An estimate of the scale of COVID-19 in US in the very early time point: 03/2020

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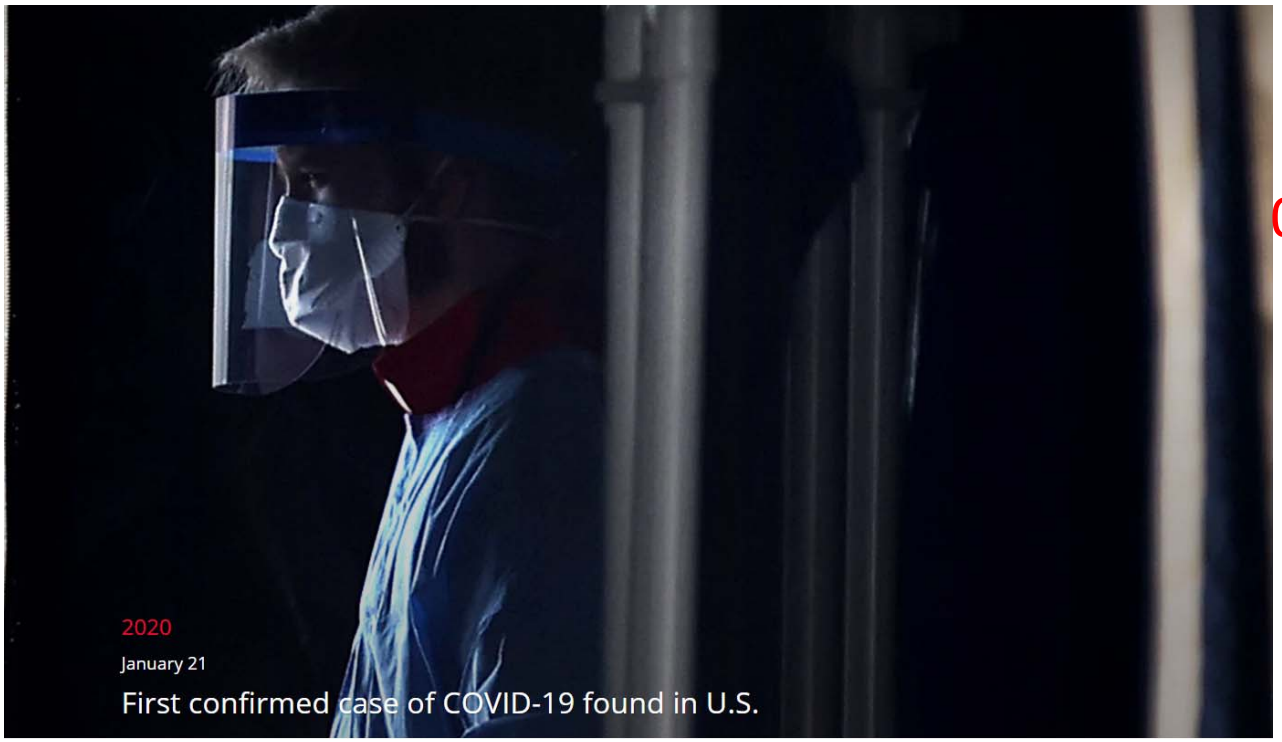
Early 2020 in a rear view



01/21/2020: The 1st COVID-19 case in US

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Early 2020 in a rear view

THE CORONAVIRUS CRISIS

Trump Declares Coronavirus A Public Health Emergency And Restricts Travel From China

January 31, 2020 · 4:42 PM ET

ALLISON AUBREY

On Friday, Health and Human Services Secretary Alex Azar declared the novel coronavirus a public health emergency in the United States. From left, in Washington D.C., are Deputy Secretary of State Stephen Biegun, Acting Transportation Undersecretary Joel Szabat, Azar, and National Institute of Allergy and Infectious Diseases Director Anthony Fauci.

01/31/2020: Air travel from China Shut down

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Early 2020 in a rear view

Washington state man becomes first U.S. death from coronavirus

The CDC says it's responding to "the first possible outbreak" of the virus at a U.S. long-term care facility in Washington.

02/29/2020: The 1st death from COVID-19 in US

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Early 2020 in a rear view

Coronavirus Has Become a Pandemic, W.H.O. Says

But the virus can still be stopped if nations are willing to take aggressive measures, said the organization's director-general.

