Working paper: Projected COVID-19 epidemic trends and health system needs for Oregon

Authors: Cliff Kerr[1], Brittany Hagedorn[1], Dina Mistry[1], Daniel Klein[1]

Reviewers: Assaf Oron[1], Prashanth Selvaraj[1], Jen Schripsema[1], Roy Burstein[1]

[1]Institute for Disease Modeling, Bellevue, Washington

Contact: covid@idmod.org

Results as of 2020-03-23, 12:00pm

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 8 under four different intervention levels.

What are the implications for public health practice?

The interventions as of March 22, 2020 appear to be keeping current numbers of active infections constant or growing relatively slowly. Additional aggressive measures were implemented on March 23rd (i.e., shelter-in-place), and are predicted to decrease the number of active infections by May 8. Health care systems are likely to be overburdened by late April without 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 March 23rd, 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.
- **Background:** This report builds on one prepared by Peter Graven, PhD (Office of Advanced Analytics, BIAA, OHSU), with updates in the data and methods using COVASim (for epidemic projections) and Simul8 (for health systems requirements).
- **Geography:** All of Oregon.
- **Epidemiological projections:** We predict that there are currently approximately 800 infections in Oregon, of which only 184 have been diagnosed. With interventions in place as of March 22 (including indefinite school closures and bans on large public gatherings), we estimate 6,100 [2,000, 12,000] cumulative infections by May 8th. If the aggressive interventions implemented on March 23 (i.e.,"stay home, save lives") are adhered to we estimate 1,000 [700, 3,800] cumulative infections by May 8th. In contrast, if current social distancing measures cease, there will be 15,000 (80% forecast interval: [5,900, 26,000]) cumulative infections. Critically, the number of active infections on May 8th for each scenario are estimated to be: current interventions, 2,000 [700, 3,800]; aggressive interventions, close to zero infections; return-to-business-as-usual, 6,600 [3,000, 10,000]; **Only aggressive interventions are predicted to decrease the number of active infections** compared to current conditions.
- **Health system projections:** We find that by May 8th, under the interventions in place as of March 22, we predict the number of beds will grow slowly: 340 people will need inpatient beds (260 AAC/80 ICU) by May 8th. If aggressive measures implemented on March 23rd (i.e., "stay home, save lives") are strictly adhered to, we predict that only a small number of inpatient beds will be required by May 8th, driven largely by expected importations. In contrast, under a return-to-business-as-usual scenario, 1,100 people will need inpatient beds (850 AAC/250 ICU) across Oregon.

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 all cases (including symptomatic and asymptomatic), 18.8% require hospitalization and 5.4% have severe illness requiring an ICU bed;
- Length of stay is roughly 8-13, 9-16, and 13-21 days for moderate, intermediate, and severe cases, respectively;
- ICU-bound patients spend the first third of their stay in an AAC bed.

Intervention scenario assumptions

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. From calibrating the model to diagnoses 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 40-60% reduction in transmission. With additional data, including from Facebook Data for Good and ongoing COVID-19 notifications, we will be able to improve our estimates of the impact. At this time, we model three scenarios from now until May 8th:

1. "Return to business as usual" (existing measures are removed but vigilance remains, corresponding to a 20% reduction in transmission compared to baseline)
2. "Moderate interventions" (interventions from March 16th to March 22nd 2020 are continued, corresponding to a conservatively estimated 40% reduction in transmission compared to baseline)
3. "Aggressive interventions" (shelter-in-place, comparable to new "stay home, save lives" recommendations as of March 23rd 2020 with at least 90% adherence, corresponding to 80% reduction in transmission compared to baseline)

We stress that these are only assumptions; if the true effect of aggressive interventions is closer to a 60% reduction in transmission than 80%, then the projections would be approximately halfway between the modeled "aggressive interventions" and "current interventions" scenarios. We use these epidemiological results to model the number of inpatient beds required to meet patient care needs.

