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A migrant worker outside a dormitory in Singapore — such high-rise sites have seen some of the city's worst clusters of COVID-19.

Cities — try to predict superspreading hotspots for COVID-19

Roland Bouffanais & Sun Sun Lim

Tracking how people move around urban areas can pinpoint where disease might transmit fastest and farthest.

Two months ago in Singapore, walkers, joggers and cyclists in Bishan-Ang Mo Kio Park got a surprise — a robotic dog nipping at their heels. It 'barked' at them to stay metres away from others. No tactic seems too outlandish to deal with the COVID-19 pandemic, which has confined billions of people across the world to their homes.

Now, leaders face a conundrum. Reopen facilities too slowly and prolong hardship, or relax restrictions too quickly and ignite a fresh wave of infections. It's a precarious balancing act. The spread of the SARS-CoV-2 virus can be lightning fast and surreptitious. Superspreading sites — where transmission rates are particularly high — can seed tens or hundreds of cases in days.

For example, last month in Beijing, more than 100 cases were tied to one central food market. Cases have surged in apartment blocks in Melbourne, Australia, triggering a fresh lockdown. In May, more than 200 visitors to Seoul's Itaewon nightclub district became infected.

Governments need tools to assess where the riskiest spots in the riskiest places — cities — might be. Big-data studies of human mobility need to be combined with epidemiological models. And the demographic profiles of people coming into contact at any particular location need to be included.

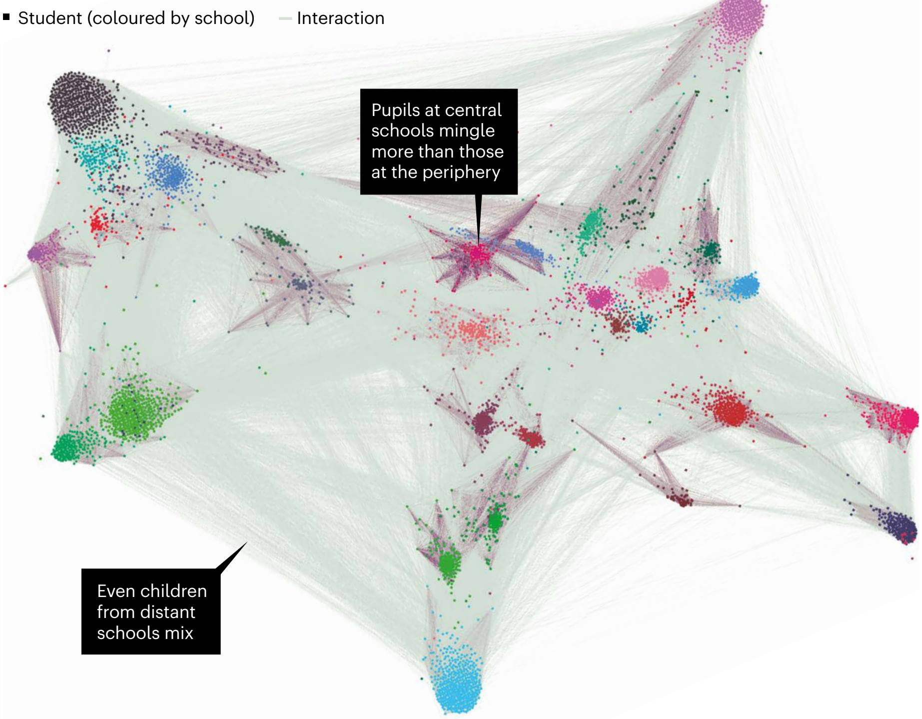
Close contact

Researchers understand reasonably well that the disease spreads in places where people spend a lot of time face-to-face, such as care homes, hospitals and restaurants[1–3]. Duration of contact, physical proximity and environmental conditions are the main factors. A fleeting encounter with a passer-by on a path is less likely to result in infection than sitting inside next to a person for 20 minutes. Cramped and poorly ventilated indoor spaces are riskier than expansive outdoor ones.

