

COVID-19 intervention effectiveness and epidemic trends for Oregon: a model-based analysis

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What is already known?

The global COVID-19 pandemic threatens to overload health care systems. Patients with severe symptoms will have significantly higher mortality if they are unable to receive timely care.

What is added by this report?

We ran model simulations specific to Oregon projecting the number of cumulative, active, and severe infections (requiring inpatient care) as of May 18th under different intervention assumptions.

What are the implications for public health practice?

The interventions until March 22, 2020 appear to have kept current numbers of active infections growing relatively slowly. Additional aggressive measures were implemented on March 23rd (i.e., shelter-in-place), which appear to have reversed the growth of the epidemic. These interventions are estimated to have reduced cumulative infections as of April 10th to approximately 7,000 from almost 25,000 in the absence of interventions. Health care systems would likely have become overburdened by late April in the absence of these sustained interventions to keep the number of infections under control.

What are the limitations of this report?

The projections included in this report are based on the best available evidence as of April 10th, 2020. However, there remain significant unknowns, including the current extent of social distancing, testing policies, and compliance with new interventions. These projections should thus be considered preliminary and subject to change as more data become available.

Executive summary

- **Purpose:** To estimate the number of people who are likely to have COVID-19 and need hospital services in Oregon over the next 6 weeks, assuming different nonpharmaceutical interventions are implemented. These estimates can be used to assess availability of beds, staff, and equipment for treating patients likely to need services.
- **Methodology:** This report uses available data on confirmed positive diagnoses, number of tests completed, hospitalizations, ICU admittance, and deaths for Oregon to calibrate an agent-based COVID-19 model (Covasim), which can then be used for projecting future epidemic trends.
- **Geography:** All of Oregon.
- **Epidemiological projections:** We predict that there are currently approximately 7,000 infections in Oregon, of which 1,300 had been diagnosed by April 6st. We estimate that current interventions have already averted approximately 18,000 infections and 500 hospitalizations. **Current aggressive interventions will need to be maintained in order to decrease the number of active infections.**

Summary of methods

A detailed summary of our methods is available for transmission modeling in Appendix 1, and for health systems usage in Appendix 2. In brief, we have coupled an individual-based transmission model (COVID-19 Agent-based Simulator, or Covasim) to a discrete event care usage model as follows.

COVID-19 transmission takes place on a fixed network of contacts with best-available disease parameters. In fitting transmission model output to testing and diagnosis data for Oregon, we found that a single importation in the week prior to February 17th, the date of the first positive diagnosis, was insufficient to match the data. Either the importation occurred much earlier (mid to late January), and/or multiple importations occurred.

Results from the transmission model were used as input to the hospital utilization module, which has the following assumptions:

- Of symptomatic cases, 20% require hospitalization (severe cases) and 7% have critical illness requiring an ICU bed;
- Length of stay is roughly 12-15 and 20-30 days for severe and critical cases, respectively;
- ICU-bound patients spend the first third of their stay in an adult acute care (AAC) bed.

Impact of current interventions

There is strong evidence that current interventions have significantly reduced the burden of COVID-19 in Oregon. Figure 1 shows the result of calibrating the model to Oregon data. The data are consistent with a stepped reduction in transmission in Oregon, beginning with a 10% decrease in transmission by March 8th, through to a sustained 60% decrease in transmission after March 23rd. Estimates are higher than previously reported due to an increase in reported diagnoses and hospitalizations.

Figure 2 shows what would have happened if no social distancing measures were put in place in Oregon. The epidemic would have continued to grow exponentially, doubling every 5-7 days. By April 10th, the number of cumulative hospitalizations would have been more than twice the actual number (approximately 700 compared to approximately 300).

