Working paper: COVID-19 intervention effectiveness and epidemic trends for Oregon

Results as of 4/22/2020, 12:15pm

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Executive Summary

Purpose of this report: 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.

Methods: This report uses available data from April 20, 2020 on confirmed positive diagnoses, number of tests completed, hospitalizations, intensive care unit (ICU) admittance, and deaths for Oregon to calibrate an agent-based COVID-19 model (Covasim), which is then used for projecting future epidemic trends.

Key Findings: We predict that there have been approximately 8,400 cumulative infections in Oregon, of which 1,900 had been diagnosed by April 16th. We estimate that current interventions have already averted over 70,000 infections, including over 1,500 hospitalizations. Current aggressive interventions will need to be maintained in order to decrease the number of active infections.

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Methods

Orpheus data on COVID-19 cases were used. Orpheus is an integrated electronic disease surveillance system for public health to manage communicable disease reports (Orpheus description). The data file was obtained on April 20th, but data after April 16th were considered incomplete because of lags in reporting.

We applied Covasim (Covasim code), an individual-based COVID-19 transmission model with parameters informed by literature (assumptions given in the Appendix). The model was calibrated by modifying the assumptions to best fit data from Orpheus on confirmed positive COVID-19 diagnoses, number of tests completed, hospitalizations (referred to as severe cases below), intensive care unit (ICU) admittance (referred to as critical cases below, and included in severe case counts), and deaths for Oregon. The model was then used for projecting future epidemic trends.

Interventions

Oregon has implemented numerous measures to slow the transmission of COVID-19 over time:

- On March 12, 2020: A large number of measures were put in place, such as bans on gatherings of more than 250 people; these are detailed here.
- On March 16, 2020: Schools were closed statewide, 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.
- On March 23, 2020: Aggressive interventions, namely the "Stay Home, Save Lives" recommendations, were put in place.

Results

From modeling results calibrated to Oregon data, we predict that there have been approximately 8,400 cumulative infections in Oregon, of which 1,900 had been diagnosed by April 16th (Figure 1).

There is evidence that Oregon's interventions -- combined with increased hygiene and other measures that appear to have begun earlier -- have dramatically reduced the burden of COVID-19 in Oregon (Figure 1). The data are consistent with a stepped reduction in transmission in Oregon, beginning with a 5% decrease in transmission by March 8th, through to a sustained 70% decrease in transmission after March 23rd. Indeed, while the interventions before March 23rd appeared to have slowed epidemic growth, the additional aggressive measures implemented on March 23rd (i.e., Stay Home, Save Lives) appear to have reversed the growth. These results are consistent with large reductions in movement as shown in Google data for Oregon (Google mobility reports).

In Figure 2, model results are shown for what would have happened if no social distancing measures were put in place. The epidemic would have continued to grow exponentially, doubling every week. By April 16th, the number of cumulative infections would have been about 80,000, including 2,000 hospitalizations. Hence, the interventions are estimated to have averted over 70,000 infections, including over 1,500 hospitalizations (450 instead of 2,000), by April 16th.

