The Current State of COVID-19 in Colorado

02/24/2021

Prepared by the Colorado COVID-19 Modeling Group

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Summary

- The effective reproduction number is close to 1 at 0.95, while transmission control has decreased to 76% from 83% last week.
- Estimated infection prevalence is estimated at 1 in 194 people in Colorado currently infectious.
- If Colorado remains on the current trajectory, state-wide hospital demand and cases will continue to decline. It will be over a month before hospital demand and infection prevalence reach levels comparable to last summer.
- In the coming months, transmission control measures will help prevent another surge in infections, hospitalizations, and deaths while the rate of vaccination increases.
- If the B.1.1.7 variant spreads rapidly in Colorado and transmission control lessens over the short-term, we could see another peak in hospital demand. In the bounding scenario with reduction of transmission control to 60% immediately and rapid spread of the variant, demand could exceed ICU capacity and approach hospital capacity.
- With regard to vaccination, increased vaccine distribution and high levels of vaccine uptake will lead to more immediate benefit and would increase the level of protection should there be a surge of the B.1.1.7 variant.
- Mobility is stable in the Denver metro area. Restaurant visits have spiked in ski regions over the long holiday weekend.

Snapshot of Current SARS-CoV-2 Transmission in Colorado Based on COVID-19 Hospitalization Data Through 02/22

Effective reproduction number: 0.95.

Infections are decreasing.

Estimated prevalence of infections: Approximately 520 of every 100,000 Coloradans or 1 in every 194 Coloradans are currently infectious.

The estimated infection prevalence is higher than last week.

Estimated number of infections to date: Approximately 27% of the Colorado population has been infected to date.

Estimated current level of transmission control: 76% for the period of 01/30 to 02/09.

There is an approximate 76% reduction in total transmission-relevant contacts, including reductions due to mask-wearing, physical distancing, contact tracing, self-isolation, and all other policy and behavioral changes compared to uncontrolled transmission, as in the very early days of the pandemic.

Snapshot of the Potential Future Trajectory of SARS-CoV-2 in Colorado

In the next two weeks: At the end of the next two weeks, there is a 50% chance that the count of patients hospitalized with COVID-19 will be approximately 310, including 100 patients in the ICU, if we remain on the current trajectory at 76% transmission control.

Introduction

We used our age-structured SEIR (susceptible-exposed-infected-recovered) model and COVID-19 hospital census data to characterize the current status of the COVID-19 epidemic in Colorado and the collective impact of efforts to date to reduce the spread of the SARS-CoV-2 virus. We use these estimates of the current state of the epidemic to generate projections of the potential future course of SARS-CoV-2 in Colorado under different scenarios of transmission control measures. These include estimates of hospital needs over the next two weeks based on the current estimated trajectory, and long-term projections that consider the impact of changes in transmission control level due to policies and/or behaviors.

The model has been parameterized to Colorado-specific data whenever possible. For example, the length of time a COVID-19 patient is assumed to spend in the hospital varies by age and over time, and is based on data provided by Colorado hospitals. Further details and a link to model documentation are provided in the appendix at the bottom of this report. The estimates presented in this report are based on hospitalization data through **02/22.**

COVID-19 Hospitalizations

Figure 1 shows the daily number of people hospitalized with COVID-19 since March 2020, when the first case of SARS-CoV-2 was reported in Colorado. COVID-19 hospitalizations are a sensitive measure of SARS-CoV-2 transmission. While many SARS-CoV-2 infections are not captured by surveillance systems, we expect that almost all COVID-19 hospitalizations are identified.