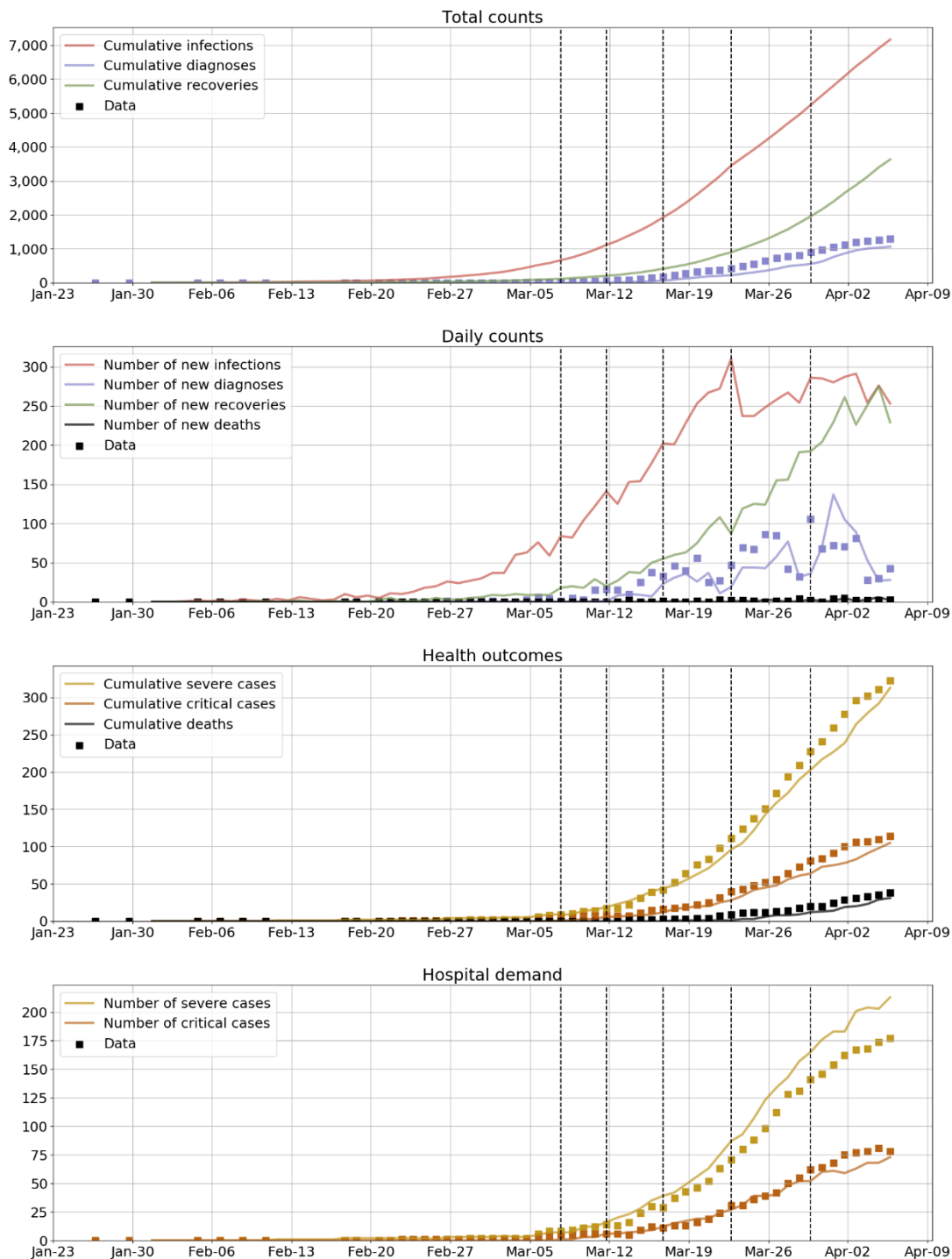


Figure 1: Best-fit model calibration with case data up to April 6th, showing approximately 7,000 infections by April 6th. Dotted lines correspond to estimated reductions in transmission relative to baseline, from left to right, of 10%, 20%, 30%, 45%, and 60%. The impacts of these interventions were estimated by calibrating to numbers of positive diagnoses (dots, top two plots), plus severe (hospital) cases, critical (ICU) cases, and deaths (bottom two plots). Note that data on numbers of tests per day are not available after April 6th.