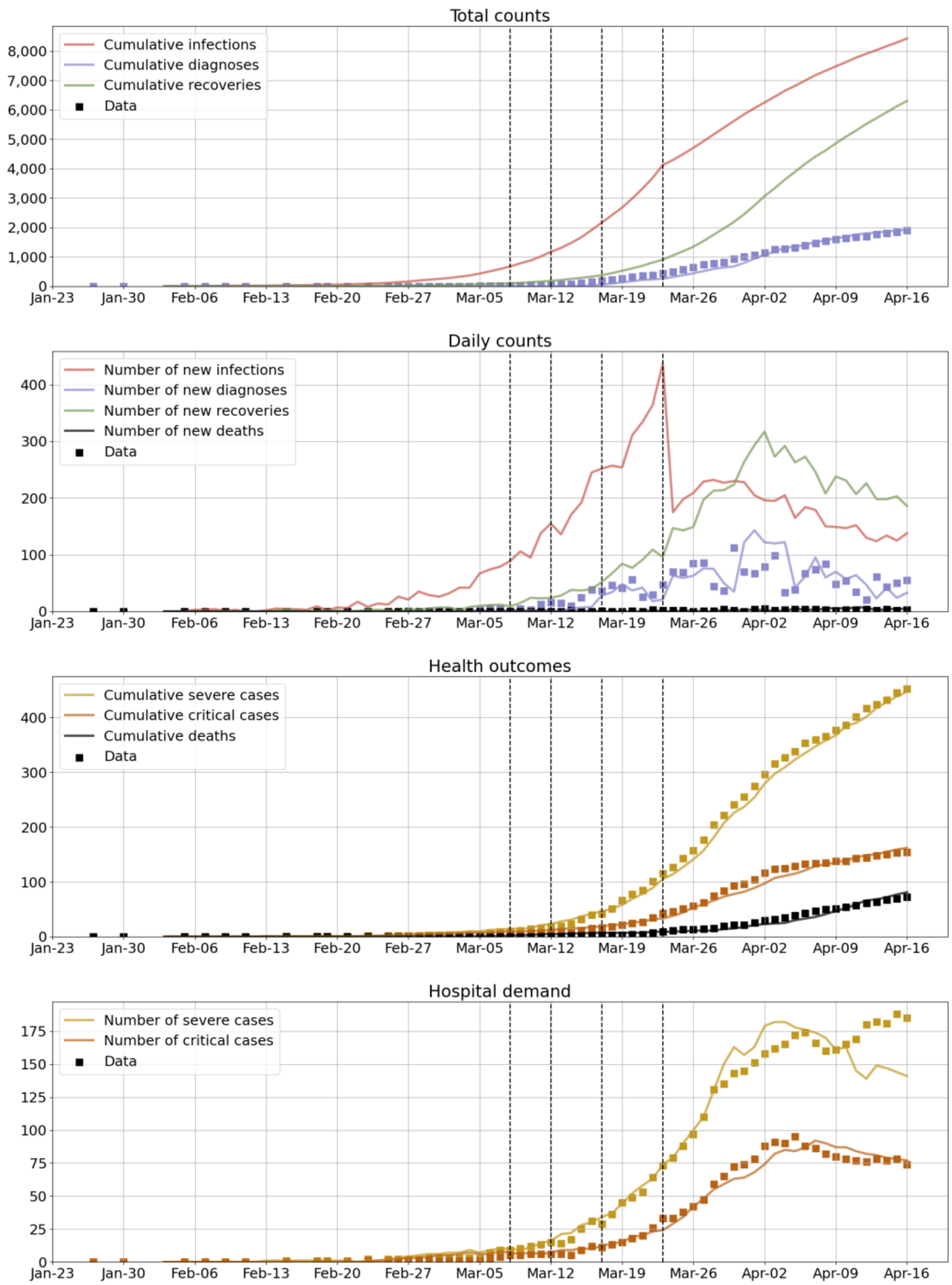

Figure 1: Best-fit model calibration with Oregon case data. Dotted vertical lines correspond to estimated reductions in transmission relative to baseline, from left to right, of 5%, 15%, 20%, and 70%. The impacts of these interventions were estimated by calibrating to numbers of positive diagnoses (squares, top two plots), plus severe (hospital) cases, critical (ICU) cases, and deaths (bottom two plots). Note that because of delays in reporting, data after April 16th were considered incomplete.

