COVID-19 Spatial Agent-based Modeling: Single Room Infection

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Introduction

Several models exist for the transmission of SARS-CoV-2 (severe acute respiratory syndrome coronavirus 2) based on varying assumptions and parameters. The Chu and Chen models investigate coronavirus transmission and infection as functions of nonpharmaceutical interventions (physical distances, masks) and respiratory droplets, respectively. The results of the Chu model suggest guidelines for social distancing (1 meter or more) between individuals and public usage of facial and eye protection, while the Chen model shows the relationship between droplet size and transmission range. The two models both attempt to examine coronavirus transmission, but they report results that are not necessarily conflicting, but rather, incomplete on their own. The significance of this problem is that because models vary depending on the parameters and underlying assumptions, there is uncertainty on how to filter out the valid and optimal inputs. In this replication study, we develop a simple infection rate model based on the results and parameters reported by the Chu and Chen models, the MIT COVID-19 Indoor Safety Tool, and the airborne.cam tool by Cambridge.

The output of this experiment will be primarily a simulation where a user will be able to set parameters to see the resulting risks and infections caused by in person instructions. This report will be a secondary output along with the website and visual presentation and will be used as a guide to explain methods as well as theory behind the work.

Definitions and existing models

- 'Chu' model: Meta analysis of many COVID papers, resulting in part in a model that approximately halves transmission rates for every meter traveled by the airborne particles (rate ~= 1/2.02 per meter).[1]
- 'Chen' model: Fluid Dynamics Simulation to determine prevalence of short-range aerial and droplet transmission. This model shows that at very close ranges (<.3 meters, i.e. ~1 foot), there is an infection rate much higher than other linear models. This indicates that multiple models are needed to be considered to create our final schema and model.[2]
- MIT COVID-19 Indoor Safety Tool: A set of safety protocols determined by mathematical models accounting for physical distances, number of people in a given room, ventilation, and mask-wearing.
- Cambridge model: A risk calculator for determining infection based on room features, occupancy, ventilation, and viral loads (as input parameters).
- Six-Foot Rule: A guideline that states that an individual may safely interact socially with another person with minimal risk of contracting covid-19 virus when wearing the necessary equipment.

Assumptions

- Agents wearing a mask will continue to do so
- All school-mandated guidelines (windows, masks, etc) are enforced without incident
- Transmission is limited to current knowledge of COVID-19, however newer strains may have a higher base infection rate (see Wave 4)
- Individual effects of COVID and Vaccination rates are not considered
- 2 initial students are infected
- All students 'infected' are considered to have received an eventually infective dose

Constraints

- Infectiousness of viral particles is an ongoing field of study. The thorough methodology of the 'Chen' study, providing model parameters such as 'Inhalation fraction' (used for mask usage), 'Thermal conductivity of air [Watts * meter^-1 * Kelvin^-1]', and '[exhaled] air jet initial momentum [meters^4 * seconds^-2]
- As viral load deposition at a distance is not the primary function of this model (and as our model has to be run in time steps), the computation necessary for adding the first model's parameters to ours is prohibitive, leading us to use their conclusions and cite their workings as a source instead.

Well-mixed Room

The definition of a room that is well mixed is that the pathogen is distributed uniformly throughout the room (Bazant)[3]. Furthermore according to Bazant, one is no safer from airborne pathogens at 60 feet than 6 feet. This renders the Six-Foot Rule somewhat ineffective to reduce the spread of the Covid-19 Viruses.

Bazant's theory can be further supported with data presented in Sture Holmberg and Qingyan Chen's simulations of different ventilation systems in the classroom.[6] In the result of their simulation, a classroom with mix ventilation system implemented will have a roughly uniform distribution of aerosol particles across the room. Since most mechanical ventilation systems in real life like air conditioners are designed to realize mix ventilation, it is reasonable to assume that school classrooms will be under such mix ventilation conditions. Therefore, the well-mixed room theory is well supported and it is safe to implement the MIT model in our one room modeling.

Within our model, we are assuming that all rooms are initially well mixed given no ventilation or air filtration. This is because we want to make sure that our simulation gives the safest results. "Experts agree that good ventilation is the most effective and practical way to rid a space of contaminants."(Bartzokas) Without ventilation any infected patient will in time be able to spread the virus all around the room due to there being no fresh intake of air nor any action to clean the air up. Many of the papers that have been referenced agree and follow this idea due to it being the most realistic idea to follow as well. The implementation of ventilation will allow us to more accurately gauge the risk of having in person instructions and measure how severe it would be as well.

