



Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.



Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv



Lockdown, one, two, none, or smart. Modeling containing covid-19 infection. A conceptual model

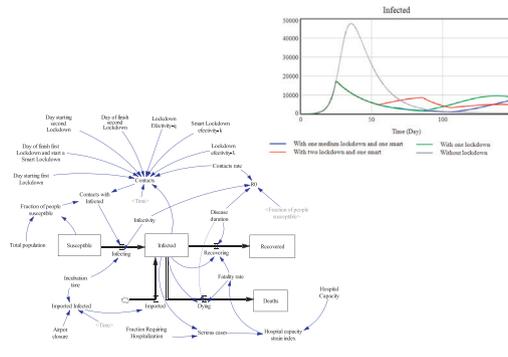
Danny Ibarra-Vega

IRACAS-International Research Center for Applied Complexity Sciences, Colombia

HIGHLIGHTS

- Using piecewise functions, it was possible to model the quarantines or lockdowns.
- Quarantine periods must be very cautious as they could shift the contagion over time.
- The model can be applied in several cities to identify the appropriate quarantines.
- A System Dynamics model of the COVID-19 outbreak, and quarantine periods is presented.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
 Received 17 April 2020
 Received in revised form 20 April 2020
 Accepted 21 April 2020
 Available online 22 April 2020

Keywords:
 COVID 19
 Mathematical modeling
 Lockdown
 System dynamics
 Epidemic

ABSTRACT

A mathematical model has been created with the Systems Dynamics methodology. It is based on a SIR model, with the addition of auxiliary and state variables that represent hospital capacity, contacts, contacts with infected, deaths, giving, as a result, a model of four stock variables. Similarly, using piecewise functions, it was possible to model the “quarantines” or lockdowns, and the effectiveness of reduction in the contacts, Results show the decrease in infected people due to the quarantines. The model was simulated for a population of 100,000. The simulations show trends of infections that could occur in three different scenarios: A) one extended lockdown (60 days), B) two medium lockdowns of 30 days, with a 30-day smart lockdown space, and C) an initial 40-day lockdown and then a 30-day smart lockdown. All the lockdowns start on day 25 after the first reported infection. The model presents a compact structure of broad understanding and successful capture of a COVID-19 outbreak and therefore provides an overview to improve knowledge of outbreak trends and quarantine effectiveness in reducing infection.

© 2020 Elsevier B.V. All rights reserved.

1. Introduction

The 2019–2020 coronavirus disease pandemic is a pandemic started by an outbreak that emerged in late 2019 (COVID-19), caused by the coronavirus-2 virus of the severe acute respiratory syndrome (SARS-CoV-2). It was first identified in December 2019 in Wuhan City

(Chang et al., 2020; Liu et al., 2020). To April 17, 2020, there are about 2,200,000 confirmed cases worldwide (CSSE, 2020). This virus in different cities has presented a value of R_0 (Reproductive number of): 2.2 and 3.5 (Liu et al., 2020). This epidemic has a high rate of spread and a high case fatality rate (Wang et al., 2020).

To prevent the spread of the virus, governments have imposed travel restrictions, confinements, event cancellations, and the closure of establishments and quarantines as described in (Zhu et al., 2020). These

E-mail address: dwbarrave@unal.edu.co.

