# Covid Act Now Model Reference/Assumptions

Author: Max Henderson, Eric Carlson, and many others
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This document provides details on the model used by Coronavirus Act Now, including how it works, what inputs drive it, and where the data for those inputs is sourced from. The Coronavirus Act Now site was developed to provide decision-makers at the state, local, and federal levels the information they need to advance effective policy responses to COVID-19, including communicating information on the expected impact of implementing social distancing measures to "flatten the curve". **The model and its predictions are not intended to predict the future and should not be used to assume *specific* numbers of cases, hospitalizations, or deaths.**

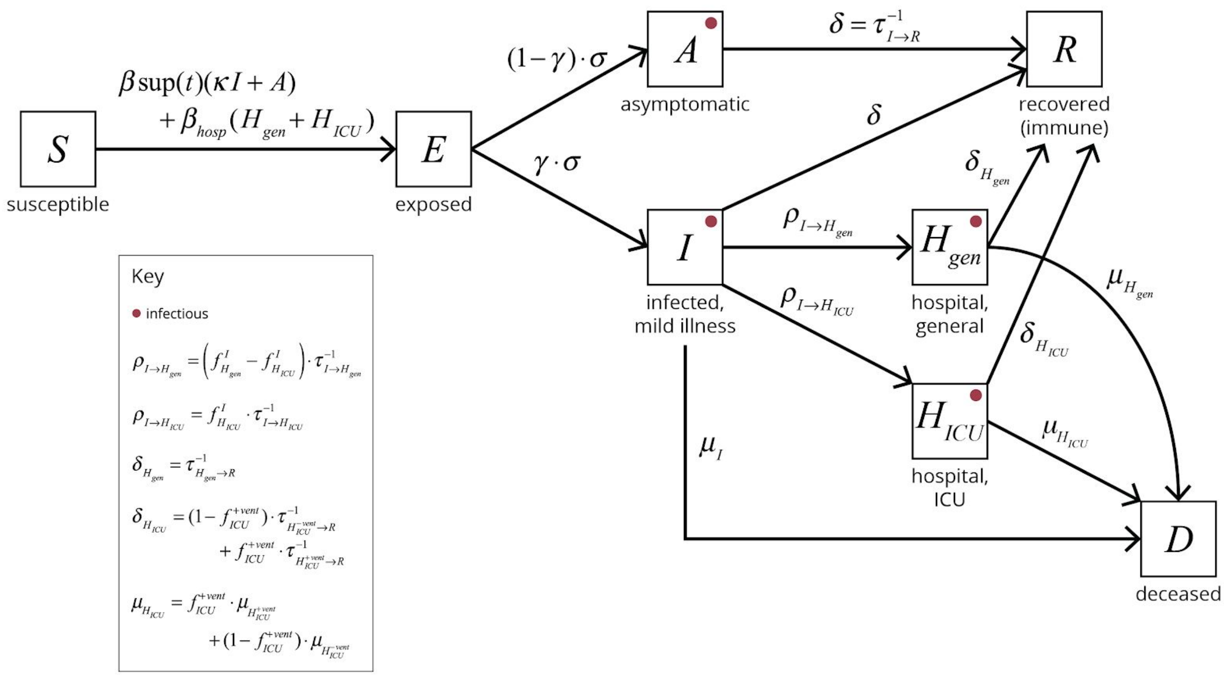
In general, we attempt to follow all the best practices for modeling as published by the UK government COVID task force here.



## How the Model Works

The Coronavirus Act Now model is what is known as an SEIR model, widely used by epidemiologists to model disease outbreaks in both research and practical settings. Our model is adapted from [a model originally developed and built by Dr. Alison Hill][1], a research fellow at Harvard's Program for Evolutionary Dynamics.

An SEIR model attempts to predict how a disease will evolve in a population, by categorizing people as existing in one of various states, and then modeling how they progress through them. Susceptible (S) individuals may become exposed (E) to the virus, then infected (I) at varying levels of disease severity (mild, moderate, or severe, illustrated as $I_1$, $I_2$, and $I_3$ respectively). Infected individuals then either recover (R) or die (D). The figure below describes this process:




**A more detailed explanation of these states and how we treat them:**

- Susceptible: Everyone starts here (except whomever introduces the disease into the population). People move to being "exposed" when they come in contact with the disease. That happens at some rate, which we extrapolate from actual data.

- Exposed: There are various definitions for "exposed," but in our model, people in this state have been infected, but are not yet capable of infecting others, nor do they have symptoms. People stay in this category for 3 days, and then move on to become mild cases ($\text{Infected}_1$).

- Asymptomatic + $\text{Infected}_{\text{mild}}$: These are mild cases. After approximately a week, 4% of the sum of the cases in these two categories worsen, thus requiring hospitalization ($\text{Infected}_2$), while the remaining 96% progress to Recovered.

- <u>Infected$_{hospital}$</u>: These are severe, hospitalized cases, requiring non-ICU treatment. After approximately a week, 30% of these cases worsen, thus requiring ICU/ventilation (Infected$_3$), while the remaining 70% progress to Recovered.

- <u>Infected$_{ICU + ventilator}$</u>: These are critical cases requiring ICU treatment. Our model assumes all deaths must first pass through this category. After approximately a week, 40% of these cases lead to death, while the remaining 60% progress to Recovered.