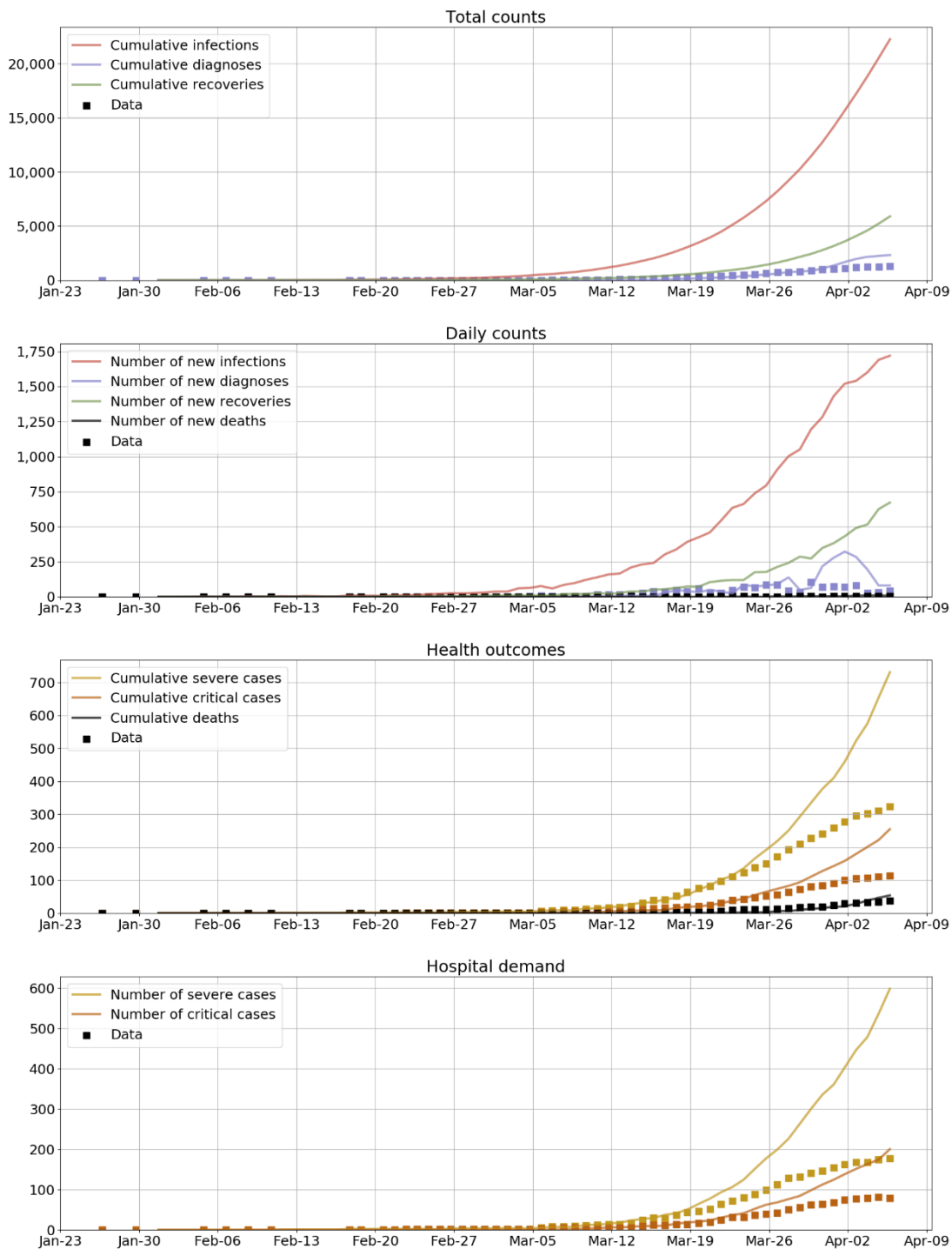


Figure 2: Model projections under the counterfactual scenario that no interventions were put in place, comparing the data (squares) with the model the same as in Figure 1 but with interventions removed. As above, numbers of tests per day are not projected beyond April 6th.

Scenario projections

A large number of measures intended to slow the transmission of COVID-19 were put in place on March 12th 2020, such as bans on gatherings of more than 250 people; these are detailed [here](#). Schools were closed statewide on March 16th, as detailed [here](#). Further measures were put in place on March 16th, including the closure of restaurants and bars and gatherings of more than 25 people, as detailed [here](#). Aggressive interventions, namely the [“stay home, save lives” recommendations](#), were put in place on March 23rd 2020. From calibrating the model to the data, there is evidence that these measures, combined with increased hygiene and other measures that appear to have begun earlier, have led to an approximately 55-75% reduction in transmission. These results are consistent with reductions in movement as shown in [Facebook Data for Good](#) data.

We model two scenarios from now until May 18th:

1. “Return to moderate interventions”, interventions from March 16th to March 22nd 2020 are resumed, corresponding to a conservatively estimated 30% reduction in transmission compared to baseline;
2. “Aggressive interventions continue”, corresponding to 60% reduction in transmission compared to baseline;

These results are shown in Figures 3 and 4. With continued aggressive interventions, the number of cumulative infections slowly increases, while the number of active infections slowly declines over the next 6 weeks. However, with a return to moderate interventions, the number of both cumulative and active infections will rapidly increase.

