Mitigation of COVID-19 outbreak while continuing economic activities

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Abstract

Minimization of human contact is effective in managing COVID-19 outbreaks caused by SARS-CoV2; however, it causes severe economic damages to several categories of occupations such as restaurants and travel industries. Strategies are required to address this issue by considering the interrelation between the spread of the virus and economic activities. In a previous paper, we have proposed an abstract agent-based model of the COVID-19 outbreak that considers economic activities. Herein, we briefly review our previous research and discuss how the issue mentioned earlier can be solved using the proposed model. Based on the simulation results, we suggest that urging wealthy people to use their money may help mitigate the outbreaks while minimizing economic losses.

Introduction

The COVID-19 disease caused by SARS-CoV2 was first reported in Wuhan in December 2019 (Nishiura et al. (2020); Zhu et al. (2020)); it has spread globally, causing severe damages to health and economy. As of May 6th, 2021, a total of over 154 million people have tested positive, and over 3 million people have died owing to COVID-19 (https://coronavirus.jhu.edu/map.html). Many people have suffered economic losses and lost their jobs. Thus, a solution to the dilemma of mitigating the spread of COVID-19 or reducing the economic losses is urgently required.

Mathematical modeling is useful for discussing problems related to outbreaks of infectious diseases (Wells et al. (2020); Tang et al. (2020); Stutt et al. (2020); Kermack and McKendrick (1927); Frias-Martinnez et al. (2011); Currie et al. (2020); Urabe et al. (2016); Kano et al. (2021)). In a previous paper, we have proposed a simple agent-based model that considers both COVID-19 infections and economic activities (Kano et al. (2021)) to deduce their relationship rather than providing a quantitative prediction. It was expected to serve as a platform for discussing solutions to this dilemma.

The main contribution of this paper is to briefly review our previous research (Kano et al. (2021)). In addition, we discuss how the COVID-19 outbreak can be mitigated while continuing economic activities using the proposed model. We hypothesize that savings of rich people cause economic difficulties to poor people. To verify this, we modify the model such that wealthy people do not undergo voluntary restraints but still use their money. Then, simulation results of the modified and original models were compared.

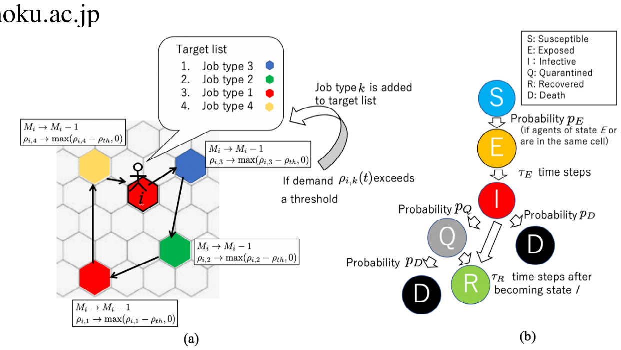

Figure 1: (a) Outline of proposed model. (b) Rule for transition of health state.

Previous Model

In this section, we briefly explain the previously proposed model (details presented in Kano et al. (2021)).

Model Overview

In this study, we consider a cellular automaton model in which hexagonal cells are regularly aligned on a two-dimensional plane (Fig. 1(a)) with N agents. Each agent has a home cell and can remain there or move to the adjacent cell at each time step. Each agent has a health state, $State_i$, and money, M_i, which are updated through interactions with other agents. An agent dies when it fails to recover from an infection or when its money becomes zero.

Agents have their own businesses. Several types of businesses exist, which include selling of commodities or nonessentials. Each agent selects one type and does not change temporarily. Every agent has a demand for goods. When the demand exceeds a certain threshold, the agent goes out to buy them. The agent pays money when it reaches the home of an agent selling the goods (Fig. 1(a)). We assume that agent i sells goods to agent j when agent j visits the home cell of agent i. The model does not include the prime cost of the goods. When agents perceive that an infection is spreading, they tend not to demand nonessentials, whereas they demand commodities as usual.

Infection Model

We model the spread of COVID-19 by drawing inspiration from a spatial susceptible–exposed–infectious–recovered model (Urabe et al. (2016)). Each agent has a health state, $State_i$, which has a susceptibility state (S), asymptomatic infection state (E), symptomatic infection state (I), quarantine state (Q), recovered state (R), and death state (D).

The state changes according to the rule illustrated in Fig. 1(b). When an agent with state S is in a cell occupied by an agent with state E or I, $State_i$ changes from S to E with probability p_E at every time step. When τ_E time steps have passed, following the transition from state S to E, the state changes to I. Agents with state I change to state-Q and state-D agents with probabilities p_D and p_Q, respectively, at every time step. Agents with state Q, representing hospitalized patients, do not have infectability and stop any economic activity. Agents with state Q also die with probability p_D at every time step. Regardless of whether the agent is quarantined, the state changes to R when τ_R has passed, following the transition from states E to I.

