Testing more and earlier = better control of the epidemic and lower social costs.

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Abstract In this note we explore the effect of the number of daily tests on an epidemics control policy purely based on testing and selective quarantine, and the impact of these actions depending on the time their application starts. Surprisingly, the results not only confirm that increasing the number of tests lowers the number of infected individuals, but also that it has a very beneficial effect limiting the number of quarantined individuals, and thus the socio-economical costs of the epidemics. The results also show that the timing in the application of the measures is as important as the measures themselves. The results suggest that fast decision making and investments to increase testing capabilities are highly rewarded not only from the public health viewpoint, but also from the socio-economical one. The study is carried out in simulation using stochastic cellular automata representing a community of 50'000 individuals. The selection of the tested individuals is carried out based on a contact tracing strategy focused on the closer contacts.

Keywords COVID-19 · Mathematical modelling · Small-world network · Simulations
1 Introduction

Since the start of the COVID-19 epidemic, many researchers and governments have studied the use of different strategies to ensure health safety while trying to lower the social costs associated to these measures [21]. In this regard, the use of total lockdowns is currently seen as a last resort, backed by studies showing their harm not only to economy [9] but also to mental health [18,13, 3]. Generally, efficient strategies can be described as the ones that allow the containment (or total eradication if possible) of the epidemic while maximizing the social, economical and psychological conditions of the citizens [22].

To achieve such results it is important to be able to apply focused measures [12]. Following this idea, several actions have been proposed during the last months. The use of tests able to identify infected individuals (symptomatic or not) has allowed the implementation of strategies like test and trace, allowing more pro-active measures to trace the source of infection and isolate potentially infected individuals. This approach has proven to be very effective in some countries [11]. However, the effectiveness of these measures has widely varied depending on the testing infrastructures and the testing capabilities of the countries [20,6].

A second important factor when speaking about control measures is the timing of their application with respect to the evolution of the epidemic. The application of early measures has been a vital factor to keep the epidemic under control in the case of the first wave of COVID-19 [19] and various studies have correlated the success of certain strategies based to the time of application [14, 4,8,6].

In this note we reproduce, through mathematical simulations, the effects of test and trace policies for a same population in function of the number of tests and of the timing at which the policy is initiated.

2 Methodology

The simulations are based on a graph-based cellular automata model with a small-world network structure. This type of model allows to simulate the state of each individual of the studied population [10]. Also, these models allow to evaluate the effect of super-spreaders and to take into account the heterogeneity of the population by representing the contacts as links of the graph and their weight as indicator of the closeness between individuals. In this paper, the model used assumes a SIR configuration, where each individual belongs to one of the three states: Susceptible, Infected, or Removed. The evolution between these states is stochastic, in order to reproduce the high variability in the different steps of the virus. A detailed description of the model used for the simulation is reported in [16].

The parameters of the model have been chosen and tuned in order to obtain an equivalent to a basic reproductive ratio $R_0 = 2$. The value chosen
aims at reproducing the spread of the COVID-19 when only very basic social distancing measures are adopted [7,17].

The mathematical model assumes that an average value of 20% of new infected individuals are symptomatic and self-report their infected state before recovery or death. This value estimates that a high percentage of infected is asymptomatic [15] and that not all symptomatic individuals communicate their state.

The control action evaluated in this paper is the well-known test and trace strategy. The strategy focuses on tracing and testing a high number of close contacts (up to 25) for each known positive case. The quarantine policy is performed as a result of the outcome of the tests, isolating the 5 closest individuals of each individual with positive test for 14 days. This action is based on the CDC recommended measures [1].

Initial conditions, i.e. which individuals are initially infected, are stochastically generated in each simulation. Each simulation assumes that 0.05% of the population is initially infected. It is also assumed that not all connections between individuals are known in the search of closed contacts and that an average of 10% of contacts is completely unknown.

To study the variation with respect to the number of tests, we assume a testing capacity within the range of 0.1% up to 0.5% of the population daily tested. The upper limit is obtained based on the values reported by South Korea or USA in December 2020 [2].

3 Results

The simulations are carried out for a closed population of 50'000 individuals. We study two cases: the variation in the number of tests and the variation at the time of application of the measures.