Give this article

Tedros Adhanom Ghebreyesus, the World Health Organization's director-general, on Wednesday. He called for countries to help protect one another against a common threat. Fabrice Coffrini/Agence

03/11/2020: WHO announce COVID-19 a Pandemic

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Early 2020 in a rear view

Donald Trump declares national emergency over coronavirus pandemic

US cases have spread to 44 states involving at least 1,920 patients and 41 deaths

Trump declares national emergency – follow live updates

Coronavirus: Trump declares national emergency but denies responsibility for any failings – video

03/13/2020: National lockdown due to COVID-19

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What people knew about COVID-19: as of 03/01/2020

- COVID-19
  - Originated from Wuhan, China
  - >90,000 people infected, claimed ~3000 lives
  - Highly Contagious
  - Potential to cause large cluster of infected cases

- Spread to more 60 countries
  - Outbreak in countries with large volume of air traffic with China
    - E.g. south Korea, > 3,000 cases as of 02/29/2020
  - US is among countries with most air traffic with China
    - 20 domestic cases reported till 02/29/2020

That's when we started this study.

First batch of results in 03/06/2020

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Data and parameters (1)

We assume at least 8 cases imported from Wuhan area by 01/31/2020

State	gender	traveled history	Date_return	age	eport	index2	Comments
Washington	M	Wuhan	Jan 15.	30s	Jan. 21	1	
Illinois	F	Wuhan	Jan.13		Jan. 24	2	
California	unkn.	Wuhan		unkn.	Jan. 26	3	
California	unkn.	Wuhan		unkn.	Jan. 26	4	
Arizona	unkn.	Wuhan		unkn.	Jan.26	5	
Illinois	M	NO		60s	Jan. 30	6	Husband of case #2
California	M	Wuhan		adult	Jan. 31	7	
Massachusetts	unkn.	Wuhan		unkn.	Feb. 1	8	
California	F	Wuhan		unkn.	Feb. 2	9	
California	M	NO		57	Feb. 2	10	husband of case #8
California	F	Unknown		57	Feb. 2	11	
Wisconsin	F	Beijing			Feb. 7	12	
California	F	Unknown			Feb. 21	13	
California		Unknown			Feb. 21	14	
Washington		Unknown			Feb. 26	15	
California		NO		65	Feb. 28	16	
Oregon		NO			Feb. 28	17	
Washington		NO			Feb. 29	18	
Washington		NO			Feb. 29	19	
Washington		NO			Feb. 29	20	

Assuming that

Data till 02/29/2020; Information extracted from news release of US CDC

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Air traffic and migration data: Direct airline from Wuhan to U.S.

Table 2. Air traffic statistics from Wuhan Tianhe International Airport (WUH) to United states*.

Year	Month	Airport_from	City_from	Airport_to	City_to	Number of Passengers
2019	8	WUH	Wuhan	JFK	New York	3209
2019	7	WUH	Wuhan	JFK	New York	2417
2018	9	WUH	Wuhan	SFO	San Francisco	3122
2018	10	WUH	Wuhan	SFO	San Francisco	2831
2018	11	WUH	Wuhan	SFO	San Francisco	3233
2018	12	WUH	Wuhan	SFO	San Francisco	3239
2019	1	WUH	Wuhan	SFO	San Francisco	4111
2019	2	WUH	Wuhan	SFO	San Francisco	3318
2019	3	WUH	Wuhan	SFO	San Francisco	3329
2019	4	WUH	Wuhan	SFO	San Francisco	3325
2019	5	WUH	Wuhan	SFO	San Francisco	3506
2019	6	WUH	Wuhan	SFO	San Francisco	3756
2019	7	WUH	Wuhan	SFO	San Francisco	3009
2019	8	WUH	Wuhan	SFO	San Francisco	3647

*: Data from Bureau of Transportation Statistics (https://www.bts.gov/); no data available after 08/2019 as of the manuscript drafting.