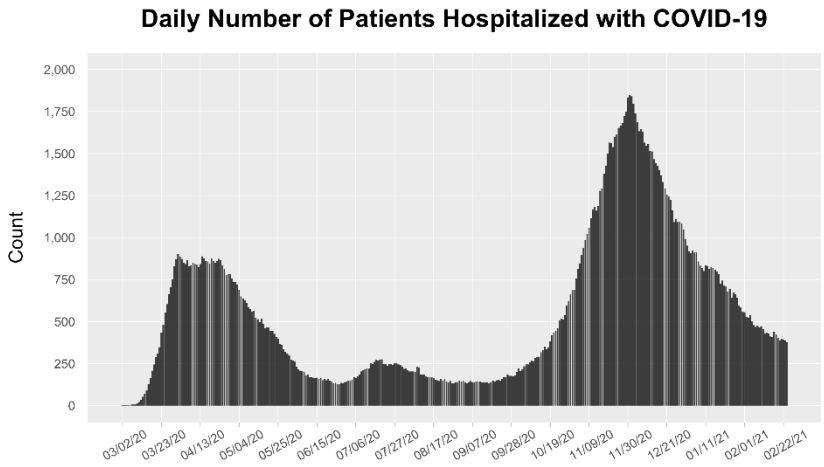


Figure 1 (above). Daily count of hospitalized COVID-19 cases through 02/22. The time series of COVID-19 hospitalizations in Colorado is based on hospitalization data provided by CDPHE through 4/07/2020 and the EMResource hospital census of COVID-19 hospitalizations starting 4/08/2020 (EMResource hospital census appeared to undercount COVID-19 hospitalizations before that date).

Transmission Control

Transmission control is an estimate of the collective impact of behaviors and policies such as mask wearing, physical distancing, case isolation, contact tracing, and moving activities outside. When transmission control is 0%,

spread of infections is uncontrolled, as in the very early days of the pandemic. When transmission control is close to 100%, the spread of the virus from an infected person to others is rare. We estimate transmission control for each two-week period since March (Figure 2). Transmission control is estimated by fitting model output to hospitalization data using model fitting approaches.

Our current estimate of transmission control is 76% (95% CI: 71.6%, 79.9%). This estimate is for the period 01/30 to 02/09, given the timespan between infection and hospitalization.

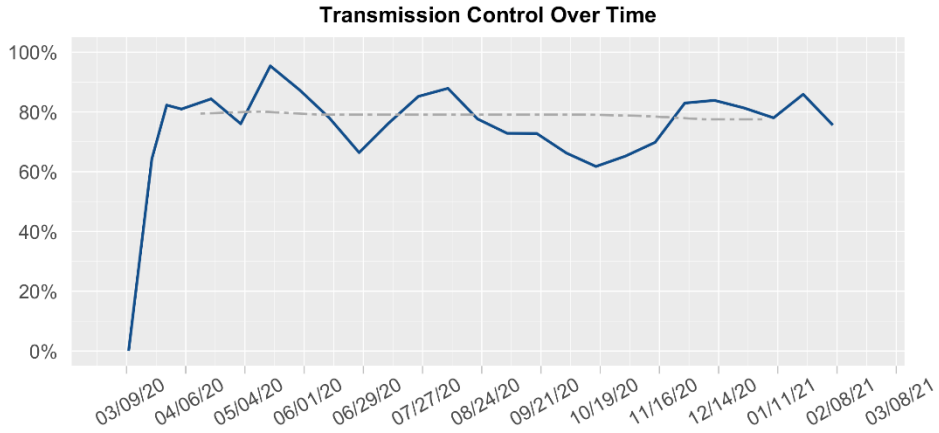


Figure 2 (above). The estimated transmission control value for each two-week period since the beginning of the epidemic. On the graph, the value is shown for the mid-point of each two-week period. Transmission control is estimated using model fitting approaches to align model output with COVID-19 hospitalizations. The grey dashed line indicates the estimated value of TC at which the effective reproduction number Re crosses 1.

Model Fit

We assess model fit by comparing the model-estimated number of hospitalizations to actual hospitalizations. Figure 3 shows the current estimated trajectory of hospitalizations, based on the most recent model-fit, compared to the daily reported number of people hospitalized with COVID-19. For reference, a line showing the estimated trajectory one-week prior is also shown. A figure showing model fit since the beginning of the pandemic is provided in the appendix.