Intervention scenario results

Results from our epidemiological projections are shown in Figures 1 and 2. We predict that there are currently approximately 800 infections in Oregon, of which only 184 have been diagnosed. With interventions in place as of March 22 (including indefinite school closures and bans on large public gatherings), we estimate 6,100 [2,000, 12,000] cumulative infections by May 8th. If the aggressive interventions implemented on March 23 (i.e.,"stay home, save lives") are adhered to, we estimate 1,000 [700, 3,800] cumulative infections by May 8th. In contrast, if current social distancing measures cease, there will be 15,000 (80% forecast interval: [5,900, 26,000]) cumulative infections. Critically, the number of active infections on May 8th for each scenario are estimated to be: current interventions, 2,000 [700, 3,800]; aggressive interventions, close to zero infections; return-to-business-as-usual, 6,600 [3,000, 10,000].

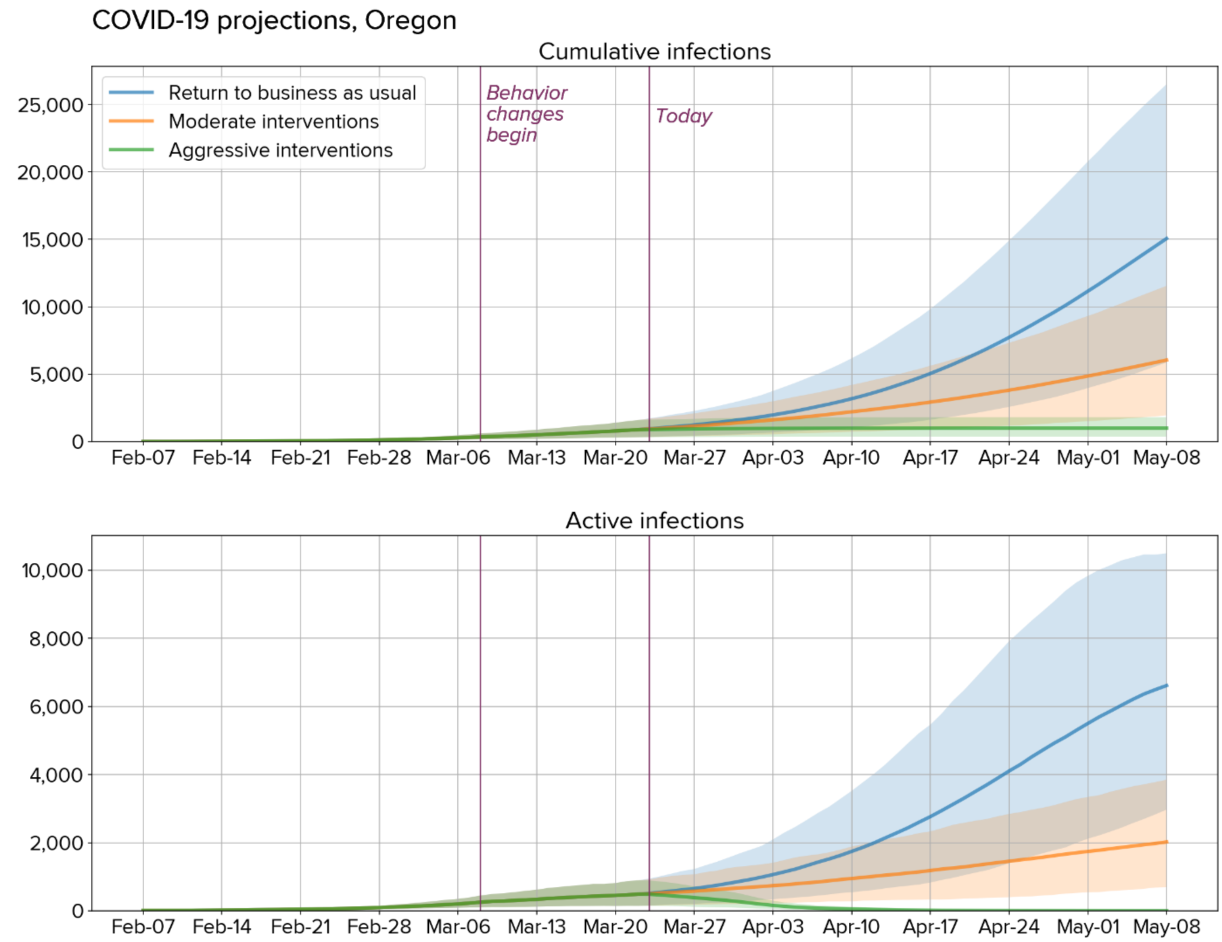

Figure 1. COVASim projections of cumulative and active infections by May 8th. Shaded areas correspond to 80% forecast intervals (i.e., 10th and 90th percentiles of the projection).

