician ratio. In addition, during this pandemic there is a very high ratio of beds to patients, hospitals are filled to their capacities.

After finding this information about the demographics for the hospital wing it was crucial to find rates of transmission for the virus. When doctors and nurses, who have the best PPE, wear N95 masks, they have 95% protection (National Library of Medicine 2020). When regular surgical masks or cloth masks are worn, there is

80% protection (Personal Protective Equipment, 4). From speaker Max Adelman, most transmission occurs when a patient is presymptomatic at about 44%. This peaks on the first day of symptoms onset. Based on general human behavior, it can be assumed that patients would reach the hospital on this day or in the days immediately after which means that the rate of transmission is high.

The final aspect to research for the model was pathways of doctors and nurses. For purposes of simplicity, it was assumed that patients never left their rooms. Many articles written online by doctors and nurses chronicling their daily lives suggested that in hospitals across the nation, they have similar routines. Based on this, developing a standard pathway of movement was simple as the human behavior was quantified by real humans working in the field. After setting distinct paths of movement for doctors and nurses, it was time to begin working on the model.

Variables

When creating a model to simulate the complicated spread of COVID-19, there are many variables to consider. To maintain a manageable simulation, we begin with a simplified working model that can be built upon and then lead to a more sophisticated approach. The variables we start with are, in essence, the minimum necessary to set up our system environment. Each agent type has a specified number of present agents; for example, sick patients are allotted to all open bed spaces due to the healthcare system overload, while the amount doctors and nurses depend on worker-to-patient ratios. Doctors and nurses also have specified movement patterns on account of their workplace responsibilities, while patients remain immobile in their beds. Agents can also gain viral protection if they use PPE, which varies depending on who or where someone is. Apart from patients, doctors, and nurses, the model can also implement visitors; however, due to the nature of the pandemic and modified visitation policies, visitors do not appear in the simulation (current policies bar visitor entrance from COVID-19 areas). The last important variable is the rate of transmission, which generates a likelihood of contracting COVID-19 upon interacting with a contaminated individual.

Spatial Considerations

Research was done with regards to spatial needs for a hospital wing to be converted to accomodate a pandemic flow. A document named Pandemic Outbreak Design Solutions (HKS Architects 2020, 14-15), one of the leading designers in the field of healthcare proved to be helpful in this matter. Design for the Queen Mary Hospital in Hong Kong was a comprehensive strategy to deal with potentially high contagious diseases like COVID-19. The design was especially challenging for HKS because the hospital is located in a tight urban space where in the last decade there have been outbreaks of H1N1, SARS and recently COVID-19. The design had to address concerns of how to control and isolate patients with these contagious diseases especially in tall dense hospitals. In response, HKS proposed a method to compartmentalize entire floor levels during pandemic events. Separate access points for infectious and non infectious patients are provided on the A&E floors and two separate patient lift banks for infectious and non infectious patients can help in separation throughout the building. The project also features a mechanical system infrastructure with seasonal/pandemic exhaust design.

Using the Queen Mary Hospital floor plan (Figure.1) as a guideline we developed a floor plan (Figure.2) with the different entrances for incoming patients, emergency and staff. The inpatient rooms or the wards are along the perimeter and the critical care rooms are located at the center thereby allowing for a compartmentalization. it can be further zoomed in if needed and we could look into simulating the behavior of agents even at a smaller scale since it easily allows for the normal flow to be converted into a pandemic flow. The legend here highlights the areas that different agents can be zoned into during the Normal flow. (Figure.3) The white are the common spaces accessible to everyone. The red is the area where only staff and critical care patients are allowed and the yellow is the staff only zone.

During the pandemic flow, (Figure.4) the floor plan adjusts itself to accommodate the segregation of the different agents as per requirements. The main entrance will function as a thermal check point to segregate symptomatic and asymptomatic patients. The inpatients rooms are converted into isolation wards and will now not be accessible to the visitors. The yellow still functions as a staff only zone allowing for the movement of staff between the critical care and the isolation wards. We simulated the agent behaviour with a focus on this area of the wing with isolation wards and movement of staff or nurse.

