A Linked Shared Space Model for COVID-19 Transmission and its Prevention by forming Closed Social Circles

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COVID-19 transmission occurs primarily thorough sneezing (respiratory droplets), physical contact, breathing the same air, and through physical contact with surfaces that have been contaminated by deposited viral particles from sneezes, physical contact or breathed out air. This description helps us understand individual transmission events from one person to another. However, an individual transmission event is not in itself a network of transmission. Each individual in a society has hundreds of opportunities daily to be in contact with other individuals through proximity, breathing the same air, and touching surfaces that other individuals have touched or breathed upon. If transmission through such contact were highly likely then the transmission rate would be many times what is observed. Instead it appears that the transmission rate is low for any single casual event, requiring extensive exposure. What therefore characterizes the transmission process across the population? We propose a concept of "shared space" as a way of thinking about the high likelihood transmission events. In this picture two individuals are likely to transmit one to the other if they regularly or intensively share the same space. This leads us to consider the way transmission occurs as a set of linked shared spaces. Similarly, to prevent transmission, is to have separated islands of socially linked shared spaces—closed "Social Circles". Since there are many contexts in which eliminating contact entirely is impossible, this provides guidance about how to drastically reduce transmission. Validation of this model requires extensive study of individual transmission cases. One indicator that this is the case, is that extensive contact tracing is possible, so that anonymous casual contacts are unlikely to lead to transmission.

As we respond to the challenge of COVID-19, one of the important aspects of the effort is understanding its transmission. How we think about transmission affects both how we model it mathematically and what actions we take to limit transmission both for individuals and for the society. Epidemiological models often assume that each individual has a typical transmission rate that is similar among individuals. Another model is that of network science in which we consider the transmission through a social network that depends on the individual connectivity within the society. In this picture, individuals may have high connectivity or low connectivity. The transmission is dominated by the hubs that have large numbers of contacts. Identifying which individuals are hubs then can serve to provide an opportunity to reduce transmission by targeting those hubs, reducing their individual connectivities. More in detail, mapping the network becomes an important aspect of understanding transmission. Another framework is that of transmission events that occur dynamically. By describing the nature of events in which two individuals transmit from one to the other through, e.g. physical contact. This approach is commonly applicable to sexual disease networks, where there is a discrete transmission event between two individuals.

These concepts are not well applicable to COVID-19 transmission as we understand it today. Transmission occurs through sneezing, physical contact, contact with contaminated surfaces and breathing the same air.* It is therefore more linked to the physical space than a specific contact process. This makes both standard social network structures and specific pairwise individual contacts of limited use in understanding the transmission. It is also well known that transmission events can be highly fat tailed as was found in superspreader events in the exotic meat market in Wuhan, a religious gathering in South Korea, and at a biotech meeting in Boston. Such transmission events are not well described by assuming typical or average individual transmission rates (e.g. Gamma distributions, which have exponential tails, regardless of how skewed they are). Moreover, the low transmission rate relative to the typical number of individuals an individual has proximity to in a single day, indicates that casual contact is not sufficient. Indeed, the success of contact tracing efforts to limit disease spread indicates that treating transmission as low probability individual event and describing the overall probability as an accumulation of such low probability events is not appropriate. Transmission occurs between identified individuals rather than many low probability casual events. Thus statistical models of populations do not capture the key structure of the transmission process. This concept is important enough to describe in a second way: Low probability but significant cumulative probability of casual transmission (well described by a statistical model), is different from no (extremely low) probability for casual transmission and transmission through close contact (poorly described by statistical model as it depends directly on the social network structure which is heterogeneous).

In simple terms, this means that individuals passing by each other in the street doesn't result in transmission. Transmission occurs when an infected individual is in proximity, direct contact, or indirect contact with an uninfected individual over an extended time in the same space, or over multiple times, even when each contact is time limited.

Given these known properties of the COVID-19 transmission a different concept may be appropriate and should be considered. We therefore propose a "Shared Space" transmission framework for considering COVID-19 transmission and identify individuals, events, and the transmission network. Our analysis is consistent with the concept of modularity in

*Caution about contact with feces is also recommended.

networks and systems in general as a means of reducing the impact of harmful propagating events.