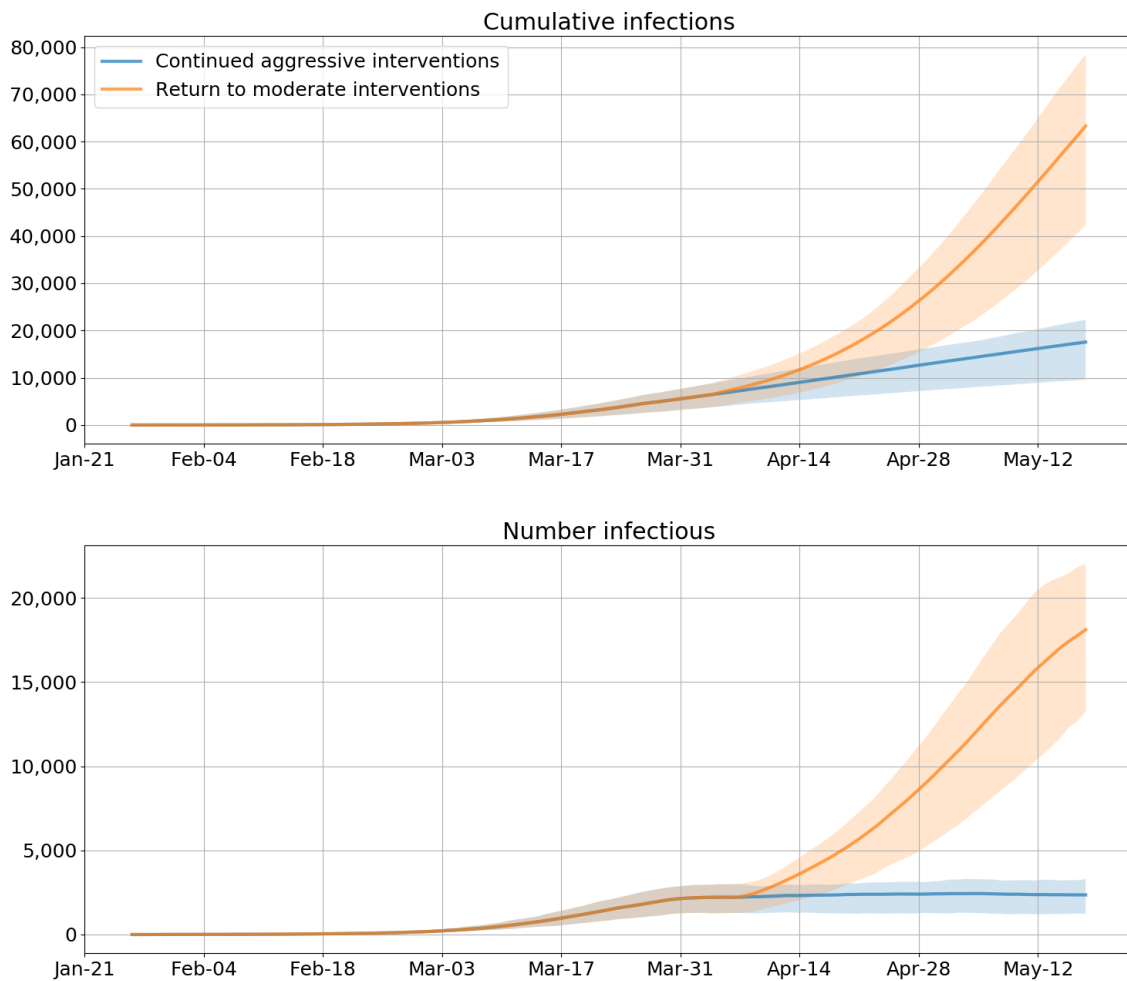


Figure 3: Model projections for the next 6 weeks assuming either a continuation of current social distancing interventions (blue), or a return to the moderate social distancing interventions as of March 22nd (orange).