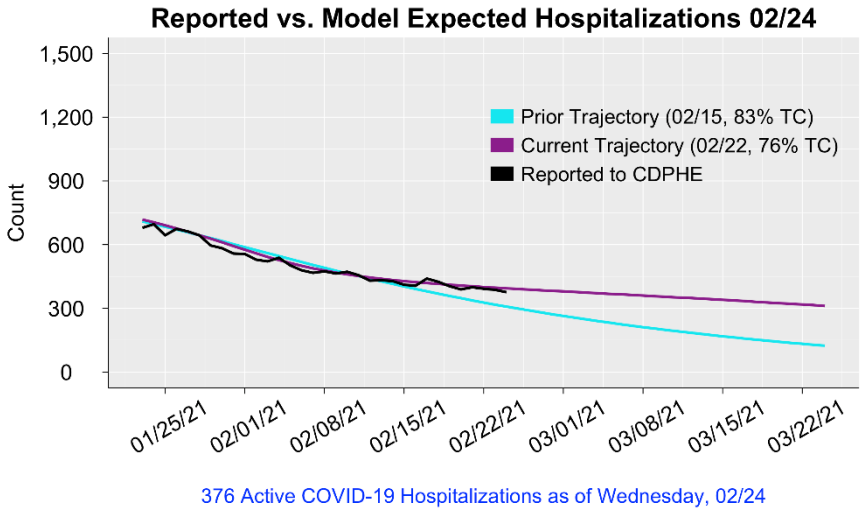


Figure 3 (above). The projected course of COVID-19 hospitalizations if Colorado were to remain on the current estimated trajectory (purple line) or on the trajectory estimated one week prior (turquoise line). Each trajectory is generated assuming Colorado rolls out vaccines on schedule, as described in the long-term projections.

The Effective Reproduction Number

The effective reproduction number (Re) is a measure of how rapidly infections are spreading or declining. When the effective reproduction number is below 1, infections are decreasing. When the effective reproduction number is above 1, infections are increasing. The effective reproduction number is estimated using our age-structured SEIR model fit to hospitalization data.

Our current estimate of Re is 0.95. Due to the lag between infections and hospitalizations, this estimate of Re reflects the spread of infections occurring on approximately 02/09. The estimated values of the reproduction number since March are shown in Figure 4 and the most recent three estimates are presented in Table 1.

Table 1 (below). Estimates of the effective reproduction number (Re) in Colorado over the last three weeks based on the SEIR model. As of 01/31/2021, estimates from RT-Live have been decommissioned and are no longer being used as an external reference for this report.

	Current Estimate (02/22)	Estimate One Week Prior (02/15)	Estimate Two Weeks Prior (02/08)
Approach 1*	0.95 (0.80, 1.1)	0.68 (0.59, 0.75)	0.60 (0.47, 0.73)
Approach 2*	0.94	0.65	0.65

*Our estimates are based on hospitalization data through the date listed. Estimates from the external sites are extracted on the date listed. Due to the lag between infection and hospitalization, our estimates reflect transmission approximately 13 days prior to the date listed. Approach 1 uses model output to estimate the average number of new cases generated by existing cases, accounting for the latent period and duration of infectiousness. The second method uses the model structure to estimate the dominant eigenvalue for a matrix describing population flows across the model compartments.

