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RESEARCH NOTE

Effect of Social Distancing on COVID-19 Infection Determined by a Multi-agent Simulation

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Abstract **COVID-19 has spread all over the world, and the cumulative number of infected people is still increasing dairy. Therefore, interventions to limit the spread of COVID-19 should be considered for each social situation. Effective interventions to minimize COVID-19 transmission vary for each situation in accordance with a quantitative framework called event R. Of those various events, the example of a school has the highest possibility of infection, but distancing as an intervention cuts the number of new infections in half. Therefore, perform we multi-agent simulation of COVID-19 transmission without measures and with social distancing. To perform simulation under the same conditions as those in the event R calculation, our simulation is performed under the following conditions: a single infected person enters the classroom with the first set of multiple uninfected people and a certain amount of time passes. After that, the infected person enters another classroom with the same number of new uninfected people, and the process is repeated eight times. The simulation results show that there is a relationship between social distancing and the spread of infection, but the rate of decrease is not constant.**

Keywords: COVID-19, multi-agent simulation, social distancing

1. Introduction

Recently, there has been much discussion about co-existing with COVID-19, and some states are not requiring the wearing of masks. Therefore, the effectiveness of interventions for infection control other than mask wearing must be emphasized inlight of these discussions. An effective intervention that can be considered is social distancing.

The interventions to limit the spread of COVID-19 should be considered for each social situation such as public transport and high schools because the spread has not yet been sufficiency controlled around the world. Here, there is a quantitative framework to determine which intervention is likely to have the most effect in which situation. The concept of "event R" refers to the expected number of new infected people owing to the presence of a single infected person in a situation [1].

Then, in workplaces and businesses, it is necessary to determine whether the conditions are linear or saturating, and whether people are strongly mixed or bubbling. Figure 1, adapted from Tuppera et al. [1], shows the values of event R for no measures and each intervention. In Fig. 1, the settings of high schools are saturating and mixing, and the results show that different events have different effective interventions.

High schools, which are most likely to be susceptible to infection among these four settings, are focused on. Then, event R is halved by halving the number of contacts in event R considering social distancing. In addition, the calculations are made under the following conditions in high schools: a single infected person comes in contacts with the first set of multiple uninfected people for a certain length of time. After that, the infected person comes in contact with the same number of new uninfected people. This is repeated eight times for a total time of one week.

We perform multi-agent simulation (MAS) of COVID-19 transmission in a high school without measures and with social distancing. Then, we examine whether the number of new infections is reduced by half by practicing social distancing, as in the event R calculation. In addition, we examine the effect of infection reduction on changes in the proportion of people practicing social distancing.

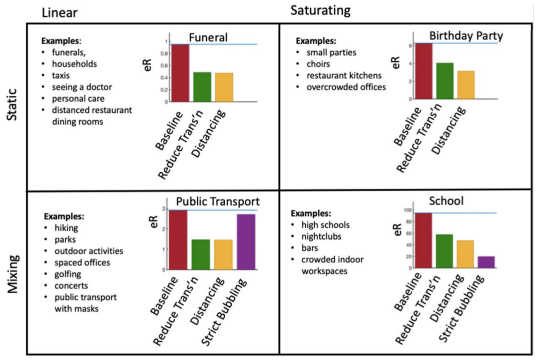

Fig. 1 Four different kinds of events: (left) linear (low transmission probability), (right) saturating (high transmission probability), (upper) static (same contacts for whole event), and (lower) mixing (high turnover of contacts).

2. MAS

MAS [2] is based on the idea that programs exhibit behaviors entirely described by the program instructions. It is possible to simulate an artificial world inhabited by interacting processes by relating an individual to a program. We can simulate by transposing the population of a real biosystem to its artificial counterpart in which particular hypotheses can be explored by repeating experiments. Each organism of the population is represented as an agent whose behavior is programmed with all the required details.

The simulation of the number of people infected with infectious diseases is sometimes performed using a mathematical model based on differential equations. In addition, overall parameters such as infection rate and mortality rate are defined, in the simulation using a mathematical model. However, in MAS, it is possible to consider more details than in a simulation using a mathematical model because several parameters are given to each agent.