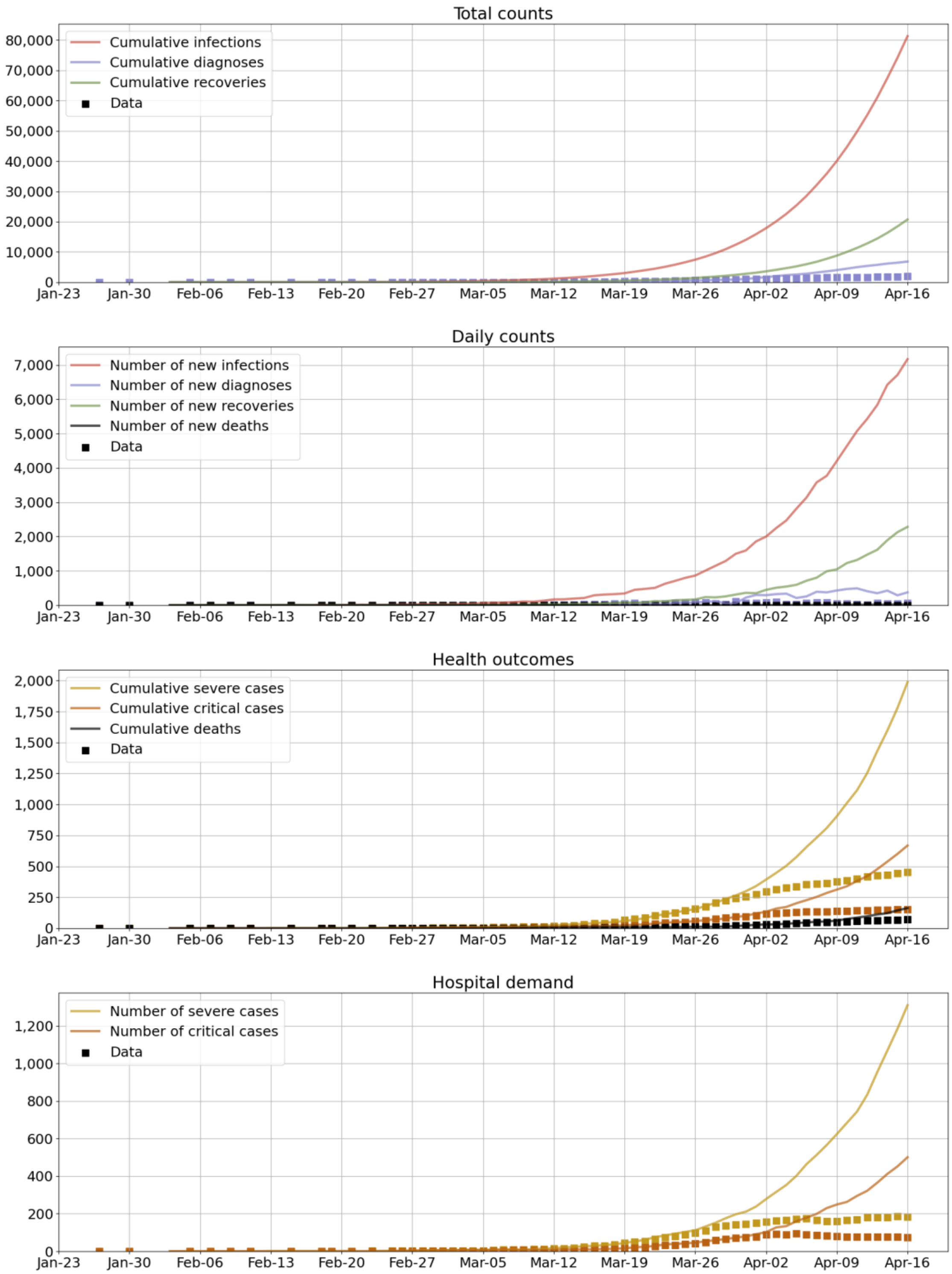

Figure 2: Model projections if no interventions were put in place, comparing the data (squares) with the model the same as in Figure 1 but with interventions removed. Data points are for the numbers of positive diagnoses (squares, top two plots), plus severe (hospital) cases, critical (ICU) cases, and deaths (bottom two plots). Note that because of delays in reporting, data after April 16th were considered incomplete.

Scenario projections

We modeled two scenarios from April 27th until May 28th:

1. "Return to moderate interventions": Interventions from March 16th to March 22nd, corresponding to an estimated 20% reduction in transmission compared to baseline, are resumed on April 27th.
2. "Aggressive interventions continue": Interventions starting March 23rd (i.e., Stay Home, Save Lives), corresponding to an estimated 70% reduction in transmission compared to baseline, are maintained.

With continued aggressive interventions, the number of cumulative infections slowly increases, while the number of active infections slowly declines over the next 6 weeks (Figure 3). However, with a return to moderate interventions, the number of infections will rapidly increase. A similar pattern is seen for hospitalizations (Figure 4). Current aggressive interventions will need to be maintained in order to decrease the number of active infections and hospitalizations.