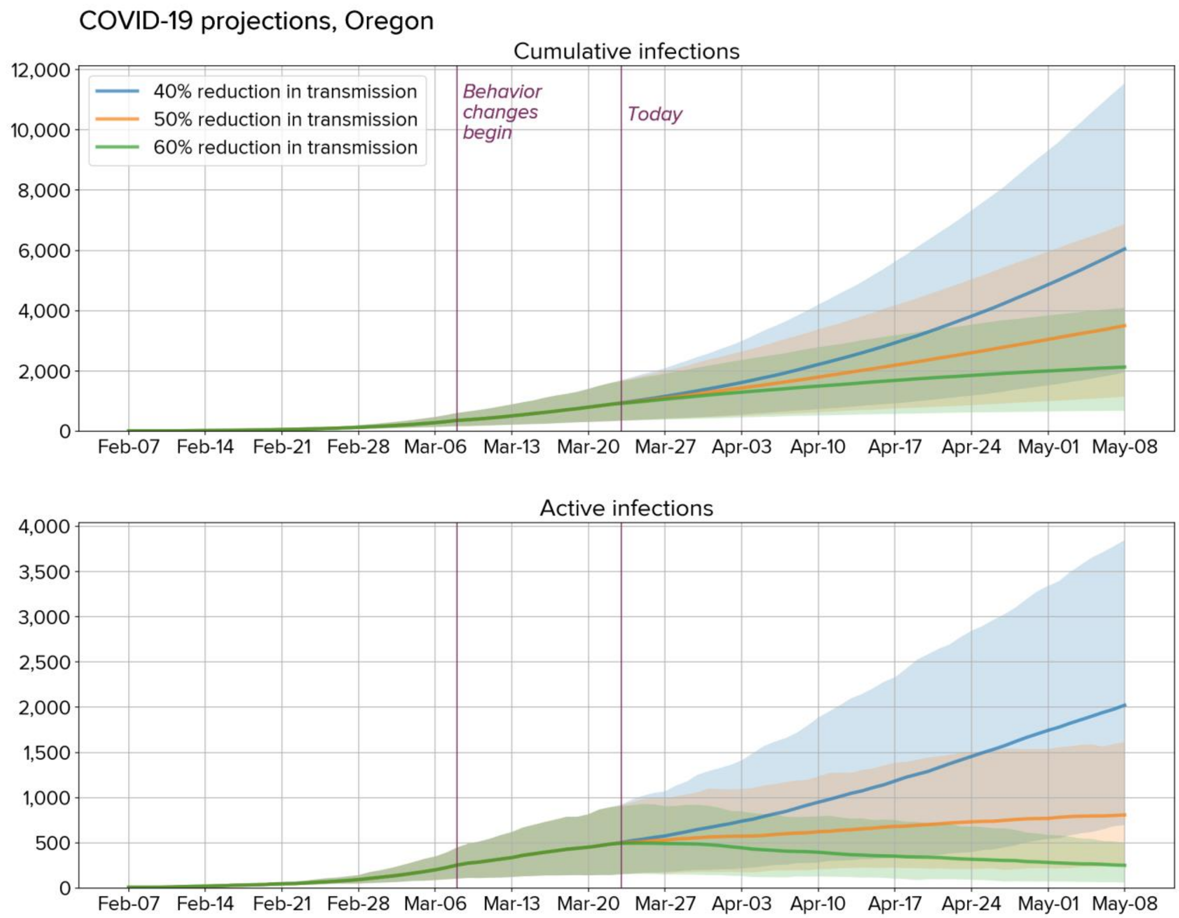

Figure 2. Sensitivity analysis of changes in transmissibility estimated to be consistent with interventions as of March 22 (40-60% reduction compared to baseline). With 40% reduction, new infections climb at a moderate rate, reaching an estimated 2000 concurrently active infections by May 8th. With 50% reduction, active infections remain relatively constant, although both significant increases and modest declines are within the uncertainty interval. With 60% reductions, active infections decline, albeit slowly, with an estimated 250 concurrently active infections by May 8th.