- <u>Recovered</u>: Those who have had the disease already. We assume that these people acquire long-lasting immunity, though people only remain immune to other coronaviruses for 1-2 years on average, and there is some early evidence to suggest COVID-19 infection may not create immunity in some people.

- <u>Deceased/Dead</u>: Those that have died from the disease. All of these come from ICU cases, and make up about ~0.6% of all infections (2% of all confirmed cases, assuming roughly ⅓ of cases are discovered).

# Inputs and Where They Come From

The model described above uses actual data of current disease outbreaks to try to estimate the future progression of the disease. There are 4 types of data used: 1) case, hospitalization, death, and recover counts; 2) demographic data, 3) estimates of disease characteristics such as death rate, hospitalization rate, etc, from scientific studies, and 4) intervention impact estimates.

## Case Counts, Estimates, and Initial Conditions

- Current and historical caseload data (confirmed, recovered, deaths) are updated daily from the Johns Hopkins Center for Systems Science and Engineering's Coronavirus Tracking Dashboard [2].

- Hospitalizations, when available, are scraped from Covid Tracking Project [10] and Covid Data Scraper [19]. When not available, they are estimated by dividing confirmed cases by 4. (This presumes that about ¼ of tested patients are hospitalized, though this may vary from place to place. As soon as death data becomes a reliable predictor, we will switch to using that instead of confirmed cases.) Initial conditions for total cases and total exposed are calculated by dividing hospitalizations by the hospitalization rate.

## Demographic Data

- Population size data at the state-level are obtained from Wikipedia [6]. County-level data from Covid Data Scraper [19].

- USA demographics used are as reported by statista here.

## Hospital Capacity Assumptions

- Hospital bed and ICU capacity data at the state and county level are obtained from Definitive Health [3]. These data describe how many hospital beds are available, per state, per 1,000 population.

- We assume a baseline general hospital occupancy rate of 60% across all hospitals, accounting for hospitalized non-COVID patients [4]. We assume that hospitals can increase their available beds for COVID-19 patients by roughly double (207%).

- We assume a ICU occupancy rate of 85% across all hospitals, accounting for hospitalized non-COVID patients [14], and because ICU capacity is very hard to scale, assume no capacity build in the short term.

## Inferred Disease Parameters

| Parameter name | Value | Reference |
|---|---|---|
| $R_0$, limited intervention | 0.0 - 5.7 | Our model does not take $R_0$ as an input, but rather calculates an inferred one, based on other characteristics of the system. |
| % total infections requiring hospitalization (including mild and asymptomatic) | 4% | [7] Ferguson, Neil, et al., weighted by US demographics, and further adjusted for estimate of asymptomatic cases as reported by [12] Verity, Robert. et al. |
| Inferred infection fatality rate (IFR) | 0.6% - 1.5% | Our model does not take an infection fatality rate as an input, but rather infers one from the various CFRs below. Validated against [12] Verity, Robert. et al. (This implies a CFR of 2% - 5% assuming ⅓ of cases are detected) |

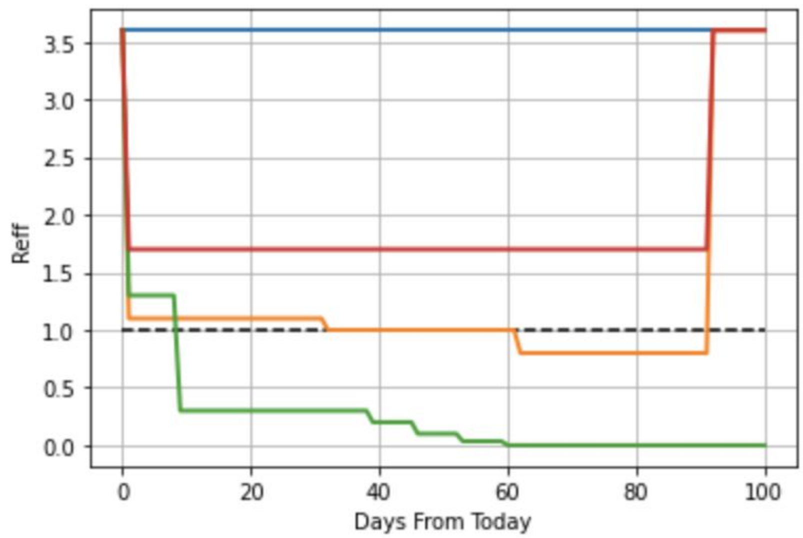
## Disease Input Parameters

| | | |
|---|---|---|
| % hospitalizations requiring ICU care | 30% | [13] Zhou et al., calibrated to US empirical data [15] |
| % ICU cases requiring ventilators | 60% | [16] Ñamendys-Silva |
| Non-severe hospitalization case fatality rate (CFR) | 0% | Optimistic logical assumption - all cases at risk of death must first pass through an ICU |
| ICU Case fatality rate (CFR) | 40% | [17] Ruan et al [18] Pavan K. Bhatraju, M.D., et al. |
| Ventilator Case fatality rate (CFR) | 60% | [18] Pavan K. Bhatraju, M.D., et al. |

