A Three-dimensional, Spatially-Explicit Agent-based Model to Evaluate the Effectiveness of Non-pharmacological Interventions of COVID-19 in Hong Kong Using Secondary Data

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BACKGROUND

- The coronavirus disease 2019 (COVID-19) is an ongoing pandemic across the world imposing heavy, multifaceted burdens on public health as well as the society.
- The unique physical and social environments of Hong Kong (HK) related to COVID-19 include:
  1) the earlier histories of infectious diseases such as the Hong Kong Flu (1968–1969), the Avian Influenza (1997-2002), and the SARS outbreak (2002-2004);
  2) a thriving East Asian metropolis with extensive global networks and connections;
  3) a most densely populated city in the world; and
  4) unwillingness to follow the government's guidelines and non-pharmacological interventions (NPIs) among the public (Wan, 2020; Yu et al., 2021).
- During the pandemic, a volume of literature has examined various aspects of COVID-19 using SEIR (Susceptible, Exposed, Infectious, and Recovered) simulation modeling.
- The literature also listed several challenges to build a realistic, reliable simulation model:
  1) aspatial vs. spatial: since the COVID-19 spreads through people's contacts, spatial models would be more realistic;
  2) model granularity: modelling and identifying vulnerable populations/areas at a smaller level would be more impactful to support decision-making processes;
  3) data availability: except the issues from privacy and computing capacity, obtaining individual-level, primary data (e.g., clinical data, mobile-phone data, personal transport data) is challenging for researchers; and
  4) urban density: there is no study to our knowledge that takes urban density into modelling in a three-dimensional (3D) setting.

PROJECT OBJECTIVES

- By creating an 3D, spatially-explicit agent-based model (ABM) using secondary data in Hong Kong, this study aims to
  1) simulating the COVID-19 spread patterns in Hong Kong;
  2) identify the most vulnerable areas/populations to COVID-19; and
  3) evaluate the effectiveness of common NPIs to control COVID-19.

MATERIALS and METHODS

Data

- The datasets and their sources for this research include:
  1) the 2011 Travel Characteristics Survey (TCS): the largest, territory-wide household interview survey for transport studies decennially collected by the HK Transport Department. We used each respondent's age, gender, occupation, trip starting/ending time, locations of trip origins/destinations (street block (SB) identifiers (IDs)), and trip purposes (Fig 1);
  2) the GeoCommunity Database (iGeoCom): the points of interest (POIs) data for shopping malls, supermarkets, and wet markets were obtained from the HK Lands Department's iGeoCom;
  3) The HK Lands DepartmentGeo-Reference Database (iG-1000): the locations of residential building and their heights, and the locations of workplaces were retrieved from iG-1000.
  4) DATA.GOV.HK: the POIs of restaurants and educational institutions were collected from the HK government's largest data portal; and
  5) COVID-19 Situation Dashboard: the details of confirmed cases were available from HK Department of Health's COVID-19 data dashboard.

Steps for Model Granularity

- The smallest geographic information of the 2011 TCS is a unique ID of SBs. To make our model more spatial and granular, a set of geospatial data processing was conducted:
  1) each individual from the 2011 TCS was allocated to a random residential building in one's own SB (Fig 2A);
  2) we also allocate each individual to different floors at a residential building using the building height information from the Geo-Reference Database (iG-1000). This novel process of 3D environment prevents a potential overestimation of contacts and transmission when modelled in a 2D setting;
  3) each individual's trip destinations were assigned to random POIs based on one's own occupation, trip purposes, and SBIDs in the 2011 TCS. For example, a random work building location filtered by the occupation type in a SB was assigned as a destination if s/he commutes to the SB for work; and
  4) As a proxy of a destination's area/size, a radius-long buffer from a building's centroid was made for each destination in order to minimize the issue of overlapping agents (Fig 2B).