But many more factors have a role, and these are less understood. Some people do not comply with safety measures, for many reasons. Inebriated diners and excitable theme-park visitors, for example, are unlikely to stay metres apart. The degree of mixing differs. The same group of students might sit together in a classroom every day. But children in secondary school mingle with more students and teachers than do those in preschools. And schoolchildren meet widely outside school hours, when commuting, playing sports or attending tutorials (see 'School networks').

SCHOOL NETWORKS

The movements of almost 6,000 schoolchildren across 33 schools tracked over one day (12 July 2016) in Singapore reveal how the students mingled. They spent most of their time in close proximity to their classmates. But they also came into contact with many more people on public transport, in shopping centres and at after-school activities.



SOURCE: R. BOUFFANAIS/S. S. LIM

The details of such everyday interactions are documented too poorly to model risk factors accurately, as experiences with COVID-19 show. Resorts, conferences, religious gatherings and workplaces have all experienced notable outbreaks. In late May, the South Korean city of Bucheon saw hundreds of cases at an e-commerce distribution warehouse. Meat-packing plants in the United States, Canada, Germany, Spain, Ireland, Brazil and Australia have seen surges. Some of the first superspreading events took place on cruise ships — more than 700 people on board the British-registered *Diamond Princess* tested positive in February.

Care homes with many elderly or immune-compromised residents are especially vulnerable. Long-term care facilities have seen almost 60% of the COVID-19 deaths in Washington state, 45% in Sweden and almost one-third in the United Kingdom. Health-care workers are, of course, highly exposed, with more than 92,000 infections and more than 500 deaths among US health-care personnel alone.

Groups living in close proximity are at risk. For example, almost 93% of Singapore's COVID-19 cases in the first 48 days occurred in dormitories for migrant workers (see 'Housing risks'). Each block houses thousands of workers, sometimes 20 per room. Cases there skyrocketed to more than 40,000, or more than 12% of that population, compared with fewer than 2,600 infections elsewhere in the compact city-state of 5.3 million people.

On 18 June, 700 residents of a tower block in the German city of Göttingen were quarantined, with some 100 cases detected. Some residents clashed with police as they tried to flee. Hong Kong saw something similar in 2003, at the start of its epidemic of severe acute respiratory syndrome (SARS) — more than 300 people living in block E of Amoy Gardens became infected, almost overnight.

> **"Very little is known about how the disease spreads in dynamic spaces."**

Indeed, many of the same factors that lie behind superspreading of COVID-19 today — high population densities, poor accommodation and narrow streets — contributed to some of the worst pockets of past outbreaks, including those of cholera, typhoid, tuberculosis and SARS (see 'Cleaner cities').

Much stands to be learnt. For example, after SARS in 2003, Hong Kong adopted 'healthy building' reforms across ventilation, drainage, refuse and building maintenance[4]. Air purification systems were installed in hospitals. A research programme looked into the impacts of the built environment on health. Studies showed that residents were affected by, for example, the orientation of the building they lived in, the height of their apartment above ground and their immediate outdoor environment[4].

Flows of people

But people don't stay put. Cities are bustling places — open systems in which many people from many different locations come and go. An urbanite might cross paths with thousands of people each day, during long commutes in packed trains and buses and in stations in rush hour[5,6]. Even car drivers encounter lots of people, at petrol stations or while running errands. Any of these interactions could expose them to COVID-19. Yet very little is known about how the disease spreads in dynamic spaces, such as airports, stations, bars, restaurants, cinemas and aeroplanes.

It's clear that long-distance travel extends the reach of an outbreak. Contact tracing tied a nightclub visitor in Seoul's Itaewon district to a staggering 1,300 others — he had travelled 42 kilometres to get there from the city of Yongin, and visited other districts and provinces before testing positive. Air travel spread COVID-19 quickly to the world's most connected metropolises – from Wuhan to Singapore, Hong Kong, London and Milan, or through Europe to New York and Boston.

We don't know how the virus was carried and which measures might have prevented or slowed its transmission. For example, would more mask-wearing, social distancing or cleaning at airports have helped? Or was it the time spent on the plane breathing in others' air or touching surfaces that was crucial? Or did the disease spread in the streets and restaurants after passengers had disembarked? We need to learn more.