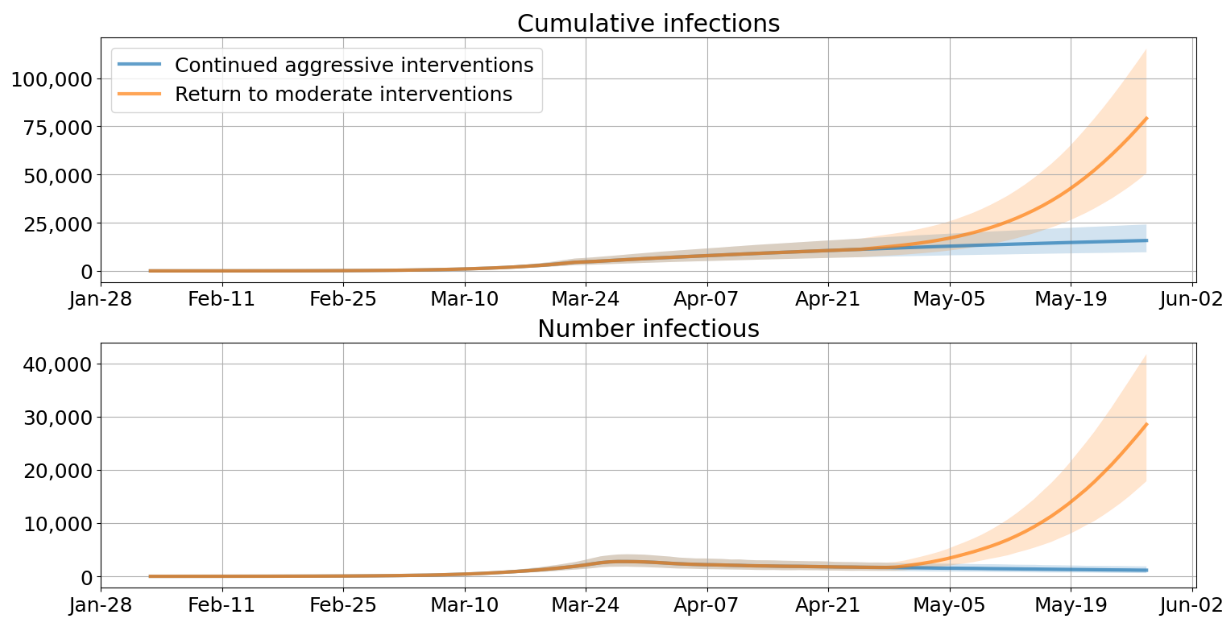

Figure 3: Model projections for the next 6 weeks assuming either a continuation of current physical distancing interventions (blue), or a return to the moderate physical distancing interventions as of March 22nd (orange).