Mask Wearing

Understanding the capability of the masks in this pandemic is one important thing in making epidemic prevention decisions and policies. Many health authorities suggested that masks are able to prevent sick patients from spreading the virus to others by filtering out the virus from their exhaled breath. “Results clearly indicate that wearing surgical masks or unvented KN95 respirators reduce the outward particle emission rates by 90% and 74% on average during speaking and coughing, respectively, compared to wearing no mask.” These results further highlight the importance and significance of mask wearing and therefore we will also replicate this fact into our model.

Additional Features (Extension)

- **Airflow**: With respect to transmission, ventilation systems and transmission media may be significant factors in infection risks. A study was done in China regarding transmissions related to air-conditioning in restaurants, concluding that large droplet-based transmissions were likely a result of the air-conditioning systems. The significance of this is that airflow is a potential risk factor for transmission/infections, which was not considered in the one-room model. Airflow may be an additional parameter that is implemented in our model for determining how likely an individual is infected (or can transmit the virus) based on their position relative to the direction and speed of airflow.
- **Exhalation Activity:** Exhalation activity directly relates to the amount of aerosol droplets that an individual exhales towards the room. This measure will be called quanta emission rates $\lambda_q = Q_b C_q$, (Q_b = exhaled volume per time, C_q = quanta of infection concentration) and will apply for various forms of respiration.[3] Preliminary results and discussions are taken from Bazant’s paper which showcases the different measures of Cq or virus emissions based on the activity being done.

Methods and Results

The one-room model is scaled-down to determine transmission and infection in a consolidated area. The back-end assumptions and calculations are based on the findings from the Chu[1], Chen[2] models, the MIT Indoor Safety Guidelines[3], and Cambridge Model (airborne.cam)[4]. Our model implements the room (physical) and viral/human (physiological and disease) parameters provided by the MIT model, and uses the assumption of a well-mixed room for aerosol transmission.[3] For validation, we compared our calculations to results we would get using the airborne.cam tool[4]. Specifically, we found that our own results were similar to the results generated by the infection tool using the Vl (viral load) = 10^8 copies/mL input and the same room parameters. Our model allows us to specify the physical room parameters, environment and viral characteristics, and occupancy. These inputs are then used to calculate the number of agents (out of the number specified in the occupancy) infected after a specified timeframe.

Our simulation will function based on a few parameters and steps done beforehand. Firstly, the simulation is first created by initializing the students according to default parameters based on the room or location that the simulation will be run on. Then the user will also input and define how long the model will run for. This is done so that we will be able to see the effect of time towards infections and the simulation will then be able to track it as time goes by through steps that are given by the input.

The model runs primarily through a series of simple loops: firstly through the number of days classes will be held in a sample week (1, 3, or 5), then through each class to be attended that day (each class being a proxy for an hour passing, options being 3, 5, or 7 classes per day), and lastly through a series of 5-minute timesteps during each hour, for a total of 12 per class. At each step, every infected student will loop through all uninfected students and call the function droplet_infect, which takes care of the transmission route caused by droplets larger than 2 microns. The transmission rates are stored for comparison purposes, and in the case of the function breaking due to an empty output, transmission is assumed to be 0 (the function handles 99.5% of potential infective cases and individual's beyond the curve are effectively non-infectious). One of the outputs available through the command line is 'test', which displays the distribution of transmission likelihood post-processing, after utilizing calculations to deal with distance, masks, and breathing rate.

We evaluated how varying levels of preventative measures affect the output, namely masking wearing, movement, and student activity. We defined student activity as the level of respiratory activity, which is related to the amount of speaking/discussions between students. The output for the minimal level of preventative measures is shown in **Figure 1**, in which masks are not used at all, and there are no restrictions on movement and speaking. **Figure 2** shows the results for a high level of preventative measures, i.e. 90% masking usage, and some level of movement and speaking. **Figure 3** shows the results for the highest level of preventative measures, that is, 100% mask usage, no movement allowed, and restricted levels of respiratory activity.

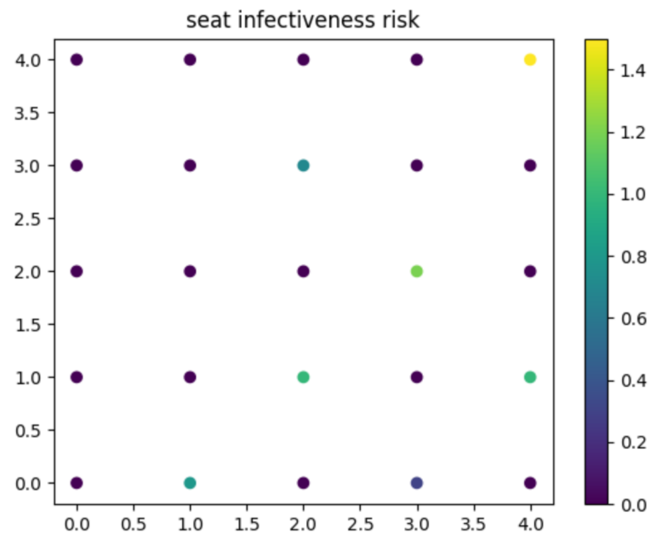

Figure 1. This plot is a result of having no preventative measures, i.e. 0% mask wearing, unrestricted movement within the boundaries of the room, and high student activity (can be described as unrestricted discussions/talking).