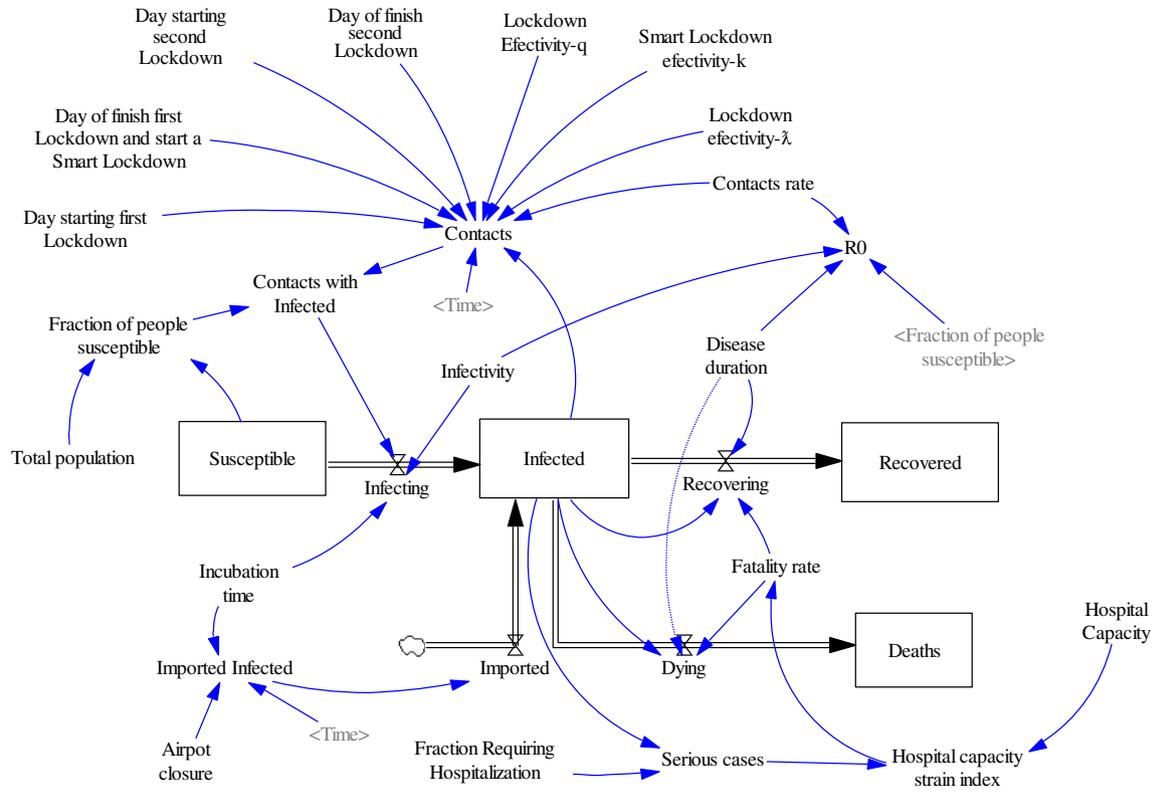


Fig. 1. Stock and flows diagram.

restrictive measures have focused mainly on trying to flatten the epidemic curve (Tobias, 2020).

In this article, a Systems Dynamics model has been developed, this methodology is widely known to model and simulate epidemics, such as Ebola, MERS, and other infectious diseases (SDS, 2020). With this model, different quarantine periods were simulated and evaluated, and it was possible to see the effectiveness in reducing contacts and deaths.

2. The model

The Stock and Flows diagram for the COVID-19 epidemic is presented in Fig. 1. The model was elaborated with the Systems Dynamics methodology, following to Sterman (2000) and is composed of four stock variables: the susceptible, infected, recovered, and deaths. Similarly, piecewise functions were included to represent the different quarantine scenarios. The model also presents auxiliary variables and parameters that were constructed from bibliographic references or some estimated, as shown in the Table 1. For the simulation of the model, a time limit of 150 days was taken into account, and the

integration method was the RK-4 established in the Vensim Ple software (see Tables 2 and 3).

From the Stock and Flows diagram, it is possible to obtain the mathematical model (Complete model and notation in Appendix 1) that represents the studied problem, as shown below:

$$\frac{dS}{dt} = -\frac{\beta Ci}{it} \tag{1}$$

$$\frac{dI}{dt} = \frac{\beta C}{it} - \frac{I}{Dd} \cdot (1 - Fr) \tag{2}$$

$$\frac{dR}{dt} = \frac{I}{Dd} \cdot (1 - Fr) \tag{3}$$

$$\frac{dD}{dt} = \frac{I}{Dd} \cdot (Fr) \tag{4}$$

The simulation without any type of intervention (Scenario 0) is presented in Fig. 2, where the typical behavior of an epidemic is presented. Here we start with a daily contact rate of 70 contacts/person and an

Table 1
Initial conditions.

Name	Initial value	Units	Reference
Susceptible	100,000	People	Assumed
Incubation time	5	Days	Wu et al. (2020)
Disease duration	14	Days	Wu et al. (2020)
Fraction requiring hospitalization	13	%	WHO report 73 (2020), Li et al. (2020)
Infectivity	0.025	Dimensionless	Estimated with R0
Contacts rate	70	Contacts/person	Assumed
Hospital capacity	1000	Beds	Assumed
Fatality rate	3	%	WHO report 73 (2020), Wu et al. (2020)

Table 2
Quarantine scenarios.