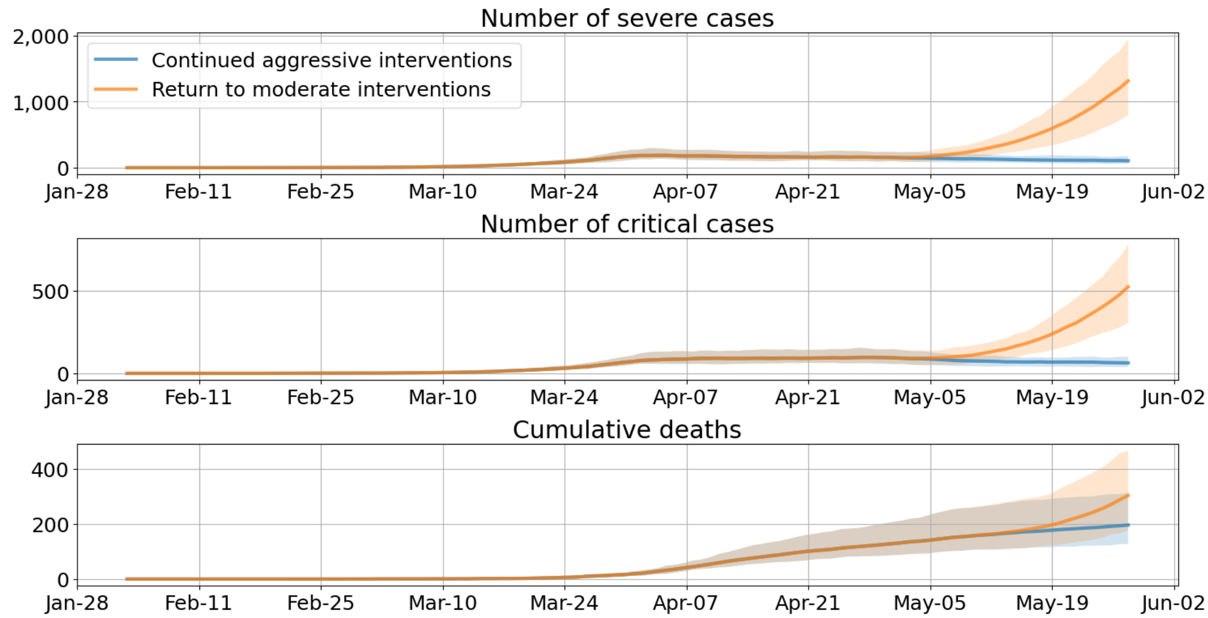

Figure 4: Model projections on hospital demand and deaths over the next 6 weeks assuming either a continuation of current physical distancing interventions (blue), or a return to the moderate physical distancing interventions as of March 22nd (orange). Top two graphs depict active cases; bottom graph depicts cumulative deaths.

Limitations

These projections should be considered preliminary and subject to change as more data become available and methods continue to improve. The projections included in this report are based on the best available local data and evidence as of April 20, 2020. However, the local collection of epidemiology data on COVID-19 cases may lag in ways we did not account for, and data improvement efforts are ongoing. In addition, there remain significant unknowns, including the current extent of social distancing, testing policies, and compliance with new interventions and how these vary throughout the state.

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. Governor Kate Brown recently announced a framework for reopening Oregon, which is consistent with these measures, and expressed her commitment to collaborating with the Washington and California Governors in developing a coordinated plan for reopening (framework).

Appendices

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 model simulated a population based on American Community Survey 2018 single-year, age-specific estimates for Oregon. The simulation begins on 2020-02-03. 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 2020-02-03. 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 (Zou et al., 2020).

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. We began by assuming the daily probability of an infectious individual infecting each neighboring susceptible individual is binomially distributed with $p = 0.015$, but modified this to 0.018 to fit the pattern in the Oregon data. 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 = 2.9. Before being diagnosed, all infected individuals with symptoms are assumed to be equally infectious; those who remain asymptomatic are assumed to be 20% less infectious. Once a case is diagnosed, they are assumed to be in isolation, so the transmission rate is assumed to be zero.

The probability of death for each infection is approximately 0.8%, dependent on age (Ferguson et al., 2020). Time from infection to death is drawn from a normal distribution with mean of 17 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 triangulated between several published sources in order to estimate starting parameters, and then modified those during the calibration process to best fit trends in the Orpheus data.

We extrapolated the symptomatic rate, the hospitalization rate, and the rate of ICU bed needs based on various sources. We assumed an overall symptomatic rate of 68%, similar to Ferguson et al (2020), and assumed the symptomatic rate was higher for older cases. Age-specific hospitalization rates were taken from Verity et al. (2020) and age-specific rates of ICU bed need from CDC COVID-19 Response Team (2020). Combining these sources and applying to the Oregon population, we estimate that 6.3% of all cases (symptomatic or not) require hospitalization and 2.0% of all cases have severe illness that requires an ICU bed as part of an inpatient stay. This translates to about 30% of hospitalized cases requiring an ICU bed, which is consistent with our local Hospital Capacity Web System (HOSCAP) data (Oregon COVID-19 Daily Update) and Bouadma et al. (2020).

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 more severe cases have longer length of stay, and that most ICU-bound patients start out in an adult acute care (AAC) bed and eventually progress to more serious symptoms that require ICU care. We reflect this in the model with length of stay for severe cases of 8 days, and for critical cases 36 days based on best fit to the data in the calibration process. Based on limited clinical data from Arentz et al. (2020), we assume that ICU-bound patients first spend one day 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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