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Simulations(1)

- # of COVID-cases in Wuhan was simulated based on a SEIR model

$$\frac{dS(t)}{dt} = -\frac{S(t)}{N_w}(e(t) + Z(t)) + L_{I,W} + L_{C,w}(t) - \frac{S(t)}{N_w}\left(L_{W,I} + L_{w,c}(t)\right)$$

$$\frac{dE}{dt} = \frac{S(t)}{N_w}(e(t) + Z(t)) - \frac{dE(t - D_E)}{dt} - \frac{E(t)}{N_w}\left(L_{W,I} + L_{w,c}(t)\right)$$

$$\frac{dI(t)}{dt} = \frac{dE(t - D_E)}{dt} - \frac{dI(t - D_I)}{dt} - \frac{I(t)}{N_w}\left(L_{W,I} + L_{w,c}(t)\right)$$

$$e(t) \sim Poisson\left(\frac{R_0}{D_I} I_t\right)$$

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Simulations(2)

- # of COVID-cases in US was simulated with a similar SEIR model

$$\frac{dS(t)}{dt} = -\frac{S(t)}{N_{US}} e(t)$$

$$\frac{dE}{dt} = \frac{S(t)}{N_{US}} e(t) - \frac{dE(t - D_E)}{dt} + M_E(t)$$

$$\frac{dI(t)}{dt} = \frac{dE(t - D_E)}{dt} - \frac{dI(t - D_I)}{dt} - \delta(t) + M_I(t)$$

$$e(t) \sim Poisson\left(\frac{R_0}{D_I} I_t\right)$$

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Simulations(3)

- Key measure of the model
  - Total # of imported cases till 01/31/2020 from Wuhan area
  - Minimum: 8 cases, assuming CDC captured all the imported cases
  - Maximum: 16 cases, assuming CDC only captured 50% of imported cases

- In 1000 repeated simulations, we examine how many simulations gives 8-16 imported cases from Wuhan
- To determine the best parameters for the model
  - R0: basic reproduction number;
  - z: zoonotic source that infects individuals each day in Wuhan

- Key outcome
  - # of COVID-19 cases in the US as of 03/01/2020
  - # of COVID-19 cases in the US as of 05/01/2020