| | | |
|---|---|---|
| CFR of non-severe hospitalizations when hospital capacity is exceeded | 5% | Logical assumption given severity of these cases |
| CFR of ICU and Ventilator cases when hospital capacity is exceeded | 100% | Logical assumption given severity of these cases |
| Pre-symptomatic (pre-infectious) period | 3 days | [9] Guan, Wei-ji, et al. |
| Duration of mild infections | 6 days | [1] Hill, Alison et al. |
| Serial period | 6 days | [11] Flaxman et al. |
| Duration of non-ICU hospitalization | 6 days | [1] Hill, Alison et al. |
| Duration of severe/ICU hospitalization | 14 days | [13] Zhou et al. |
| Rate at which infected individuals with mild disease infect susceptible individuals without any intervention ($\beta_{mild}$) | 0.6 / day default | [1] Hill, Alison et al., selected based on actual observed doubling periods in the USA of roughly 3-4 days. |
| Rate at which infected, hospitalized individuals infect susceptible individuals ($\beta_{hospitalized}$) | 0.1 / day | [1] Hill, Alison et al. |
| Rate at which critical, ICU admitted, infected individuals infect susceptible individuals ($\beta_{ICU}$) | 0.1 / day | [1] Hill, Alison et al. |

## Interventions

Interventions are modeled as a percent reduction in transmission rate from mildly infected individuals to the susceptible population. As social distancing and quarantine measures do not affect individuals that are hospitalized, severe and critical cases are assumed to have no reduction in transmission. In addition to the baseline scenario (assumes limited action), three intervention scenarios are modeled: three months of shelter in place with poor compliance, three months of shelter in place with strict compliance, and two months of a mandatory, full lock down.

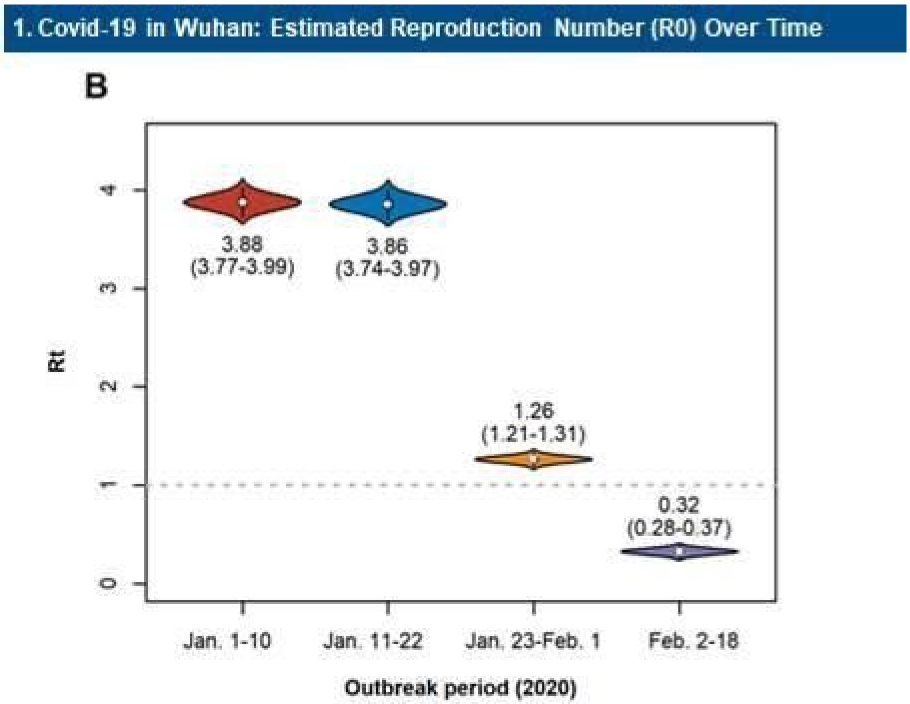



Modeled intervention impact to R_effective over time.
Blue: no action; Red: stay at home (lax); Yellow: stay at home (strict); Green: Wuhan.

Specific interventions are modeled as follows:

- **"Limited Action," "Restrictions Lifted," or "No Action"** all refer to if no interventions are put in place (or if those interventions are fully lifted), and the disease is able to spread at its natural rate (R0 = ~3.7).

- **Wuhan-style Containment,** reflecting about a 92% contact rate reduction
  - Goal: Fully and permanently contain disease until vaccine is developed
  - Duration: 3 months (12 weeks). Note that although the Wuhan containment only lasted 6 weeks, it is unclear that containment has actually succeeded, so we model it longer here.
  - Measures: Treat everyone as infected. Forced community-wide home quarantine, full shutdown of all businesses, closed borders, active monitoring, full population-wide mandatory testing and aggressive quarantine. Public aid relief bill.
  - After-effects: Once ended, long-term implementation of border quarantines (14 days), active monitoring, and potential for repeat of measures above to ensure containment.
  - R0 assumptions: 1.3 for 1 week, 0.3 for 6 weeks, 0.2 for 1 week, 0.035 for 4 weeks. Based on early reported Wuhan actuals, for the first 6 weeks, and extrapolations for the remaining 6 weeks. See this chart (lockdown was announced on ~Jan 23):