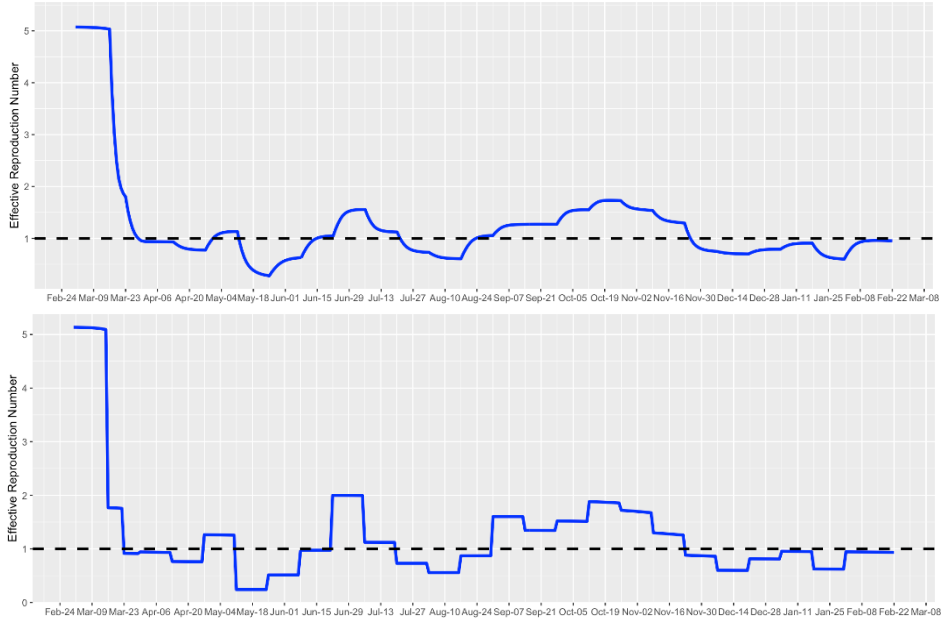


Figure 4 (above). Estimates of the effective reproduction number over time, using approach 1 (top) and approach 2 (bottom) based on the TC model.

Infection Prevalence

Infection prevalence provides an estimate of the proportion of the population that is currently (as of 02/22) infected with SARS-CoV-2 and capable of spreading infections. At higher levels of infection prevalence, susceptible individuals are more likely to encounter infectious individuals among their contacts. Because many people experience no symptoms or mild symptoms of COVID-19, many infections are not identified by surveillance systems. The estimates we present here are intended to provide an approximation of all infections, including those detected and not detected by the Colorado Electronic Disease Reporting System (CEDRS).

Infection prevalence is estimated using our age-structured SEIR model fit to hospitalization data. These estimates are generated by assuming the most recent transmission control parameter (estimated for the period 01/30 to 02/09) remains at the estimated value through 02/22. These estimates are sensitive to the model assumptions, including assumptions about the probability an infected individual will be symptomatic and require hospital care, and assumptions about length of hospital stay, which vary over time; we assume that all variables vary by age category.

We estimate that there are approximately 30,100 (95% CI: 24,400, 35,600) infectious individuals in Colorado at present (02/22): approximately 520 (95% CI: 418, 610) of every 100,000 Coloradoans or 1 in every 194 people (95% CI: 164, 240).

Figure 5 illustrates the estimated infection prevalence over time.

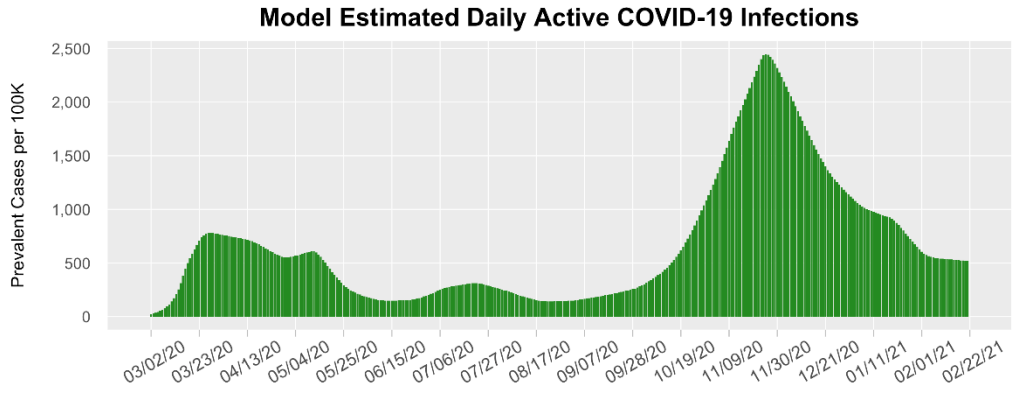


Figure 5 (above). Estimated daily number of people who are infectious and infected with SARS-CoV-2 (point prevalence). Estimate is shown per 100,000 population. The number of infectious individuals is inferred using the model and based on hospitalizations.