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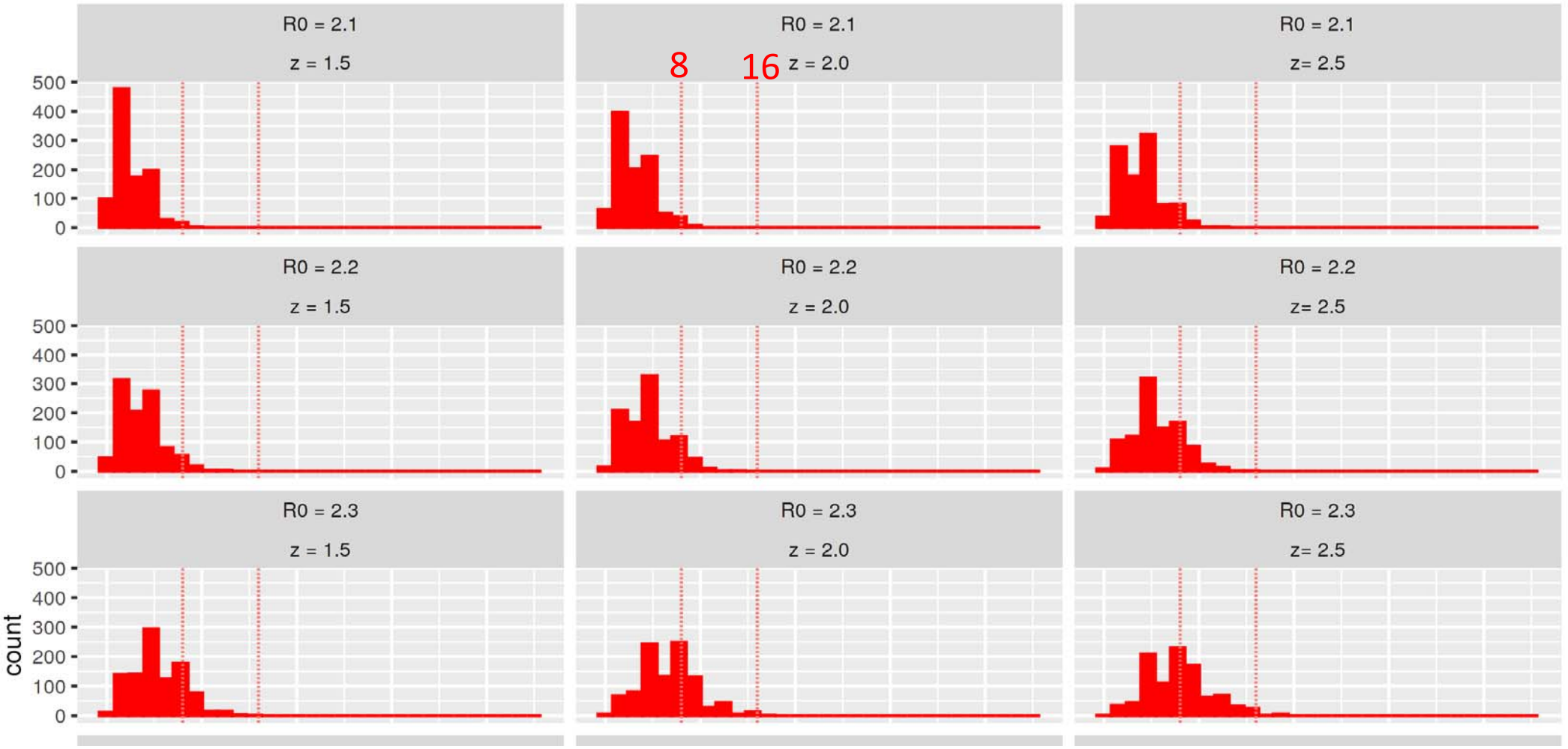
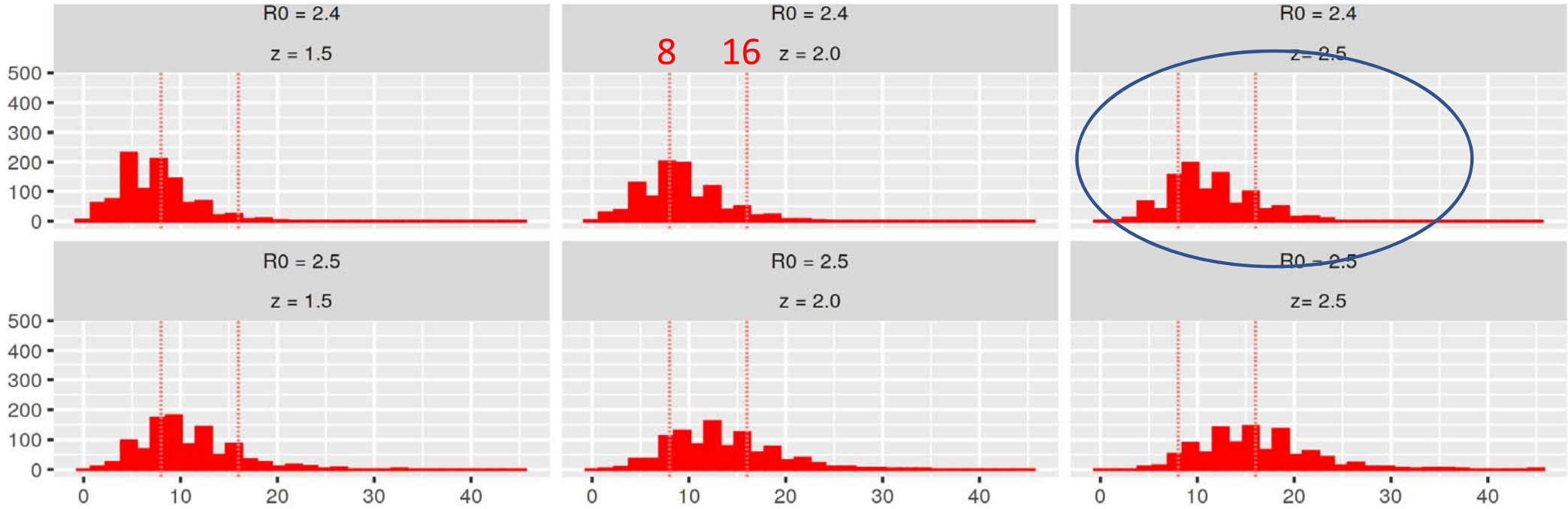


Number of imported COVID-19 cases (as of 01/31/2020) in different simulated scenarios

R0: basic reproduction number; z: zoonotic source that infects individuals each day in Wuhan



Number of imported COVID-19 cases (as of 01/31/2020) in different simulated scenarios