Likewise, little is known about how people move through cities. Some municipalities, including Paris, Singapore and Taipei, release real-time data on land transport, including passenger volumes at stops or stations by origin and destination. These data sets are made available to companies, third-party developers and researchers to develop route-planning apps, for example. But most cities don't supply, and might not even collect, such data. They lack the technology and regulatory frameworks needed to share sensitive personal information on where and when someone has travelled. Privacy must be assured.

Also, trip data cannot tell you how much time someone spent in a certain location, or with whom or for how long. Little is known about people entering or leaving a city, including tourists. And detailed information on the locations of COVID-19 cases is largely missing. Some countries have comprehensive test and trace systems; most do not. GPS data from mobile phones have been used in Singapore and South Korea as part of contact tracing, but not in countries such as the United States, where tracing has not happened at scale. Contact-tracing apps and the data they generate are potentially valuable, but surveillance fears, among other concerns, have stymied their adoption.

Modelling flows

A model of disease spread can be built and refined as data and knowledge improve on human flows on the following three levels.

City-wide. A base map is needed to represent the main flows of people throughout a city. This should cover the numbers and timings of people travelling between key sites, such as schools, shopping centres, train stations or care homes. Such data might be drawn from anonymized mobile-phone records or information about trips on public transport – local authorities need to be encouraged to release the information to researchers. Travel into and out of the city should be estimated at major stations or airports, where a high volume of mixing occurs. The availability and quality of data, as well as overcoming privacy concerns, are the main limitations. Individuals in cars are difficult to monitor, for example. The modelling frameworks are well established in the field of transportation and mobility research for planning and development purposes. For example, in 2016 in Singapore, a National Science Experiment tracked the movements of 43,000 students from 128 schools using a custom-built pocket sensor.

Bottlenecks. The mixing indoors at transport hubs, airports, large shopping centres or libraries should be added to the base map, for example by using Wi-Fi signals from smart devices[5]. Locations can then be ranked according to the intensity of incoming and outgoing flows and the diversity of journey origins and destinations[7]. Typical flow patterns can be extrapolated from previous studies. For example, shopping centres and parks are known to be busiest at weekends, train stations at rush hours on weekdays, schools at the beginning and end of the day and airports during long weekends. The proximities of people and the durations of interaction can be estimated, with assumptions such as geographer Waldo Tobler's 'first law of geography' – "everything is related to everything else, but near things are more related than distant things". More accurate data should then be sought at key points of convergence, such as stadiums, bars, nightclubs and theatres, and the model refined accordingly.

Epidemiology. All known factors affecting disease transmission, in terms of demographics and human interactions, should be included across a representative range of human activities. For example, preschoolers mingling in playgrounds, co-workers interacting in factories and offices or elderly residents shopping and socializing. Environmental factors must also be considered, such as risk of

Cleaner cities

How changes to the built environment have thwarted infection.

Underground sewers and pipes led to straighter and wider streets in London, after a severe cholera outbreak was linked to raw sewage in drinking water in the 1850s.

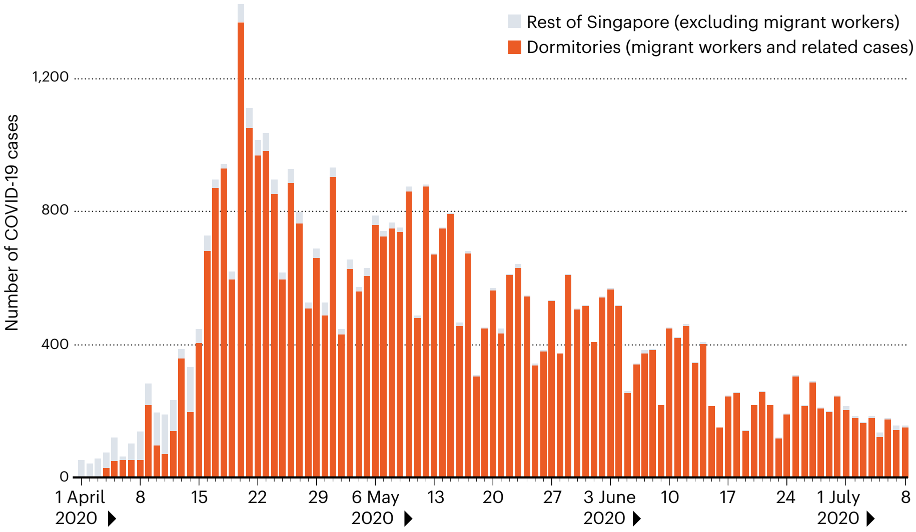
Wipe-down surfaces made homes easier to clean after 'germ theory' arrived in the nineteenth century. Dusty draperies made way for tile and linoleum.