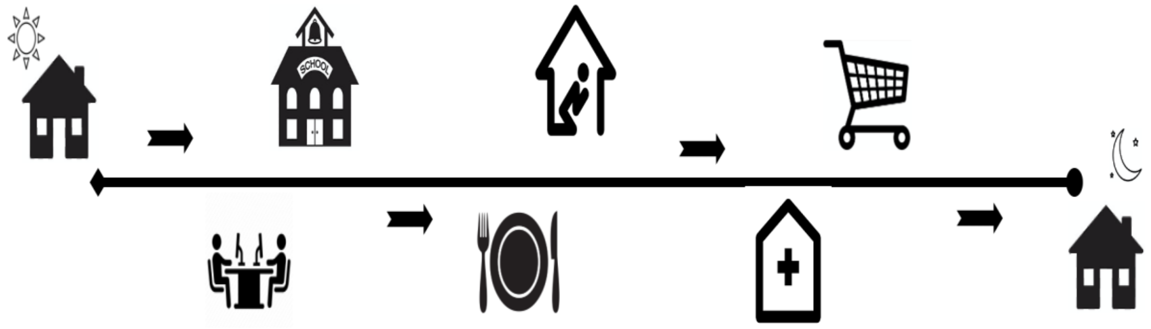

Fig 1. A Conceptual Model of Daily Mobility Patterns from the 2011 TCS

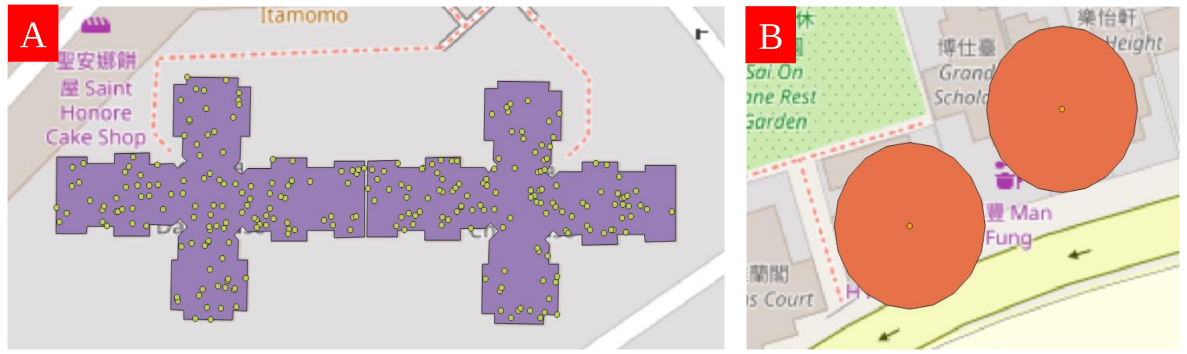

Fig 2. Examples of Geospatial Data Processing for Model Granularity

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MATERIALS and METHODS (cont'd)

Agent-based Model (ABM)

- An ABM is a computational model to simulate the behaviors and interactions of individual agents for understanding a system as well as an impact from a counterfactual event (Bonabeau, 2002).
- Our model simulates both daily mobility patterns and the COVID-19 infection patterns:
  1) as an individual has trips following the 2011 TCS, s/he could be exposed to COVID-19 by proximity to infected persons;
  2) an SEIQR (Susceptible-Exposed-Infectious-Quarantine-Recovered) model was adopted for COVID-19 infection stage (Fig 3);
  3) using a formula of droplet exposure (Sun and John, 2020), the COVID-19 transmission probability by proximity was calculated when an individual is exposed to an infected person(s) within 2 meters.
- Software used: AnyLogic v.8.5 (for ABM) and QGIS (for mapping)