Estimated # of case as of 03/01/2020

R0	Z	Median	Quantile 5%	Quantile 95%
2.3	1.5	4533	444	11316
	2	5066	668	12294
	2.5	5683	1198	13738
2.4	1.5	7975	1680	19370
	2	9001	2299	20403
	2.5	9484	2054	21241
2.5	1.5	13968	3971	30625
	2	14141	3773	31156
	2.5	16250	4187	33055

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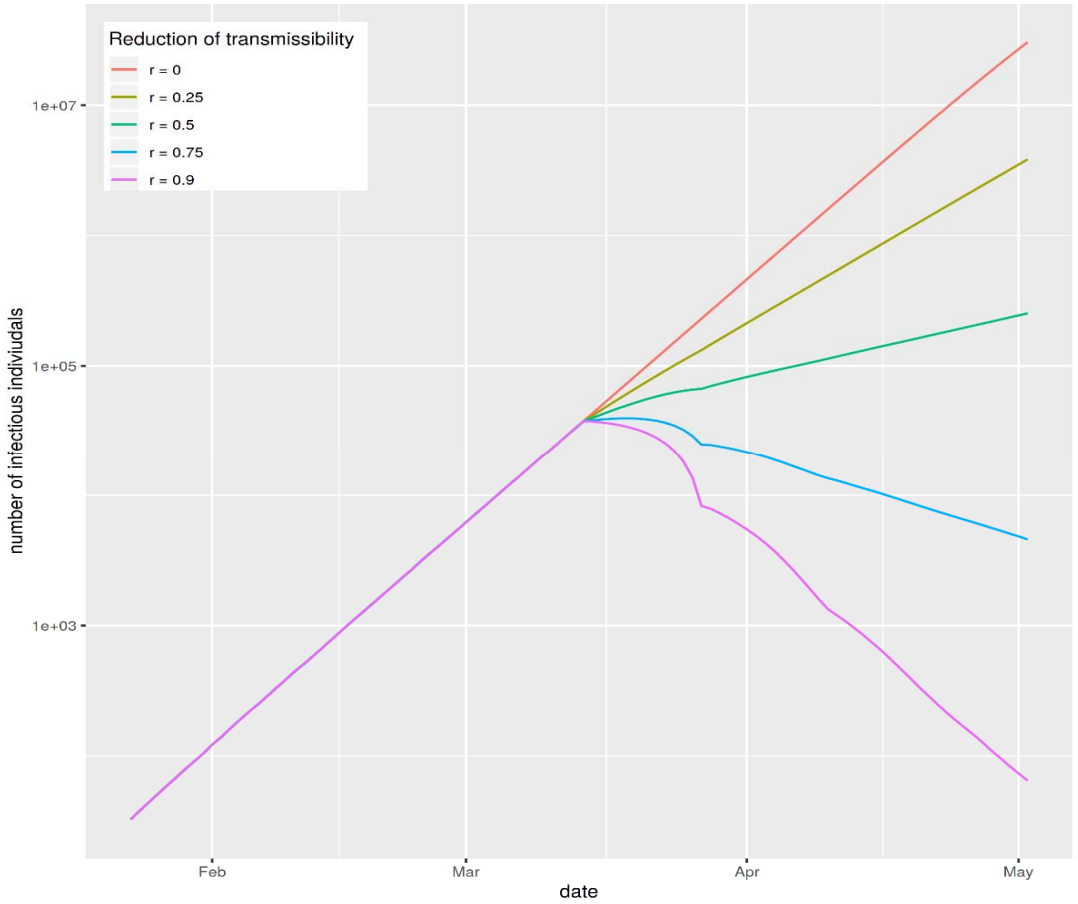
Estimated # of infected individuals: 05/2020



Estimated # of infected individuals, with different proportion of reduction(r) of transmission by the pre