3. Model

We use the SIR model in our one-week MAS simulation of the number of new infections. In the SIR model, agents are given the state S (susceptible), I (infectious), or Re (recovered), which changes in turn. The SIR model is also applied to the early spread of SARS-CoV-2 and the fitting of the reported COVID-19 cases in Italy [3].

In this study, MAS is performed for the cases without measures and with social distancing. Recovery and death are not considered in this one-week simulation because the infectious period is approximately eight days [4].

4. Simulation and Conditions

4.1 Conditions of all simulations

To perform simulation under the same conditions as those in the event R calculation, the following conditions are adopted.

- The simulation is repeated eight times with one initially infected person, 20 uninfected people, and a 400 m^2(20 m × 20 m) classroom. Because the people are replaced seven times in the event R calculations, the simulations in this study are adapted to these conditions as well.
- In this one-week simulation, the initially infected person is always in the classroom and infectious.
- The agent's initial position and direction of movement are determined randomly.
- All of the agents are between the ages of 15 and 18, and all of the infected people are infectious and asymptomatic, and there is no quarantine of the infected people.
- If an infected person enters within a radius of 1[m] around an uninfected person, the uninfected person becomes infected, and the time required for virus transmission is 15 minutes. This is based on the definition of intensive contact in Japan.
- For all agents, behavior and contact outside the classroom are not considered.
- To obtain results under the same conditions as those in the event R calculation, the time of our eight repeated simulations is set to one week. Weekends are not taken into account, and the time for one simulation is set at 8 hours.

4.2 Conditions of simulation with social distancing

The simulations are performed without measures and with social distancing. In the simulation with social distancing, a repulsion force that is inversely proportional to the distance between the agents should be applied if another agent enters within a radius of 2[m] around one agent. Furthermore, agents are programmed to predict where other agents are going, so when there is interference by many other agents, they cannot avoid contact completely.

5. Proposed Method

The total number of initially uninfected people in the eight simulations is 160 because the simulation of 20 uninfected people is performed eight times. The proportion of the total number of new infected people to the total number of these 160 people is calculated. Then, this simulation is performed 10 times and the mean and median of the data from these 10 times are obtained. Furthermore, the simulations are performed without measures and with the number of agents practicing social distancing set to 10 different values from 10 to 100% of the number of uninfected people. However, in the simulation with social distancing, the initially infected person practices social distancing in all situations. For example, the total number of agents practicing social distancing is 11 if 50% of the agents practice social distancing.

6. Results

Figure 2 shows a scatter plot and graph of the result of one of the eight repeated simulations without measures. The scatter plot shows the agents, and the movement of the agents and the infection situation can be seen in a video. The red points are the infected agents and the blue points are the uninfected agents. The graph below shows the number of infected and uninfected people at the same time as that indicated in the scatter plot above. In this graph, the horizontal axis is time and the vertical axis is the number of infected people. The red area increases as the number of infected people increases. In the case of the simulation shown in Fig. 2, one initially infected person eventually generates 14 new infected people.

Likewise, Fig. 3 shows a scatter plot of the result of one of the eight repeated simulations with social distancing. the orange points are the agents infected despite practicing social distancing. In the case of the simulation shown in Fig. 3, one initially infected person eventually generates 11 new infected people.

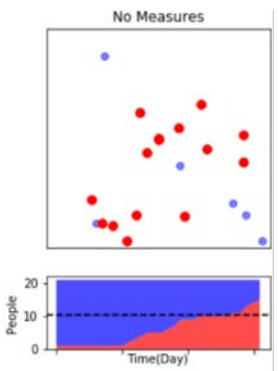

Fig. 2 Scatter plot and graph of result of one of the simulations without measures

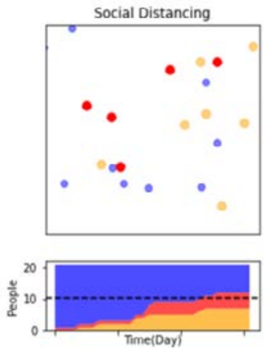

Fig. 3 Scatter plot and graph of result of one of the simulations with social distancing

The means and medians obtained from all simulations are shown in Figs. 4 and 5. In these figures, 0% people practicing social distancing corresponds to the result of the simulation without measures.