Scenario	Initial day	Final day	Initial day of second lockdown	Final second lockdown
A. Long lockdown	25	85	–	–
B. Two shorts lockdown and one smart	25	55	85	115
C. One medium lockdown and one smart	25	65	66	106
O. None	–	–	–	–

infectivity rate of 0.025 for an $R_0 = 2.5$. Table 1 shows the initial conditions of the model.

Scenario A is when only an extended lockdown or quarantine is considered, and it is want to try to decrease the contagion curve, this could be useful when the local economy is durable and can withstand a long period of confinement.

Scenario B considers two short lockdowns and a smart lockdown between them, that is, after the end of the first lockdown, another period of equal duration is left, where activities are resumed, but guaranteeing a reduction in daily contacts of at least 50%.

Scenario C represents a first “medium” lockdown of 40 days is implemented. Then a 40-day smart lockdown is opened, guaranteeing in this a limit of contacts of up to 40% of the contacts in ordinary life.

For all initial quarantines, isolation effectiveness of 90% was considered, that is, they reduce contacts by this percentage.

Once the lockdown scenarios were over, a contact restriction of 50% was maintained, to prevent future infection so that it can gradually return to normal activities.

3. Discussions

Fig. 3 shows the comparison of the behavior of the infected with the different quarantines or lockdowns implemented. Suddenly, it could be said that the three types of quarantine proposed are effective in reducing infected concerning the scenario in which there is no quarantine. However, scenario B and scenario C may be the best strategies in which the infected do not collapse hospital capacity. Fig. 4 shows the comparison of the number of deaths that could have in the four proposed scenarios.

A lockdown to prevent the increase of COVID infection must be evaluated for well-defined contexts. It is different from doing a lockdown in Wuhan than Buenos Aires or Bogotá or Madrid, each city has different characteristics, such as the population, economy, transport, and health systems, this changes the levels of contact that a person can have daily. However, it is also necessary to evaluate the lockdown for intermediate and small cities since their economic models could have damages that are almost impossible to repair.

Table 3
Notation and variables.

Types of variable	Variable/parameter	Notation
Auxiliary	Contacts rate	μ
Auxiliary	Fatality rate	Fr
Auxiliary	Hospital capacity strain index	HiC
Parameter	Incubation time	it
Parameter	Disease duration	Dd
Parameter	Fraction requiring hospitalization	Fh
Parameter	Infectivity	β
Parameter	Hospital capacity	HC
Parameter	Lockdown effectivity	λ
Parameter	Smart lockdown effectivity	k
Parameter	Post lockdown effectivity	q
Parameter	Serious cases	SC
Parameter	Hospital capacity	HC
Stock	Susceptible	S
Stock	Infected	I
Stock	Recovered	R
Stock	Deaths	D

Lockdowns are essential to save time and strengthen health systems that can become overloaded. The actual contagion data is limited and short, so it is necessary to prospectively evaluate each measure that public health authorities and governments wish to implement.

Systems Dynamics models seek to guide the understanding of trends behavior, under policies or strategies that are implemented, knowing their structure and the relationships that exist, are not predictive models.

4. Conclusions

Through modeling with Systems Dynamics, successful representation of the coronavirus outbreak was created for a population of 100,000 inhabitants. The mathematical model has a general structure like that of the SIRD model presented by (Fanelli and Piazza, 2020). However, due to the flexibility of the methodology, the effects of implemented quarantines have been modeled, whether they are long quarantines, double quarantines, smart, or combined quarantines.

The recommendation, according to the simulations, is to carry out an extended initial lockdown and then gradually return to activities, controlling social contacts so that at the end of this period should only be a maximum of 40% of the contacts they had before the quarantine.

Quarantine duration times should be very cautious as they could shift the contagion curve over time and generate a spike with a delay time.

CRediT authorship contribution statement

Danny Ibarra-Vega: Writing- original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

Thanks to Robert Eberlein for the Webinar of Modeling the COVID-19 Pandemic: A Primer and Overview, in Isee Systems, and thanks to Tom Fiddaman for the Community Coronavirus Model in Ventana System.

