Considering network interventions

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One of the greatest challenges to emerge from the COVID-19 pandemic is the need to develop new economic policies that steer nations safely between the Scylla of exponentially increasing infection rates and the Charybdis of a severe economic downturn. The obvious solution to curtail the rapidly increasing rate of COVID-19 infection is "lockdown"—government sanctions that limit the physical mobility of citizens within a city, region, or entire nation. However, strict lockdown policies can severely impact a wide range of economic sectors (1). Moreover, these policies can have compounding social consequences, disproportionately impacting vulnerable populations and women (2). The other side of the dilemma is equally treacherous. If public policies are unable to prevent the unchecked growth of the pandemic, the disease will spread aggressively, ultimately undercutting the stability of an even wider range of economic sectors and resulting in graver social consequences (3). In PNAS, Nishi et al. (4) bravely propose a solution to this critical dilemma. Using the lockdown model as their baseline measure for an effective disease prevention strategy, Nishi et al. (4) use computational "experiments" to explore the effectiveness of adopting public health policies that might sustain normal economic activity—in schools, offices, restaurants, and supermarkets—while steering clear of the deadly consequences of unchecked disease transmission.

The Network Approach to Lockdown

The core idea behind their approach is to focus on social networks. Social contact networks are the primary pathways for the transmission of COVID-19 (5). There are several different kinds of interpersonal networks—such as intimate partner networks, family and friend networks, acquaintanceship and coworker networks, and causal/accidental contact networks (e.g., in a grocery store or a subway). All of these networks can be pathways for COVID-19 transmission. However, the likelihood of transmission increases with the duration and closeness of contact. Building on well-established social networks research on the differences between "strong ties" (family and close friends) and "weak ties" (casual contacts) (6), Nishi et al. (4) develop a three-tier system for classifying social networks as 1) family ties, 2) nonfamily close ties, and 3) weak ties. This three-tier division of network ties is grounded by the second feature of their model (4): the locations in which people interact.

Past sociological research on behavior spread has found that family ties and close friendship ties may both be considered strong ties (6, 7). However, it is different for diseases. The "strength" of the transmission networks for COVID-19 is defined by physical colocation. For instance, people who live in the same house typically share many compounding factors that increase the likelihood of transmission (e.g., duration of time in the same room, touching common surfaces, shared air circulation system, etc.).

With these considerations in mind, Nishi et al. (4) explore how changes in people's patterns of colocation can alter the resulting disease transmission networks. For instance, if Bob and Mary happen to work in the same office, this creates a weak transmission tie between them. If Mary happens to contract COVID-19, she can infect Bob without realizing it. However, if Bob's and Mary's employer decides to divide the employees' work hours into "shifts," such that Bob works from 9 to 12 and Mary works from 1 to 4, then even though Bob and Mary still work in the same physical office, they will never be colocated. This removes the transmission tie between Bob and Mary, which would not only protect Bob from a potential COVID-19 infection, but would also protect the people in Bob's household; in turn, it would protect the people with whom the members of Bob's household interact (at work, at school, and so forth).

This is the core idea behind the strategy of Nishi et al. (4). By reducing the number of colocations that people have, Nishi et al. (4) aim to effectively "disconnect"

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Author contributions: D.C. wrote the paper.

The author declares no competing interest.

See companion article, "Network interventions for managing the COVID-19 pandemic and sustaining economy," 10.1073/pnas.2014297117.

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First published December 21, 2020.

the contact network that links some groups of people to other groups of people (8). (More on the idea "groups" is given below.) The upshot is that if COVID-19 happens to catch on in one group, there will be no opportunities for the virus to spread to people in other groups. The downside of this approach is that any outbreak in one group would likely spread to all of the people in that group. However, the key to the approach of Nishi et al. (4) is that a minioutbreak in one group (say Mary's group) would never reach the rest of the population.

As with any public policy strategy, there are important ethical and practical issues to consider. Just because a strategy is shown to be effective computationally does not mean that people will abide by it, nor does it mean that it is a morally justifiable solution, particularly if it puts some members of the population at disproportionately greater risk. The proposal of Nishi et al. (4) carefully navigates this terrain by focusing on a random approach to dividing people into groups.

Nishi et al. (4) propose two implementation plans for their social network strategy. The first plan is to divide the population into shifts (e.g., Bob works 9 AM to 12 PM, and Mary works 1 PM to 4 PM). There are several subtleties to consider with this grouping strategy. First, suppose that assignments into groups are made randomly. Suppose further that Bob and Mary happen to be friends. Because they no longer encounter each other at work, they may seek other opportunities for colocated interaction. In that case, a transmission tie would still exist between them despite the new workplace policy.

Second, there is a large number of formal and informal possibilities for colocation. For instance, even if Bob and Mary are not friends, they may, by virtue of geography, be colocated in several settings (8, 9). Perhaps they both live nearby their place of employment and thus, both shop at the same corner store. While the new workplace grouping policy may ensure that Bob and Mary are never colocated in the office at the same time, they may nevertheless happen to show up in the grocery store at the same time. In that case, a transmission tie would still exist between them.