- **"Stay at Home (strict)" aka "Shelter-in-place"**, reflecting about a 70% contact rate reduction
    - Goal: Ideally fully contain disease until vaccine is developed, or at least delay spread until healthcare capacity can be built and therapeutic becomes available
    - Duration: 3 months (12 weeks)
    - Measures: Voluntary/VolunTold "shelter-in-place" community-wide home quarantine (especially firm for high-risk groups), shutdown of non-essential businesses, close schools, ban on events over 10 people, passive monitoring, public advocacy around social distancing and enhanced hygiene. Possibly closed borders or restricted travel. Public aid relief bill. Roll-out of free population-wide testing and quarantine, so that quarantines can be relaxed for those who are not infected.
    - After-effects: If contained, long-term implementation of border quarantines (14 days), active monitoring, and potential for repeat of measures above to ensure containment. If not contained, measures likely to be extended for 12-18 months in order to fully #flattenthecurve, with testing making quarantines more targeted.
    - R0 assumptions: 1.1 for 4 weeks, 1.0 for 4 weeks, 0.8 for 4 weeks. Based on conjecture and extrapolation from Wuhan data above to a less ideal/strict containment scenario.

- **"Stay at home (lax)" aka "Delay/Distancing",** reflecting about a 50% contact rate reduction
    - Goal: Delay the overloading of the healthcares system to minimize unnecessary deaths, while minimizing damage to the economy

- Duration: 3 months (12 weeks)
- Measures: Voluntary "shelter-in-place" for high-risk groups, ban on events over 50 people, public advocacy around "social distancing" and enhanced hygiene, possible school closures, restricted travel, and passive monitoring. Roll-out of population-wide testing and quarantine, so that quarantines can be relaxed for those who are not infected.
- After-effects: Measures likely to be extended for 12-18 months in order to fully #flattenthecurve
- R0 assumptions: 1.7 for 3 months. Based on rough extrapolation of reducing 50% of overall transmission opportunities in society, thus cutting a worst-cases R0 of ~3.2 to roughly 1.7.

# Term Definitions

| Conventional Definitions and Terms from https://www.cdc.gov/sars/guidance/index.html | | |
|---|---|---|
| Defined terms | Meaning | Associated Details |
| *Quarantine* | Separation or restriction of activities of individuals who are not ill but who are believed to be at high risk of becoming infected (*e.g.* close contacts of SARS patients). | • Can be voluntary or compulsory<br>• Accompanied by active monitoring<br>• Quarantine is a class of "*containment measure*".<br>• Beneficial for diseases where period of communicability precedes onset of symptoms |
| *Isolation* | Separation of ill persons with a communicable disease (*e.g.* SARS patients) from those who are healthy | • Could be at home ("home isolation"), hospital, or other designated facility.<br>• Isolation is a form of "*containment measure*". |
| *Community-wide home quarantine* | Community members stay at home (as they would during a major snow storm "snow day" style). | • Schools closed<br>• Workplaces closed/restricted<br>• Public events/gatherings cancelled/prohibited<br>• Public transport reduced/halted<br>• May entail unusual measures to supply essential goods to homes<br>• Can vary from voluntary ("snow day" style) to more drastically enforced<br>• Marginal benefits of increasingly draconian enforcement. Also comes at |

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|---|---|---|
| | | increasing cost and complexity of implementation (In *Supplement D*). |
| *Passive monitoring* | Individuals report the appearance of their own symptoms | |
| *Active Monitoring* | Professionals periodically/systematically assess individuals for symptoms | |
| *Community containment measures* | Activities applied to groups or communities during outbreaks of extensive transmission | Scales up: e.g. increase social distance vs community-wide home-quarantine. |

| Appendix D4: Threshold Determinants for the Use of Community Containment Measures<br>From Supplement D: Community Containment Measures, Including Non-Hospital Isolation and Quarantine, CDC: https://www.cdc.gov/sars/guidance/d-quarantine/index.html (See: https://www.cdc.gov/sars/guidance/index.html ) | |
|---|---|
| Parameter | Variable |
| Epidemiologic parameters of the outbreak | Absolute number of cases |
| | Rate of incident cases |
| | Number of hospitalized cases |
| | Number and percent of cases with no identified epidemiologic link |
| | Morbidity (including disease severity) and mortality |
| | Number of contacts under surveillance and/or quarantine |
| | |
| Healthcare resources | Hospital/facility bed capacity |
| | Isolation/negative pressure room capacity |
| | Staff resources |
| | Patient/staff ratio |
| | Number of isolated or quarantined staff |
| | Availability of specifically trained specialists and ancillary staff |
| | |
| Equipment and supplies | Availability of ventilators |
| | Availability of other respiratory equipment |
| | Availability of personal protective equipment and other measures |
| | Availability of therapeutic medications (SARS and non-SARS specific) |
| | |
| Public health resources | Investigator to case and contact ratios |
| | Number of contacts under active surveillance |
| | Number of contacts under quarantine |
| | Ability to rapidly trace contacts (number of untraced/interviewed contacts) |
| | Ability to implement and monitor quarantine (staff to contact ratio) |
| | Ability to provide essential services (food, water, etc.) |
| | |
| Community cooperation, mobility and compliance | Degree of compliance with voluntary individual isolation |

| | |
|---|---|
| | Degree of compliance with active surveillance and voluntary individual quarantine |
| | Degree of movement out of the community |
| | Degree of compliance with community-containment measures |