3.1 Variation in the number of tests

Figure 1 shows the evolution of active cases during a time span of 300 days. The depicted data correspond to the averaged results of 100 simulations performed for each scenario. In each simulation, the initially infected individuals and the structure of the network are randomly generated. This plot shows the great difference in effectiveness when the number of daily tests decreases to 100 (0.02% of the population). In Fig. 2 the total number of cases presents even more clearly the difference in the containment of the virus as the number of available tests varies.

The evolution of the number of people in quarantine is depicted in Fig. 3. It is worth to note that the use of more tests, which provides a lower number of cases, does not require a higher number of quarantined individuals as the spread of the virus is never out of control.
3.2 Delay on the application of measures

In this subsection we compare the evolution of the epidemic when the same measures (same strategy and testing capacity) are applied with different time delays. Simulations consider the same number of available tests, 250 per day (0.5% of the population), a number of tests that in the first subsection has been proven to be very effective. With respect to the timing of application,
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Fig. 3 Evolution of the number of people in quarantine.

Fig. 4 Evolution of the performance of the strategy with respect to the number of tests.

The scenarios go from no delay of action up to 50 days of delay w.r.t. to the appearance of the first infected individual.

In Fig. 5 we can observe the evolution in the number of active cases for the different scenarios. It can be seen that in the case of 30 days of delay the peak of active cases already surpasses the 500 infected individuals and it stays around that level for more than 100 days. The evolution of the total number of cases is depicted in Fig. 6.

Figure 7 shows the temporal evolution of the number of people in quarantine for the different cases. This plot shows the great number of people that needs to be quarantined after a late reaction despite the targeted approach of the strategy used.
4 Discussion

The results shown in Fig. 1 and Fig. 2 depict the high non-linearity in the performance of a strategy like test and trace. While the outcomes of the simulations between 150 and 250 tests (0.3% and 0.5% of the population, respectively) are almost identical, a reduction to 100 or 50 tests (0.2% − 0.1%)
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Fig. 7  Evolution of the number of people in quarantine.

Fig. 8  Evolution of the performance of the strategy with respect to the delay in the application of the measures.

suddenly degenerates to a situation that is out of control. This high sensitivity to the number of tests and to the tracing capacity could explain the high variance observed in the outcome of similar strategies in different countries. Fig. 4 provides a more comprehensive picture of this variation in performance with respect to the number of tests. The same figure also suggests that measures aiming at improving the test capacity are cost-effective only up to a "threshold level" (in this case 150 tests/day) after which extra investments have a limited effect on the epidemic.

Regarding the timing of application, Fig. 5 shows that even with a high number of daily tests an excessive delay in the application of measures can dramatically affect the situation during various months. The previous subsection
showed that 250 daily tests for the simulated conditions provided very good results and that a high efficiency in the control actions was already reached by 150 tests per day. However, even with this high margin in the testing capacity, Fig. 5 reveals that if the delay is superior to 20 days, the peak of active cases remains at more than 500 cases for more than 150 days, providing a total number of cases several times higher. This breakout point is clear in Fig. 8 where all 3 indicators drastically increase after this point. As mentioned before, the delay is computed starting from the moment the first infected case appears in the population. Of course in several real-world scenarios it is unrealistic to have no delays, as decision makers must have the time to realize the situation, decide and communicate the policy to follow, and organize the logistics to implement it. However, this analysis gives a quantitative measure of the importance of making these operations as fast as possible and, whenever possible, to anticipate them before the actual outbreak, as every single day of delay counts.

Another important aspect that can be deduced from the simulations is that more testing does not necessarily imply more people in quarantine. In fact, the number of individuals in quarantine is much more influenced by the number of infected individuals than by the number of daily tests. Accordingly, testing more does not only imply to control better the epidemic, but also to limit the damage of the epidemic on the social and economical life of citizens.

Regarding the numerical simulations performed in this paper, it must be mentioned that the model used simplifies the period of incubation of the virus with respect to more complex models and considers a time-invariant topology of the network. However, we believe that the graph-based network structure and the stochasticity of the model provide a realistic outcome and account for the high variability in the spreading and impact of the epidemic.

5 Conclusions

This short note suggests two very important facts: i) widespread testing does not only greatly reduce the evolution of the epidemic but also the social and economical costs (number of people in quarantine at each instant), and ii) the timing of application of the testing policy is as important as the policy itself. We believe that these results can be of help to decision makers to support larger investments in terms of testing facilities and to understand the importance of fast actions.

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