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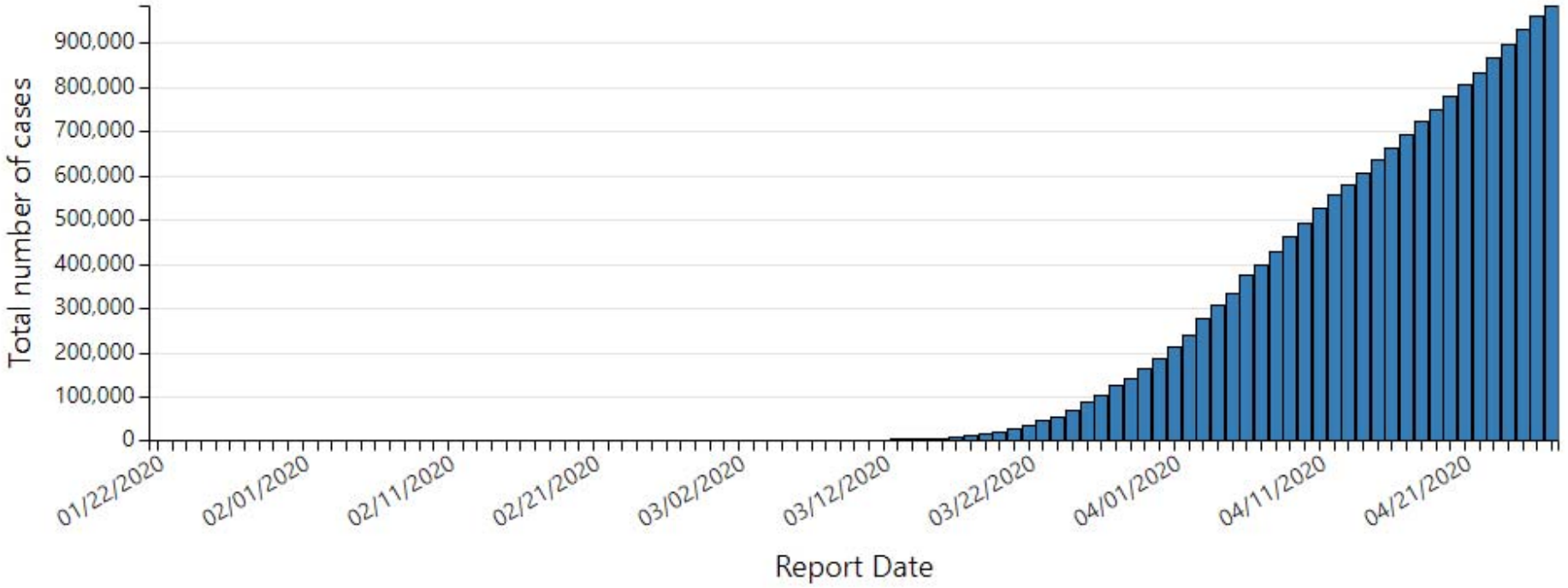
of COVID-19 cases: real-life numbers



From CDC.org

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Conclusions

- The first study that ring the alarm of COVID-19 pandemic in U.S.;
- A very conservative estimate of scope of COVID-19 infection in the U.S.
- There were tens of thousands of individuals infected with the virus as of 03/01/2020;
- Millions of ppl were expected to be infected in the few following months.