Appendix 1

The Mathematical model.

$$\frac{dS}{dt} = -\frac{\beta Ci}{it}$$

$$\frac{dI}{dt} = \frac{\beta C}{it} - \frac{I}{Dd} \cdot (1 - Fr)$$

$$\frac{dR}{dt} = \frac{I}{Dd} \cdot (1 - Fr)$$

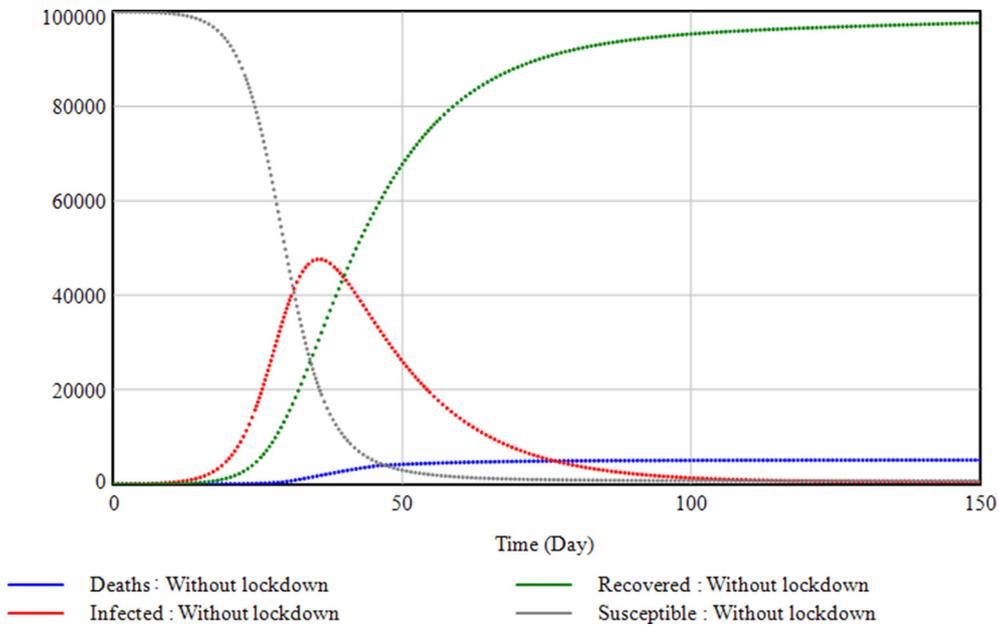


Fig. 2. Scenario without lockdown.