Bright light and fresh air were championed by modernist architects to promote health. People with tuberculosis were put in airy sanatoriums with whitewashed walls, large windows and balconies. Old tenements were torn down to avoid contagion. And green spaces, such as New York's Central Park, were protected as urban 'lungs'.

Medicines such as vaccines, antibiotics and antiviral drugs now deflect attention from the state of our streets. Yet poor people in urban settings still experience ill health in overcrowded and cramped housing. Diseases such as malaria are spreading fast in rapidly developing urban fringes in Africa. Severe acute respiratory syndrome (SARS) and COVID-19 highlight the risks of outbreaks in densely populated and high-throughput locations.

HOUSING RISKS

Almost 95% of Singapore's cases of COVID-19 have occurred in dormitories that house migrant workers. So far, more than 42,000 workers have been infected — 12.5% of the people living in these high-density blocks. In the rest of the population of around 5.3 million people, just 2,600 cases have been recorded.



SOURCE: SINGAPORE MINISTRY OF HEALTH

EDGAR SU/REUTERS

A robot dog reminds park users in Singapore to stay apart.

infection in an outdoor stadium versus gyms, hair salons and theatres. Such knowledge is rapidly evolving for SARS-CoV-2. Where there are gaps, information on other viral diseases with similar transmission modes (such as rubella, SARS, pertussis, smallpox and influenza) can inform preliminary strategies.

By combining all these insights, governments will be better able to anticipate superspreading locations and target precautionary measures, such as delaying reopening businesses, quarantining arrivals, tightening crowd control and intensifying cleaning and disinfection in particular places.

Next steps

Funding agencies should support accelerated studies of human movement and interactions in key superspreading locations such as transport hubs. Scientists need to rank superspreading potential and compute the effect of measures such as social distancing or mask-wearing. For example, might primary schools with a small catchment area reopen at full capacity if all students and educators wear a mask? What about secondary schools, which have a more diverse student body that is likely to engage in riskier behaviours, such as dating or drug-taking?

Urban analysts and modellers need to understand the dynamics of face-to-face interactions, networks and crowd mixing. Key questions include: how often are we in close contact with people? For how long? What places in our normal daily movements put us in close contact with the greatest number of new people?

Wider sources of data on human mobility need to be tapped[8]. For example, 'smart' cities such as Singapore have networks of cameras on lamp posts to track traffic flows. These could be reconfigured to track the density and mixing of people (anonymously). Built-in barometers in some smartphones could follow vertical movement, such as the flows of workers in office towers and the circulation of people in high-rise shopping centres and residences. Data from geolocation and contact-tracing apps can provide insight into where people go, with whom they interact, what they do and even how they feel[9]. For instance, the GeoCoV19 study analysed 524 million geolocated tweets in 62 languages, posted over 90 days since 1 February to evaluate public sentiments, emergency needs, knowledge gaps and misinformation trails[10]. Such data would have to be anonymized to protect privacy.

Governments should use these data and models to hone their public-health strategies. More effective targeting of measures will help to avoid 'virus fatigue' among the public and help education and the economy by allowing places to minimize the risks of some kinds of reopening.

Urban planners should also re-examine disease spread in the built environment. For example, they might integrate safe-distancing measures into street and building designs. More walkways and vertical parks might separate flows of people, as at the Kampung Admiralty development in Singapore (see go.nature.com/2z9pxmz). The health impacts of dense residential blocks, such as those for migrant workers, should be examined.

Longer term, the design and management of cities should be altered to minimize the spread of disease and the chance of future pandemics. Failing that, we'll have to rely on packs of robotic dogs to shepherd us.

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