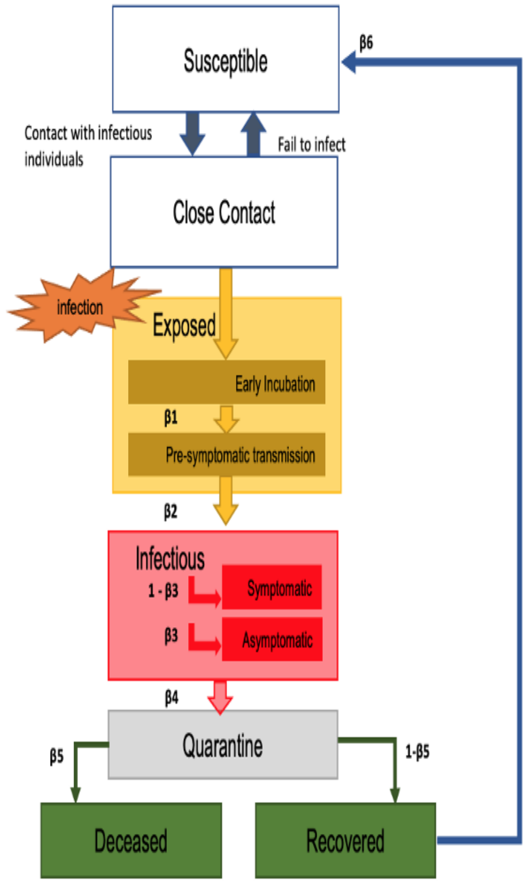


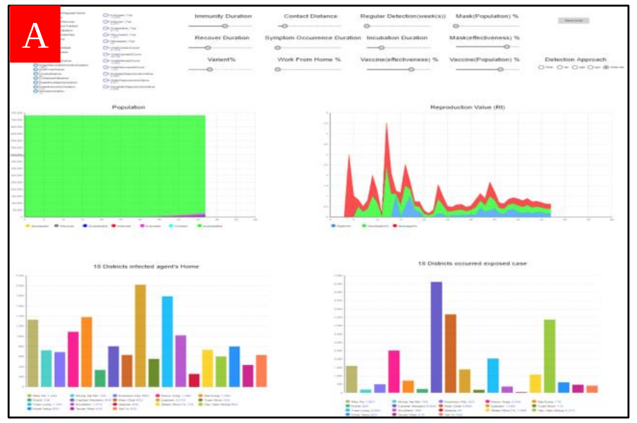
Fig 3. A Conceptual SEIQR Model

- Model details

1) total population: 740,000 (for a faster model with sufficient potential contacts among population)
2) number of POIs: 248,682
3) model period: 1 year (Feb. 1, 2020 - Jan. 31, 2021)
4) incubation period: 5 days
5) β1 = from early incubation to pre-symptomatic transmission: 2 days
6) β2 = from pre-symptomatic transmission to symptom appear: 3 days
7) β3 = Asymptomatic rate: 0.315
8) β4 = The period from illness onset to Quarantine: 1 day (symptomatic) or 2 days (non-symptom)
9) β5 = Fatality Rate: 0.0182
10) β6 = Immunity Duration: 210 days
11) seed patients: 14 persons (the actual records from Jan. 21 to Feb. 14, 2020)

(Dan et al. 2021; HK Department of Health, 2021; Johansson et al. 2021; Lauer et al., 2020)

A



B

	Infected per 100,000 populations	Deceased per 100,000 populations
Model 0 (no intervention)	11,903	214
Model 1 (WFH)	4,814	94
Model 2 (Face mask)	40	0.5
Model 3 (M1 & M2)	5	0.1
Model 4 (Vaccination)	8	0

C

	M0 (no intervention)	M1 (WFH)	M2 (Face mask)	M3 (M1 & M2)	M4 (vaccination)
1	Central Western	Yau Tsim Mong	Wan Chai	Yau Tsim Mong	Yau Tsim Mong
2	Yau Tsim Mong	Wan Chai	Yau Tsim Mong	Wan Chai	Wan Chai
3	Wan Chai	Central Western	Southern	Wong Tai Sin	Southern
4	Kwun Tong	Kwun Tong	Kowloon City	Sha Tin	Kwai Tsing
5	Eastern	Sha Tin	Tai Po	Tai Po	Sha Tin
6	Sha Tin	Yuen Long	Central Western	Kowloon City	North
7	Sham Shui Po	Sham Shui Po	Kwai Tsing	Kwun Tong	Islands
8	Yuen Long	Eastern	Eastern	Sai Kung	Wong Tai Sin
9	Kowloon City	Sai Kung	Kwun Tong	North	Kowloon City
10	Kwai Tsing	Kwai Tsing	Sham Shui Po	Central Western	Kwun Tong
11	Tsuen Wan	Tsuen Wan	Sha Tin	Eastern	Sai Kung
12	Tuen Mum	Southern	Wong Tai Sin	Tuen Mum	Central Western
13	Sai Kung	Tai Po	Sai Kung	Yuen Long	Eastern
14	Tai Po	Tuen Mum	North	Southern	Tuen Mum
15	Southern	Kowloon City	Tuen Mum	Islands	Yuen Long
16	Wong Tai Sin	North	Yuen Long	Sham Shui Po	Sham Shui Po
17	North	Wong Tai Sin	Islands	Kwai Tsing	Tsuen Wan
18	Islands	Islands	Tsuen Wan	Tsuen Wan	Tai Po