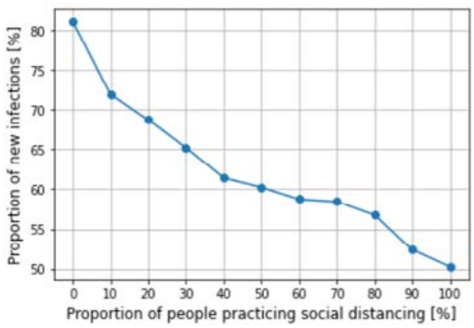

Fig. 4 Means of all simulations

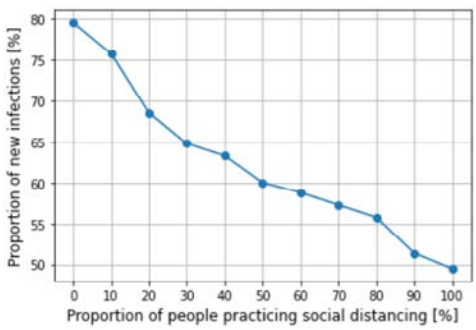

Fig. 5 Medians of all simulations

Figures 4 and 5 show that the number of new infected people decreased as the proportion of people practicing social distancing increased. However, the number of new infected people is not reduced by half compared with the simulation without measures unlike in the event R calculation. Social distancing is represented by halving the number of people in contact in the event R calculation, whereas the agents in a MAS move randomly and always try to keep a distance of 2[m] from each other. Even if the frequency of contact between the initially infected person and uninfected people is halved in MAS, the new infected people come in contact with each other in one simulation. Therefore, the number of new infected people decreases by only about 30% when people practice social distancing of 2[m] because of secondary infections in the simulation MAS.

Furthermore, the results in Fig. 4 for the case without measures and the case with 10% of the people practicing social distancing show that there is a difference of about 10% between these two values. This difference is larger than the differences in other parameters. Then, one initially infected person practices social distancing in all simulations with social distancing. Therefore, this confirms that the effect of social distancing on the spread of infection by infected people is significant.

In addition, Fig. 6 shows the proportion of new infected people among the number of agents without any measures and the proportion of new infected people among the number of agents practicing social distancing. The blue graph shows the number of agents without any measures and the orange graph shows the number of agents practicing social distancing. The proportion ranges from 10% to 90% of the number of people practicing social distancing because the aim is to compare the effects of no measures and social distancing in the same simulation. In Fig. 6, the agents without measures consistently infected more than 60% of the population, while the agents practicing social distancing consistently infected less than 50% of the new infected people.

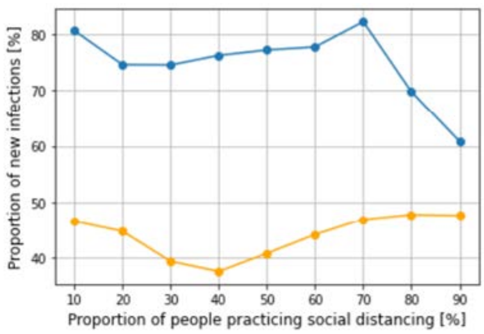

Fig. 6 Means of all simulations

7. Conclusion

The purposes of this study were as follows: to confirm whether the number of new COVID-19 infected people with social distancing was reduced by half compared with no measures and to analyze the effect of the number of people practicing social distancing on the spread of infection.

MAS was performed without measures and with the number of agents practicing social distancing set to 11 different values ranging from 0 to 100% of the total number of agents. As a result, in the simulation with social distancing, the number of new infected people was not reduced by half compared with the simulation without measures. However, the number of new infected people decreases as the proportion of people practicing social distancing increased.

In a school, students do not always move. They sit in their classes, and during breaks, some move while others do not. In the future, it is necessary to recreate this situation in MAS to make the simulation more realistic. In addition, although the number of new infected people was not reduced by half even with social distancing, it is necessary to examine whether the number of new infected people can be reduced by half when the distance between agents is greater than 2[m].

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