Case Detection

Comparing observed to model-estimated infections, **we estimate that approximately 33% of infections were detected by state surveillance systems, including both asymptomatic and symptomatic infections in the two-week period from 01/30 to 02/12 (Figure 6).**

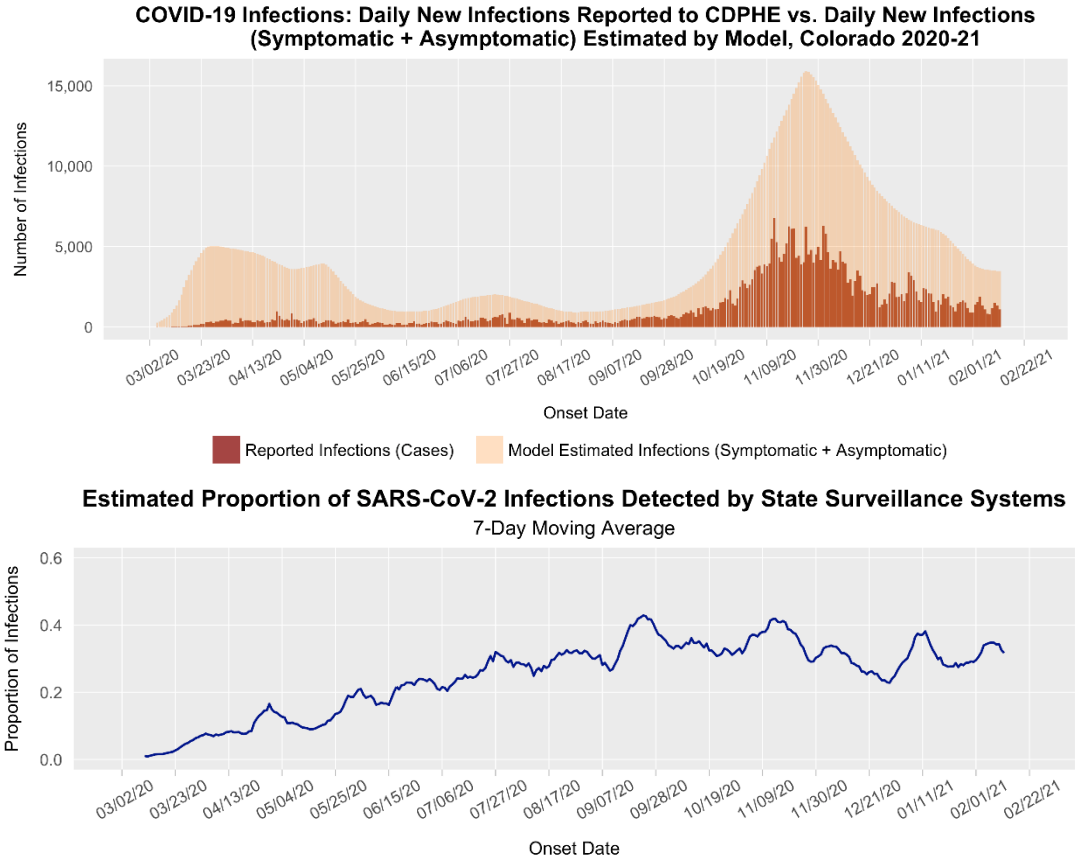


Figure 6 (above). Estimated daily number of new (incident) SARS-CoV-2 infections based on the total estimated by the SEIR model (light orange graph) and reported cases (dark orange graph) over time shown in the top panel. Lower panel shows the 7-day moving average of the estimated proportion of SARS-COV2 infections that are being captured by Colorado state surveillance systems, over time. The proportion detected is estimated by dividing the total number of new cases captured by state surveillance systems by the model-estimated number of new infections each day. The number of cases captured by the state surveillance systems is the number of cases reported by CDPHE, using the onset date of symptoms (if onset date is not available, onset date is imputed by CDPHE using a proxy distribution of recent onset dates). Data are shown through 02/12 to account for typical lags between symptom onset and case report.

Population Immunity

People can develop immunity to SARS-CoV-2 by vaccination and by prior infection. The proportion of the population immune is an important measure because as more people develop immunity, the spread of infections slows. When many people are immune, infectious individuals are less likely to encounter individuals who are still susceptible to infection (not immune).