Agent Behavior

There are two main types of agents in the model: patients and healthcare professionals. All patients are static - they do not move away from their starting position in bed. This simulates the debilitating and harsh effects of COVID-19 in extreme cases. In general, it is safe to assume that if someone requires hospital care, then their symptoms are severe enough to keep them in bed for the duration of their stay. All patients are deemed contagious. On the other side, healthcare professionals comprise doctors and nurses. Their roles are very systematic, with much more movement. Typically, their shifts begin entering the hospital department with PPE, then a routine analysis in an isolated workroom, followed by treating patient after patient for almost the entire duration of their shift. Nurses will return to the workroom occasionally to input data while doctors are more likely to stay with patients for treatment. The hospital floor layout restricts specific agents from entering certain zones, e.g., a visitor is not allowed to enter a patient's room.

Evaluation criteria

For the initial model, the main evaluation criteria on the safety of the simulated hospital was the proportion of infected healthcare workers relative to the total number of workers present at the end of the simulation. (Figure.5) These healthcare workers were given a chance to become infected by a contagious patient, based on the time spent with that patient, as well as a chance to become infected by other contagious healthcare workers. Workers would have a set number of patients to visit, and would then leave the hospital. At the end of a simulated run, the infected proportion at each discrete time was taken. If a large proportion of workers had become infected, it was an indication that an outbreak would be likely in the model's simulated hospital, with its floor plan and agent behavior, and vice versa for a small proportion of infected workers. Although this statistic varies considerably based on when workers enter and exit the hospital, as well as how agents choose their pathing, it gives a rough estimation into how dangerous a situation can be.

Results

As seen in Figure.6, each agent has pre-calculated the paths they would need to take to reach a particular room before they enter. As a result, many healthcare workers take similar paths when visiting patients and become infected by proximity. In addition, in this particular model, every worker visits the same workroom after visiting patients to update documentation and prepare for the next patient; this caused more infections by proximity, as a single worker could become infected by a contagious patient, then visit the workroom and quickly infect other healthcare workers. These quirks of agent behavior suggest the importance of identifying contagious workers quickly is important to reducing the spread in an outbreak. It also suggests that better planning of worker pathing and documentation can reduce spread by proximity; workers should take paths that evenly spread themselves over the hallways and patient rooms and avoid taking popular routes. Though these results are extrapolated from the model, it should be noted that there were issues with spatial resolution that could have caused infection by proximity to cause more infections than in reality.

Challenges

Research

Though COVID first emerged a year ago, and prolific research has been done on the virus, rapid developments in these studies made finding consistent information difficult. This was an especially prevalent issue when trying to find the rate of transmission, which was a debated topic for a considerable amount of time. We choose to focus less on pinning down some of these specifics, and estimated model parameters based on the information that could be found. Also, the changing nature of the situation made our research more challenging - new visitor policies were put in place and new ideas to limit spread were implemented, so we had to adjust our research and model appropriately.

Model

There were also many challenges that emerged in building a model with NetLogo. Though we had our floor plan, we ran into issues in using the plan with the spatial resolution desired in NetLogo, resulting in some of our model parameters becoming overly simplified, and less representative of a real hospital space. This leads to further issues, such as with pathfinding. The moving healthcare worker agents were given pre-calculated paths to patient rooms and the workroom, however, with many agents taking similar paths, the chance for infection by proximity was overrepresented, as most healthcare workers in a real setting would not be walking so close to each other. Finally, our model was not in the normal use case for NetLogo; we wanted higher spatial resolution and complex agent behaviors that could be abstracted, but running high resolution simulations often crashed the model, and the programming style of NetLogo made complex behavior difficult. Accommodating for these challenges overall reduced the accuracy of the model considerably - most likely, it can be expected that there will be less infections in a real setting than our model simulates.