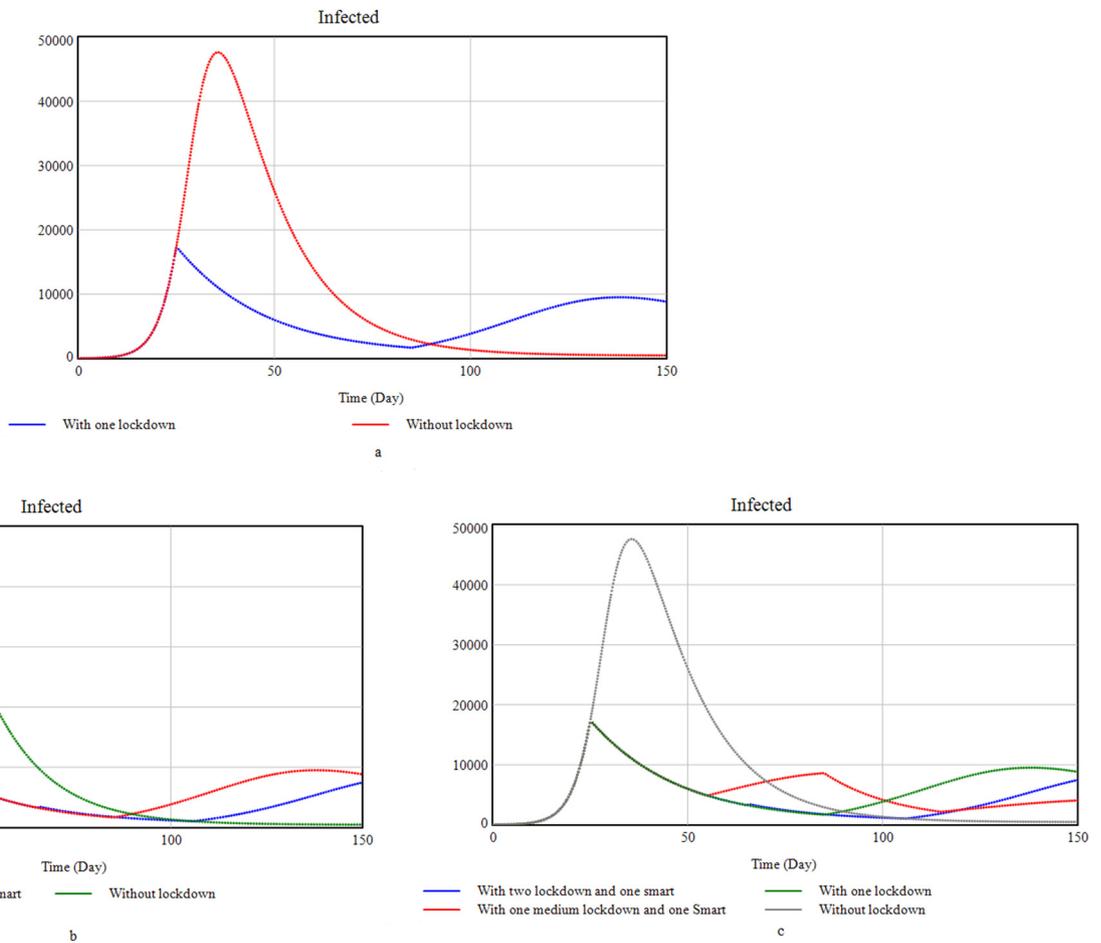


Fig. 3. a.): Scenario A. Behavior of infected in a scenario with a lockdown of 60 days (blue line), red line is the behavior without quarantine. b.) Scenario B. Behavior of infected in a scenario two lockdowns of 30 days and one smart quarantine between them of 30 days (blue line), green line is the behavior without quarantine, and the red line is scenario A. c.) Scenario C. Behavior of those infected in a scenario with an initial “Median” lockdown of 40 days and then a smart lockdown of 40 days (blue line). The red line is scenario B. The green line is scenario A, and The gray line is without lockdown.

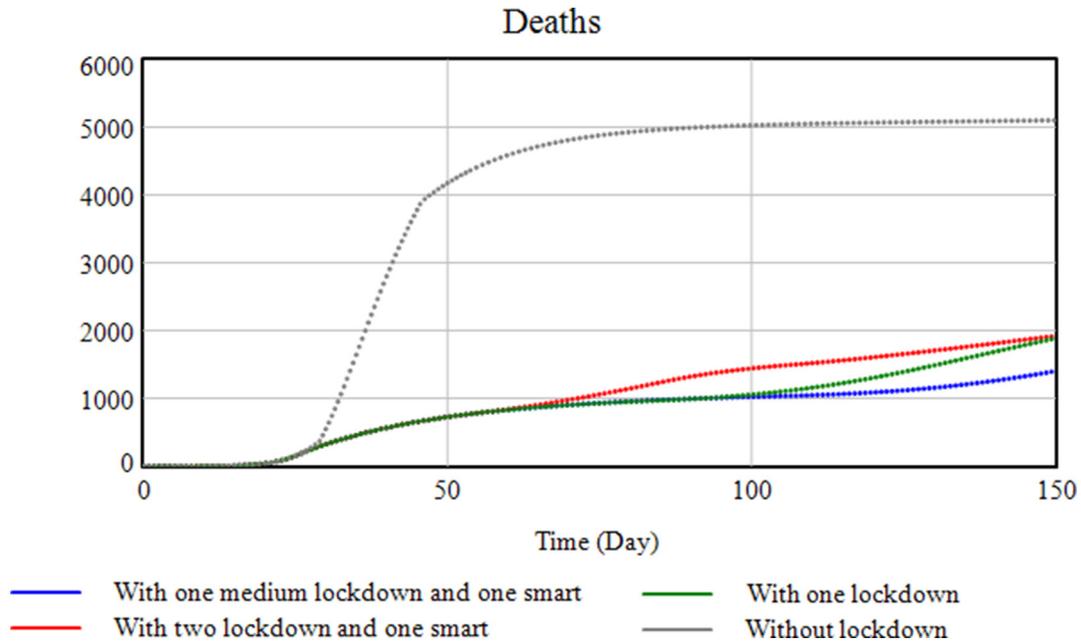


Fig. 4. Comparison of the number of deaths that could be had in the four proposed scenarios.