Under the interventions in place as of March 22, we predict the number of beds will grow slowly: 340 people will need inpatient beds (260 AAC/80 ICU) by May 8th, as shown in Figure 3. If aggressive measures implemented on March 23rd (i.e., “stay home, save lives”) are strictly adhered to, we predict that only a small number of inpatient beds will be required by May 8th, driven largely by expected importations.

It is also important to note that due to school closures and likely acquisition of COVID-19 by health workers, the true number of staffed beds may be substantially reduced in coming weeks. Furthermore, without a sustained intervention to keep the number of patients under control, capacity will likely be overwhelmed. Indeed, under a return-to-business-as-usual scenario, 1,100 people will need inpatient beds (850 AAC/250 ICU) across Oregon.

Updated modeling as the epidemic progresses, based on additional data on length of stay, hospitalization rates, and number of hospital beds that could be made available for COVID-19 patients, will be able to provide additional guidance on how long the system will be able to maintain high-quality and prompt care availability.

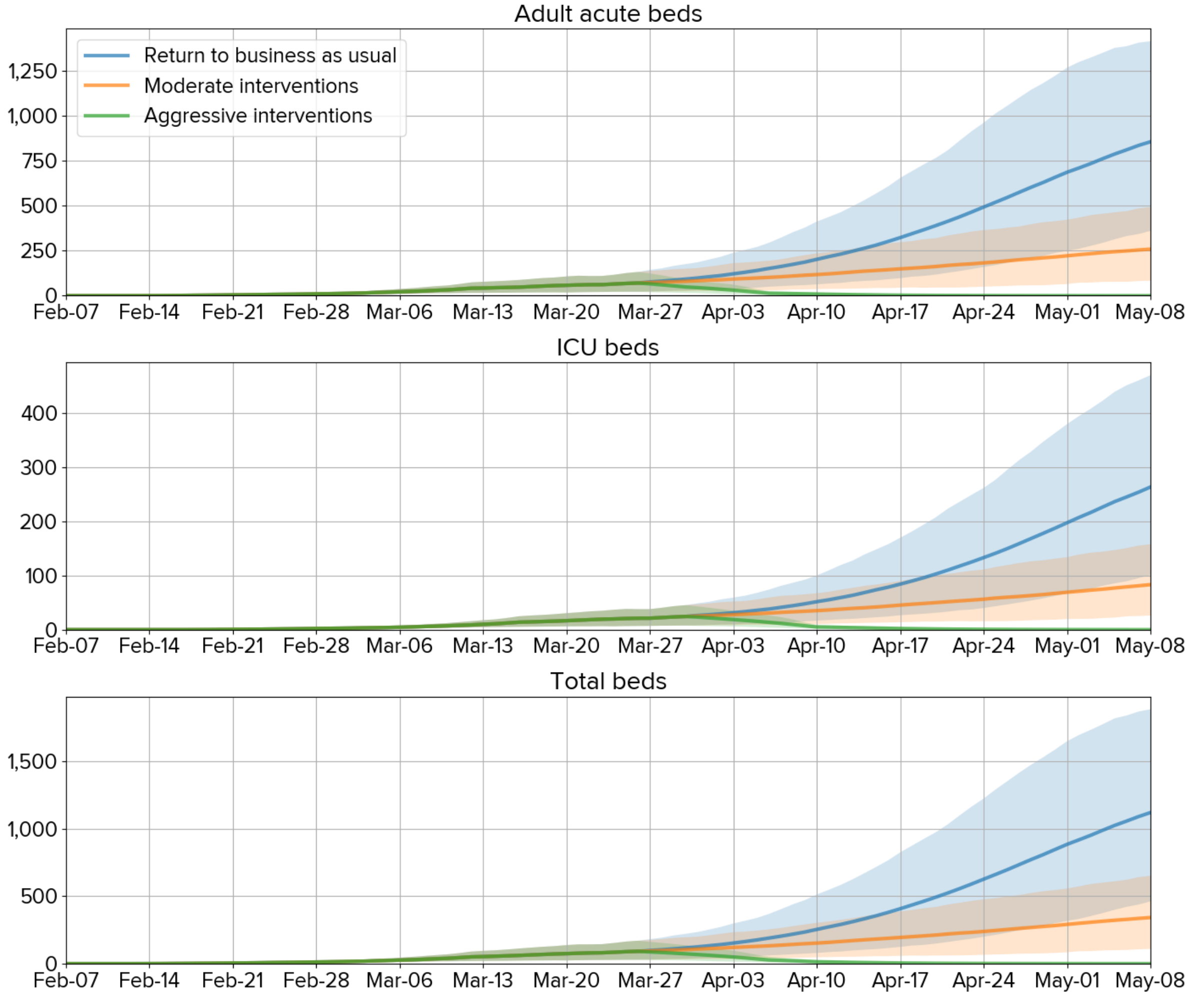

Figure 3. Projected total number of hospital beds required for COVID-19 patients in Oregon. Shaded areas correspond to 80% forecast intervals (i.e., 10th and 90th percentiles of the projection).

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 7th, and/or that multiple importation events have occurred.
- With the interventions as of March 22nd in place, we estimate that the total number of required in-patient beds will grow slowly within 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 8th, the number of active infections is predicted to keep growing unless more aggressive containment measures are in place.
- With the "stay home, save lives" (shelter-in-place) intervention announced on March 23rd in place, we predict a decrease in the number of AAC and ICU beds required, beginning April 3rd; however, this is dependent on maintenance of this intervention and high compliance (>90%). Low compliance will result in a steady increase of cases.

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.

We suggest planning for and drafting policies that would allow rapid scale-up of available healthcare capacity in the eventuality that current containment measures fail. Actions that are already being considered and implemented by hospitals and health departments include: inter-state medical professional credentialing, training additional nursing and therapist staff on respiratory care, preparing budgets and identifying sources for medical equipment purchases, identifying space for isolation and observation of low-risk patients outside of healthcare facilities, and postponing elective care where possible within the hospital's financial constraints.

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. 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 simulation begins on 2020-02-07, 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, 3-10 infected individuals are assumed by 2020-02-07. This indicates either multiple importation events, or a single importation occurring between approximately 2020-01-15 and 2020-02-01. The calibration of the model to the data is shown in Figure 4.