Figure 7 shows the proportion of the population immune over time, estimated using our age-structured SEIR model and data on vaccinations in Colorado provided by CDPHE. This estimate has two components. It accounts for the number of people estimated to be immune due to vaccination. In the model, the vaccines are assumed to confer 33% immunity 14 days after the first dose, and 90% immunity one week after the second dose. Vaccination data are provided by CDPHE and we assume all individuals who receive first doses also received second doses on schedule. It also accounts for the number of people estimated to have immunity due to prior infection. In our model, immunity from symptomatic infection is assumed to last approximately one year, and immunity from asymptomatic infection is assumed to last approximately six months. We include both detected and undetected infections. Our estimates account for overlap between the vaccinated population and those with immunity due to prior infection. We note that recent studies suggest vaccinations boost immunity in those previously infected.

We estimate that approximately 1,267,000 people in Colorado, or 22% of the Colorado population, are currently immune to SARS-CoV-2 as of 02/22.

In addition, we provide an estimate of the cumulative number of infections, noting that some people who were infected early in the pandemic may no longer be immune to infection unless they have been vaccinated. **We estimate that approximately 1,585,000 (95% CI: 1,575,000, 1,594,000) people in Colorado, or 27% (95% CI: 27%, 27.3%) of the population, have been infected to date (02/22).**

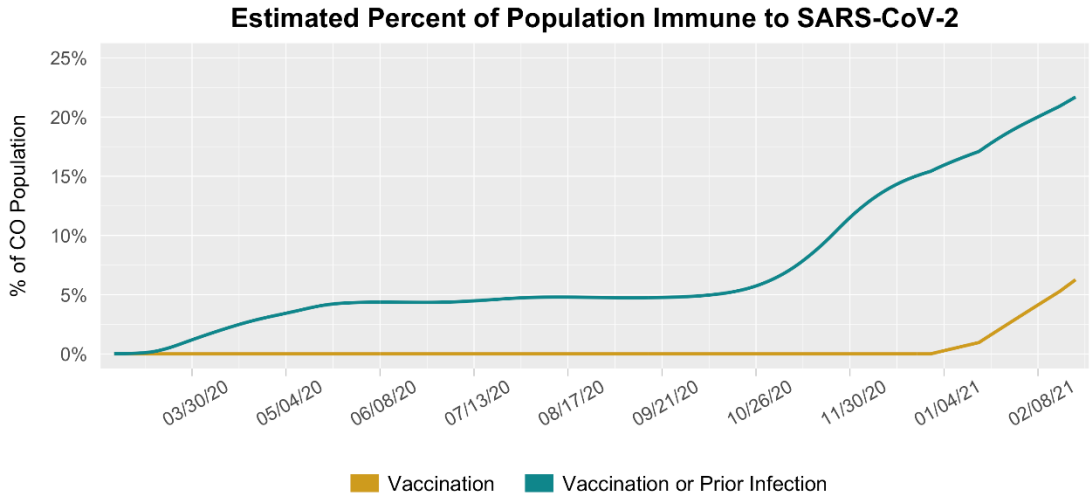


Figure 7 (above). Estimated percent of the population in Colorado assumed to be immune to COVID-19 due to infection and/or vaccination through 02/22. This estimate excludes individuals with prior infection who are no longer immune.

Reported Infections and Hospitalizations by Age and Race/Ethnicity

Like many infectious diseases, COVID-19 is not equally distributed across the population. Some groups may face higher exposures and/or more severe health effects. We use reported case and hospitalization data provided by CDPHE to examine the distribution of infections and hospitalizations by age group, as well as by race and ethnicity. Age groups are defined to align with the four age groups used in the model.

Reported SARS-CoV-2 Cases by Age Group. Figure 8 shows the 7-day moving average of reported new SARS-CoV-2 infections by age group.

People under age 40 account for 59% of reported SARS-CoV-2 cases in the two weeks between 02/01 and 02/15.