The Shared Space model assumes that when an infected individual who regularly, or closely/intensively at a particular extended time event, shares a common space with others, transmission is likely to occur. Note that this is not restricted to pairwise transmission so that a conventional network model may not be appropriate.

SHARED SPACE TRANSMISSION:

In order to construct a map of the potential or actual transmission process, we need to identify individuals, groups, and events, including their distinguishing attributes that lead to single, chain or multiple transmission processes. The dynamics of transmission must also include the history of transmission opportunities over an incubation period. If one transmission event can occur due to conditions that link two individuals, and another occurs afterwards but within the incubation period, a chain of transmission can occur because individuals involved do not recognize they have symptoms, which would motivate them to self-isolate. We identify scenarios for contagion:

1) At home (a single group). While transmission within the home group is highly likely, this is not an extended network so it doesn't lead to extended transmission chains. However, each of the individuals must not have additional shared spaces.
2) People who have two shared space homes, enable a chain of transmission, for example they go from one home to another because they stay at:
   a) their parent home and their spouse home
   b) their spouse and lover home
   c) their roommate home at the location they work, and their parent home
3) Collective or institutional homes allow multiple transmissions. This is not different in principle from usual homes in that an isolated institution will not allow extended transmission, but it leads to extended transmission chains if one individual is infected. Collective homes are vulnerable because preventing infection would require ensuring that none of the individuals have shared spaces with others.
4) Extended time group meetings allow for superspreader events due to multiple transmission that connect individuals that have their own shared spaces at home, offices, etc.
5) Individuals who have multiple close (shared space) contacts: Synchronously or serially. This may be because of
   a) professional activities, i.e. nurses, physical therapists, masseuses, prostitutes etc, and more generally hospitality and service professionals. The extent to which such serial contacts must be close or extended in time is unclear, but if they are frequently transmitting the transmission rate would be much higher.
   b) personal or professional activities that lead to going from meeting to meeting, or though participating in gathering and parties.

The implication of this concept is that vectors of transmission are individuals who have multiple shared spaces. Individuals who share space with only one set of individuals are relatively safe. However, if any one of them has multiple shared spaces, the others are at risk.

DISCUSSION:

To stop the outbreak, we need to identify individuals that share space with multiple individuals. We must select whom we share space with. And those identified individuals must be closed "Social Circles": Groups that do not connect to other groups.

Example 1: When colleges sent their students home, this was an effective way to avoid superspreader events in dormitories, which are collective homes. However, that process connected the shared space among students with the shared space of their parents. This placed both students and parents at risk. It would be much better for students to self-isolate or to occupy a separate space outside their parental home for a period of 14 days until the existence of symptoms can be identified.

This discussion also makes clear that the transmission network includes both personal and professional shared spaces. For institutions and corporations, including hospitals and other medical institutions, it is essential to identify who the employees and residents are connected through by shared spaces in order to understand the risk of transmission.

Example 2: An employee of an institution that provides care to a group of individuals, such as a nursing home, may also have shared space with a spouse or roommate at home. The spouse or roommate, if they work at home, does not lead to connection to other individuals for transmission. However, there will be a high risk of transmission if a roommate also shares space with (a) a lover or (b) is employed at a workplace that includes shared space with others, or (c) has recently or will soon go to a multi-day conference with colleagues. Any of these extends the set of individuals that have linked shared spaces. In order to stop the transmission process the set of individuals that have a linked shared space must form a social island, a closed Social Circle. Employers should develop questionnaires and inquire of employee shared spaces so as to ensure that transmission chains do not extend beyond their employee first contacts. Where this is not the case, they will be well advised to offer alternative accommodations for their employees and make decisions about the roles their employees can serve based upon transmission risk.

The utility of this model of transmission arises because it is impossible to eliminate entirely contact between individuals, and shared space among them. However, by recognizing the network of transmission we can identify which contacts must be eliminated in order to prevent or reduce transmission rates. Even without eliminating all contacts, creating closed Safe Circles should drastically reduce transmission rates. It is important to note that prior contacts occurring within an incubation period must be respected. In areas where active transmission is taking place, it is important to start by imposing as complete an isolation process as possible for 14 days. Subsequent to that isolation period, once infected individuals have been identified, it is possible, taking precautions, to develop increasing sized closed Social Circles.