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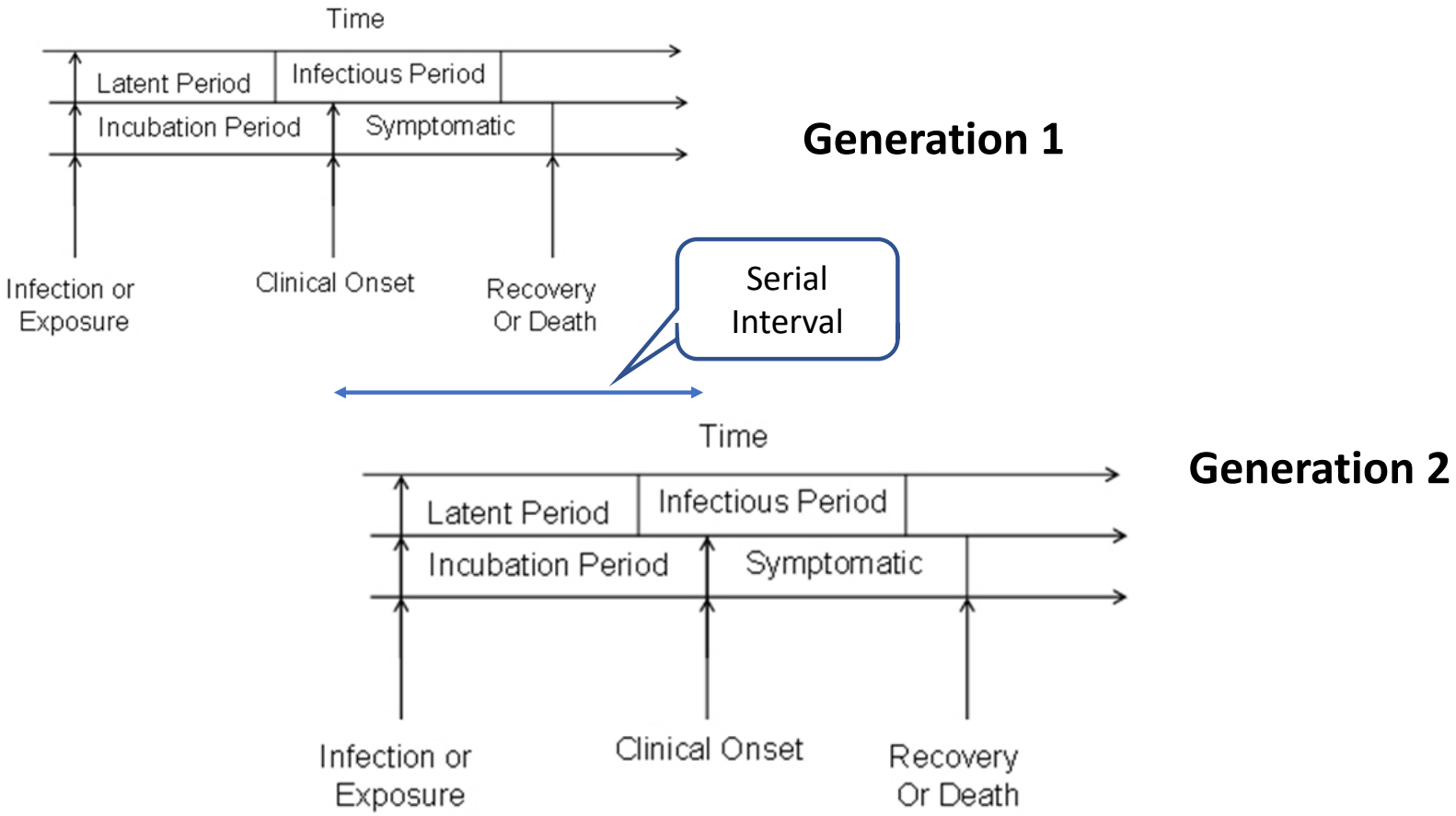
Methods: Assumption

- Parameters of transmission model in US is the same as observed in China;
- Air traffic from Wuhan to US is a random sample of the local population
- Complete traffic shutdown of Wuhan area after the city lockdown
  - Only consider cases imported directly from Wuhan before 01/23/2020
- Ignore potentially imported cases from other areas of China and outside of China (South Korea or Italy, e.g.)
  - To simplify the calculation and be conservative
- After diagnosis, cases in US is no longer infectious
  - Because of the stringent quarantine procedures

Data and parameters (2)



Data and parameters(3)

- Incubation period: From infected to symptom
  - Estimates varies from 4 -6.7 days
  - Set to be 6 in current analysis
- Serial Interval: time from one generation of cases to the next
  - Only 1 report; 7.5 days
- Latent period (sometimes confused with incubation period)
  - Define as from being infected to be infectious
  - No data available; set to be 2 days;
- Infectious period: time interval of being infectious to non-infections

  Infectious period = 2*(serial interval – latent period)
- **R0**: basic reproduction number
  - Estimates varies from 2.1-3.5
  - Examined scenarios from 2.1-2.7

Simulations(1)

- Total population size in Wuhan area: N= 19,000,000
- 1st COVID-19 case in Wuhan area has symptom at 12/01/2019
  - Assume the infection occurs at 11/25/2019 (1 incubation period back)
  - This is the start point of the simulation
- Zoonotic source of the infection
  - 43 early cases were linked to the seafood market (22% of the early reported cases)
  - Shutdown at 1/1/2020
  - We assume this is a constant Zoonotic source that led to 1.5/2/2.5 time of observed infections between 12/01/2019 and 01/01/2020.

Simulations(2)

- We sample randomly from the whole population of Wuhan area
  - based on the # of air traffic passengers
- Any infected individuals in the sampled individuals are counted as imported case
- Assume those imported cases, when infectious, spread the infection until they were diagnosed at given date;