## Known Limitations

Only a small fraction of the world has been infected. It's a new disease. Variables will change. That said, the broad shape of the curve reflects the current general scientific consensus, and is the best information we currently have. Some known limitations:

- R0s for interventions are guesses, in some cases informed by data. There is no historical precedent for what is going on right now to draw from, and there is always some risk of misinterpretation of the data.
- Many of the inputs into this model (hospitalization rate, fatality rate) are based on early estimates that are likely to be wrong. All users should err on the side of caution and interpret the results of the model conservatively.
- The default infection propagation rate ($\beta_{mild}$) used in this model is an US average extracted from actual death data. The model does not adjust for the population density, culturally-determined interaction frequency and closeness, humidity, temperature, seasonality etc in calculating ($\beta_{mild}$), though we are actively working on this.
- This is not a node-based or network-based analysis, and thus assumes "perfect mixing," meaning that everyone spreads the disease at the same rate. In practice, there are some folks who are "super-spreaders," and others who are almost isolated, and every individual does not interact with every other individual in a country. This will have the impact of over-estimating the total percentage of the population that is estimated to be infected. Interventions should be targeted primarily at those most likely to spread the disease.
- This is a discrete, rather than a stochastic, analysis. That means that rather than using probability ranges, this model assumes constant rates for infection, contagiousness, etc. Among other things, discrete models may somewhat over-estimate the total percentage of the population who contracts the disease.
- Only hospital beds at aggregate are considered. ICU beds and ventilators, which are likely to run low before beds, are not considered, though we are working on this. That means hospitals may be overloaded sooner than the model predicts.
- In general, our data sources may be unreliable in unexpected and unknown ways. Specifically, demographics, populations, and hospital bed counts are outdated (estimates from 2016-2018). Demographics for the USA as a whole are used, rather than specific to each state.

- In containment cases, we do not deal with the longer-term impacts of maintaining containment, primarily the concern with avoiding reintroduction of the disease due to incoming travelers. 14-day mandatory border quarantines, such as those currently in place in China, would likely need to continue until a vaccine or therapeutic is developed.
- Attempts at containment/mitigation of any disease may cause a spike in new infections after these Non-Pharmaceutical Interventions (NPIs) are stopped. This can happen if the disease is not fully contained, or is reintroduced from another country. Because we are highly uncertain about the future, we do not currently include post-NPI behaviors in our model, though we are working on this.

# References

[1] Hill, Alison, et al. "Modeling COVID-19 Spread vs Healthcare Capacity". https://alhill.shinyapps.io/COVID19seir/

[2] Johns Hopkins Center for Systems Science and Engineering. CSSEGISandData Github. COVID-19. https://github.com/CSSEGISandData/COVID19/tree/master/csse_covid_19_data

[3] Definitive Healthcare's COVID-19 Capacity Predictor Tool https://www.definitivehc.com/resources/covid-19-capacity-predictor

[4] Statistica. Hospital occupancy rate in the US from 1975 to 2017. https://www.statista.com/statistics/185904/hospital-occupancy-rate-in-the-us-since-2001/

[5] Davis, Daniel P., et al. "Hospital bed surge capacity in the event of a mass-casualty incident." Prehospital and Disaster Medicine 20.3 (2005): 169-176.

[6] Wikipedia. List of states and territories of the United States by population. https://en.wikipedia.org/wiki/List_of_states_and_territories_of_the_United_States_by_population

[7] Ferguson, Neil, et al. "Report 9: Impact of non-pharmaceutical interventions (NPIs) to reduce COVID19 mortality and healthcare demand." (2020).

[8] Zhaoyang, Ruixue, et al. "Age differences in adults' daily social interactions: An ecological momentary assessment study." Psychology and aging 33.4 (2018): 607.

[9] Guan, Wei-jie, et al. "Clinical characteristics of 2019 novel coronavirus infection in China." NEJM (2020) doi: 10.1056/NEJMoa2002032.

[10] Covid Tracking Project. Covid case data for each state. https://covidtracking.com/data/#AK

[11] Ferguson, Neil, et al. "Report 13: Estimating the number of infections and the impact of non-pharmaceutical interventions on COVID-19 in 11 European countries" (2020) https://www.imperial.ac.uk/mrc-global-infectious-disease-analysis/covid-19/report-13-europe-npi-impact/

[12] Verity, Robert. et al. "Estimates of the severity of coronavirus disease 2019: a model-based analysis" (2020) https://www.thelancet.com/journals/laninf/article/PIIS1473-3099(20)30243-7/fulltext

[13] Zhou et al. "Clinical course and risk factors for mortality of adult inpatients with COVID-19 in Wuhan, China: a retrospective cohort study" (2020)

https://www.sciencedirect.com/science/article/pii/S0140673620305663

[14] Giacomo Grasselli, MD, et al. “Critical Care Utilization for the COVID-19 Outbreak in Lombardy, Italy” https://jamanetwork.com/journals/jama/article-abstract/2763188

[15] Covid Tracking Project. Average for states reporting ICU and hospitalizations https://covidtracking.com/data

[16] “Respiratory support for patients with COVID-19 infection” https://www.thelancet.com/action/showPdf?pii=S2213-2600%2820%2930110-7

