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Optimal Intervention Policies for the COVID-19 Pandemic Emerge from Socioeconomic-Heterogeneous Dynamics

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Abstract

The COVID-19 pandemic is a rolling crisis that required policymakers around the world to take action to manage the pandemic spread. During the period where vaccination was not available, the pandemic spread management lied in Non-Pharmaceutical Interventions (NPIs). A large number of mathematical models have been proposed to predict the pandemic spread and analyze the influence of various NPIs on multiple scenarios, getting more accurate and sophisticated over time. In this work, we review the latest mathematical models for pandemic spread NPIs and their main shortages. Specifically, the usage of modeling a homogeneous population rather than a heterogeneous one.

Keywords: Pandemic management • Pandemic simulation • *In silico* Npis

Description

The COVID-19 pandemic has negatively impacted many aspects of our lives, causing massive unrest around the world with significant loss of life [1,2]. In the period where vaccination was inaccessible for the masses (and even afterward), policymakers were forced to rely on Non-Pharmaceutical Intervention (NPI) policies to control the epidemic all over the world [3]. Computer simulations and mathematical models are shown to be a powerful tool for healthcare professionals and policymakers to predict outcomes of multiple scenarios in a controlled, cheap, and quick manner using available clinical and epidemiological [4,5].Mathematical models for epidemiology can be divided into two main groups: Susceptible-Infected-Recovered (SIR) based models and non-SIR based models [6]. From the second group, the original SIR is too simplistic to accurately predict the spread dynamics. Indeed, for the COVID-19, Nesteruk used the data from January16 to February 9 (2020), from mainland China with the continuous SIR model, using the least mean square method, which resulted in poor fitting to later officially confirmed infected cases [2,7].Therefore, the SIR has been extended to take into consideration multiple social and economic processes.The main extensions can be divided into the following three categories. First, dividing the population into subgroups according to a biological/clinical property that is relevant for the pandemic one aims to model. For example, in the case of COVID-19, the authors of divided the population into two age groups (adults and children) as clinical data indicate different age groups experience the disease differently which has a direct influence on the spread dynamics. Second, dividing infected individuals into sub-groups according to clinical and epidemiological severity. Indeed, for the COVID-19 pandemic, 7.8% of the population is estimated to be asymptomatic [8,9]. Third, adding spatial dynamics to the population. The classical SIR model assumes that at any point in time, every individual in the population can interact with other individuals, while this is not the case in a realistic scenario. One can add spatial dynamics to the SIR model using a continuous space resulting in a Partial Differential Equation (PDE) based model like the one proposed by Domenico et al. [10]. That used data from March 17 to May 11 (2020) in Île-de-France with a stochastic extension of the SEIR (E-exposed) model. The authors investigated the influence of verge social distancing on the duration of the pandemic and the total number of infected individuals. An additional option is to model the space using a graph-based model where the nodes are either locations in which the population is distributed between and individuals in the same node can interact or each individual is a node by itself and the edges are the possible interactions in the population [5-12]. These extensions on the one hand improve the accuracy of the models in predicting the spread and impact of different NPIs, but on the other hand, making them more complex and data-demanding which be challenging for real-world application in general and for the beginning of the pandemics in particular - which is a critical time to act to prevent a large-scale epidemic. Moreover, pure epidemiological models are not able to fully represent the dynamic as additional social and economic processes and even political processes modify the population's behavior in terms of mobility and interactions.

Conclusion

Computer simulations and mathematical models where only several epidemiological processes are taken into consideration are powerful tools for investigating the global dynamics of a pandemic spread. Nevertheless, policies operate on more fine conditions based on the day-to-day activities and interactions that are dictated by social and economic processes between individuals of the population. These processes are highly different between countries and time (for example during the time of the day. As a result, to obtain an accurate prediction of the pandemic dynamics and the influence of various NPIs, a model needs to be spatio-temporal, heterogeneous and taking into consideration the influence of the pandemic on other sociological and economic processes its effects (and how they affect it back as well). A promising approach is to take advantage of an agent-based model to simulate epidemiological and social dynamics at the individual level and obtain complex dynamics emerging from these activities.

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