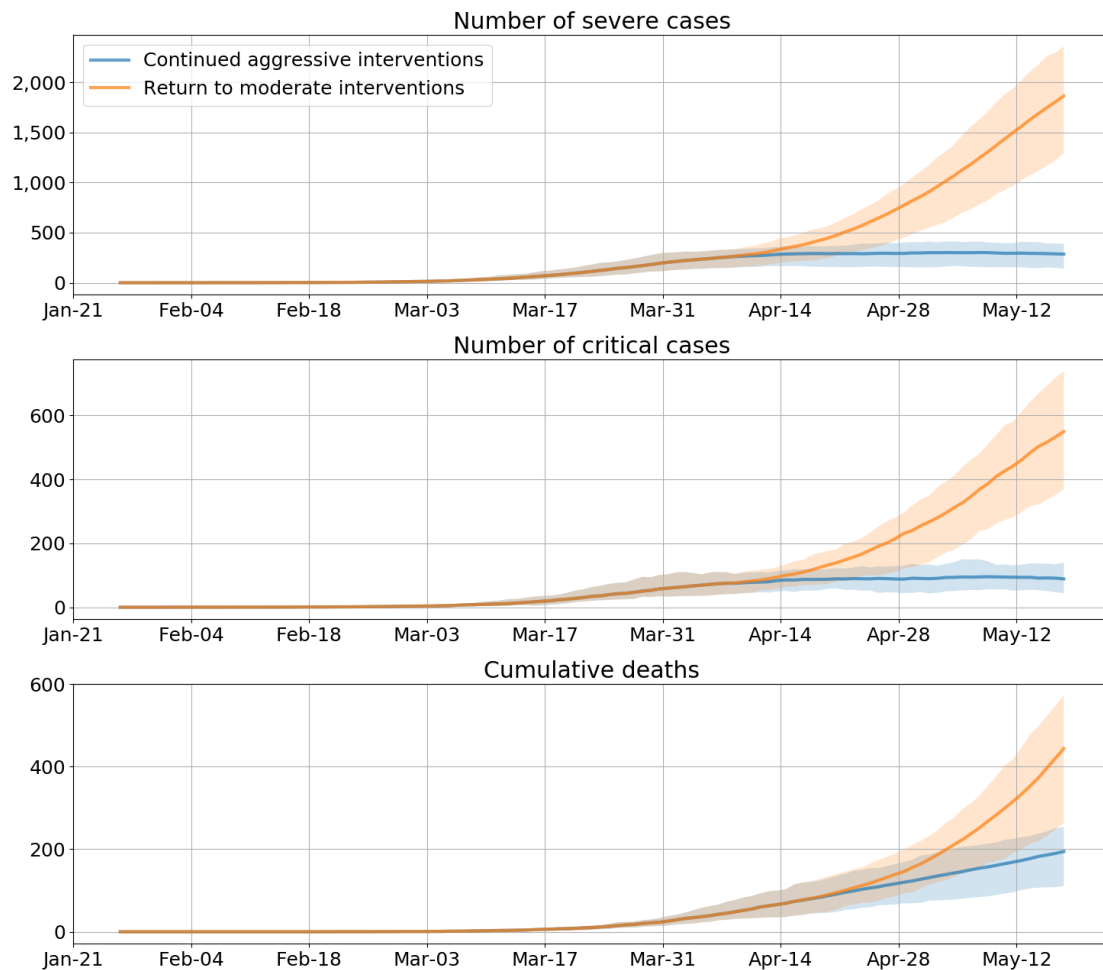


Figure 4: Model projections on hospital demand and deaths over the next 6 weeks assuming either a continuation of current social distancing interventions (blue), or a return to the moderate social distancing interventions as of March 22nd (orange).

Conclusions to date

- To fit the underlying data with best-guess epidemiological parameters, multiple importation events are required. We therefore conclude that importation happened before February 1st, and/or that multiple importation events have occurred.
- With the interventions as of March 23rd in place, we estimate that the total number of required in-patient beds will remain constant or begin to decrease over the timeframe considered. However, hospital bed capacity may diminish if healthcare workers cannot work due to infection or family-care needs. Furthermore, this projection extends only until May 18th.
- At this stage, any relaxation of the current aggressive control measures is likely to result in epidemic resurgence.

Recommendations

We commend Oregon for introducing aggressive interventions early in the epidemic. We acknowledge how strong the impacts of these measures will be across society, especially for low-income families and other vulnerable populations, and we hope Oregon will also act to mitigate the largest societal costs. Oregon's recent donation of ventilators to New York is a strong testament to the success of its early and forceful control measures.