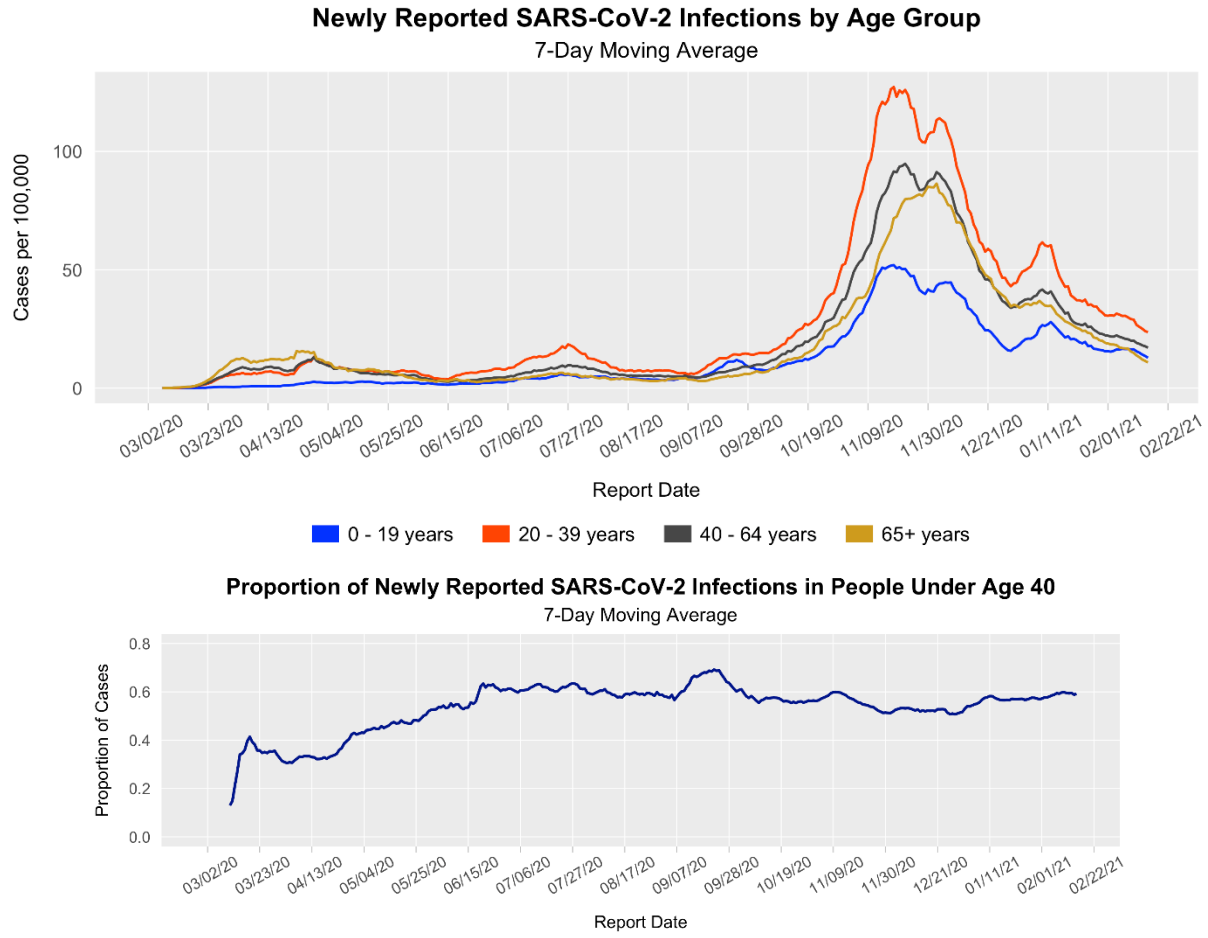


Figure 8 (above). Distribution of 7-day moving average of newly reported SARS-CoV-2 infections by age group (top) and the proportion of all cases among individuals under 40 (bottom). Reported cases are based on CDPHE data and shown by report date. Incident cases per 100,000 were obtained by standardizing weekly reported age-specific case and hospitalization counts to the Colorado population distribution by age, gathered from the Colorado Census 2020 estimates. Data are shown through 02/15, to account for typical lags in collection of age data for reported cases.