[17] Ruan et al. “Clinical predictors of mortality due to COVID-19 based on an analysis of data of 150 patients from Wuhan, China” https://link.springer.com/article/10.1007/s00134-020-05991-x?fbclid=IwAR1EbkrPza14Iwx-dNFQDrlYG2HRomm-8Lb7NEvWZIqP1Gff8EBDaLmL7lg

[18] Pavan K. Bhatraju, M.D., et al. “Covid-19 in Critically Ill Patients in the Seattle Region — Case Series” https://www.nejm.org/doi/full/10.1056/NEJMoa2004500?query=featured_home

[19] Covid Data Scraper. Covid case data for each state. https://coronadatascraper.com/#home

Additional Epidemiological Parameter References

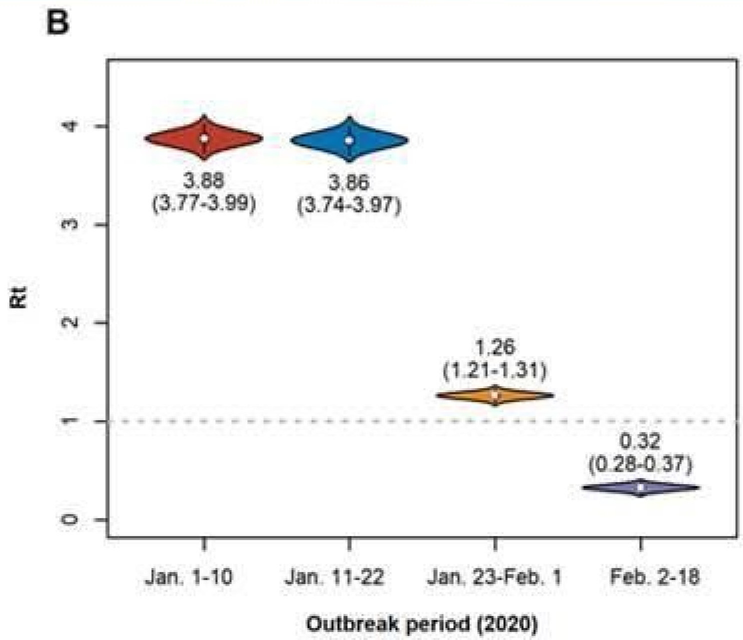
## Appendix: Old Model Intervention Definitions & Assumptions

Below are the modeling assumptions for the 4 reference scenarios, including actual policies and their R0 impacts. All terms used are as defined by the CDC (See a reference here). See actual state current policies here.

- Wuhan-style Containment
  - Goal: Fully and permanently contain disease until vaccine is developed
  - Duration: 2 months (8 weeks)
  - Measures: Treat everyone as infected. Forced community-wide home quarantine, full shutdown of all businesses, closed borders, active monitoring, full population-wide mandatory testing and aggressive quarantine. Public aid relief bill.
  - After-effects: Once ended, long-term implementation of border quarantines (14 days), active monitoring, and potential for repeat of measures above to ensure containment.
  - R0 assumptions: 1.3 for 1 week, 0.3 for 5 weeks, 0.2 for 1 week, 0.035 for 1 week. Based on early reported Wuhan actuals, for the first 6 weeks, and extrapolations for the remaining 2 weeks. See this chart (lockdown was announced on ~Jan

23):

1. Covid-19 in Wuhan: Estimated Reproduction Number (R0) Over Time




- "Shelter-in-place" Containment/Delay
    - Goal: Ideally fully contain disease until vaccine is developed, or at least delay spread until healthcare capacity can be built and therapeutic becomes available
    - Duration: 3 months (12 weeks)
    - Measures: Voluntary/VolunTold "shelter-in-place" community-wide home quarantine (especially firm for high-risk groups), shutdown of non-essential businesses, close schools, ban on events over 10 people, passive monitoring, public advocacy around social distancing and enhanced hygiene. Possibly closed borders or restricted travel. Public aid relief bill. Roll-out of free population-wide testing and quarantine, so that quarantines can be relaxed for those who are not infected.
    - After-effects: If contained, long-term implementation of border quarantines (14 days), active monitoring, and potential for repeat of measures above to ensure containment. If not contained, measures likely to be extended for 12-18 months in order to fully #flattenthecurve, with testing making quarantines more targeted.
    - R0 assumptions: 1.3 for 4 weeks, 1.1 for 4 weeks, 0.8 for 4 weeks. Based on conjecture and extrapolation from Wuhan data above to a less ideal/strict containment scenario.

- Delay/Distancing
    - Goal: Delay the overloading of the healthcares system to minimize unnecessary deaths, while minimizing damage to the economy

- Duration: 3 months (12 weeks)
- Measures: Voluntary “shelter-in-place” for high-risk groups, ban on events over 50 people, public advocacy around “social distancing” and enhanced hygiene, possible school closures, restricted travel, and passive monitoring. Roll-out of population-wide testing and quarantine, so that quarantines can be relaxed for those who are not infected.
- After-effects: Measures likely to be extended for 12-18 months in order to fully #flattenthecurve
- R0 assumptions: 1.7 for 3 months. Based on rough extrapolation of reducing 50% of overall transmission opportunities in society, thus cutting a worst-cases R0 of ~3.2 to roughly 1.7.

- Do Nothing: current historical trends continue
  - R0 assumptions: Actual data where available, 2.4 for all forward-looking periods.