D

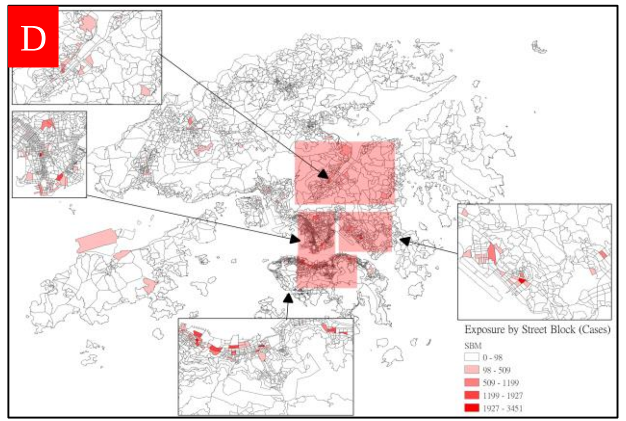


Fig 4. A Set of Images from the ABM: (A) a Screenshot of the Model; (B) a Summary of Estimated Infected and Deceased Cases; (C) A Summary by the District Level; and (D) a Map of Infected Cases Using the Results and QGIS.

RESULTS

- A total of five models were built and evaluated: Model 0 (without any intervention), Model 1 (60% population work from home), Model 2 (50% population wear face masks with an 80% of protection level), Model 3 (implementing both Models 1 and 2), and Model 4 (50% population were fully vaccinated with a 70% effectiveness). Models 3 and 4 were found most effective to control the COVID-19 compared with Models 0-2 (Fig 4B).
- The total estimated infection was higher in the working population (20-49 years old).
- The estimated durations of the pandemic vary from approximately 1 month (Models 3 and 4) to 6-9 months (Models 0-2).
- Among the 18 districts, Central Western, Yau Tsim Mong and Wan Chai were among the top 3 high-risk districts to occur transmissions and infections in all models (Fig 4C).
- Many SBs in Central Western, Yau Tsim Mong, Wan Chai, and Kwun Tong were identified as high-risk areas for transmissions and infections (Fig 4C).

CONCLUSIONS

- ABM with secondary data could be an alternative decision support tool for COVID-19 control and prevention.
- As seen in Model 3, multiple, hybrid NPIs may be recommended.
- Vaccination itself may be insufficient to achieve the "zero-infection" goal in Hong Kong (Model 4).
- Areas with high population density, entertainment venues, restaurants and bars, and high mixture land use (residential and commercial) should be controlled more effectively for preventing transmission and infection.
- Elaborated disease control and prevention measures by population groups may be recommended. For example, encouraging vaccination among younger and working population may be effective for COVID-19 control.
- A few limitations of this research include:
  1) validation: validation challenge may arise since it aims to predict future developments in COVID-19 *ex ante*;
  2) secondary data may be outdated; and
  3) cross-boundary and interdisciplinary collaboration and communication may be required to interpret analysis results and to use them as evidence in future decision-making processes (Lorig et al, 2021).

REFERENCES

1. Bonabeau, Eric. "Agent-based modeling: Methods and techniques for simulating human systems." Proceedings of the national academy of sciences 99.suppl 3 (2002): 7280-7287.
2. Dan, Jennifer M., et al. "Immunological memory to SARS-CoV-2 assessed for up to 8 months after infection." Science 371.6529 (2021).
3. Johansson, Michael A., et al. "SARS-CoV-2 transmission from people without COVID-19 symptoms." JAMA network open 4.1 (2021): e2035057-e2035057.
4. Lauer, S. A., Grantz, K. H., Bi, Q., Jones, F. K., Zheng, Q., Meredith, H. R., Azman, A. S., Reich, N. G., & Lessler, J. (2020). The incubation period of coronavirus disease 2019 (COVID-19) from publicly reported confirmed cases: Estimation and application. Annals of Internal Medicine, 172(9), 577–582.
5. Lorig, F., Johansson, E., & Davidsson, P. (2021). Agent-based Social Simulation of the Covid-19 Pandemic: A Systematic Review. JASSS: Journal of Artificial Societies and Social Simulation, 24(3).
6. Sun, Chanjuan, and Zhiqiang Zhai. "The efficacy of social distance and ventilation effectiveness in preventing COVID-19 transmission." Sustainable cities and society 62 (2020): 102390.
7. Wan, Kin-Man, et al. "Fighting COVID-19 in Hong Kong: The effects of community and social mobilization." World Development 134 (2020): 105055.