$$\frac{dD}{dt} = \frac{I}{Dd} \cdot (Fr)$$

Auxiliar equations.

$$Ci = C \cdot F$$

$$HiC = SC / HC$$

$$SC = I \cdot Fh$$

$$Fr = \begin{cases} 3\% & \text{if } HiC < 5 \\ 7\% & \text{if } HiC > 5 < 30 \\ 10\% & \text{if } HiC > 30 \end{cases}$$

Modeling of the quarantine scenarios.

$$C = \begin{cases} I \cdot \mu & \text{if } t < t1, \\ I \cdot \mu \cdot \alpha & \text{if } t \leq t2, \\ I \cdot \mu \cdot k & \text{if } t > t2 < t3, \\ I \cdot \mu \cdot q & \text{if } t > t3 < t4 \end{cases}$$

References

Chang, S.L., Harding, N., Zachreson, C., Cliff, O.M., Prokopenko, M., 2020. Modelling Transmission and Control of the COVID-19 Pandemic in Australia. Preprint. Available at: <https://arxiv.org/abs/2003.10218>.

CSSE (Center for Systems Science and Engineering), 2020. COVID-19 Dashboard. Johns Hopkins University Available at: <https://gisanddata.maps.arcgis.com/apps/opsdashboard/index.html#/bda7594740fd40299423467b48e9ecf6>.

Fanelli, D., Piazza, F., 2020. Analysis and forecast of COVID-19 spreading in China, Italy and France. *Chaos, Solitons Fractals* 134, 109761. <https://doi.org/10.1016/j.chaos.2020.109761>.

Li, Q., Guan, X., Wu, P., Wang, X., Zhou, L., Tong, Y., ... Xing, X., 2020. Early transmission dynamics in Wuhan, China, of novel coronavirus-infected pneumonia. *New England Journal of Medicine* 382, 1199–1207. <https://doi.org/10.1056/NEJMoa2001316>.

Liu, Y., Gayle, A.A., Wilder-Smith, A., Rocklöv, J., 2020. The reproductive number of COVID-19 is higher compared to SARS coronavirus. *Journal of travel medicine* 27 (2). <https://doi.org/10.1093/jtm/taaa021> March.

SDS (System Dynamics Society), 2020. COVID-19 Resource Page. Available at: <https://www.systemdynamics.org/covid-19>.

Sterman, J.D., 2000. *Business Dynamics: Systems Thinking and Modeling for a Complex World*. McGraw-Hill, New York.

Tobias, A., 2020. Evaluation of the lockdowns for the SARS-CoV-2 epidemic in Italy and Spain after one month follow up. *Sci. Total Environ.* 725, 138539. <https://doi.org/10.1016/j.scitotenv.2020.138539> 10 July 2020.

Wang, L., Li, J., Guo, S., et al., 2020. Real-time estimation and prediction of mortality caused by COVID-19 with patient information based algorithm. *Sci. Total Environ.* 727, 138394. <https://doi.org/10.1016/j.scitotenv.2020.138394>.

WHO (World Health Organization), 2020. COVID-19, Report 73. Available at: https://www.who.int/docs/default-source/coronaviruse/situation-reports/20200402-sitrep-73-covid-19.pdf?sfvrsn=5ae25bc7_2.

Wu, J.T., Leung, K., Leung, G.M., 2020. Nowcasting and forecasting the potential domestic and international spread of the 2019-nCoV outbreak originating in Wuhan, China: a modelling study. *The Lancet* 395 (10225), 689–697.

Zhu, W., Li, X., Wu, Y., Xu, C., Li, L., Yang, J., Fang, S., 2020. Community quarantine strategy against coronavirus disease 2019 in Anhui: an evaluation based on trauma center patients. *Int. J. Infect. Dis.* <https://doi.org/10.1016/j.ijid.2020.04.016> In press.