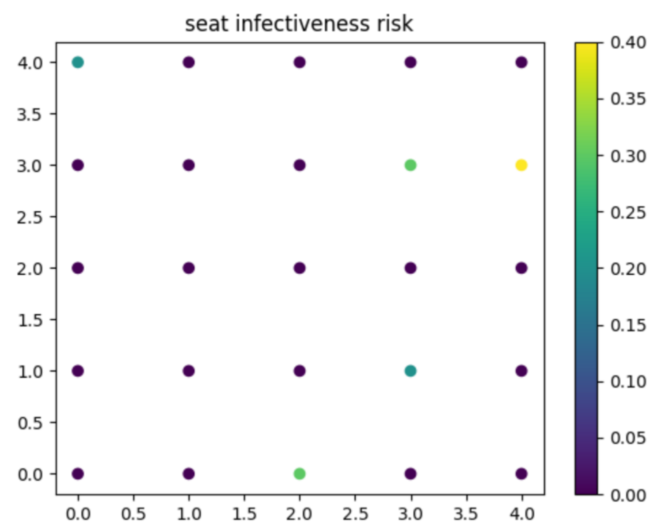

Figure 2. This plot is a result of a high level of preventative measures, i.e. 90% mask wearing, some level of movement within the boundaries of the room, and semi-limited student activity (can be described as controlled discussions/talking).

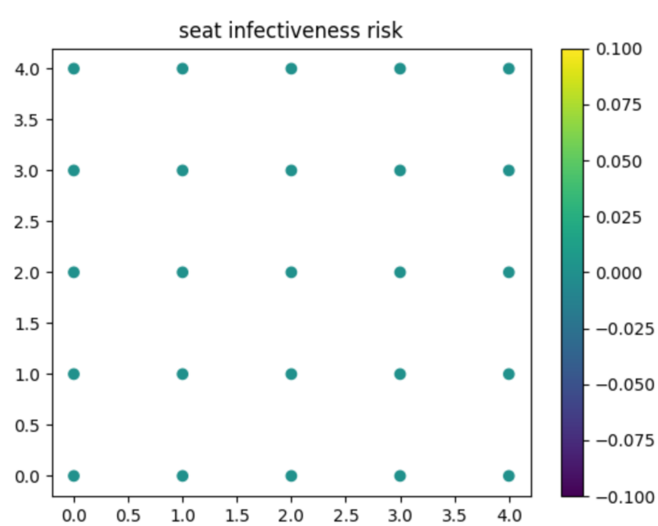

Figure 3. This plot is a result of the maximum level of preventative measures, i.e. 100% mask wearing, no movement within the boundaries of the room, and very limited student activity (can be described as highly controlled discussions/talking and limited respiratory activity).

Discussion and Further Exploration:

It is important to note that there are limitations to our study. There are many variables and aspects that have not been taken into account or are only limitedly discussed within the simulation. One big aspect that we could do further exploration on is the aerosol particle movements. Currently in our model, we assume the room is initially well mixed with virus contaminated particles evenly distributed across the whole space. Then we apply 2-D airflow direction to simulate how air particles flow through the room over time. However, air particle movement and aerosol transmission in real life is far more complicated. In our 2-D model, we assume all the virus contaminated particles stay on the same level and can all be exhaled in by the students in the environment. However, in real life, those particles may rise to the ceiling or fall to the ground, leaving the breathing zone level and changing the amount of virus particles that people can exhale in. This can largely affect the transmission risk. Therefore, instead of applying airflow in a 2-D manner, 3-D airflow direction should be implemented to better simulate the air particle movement.

Furthermore, our model assumes that students' exhalation activity is constant and there is no change between times, this is unrealistic and could also be improved upon to make the model more accurate. Furthermore, since the study of COVID-19 is still an ongoing research there are still many things that we are unsure about as to the infectiousness as well as modelling the decay rate of the virus within the rooms. Building upon this and the current situation with the vaccine rollouts, we could also start to implement a vaccinated parameter for individuals to see how much of an effect vaccines have within limiting the spread of this virus. If more resources are available it would also be useful for users to be able to add their own floor plans instead of using pre-set plans that are static, as this would be able to give a more accurate representation of risk. Finally, unifying models such as the regional study of COVID-19 risk could also be implemented to further create a more representative model for the end user.

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