

Transportation, germs, culture: a dynamic graph model of COVID-19 outbreak

Xiaofei Yang^{1,2}, Tun Xu^{2,3}, Peng Jia^{2,3}, Han Xia^{3,4}, Li Guo^{2,3,5}, Lei Zhang^{6,7,8,9} Kai Ye^{2,3,5,10, †}

¹School of Computer Science and Technology, Faculty of Electronic and Information Engineering, Xi'an Jiaotong University, Xi'an 710049, China

²MOE Key Lab for Intelligent Networks & Networks Security, Faculty of Electronic and Information Engineering, Xi'an Jiaotong University, Xi'an 710049, China

³School of Automation Science and Engineering, Faculty of Electronic and Information Engineering, Xi'an Jiaotong University, Xi'an, 710049, China

⁴Hugobiotech Co., Ltd., Beijing 102600, China

⁵ The School of Life Science and Technology, Xi'an Jiaotong University, Xi'an 710049, China

⁶China-Australia Joint Research Center for Infectious Diseases, School of Public Health, Xi'an Jiaotong University Health Science Center, Xi'an 710061, China

⁷Melbourne Sexual Health Centre, Alfred Health, Melbourne, VIC 3004, Australia

⁸Central Clinical School, Faculty of Medicine, Nursing and Health Sciences, Monash University, Melbourne, VIC 3004, Australia

⁹Department of Epidemiology and Biostatistics, College of Public Health, Zhengzhou University, Zhengzhou 450001, China

¹⁰Genome Institute, the First Affiliated Hospital of Xi'an Jiaotong University, Xi'an 710061, China

*Correspondence: kaiye@xjtu.edu.cn

The simulation of the length of incubation period

In our model, we simulated the incubation time of infected individuals as a normal distribution, and the parameters are from a recent publication¹. We set the minimal incubation length as 0 day, the maximum incubation length as 24 days, and the mean incubation length as 3 days. The probability distribution of incubation time is as formula (1).

$$p(T) = \begin{cases} 0 & T < 0 \text{ or } T > 24 \\ \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{T-\mu}{\sigma}\right)^2} & 0 \leq T \leq 24 \end{cases} \quad (1)$$

where T is the length of incubation period, μ is equal to 3, and σ is equal to 1.

Spreading probability / virus load calculation

An uninfected person has both a virus load and a spreading probability of zero, whereas infected patients with symptoms have both the virus load and the spreading probability of a designated maximum value. We assume that from an initial infection to a disease onset, the virus load is increasing and the spreading probability is positively correlated with the virus load like formula (2).

$$f(t+1) = \begin{cases} 2 \times f(t) & t < T \\ f(t) - c & t \geq T \end{cases} \quad (2)$$

where T is the length of incubation period, c is a constant number. For an infected person, we simulated the spreading probability or virus load in our model by setting a random number representing the maximum virus load. Specifically, for each infected individual, we generated a random number in range $[0, 1]$ from uniform distribution and set it as the maximal virus load of the individual. We calculated the virus load at each simulation day for each infected individual according to formula (2).

Symptom simulation in our model

For each infected individual, we calculated the virus load at each simulation day according to formula (2). We considered the individual as "symptomatic" when the virus load is larger than

0.562 (1 - 0.438), and the parameters of 0.438 means about 43.8% infections display “symptoms”¹.

Simulaiton of a health person infected process

A healthy individual may be infected by the virus depend on whether he/she had a close contact with an infected individual. In other words, he/she encounters the infected one in the same vehicle or confined space (parameters listed in Table S1 and S2). Once he/she has contact with an infected person, the probability of infection is the product of spreading probability of the infected individual and the infection probability, as formula (3).

$$p = p'_s \times p_I \quad (3)$$

where p'_s is the spreading probability positively correlated to the virus load and p_I is the infection probability setting as 0.1 according to the Chinese CDC news (https://m.sohu.com/a/369727830_120354834, Accessed on Feb. 31, 2020).

Supplementary Tables.

Table S1. Population and public transportation passengers

City	Population (thousand)	Passages of public transportation per day (thousand)		
		Taxi	Bus	Subway/Metro/Light rail
Paris	2,240	1,740	2,540	3,702
Tokyo	12,790	8,441	2,992	21,922
Singapore	5,607	785	3,947	3,123
Wuhan	11,080	860	3,920	4,050
Los Angeles	3,981	318	767	1,355
Yinchuan	1,990	326	687	---

Note: The population of Paris, Singapore, Tokyo, Wuhan, Los Angles, and Yinchuan are from

<https://en.wikipedia.org/wiki/Paris>, <https://en.wikipedia.org/wiki/Singapore> . Accessed on Feb. 20, 2020.

<https://en.wikipedia.org/wiki/Tokyo>, <https://en.wikipedia.org/wiki/Wuhan>.

https://en.wikipedia.org/wiki/Los_Angeles, and <https://en.wikipedia.org/wiki/Yinchuan>, respectively. The public transportation passengers of Paris, Singapore, Tokyo, Wuhan, Los Angeles, and Yinchuan are from <https://www.statista.com/statistics/612773/paris-public-transport-users-by-transit-type/>, <https://data.gov.sg/dataset/public-transport-utilisation-average-public-transport-ridership>, <https://www.toukei.metro.tokyo.lg.jp/tnenkan/2015/tn15q3e004.htm>, http://xxgk.mot.gov.cn/jigou/zhghs/202001/t20200120_3326622.html, <https://www.apta.com/wp-content/uploads/Resources/resources/statistics/Documents/FactBook/2018-APTA-Fact-Book.pdf>, and http://xxgk.mot.gov.cn/jigou/zhghs/202001/t20200120_3326622.html respectively. All these websites are accessed at Accessed on Feb. 20, 2020.

Table S2. Important parameters used in our model.

Parameters	default values	reference
mean incubation periods	3.00	
max incubation periods	24.00	
min incubation periods	0.00	1
patient with fever probability	0.4380	
patient with severe probability	0.1500	
patient with RNA detectable probability	0.9000	NA
fatality rate without any treatment	0.0500	NA
fatality rate with treatment	0.0100	NA
subway close contact count	5	NA
bus close contact count	5	NA
taxi close contact count	2	NA
subway passenger count	1,000	NA
bus passenger count	40	NA
taxi passenger count	3	NA
public area close contact count	10	NA
hospital close contact count	20	NA

Note: We set the incubation period of a patient is a random value generated from a gaussian distribution with mean 3, standard deviation 1.

Reference

1. Guan WJ, Ni ZY, Hu Y, et al. Clinical Characteristics of Coronavirus Disease 2019 in China. *N Engl J Med* 2020.