Finally, we emphasize the urgent need for enormously increased testing capacity. **It will not be possible to relax social distancing measures and avoid an epidemic rebound without significantly increased testing.** Increased testing must be coupled with detailed contact tracing, asymptomatic testing of at-risk individuals, and likely the quarantining of infected individuals away from households, where significant transmission occurs. Additional vigilance to reduce the risk of reintroduction if travel restrictions were relaxed would also require substantial testing capacities. These measures have been successfully used to prevent epidemic rebound in other countries, [such as South Korea](#), and provide the clearest evidence to date of successful short- to medium-term COVID-19 management.

Appendix 1: Detailed transmission model methods

We applied Covasim, an individual-based COVID transmission model with parameters informed by literature; the full source code is [available on GitHub](#). The simulation begins on 2020-01-27, the date of onset of the first test. It is not possible to calibrate the model with a single importation event near the date of the first diagnosis (2020-02-27), which is consistent with the fact that this case was community acquired, implying other infections occurred before this date. To match observed epidemic trends, five infected individuals are assumed by 2020-01-27. This indicates either multiple importation events, or a single importation occurring between approximately 2020-01-10 and 2020-01-15. Internally, COVID-19 (SARS-CoV-2) infection within each individual is represented by four stages: susceptible, exposed, infectious, recovered (SEIR). The exposed (latent) period prior to the onset of viral shedding is normally distributed with a mean of 4 days and standard deviation of 1 day; this is one day shorter than the 5-day consensus estimate of the incubation period prior to symptom onset ([MIDAS-network](#)) to acknowledge reports of pre-symptomatic shedding. The infectious period is normally distributed with mean 8 days and standard deviation 2 days, based on measured upper-respiratory viral shedding after symptom onset ([Reference](#)).

Viral transmission from one individual to the next proceeds on a fixed contact network with undirected edges. The degree distribution of the network is Poisson-distributed with rate parameter $\lambda=20$. Individual network edges are selected at random. On each day, infectious individuals expose susceptible "close contacts" (neighboring nodes in the graph) to possible infection. The daily probability of an infectious individual infecting each neighboring susceptible individual is binomially distributed with $p = 0.015$. With an average of 20 contacts per individual per day and a mean duration of infectiousness of 8 days, this per-day probability roughly translates to $R_0 = 2.3$. At this time, all infected individuals are equally infectious, and infectivity does not vary on a daily basis or by symptoms. The probability of death for each infection is approximately 1.6%, dependent on age. Time from infection to death is drawn from a normal distribution with mean of 21 days and standard deviation of 4 days. Testing probability in the model is based on an individual's symptoms, contact with known positives, and other factors, including a realistic delay between infection, symptom onset, and diagnosis.

Appendix 2: Healthcare system modeling methods

There is still a high degree of uncertainty about the healthcare needs of COVID-19 patients in the United States, since the clinical care protocols are rapidly evolving and will depend substantially on the comorbidities and level of opportunistic infections that are seen in a given patient population. With that in mind, we have triangulated between several published sources in order to estimate parameters that fit reasonably well with what is currently known.

We extrapolated the symptomatic rate, the hospitalization rate, and the rate of ICU bed needs based on data from Wu and McGoogan (2020) who report hospitalization and ICU rates, Bi, et al. (2020) who report severity rates for symptomatic cases, Guan, et al. (2020) who report ICU rates and Riou et al. (2020), who report symptomatic rates by age. Combining these sources, we estimate that 18.8% of cases require hospitalization and 5.4% of cases have severe illness that requires an ICU bed as part of an inpatient stay.

Length of stay estimates are highly variable. We extrapolated from those reported by Bi et al. (2020), Yang et al. (2020), and Sanche et al. (2020). Each study uses different definitions for length of stay, broken out by severity and symptoms. Collectively, they indicate that severe cases have longer length of stay, and that most ICU-bound patients start out in an AAC bed and eventually progress to more severe symptoms that require ICU care. We reflect this in the model with length of stay for severe cases of 15-20 days, and for critical cases 20-30 days. Based on limited clinical data from Bouadma et al. (2020), we assume that for ICU-bound patients, approximately 30% of their length of stay is first in an AAC bed.

The model is a discrete event simulation, which models each individual patient as they seek care and for their duration of time in the hospital. Patients arrive at the hospital with symptoms according to the pattern projected by the epidemiological model described above.

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