Discussion

Throughout the semester, there were two critical skills developed by the entire team. Those skills were research and modeling. Researching is a skill that was further developed because this research required specific scientific information that could only be drawn from studies and peer reviewed articles. Sorting through information on the web and finding reliable information was a challenge that allowed for growth in research skills. The other skill that was developed was modeling. Modeling softwares were completely foreign to the entire team, so this was a skill that had to be developed from scratch for every member. This required a great deal of research and tutorials on the software of choice which was netlogo.

Another aspect to consider was the importance of background research in the research process that is followed by the Vertically Integrated Project program. When constructing the model it was easy to overlook the background material that was needed. This created a constant back and forth between model development and background research.

Looking to the future, the plan for next semester is to perfect the model. This semester the model could only be run once and does not take into account every variable envisioned. This leaves much room for improvement. This means that while this semester was very heavily research focused, next semester will be heavily model based.

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Figure 1: Queen Mary Hospital Floor plan

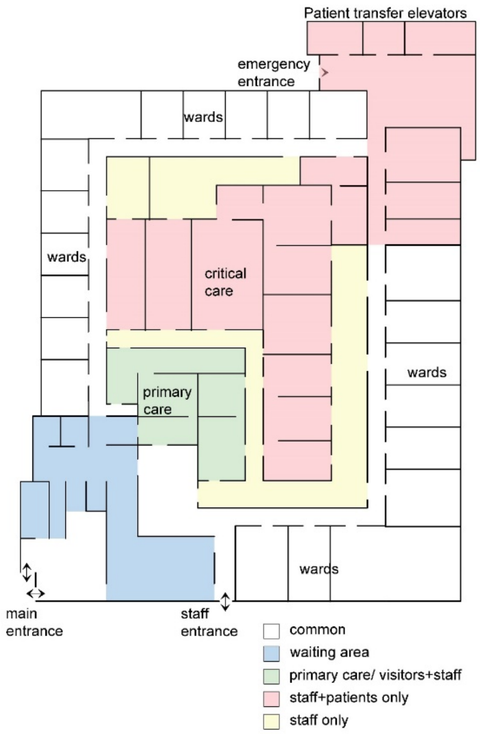

Figure 2: Zoning of the Hospital Wing

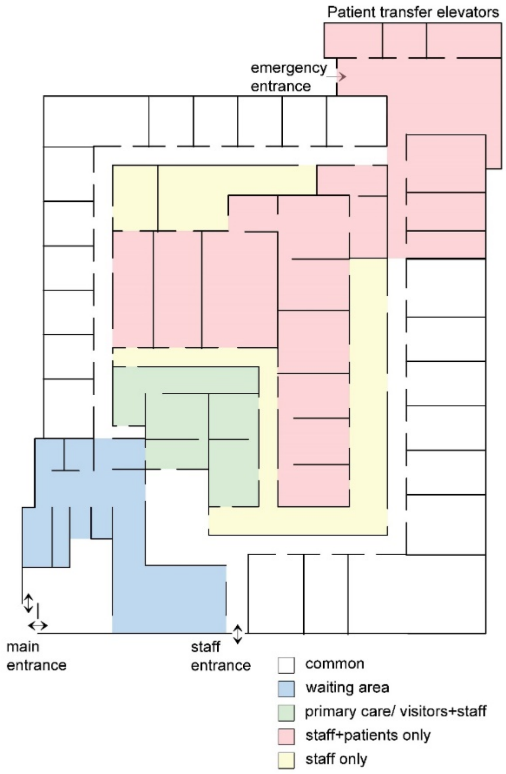

Figure 3: Normal Flow

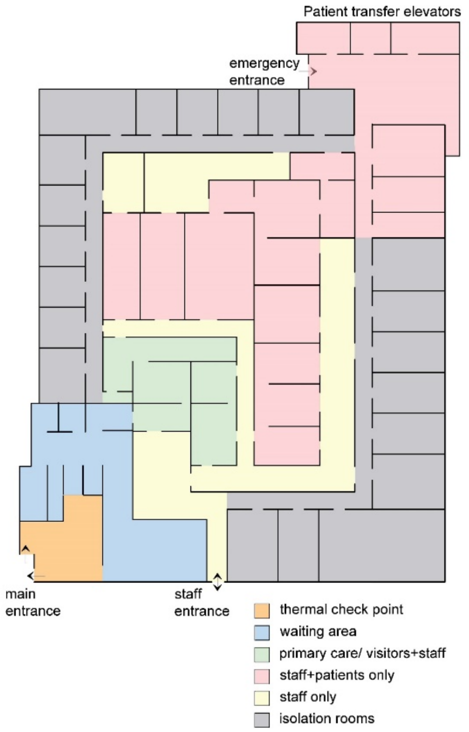

Figure 4: Pandemic Flow

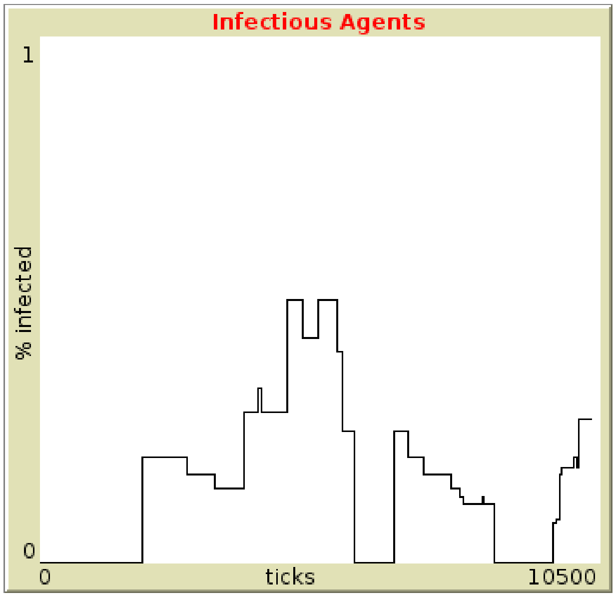

Figure 5: evaluation criteria is the ratio of infected healthcare workers relative to the total number of workers present at the end of the simulation

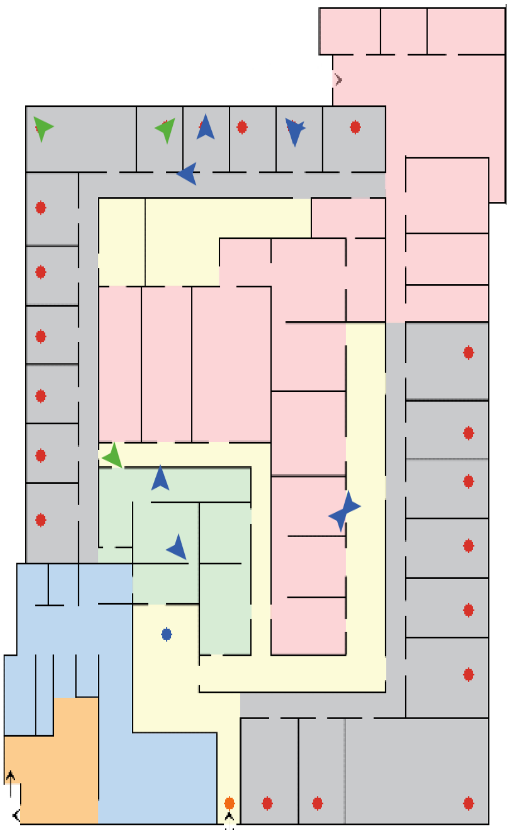

Figure 6: Snapshot of the Simulation from Netlogo