## Core Variable Assumptions

There are a few core variables that drive the model. These are listed below.

| Metric | Default Assumption | Explanation | Source Data |
|---|---|---|---|
| Estimated Initial R0 | 2.4 | R0 defines how many people each infected person further infects over the lifetime of the infection. It can happen quickly (flu, a few days) or slowly, (HIV, years).<br><br>Because CoVid only lasts 2 weeks, this model assumes people are only infectious for one 4-day period (a single model interval). In this simplified world, the R0 value determines how fast the disease spreads each period.<br><br>This behavior is roughly calibrated to actually observed doubling times (4 days). | The model uses actual data as reported by JHU. When none is present, this default is used. Range provided by Imperial College paper. |
| Hospitalization Rate | 7.3% | This is the rate at which infected people are hospitalized. Our best | Range provided by Imperial College paper, weighted by |

| | | | |
|---|---|---|---|
| | | estimates vary quite a bit by age. | actual USA demographics as reported by statistica here. |
| Case Fatality Rate | 1.1% | This is the rate at which infected people die, assuming they can access treatment. Our best estimates vary quite a bit by age. | Range provided by Imperial College paper, weighted by actual USA demographics as reported by statistica here. |
| Fatality Rate Increase If Hospitals Overloaded | 1.0% | This is the additional rate at which infected people die, assuming they cannot access treatment. It is the number of infected cases requiring at least ICU care. | Range provided by Imperial College paper, weighted by actual USA demographics as reported by statistica here. |
| Population | Varies by state | The population of each state. | Wikipedia here |
| Hospital Beds | Varies by state | The number of hospital beds in each state. | KFF here, somewhat outdated. |
| Hospital Bed Utilization | 66% | The number of beds unavailable for CoVid cases due to being occupied. | Based on data here. Could be higher. |
| Emergency Bed Capacity Build | 207.9% in 2 months | The number of additional beds made available by emergency preparation. Roughly equivalent to clearing out fully half of all other hospital bed occupants. | Guess based on discussions with experts. |

## Initial Cases

| | | | |
|---|---|---|---|
| Initial Cases | Reported cases time 20 | Cases estimated by multiplying confirmed cases by 20.<br><br>A hospitalization rate of ~5% implies ~20x the number of cases as hospitalizations.<br><br>Once this becomes a poor signal, death rates will be used to estimate caseload. This would be estimated as: (Reported Deaths / Case Fatality Rate) * 2x2x2x2. The 2^4 multiplier adjusts for ~16 days delay between infection and death. | |

## Core Model Dynamics & Disease Timeline Assumptions

| Metric | Default Assumption | Explanation | Source Data |
|---|---|---|---|
| Modelling Interval | 4 days | This is how frequently the model updates. It is roughly equivalent to one disease doubling period. | n/a. Chosen for simplicity. |
| Recovery Period | 16 days | This is how long it takes the average patient to recover. This does not change regardless of the severity of the case. | No conclusive data exists. Corroborated by various sources, but one source is here. |
| Non-contagious Incubation Period | 2 days | The average time between infection and onset of symptoms. For simplicity, also assumed to be the delay between infection and when an infected person is contagious, as we believe CoVid is likely infectious before symptoms begin. | No conclusive data exists. Corroborated by various sources, but one source is here. |
| Contagious Period | 2 days | The number of days the average case is contagious. This is likely longer than 2 days for symptomatic cases, but for simplicity we assume that an infected person isolates after 2 days if symptomatic. | No conclusive data exists. Corroborated by various sources, but one source is here. |
| Serial Interval | 4 days | The average time between the onset of symptoms in one individual and the onset of symptoms in another individual. Likely to be longer than 4 days, but was simplified down to 4 days to match the other variables and fit neatly into the model interval. | No conclusive data exists. |
| Average Hospital Stay | 4 days | How long the average patient stays in the hospital before dying or recovering. | No conclusive data exists. Extremely conservative, current consensus is 10 days. |

## Detailed Demographics Assumptions

Range provided by Imperial College paper, weighted by actual USA demographics as reported by statista here.

| Demographics | | % Hosp | % Hosp ICU | % CFR |
|---|---|---|---|---|
| 12% | 0-9 | 0.1% | 5.0% | 0.002% |
| 13% | 10-19 | 0.3% | 5.0% | 0.006% |
| 14% | 20-29 | 1.2% | 5.0% | 0.03% |
| 13% | 30-39 | 3.2% | 5.0% | 0.08% |
| 12% | 40-49 | 4.9% | 6.3% | 0.15% |
| 13% | 50-59 | 10.2% | 12.2% | 0.60% |
| 11% | 60-69 | 16.6% | 27.4% | 2.20% |
| 7% | 70-79 | 24.3% | 43.2% | 5.10% |
| 4% | 80+ | 27.3% | 70.9% | 9.30% |
| 100.0% | | 7.27% | 13.97% | 1.09% |