There is yet another wrinkle. Even if Bob and Mary do not shop for groceries at the same time, Bob's domestic partner and Mary's domestic partner may. As a result, Mary's domestic partner, who is highly likely to be infected by Mary in the home, may be colocated in the grocery store with Bob's domestic partner. This would create a transmission link between Mary's partner and Bob's partner, resulting in a chain of transmission leading from Mary (to Mary's partner to Bob's partner) to Bob. The important point for the strategy of Nishi et al. (4) is that unless Mary's partner and Bob's partner happen to be located in different groups (for all common settings for colocation, including workplace, grocery shopping, post office, etc.), there would still be a transmission link between Mary's group and Bob's group.

To address these possibilities, Nishi et al. (4) propose a second plan, which is a lot like the idea of an overflow parking lot. If too many people decide to make a run to the grocery store at the same time, the overflow sensor will redirect them to an alternative store (within a reasonable radius) that has fewer people. In this plan, everyone can shop at the same time, but since people are going to different stores, there would not be transmission links between everyone. People in the same store (or office, school building, or post office, etc.) would still share transmission ties. However, because the numbers of people in each location would be reduced, this plan would limit the problem of high contact rates during "peak hours" of activity.

Taking all of these factors into account, the highest impact policy solution proposed by Nishi et al. (4) is a clever combination of both plans. They first divide people into shifts and then segment those shifts into a discrete set of overflow locations. The upshot of this strategy is that if there was a COVID-19 occurrence in Mary's group, the number of people reached by the infection would be so small and well contained that an outbreak in the general population would be prevented. This is an ideal outcome for any disease prevention strategy. The key question for the proposal of Nishi et al. (4)—and the most important point for evaluating the effectiveness of their solution—is whether people's social networks will, in fact, conform to the groupings that Nishi et al. (4) propose.

Using the lockdown model as their baseline measure for an effective disease prevention strategy, Nishi et al. use computational "experiments" to explore the effectiveness of adopting public health policies that might sustain normal economic activity—in schools, offices, restaurants, and supermarkets—while steering clear of the deadly consequences of unchecked disease transmission.

Decades ago, networks research found that it only takes a few weak ties to enable an infectious disease to jump from one group to another (6, 10). Suppose, for example, that one person goes to the grocery store during a time that was not assigned to him or her or another person goes to a post office he or she can walk to (rather than the suggested overflow post office that requires driving). These behaviors create new links across putatively distinct groups. A small number of these weak ties can allow the disease to "escape" from an infected group and then jump from group to group, growing into a much larger outbreak. An even bigger concern is travel—including subways, trains, busses, and airplanes—all of which establish crisscrossing weak ties, well known to be associated with high rates of infectious disease spreading (10, 11).

In epidemiological models, these individual deviations in behavior from the prescribed plan are often represented as "noise." For instance, the model creates a random infection in one group or builds a random tie across groups. This is a reasonable approach to exploring these unpredictable features of social life, and the robustness of the findings of Nishi et al. (4) suggests that a sufficiently well-designed plan may be effective (within appropriate bounds) for limiting the dangers of the expanding pandemic.

The Challenge of Complexity

However, the greatest challenge for this proposal is not random deviation but systematic resistance. Even in a pandemic, people's conformity to new social behaviors is governed more by the expectations held by the people around them than it is by official policies (12). We have already seen this with the rules regarding face masks and social distancing, which groups of people violated not just out of laziness but also out of principle (e.g., on political grounds). While COVID-19 is a simple contagion that only requires a single weak tie for transmission, convincing people to conform to new social norms is a complex contagion, which requires confirmation from respected peers in order for people to find a new or uncomfortable behavior acceptable (12).

The crux of the proposed policy solution of Nishi et al. (4) is to "rewire" the social network of society by limiting people's opportunities for colocation (8, 9). The core question raised by this approach is whether people will abide this rewiring. An important implication of such a policy is that the only social contacts that people will encounter at work (or in restaurants, etc.) will be the people who are selected for them by the government.

As such, this proposal broaches a new frontier in the social contract. This is a particularly poignant consideration when issues of race and cultural heritage are taken into account. People's social networks are an essential part of their sense of identity, their feelings of belonging, and their emotional well-being (13, 14). Nishi et al. (4) appropriately consider this concern, but their solution raises the related issue of whether intentional groupings (for instance, by ethnicity) might lead to the complementary problem of making a particular subpopulation disproportionately more likely to become infected while creating de facto segregation that would protect other subpopulations.

The proposal of Nishi et al. (4) is an excellent start toward trying to grapple with the complex issues facing an administration hoping to curtail the pandemic. The next iteration of this approach is to appreciate that any policy that expects to rewire citizens' social networks must first consider whether citizens will conform to such a social norm—and whether (and how) they will receive the necessary social confirmation from their peers that would be needed to encourage them to go along with it or whether, as with face masks and vaccination, people's social networks will be the main force blocking it. Ultimately, the effectiveness of any social policy depends on people receiving support for behavior change from the people who are closest to them. Successful network interventions will need to focus on harnessing the strength of those support networks and be cautious about intervention strategies that threaten to dismantle them.

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