Economic Activity Model

Each agent selects one of the m job types, which does not change temporarily. The demand of agent i for goods produced by job types k ($i = 1, 2, \cdots, N$ and $k = 1, 2, \cdots, m$) is denoted by $\rho_{i,k}$. The demand $\rho_{i,k}$ is updated by

$$\rho_{i,k}(t+1) = \rho_{i,k}(t) + \epsilon_k + \max\{\sigma_k(M_i - \lambda U_i), 0\}, \quad (1)$$

where ϵ_k, σ_k, and λ are positive constants, and U_i quantifies the perception of agent i of "the extent to which infection is spreading around itself," which is given by the first-order delay of the number of agents with state Q around agent i. Parameter ϵ_k represents the rate of increase in the demand that does not depend on the money that agent i owns or the degree of the outbreak. In contrast, σ_k represents the rate of increase in the demand that is affected by the money that agent i owns or the degree of the outbreak. The third term on the right-hand side of Eq. (1) indicates that the demand increases rapidly when agent i has a lot of money, although the increase stops under an outbreak. Parameter λ represents the degree of voluntary restraint during an outbreak. We set ϵ_k and σ_k to large and small values, respectively, when job type k is related to commodities and vice versa when it is related to nonessentials. The demand for commodities increases constantly, whereas the demand for nonessentials is affected by the amount of money that agents own and the degree of the outbreak.

Each agent has a target list that represents the priority of the goods to be purchased (Fig. 1(a)). When demand $\rho_{i,k}$ exceeds the integral multiple of ρ_{th}, job type k is added to the bottom of the target list of agent i. Agent i visits the home of the nearest agent, whose job type corresponds to the top of the target list. When the agent reaches home, it pays a unit amount of money to buy the goods. In this case, we simply assume that this deal holds even when the selling agent is not at home. Subsequently, because the demand of agent i is satisfied, $\rho_{i,k}$ decreases by ρ_{th}. The top item in the target list is removed, and the other items in the target list move up the list. Thereafter, agent i visits the next target. When no items remain in the target list, agent i returns to its home cell and remains there.

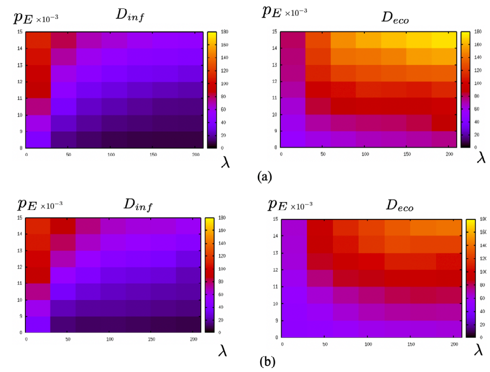

Figure 2: Simulation results. (a) Original model (Eq. (1)). (b) Modified model (Eq. (2)). Left and right color maps indicate D_{inf} and D_{eco}, respectively.

Modified Model

When Eq. (1) is adopted, the demand for nonessentials decreases during an outbreak. Alternatively, we assume the demand to be

$$\rho_{i,k}(t+1) = \rho_{i,k}(t) + \epsilon_k + \max\left\{\sigma_k\left(M_i - \frac{\lambda \bar{M} U_i}{M_i}\right), 0\right\}, \quad (2)$$

where $\bar{M}$ is a positive constant. In this case, agents with a lot of money (large M_i) tend not to be affected by the outbreak. Thus, wealthy agents do not tend to undergo voluntary restraint but tend to use their money even during an outbreak.

Simulation Results and Conclusion

Simulation results of the original (Eq. (1)) and modified (Eq. (2)) models were compared (Fig. 2). The infection rate, p_E, and degree of voluntary restraint, λ, were varied for each model, and the results of the average number of deaths caused by infection D_{inf} and that caused by economic loss D_{eco} were evaluated over ten trials for each parameter set. Most of the parameter values were the same as those in our previous research (Kano et al. (2021)), whereas the initial amount of money was set at 2/3 of that in our previous research to clearly observe the economic effect.

In both the models, D_{inf} and D_{eco} were small for a small p_E. When p_E was large, D_{inf} was large for a small λ, whereas D_{eco} was large for a large λ, which again led to the dilemma. Notably, D_{eco} for the modified model was approximately 10% smaller than that for the original model when both p_E and λ were large. This result suggests that the strategy of urging wealthy people to use money even during an outbreak may solve the dilemma. However, further careful consideration is still required owing to the simplicity of our model.

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