# Term Definitions

| Conventional Definitions and Terms from https://www.cdc.gov/sars/guidance/index.html | | |
|---|---|---|
| Defined terms | Meaning | Associated Details |
| *Quarantine* | Separation or restriction of activities of individuals who are not ill but who are believed to be at high risk of becoming infected (*e.g.* close contacts of SARS patients). | • Can be voluntary or compulsory<br>• Accompanied by active monitoring<br>• Quarantine is a class of "*containment measure*".<br>• Beneficial for diseases where period of communicability precedes onset of symptoms |
| *Isolation* | Separation of ill persons with a communicable disease (*e.g.* SARS patients) from those who are healthy | • Could be at home ("home isolation"), hospital, or other designated facility.<br>• Isolation is a form of "*containment measure*". |
| *Community-wide home quarantine* | Community members stay at home (as they would during a major snow storm "snow day" style). | • Schools closed<br>• Workplaces closed/restricted<br>• Public events/gatherings cancelled/prohibited<br>• Public transport reduced/halted |

| | | |
|---|---|---|
| | | • May entail unusual measures to supply essential goods to homes<br>• Can vary from voluntary ("snow day" style) to more drastically enforced<br>• Marginal benefits of increasingly draconian enforcement. Also comes at increasing cost and complexity of implementation (In *Supplement D*). |
| *Passive monitoring* | Individuals report the appearance of their own symptoms | |
| *Active Monitoring* | Professionals periodically/systematically assess individuals for symptoms | |
| *Community containment measures* | Activities applied to groups or communities during outbreaks of extensive transmission | Scales up: e.g. increase social distance vs community-wide home-quarantine. |

| Appendix D4: Threshold Determinants for the Use of Community Containment Measures<br>From Supplement D: Community Containment Measures, Including Non-Hospital Isolation and Quarantine, CDC: https://www.cdc.gov/sars/guidance/d-quarantine/index.html (See: https://www.cdc.gov/sars/guidance/index.html ) | |
|---|---|
| Parameter | Variable |
| Epidemiologic parameters of the outbreak | Absolute number of cases |
| | Rate of incident cases |
| | Number of hospitalized cases |
| | Number and percent of cases with no identified epidemiologic link |
| | Morbidity (including disease severity) and mortality |
| | Number of contacts under surveillance and/or quarantine |
| | |
| Healthcare resources | Hospital/facility bed capacity |
| | Isolation/negative pressure room capacity |
| | Staff resources |
| | Patient/staff ratio |
| | Number of isolated or quarantined staff |
| | Availability of specifically trained specialists and ancillary staff |
| | |
| Equipment and supplies | Availability of ventilators |
| | Availability of other respiratory equipment |
| | Availability of personal protective equipment and other measures |
| | Availability of therapeutic medications (SARS and non-SARS specific) |
| | |
| Public health resources | Investigator to case and contact ratios |
| | Number of contacts under active surveillance |
| | Number of contacts under quarantine |
| | Ability to rapidly trace contacts (number of untraced/interviewed contacts) |
| | Ability to implement and monitor quarantine (staff to contact ratio) |
| | Ability to provide essential services (food, water, etc.) |
| | |
| Community cooperation, mobility and compliance | Degree of compliance with voluntary individual isolation |

| | |
|---|---|
| | Degree of compliance with active surveillance and voluntary individual quarantine |
| | Degree of movement out of the community |
| | Degree of compliance with community-containment measures |

## Known Limitations

Only a small fraction of the world has been infected. It's a new disease. Variables will change. That said, the broad shape of the curve reflects the current general scientific consensus, and is the best information we currently have. Some known limitations:

- R0s for interventions are guesses, in some cases informed by data. There is no historical precedent for what is going on right now to draw from, and there is always some risk of misinterpretation of the data.
- Many of the inputs into this model (hospitalization rate, fatality rate) are based on early estimates that are likely to be wrong. All users should err on the side of caution and interpret the results of the model conservatively.
- The default R0 used in this model is an average. The model does not adjust for the population density, culturally-determined interaction frequency and closeness, humidity, temperature, etc in calculating R0.
- This model assumes simplified values for serial interval, contagious period, and other key disease dynamics that are likely to change model outputs somewhat when improved, but unlikely to change the general shape of the disease curve.
- This is not a node-based analysis, and thus assumes everyone spreads the disease at the same rate. In practice, there are some folks who are "super-spreaders," and others who are almost isolated. Interventions should be targeted primarily at those most likely to spread the disease.
- This is a discrete, rather than a stochastic, analysis. That means that rather than using probability ranges, this model assumes constant rates for infection, contagiousness, etc. Among other things, discrete models may somewhat over-estimate the total percentage of the population who contracts the disease.
- Only hospital beds at aggregate are considered. ICU beds and ventilators, which are likely to run low before beds, are not considered. That means hospitals may be overloaded sooner than the model predicts.
- Demographics, populations, and hospital bed counts are outdated (estimates from 2016-2018). Demographics for the USA as a whole are used, rather than specific to each state.
- In containment cases, we do not deal with the longer-term impacts of maintaining containment, primarily the concern with avoiding reintroduction of the disease due to

incoming travelers. 14-day mandatory border quarantines, such as those currently in place in China, would likely need to continue until a vaccine or therapeutic is developed.

- Attempts at containment/mitigation of any disease may cause a spike in new infections after these Non-Pharmaceutical Interventions (NPIs) are stopped. This can happen if the disease is not fully contained, or is reintroduced from another country. Because we are highly uncertain about the future, we do not currently include post-NPI behaviors in our model, though we are working on this.