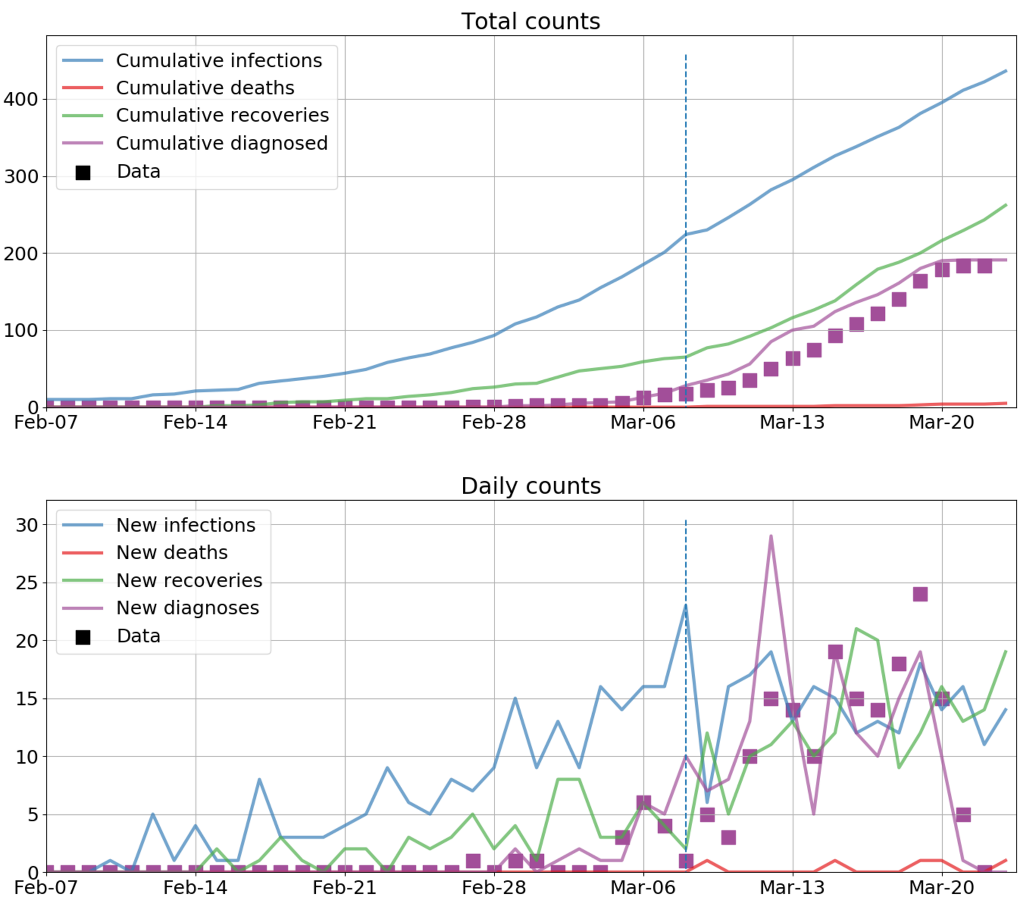

Figure 4. COVASim model outputs compared to number of tests conducted and cases diagnosed in Oregon. There is discrepancy between actual and model-estimated positive diagnoses on individual days; this is to be expected due to the small numbers of positive diagnoses on any given day. Note: testing data from March 19th-21st has not been fully reported yet, and the data points shown underestimate the true number of tests performed on each day.

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 individual 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 R0 = 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 1.6%, independent of age or other co-morbidities. Time from infection to death is drawn from a normal distribution with mean of 21 days and standard deviation of 2 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 moderate cases of 7.9-13.4 days, for moderate-severe cases of 9.4-16.0 days, and for severe cases 12.5-21.2 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 to the hospital with symptoms according to the pattern projected by the epidemiological model described above.

References

Bi Q, Wu Y, Mei S, et al. Epidemiology and transmission of COVID-19 in Shenzhen China: Analysis of 391 cases and 1,286 of their close contacts. bioRxiv. March 2020. DOI:10.1101/2020.03.03.20028423.

Bouadma L, Lescure FX, Lucet JC, Yazdanpanah Y, Timsit JF. Severe SARS-CoV-2 infections: Practical considerations and management strategy for intensivists. Intensive Care Med. February 2020. DOI:10.1007/s00134-020-05967-x.

Guan WJ, Ni ZY, Hu Y, et al. Clinical characteristics of coronavirus disease 2019 in China. N Engl J Med. February 2020. DOI:10.1056/NEJMoa2002032.

MIDAS Network. COVID-19. Cumulative case count. Available at: https://github.com/midas-network/COVID-19/tree/master/parameter_estimates/2019_novel_coronavirus. Accessed on March 13, 2020.

Riou J, Hauser A, Counotte MJ, Althaus CL. Adjusted age-specific case fatality ratio during the COVID-19 epidemic in Hubei, China, January and February 2020. bioRxiv. March 2020. DOI:10.1101/2020.03.04.20031104.

Sanche S, Lin YT, Xu C, Romero-Severson E, Hengartner N, Ke R. The novel coronavirus, 2019-nCoV, is highly contagious and more infectious than initially estimated. Epidemiology. February 2020. DOI:10.1101/2020.02.07.20021154.

Wu Z, McGoogan JM. Characteristics of and important lessons from the coronavirus disease 2019 (COVID-19) outbreak in China: Summary of a report of 72 314 cases from the Chinese Center for Disease Control and Prevention. JAMA. February 2020. DOI:10.1001/jama.2020.2648.

Yang X, Yu Y, Xu J, et al. Clinical course and outcomes of critically ill patients with SARS-CoV-2 pneumonia in Wuhan, China: A single-centered, retrospective, observational study. The Lancet. Published online: February 2020. DOI: https://doi.org/10.1016/S2213-2600(20)30079-5.

Zou L, Ruan F, Huang M, et al. SARS-CoV-2 viral load in upper respiratory specimens of infected patients. N Engl J Med. February 2020. DOI:10.1056/NEJMc2001737.