COVID-19 Hospitalizations by Age Group. Figure 9 shows the daily count of individuals hospitalized with COVID-19 by age group from March through the present, based on COVID Patient Hospitalization Surveillance (COPHS) provided by CDPHE. Due to lags in reporting, COPHS data include hospitalizations through 02/18.

People under age 40 account for **15%**, people age 40 to 64 account for **37%**, and people age 65+ account for **48%** of COVID-19 hospital use over the two weeks between 02/05 and 02/18.

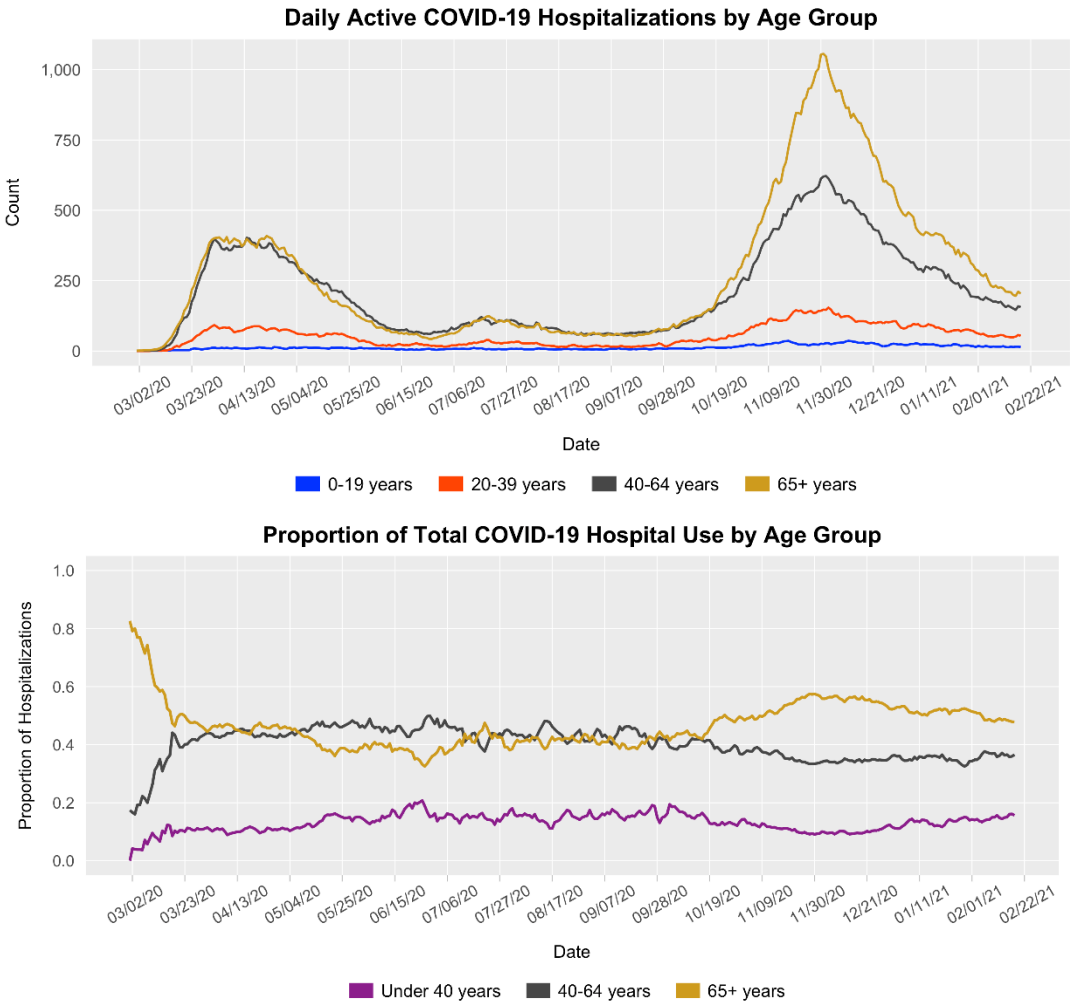


Figure 9 (above). The number of individuals hospitalized with COVID-19 by age group from March through the present (top) and the proportion of COVID-19 hospital beds occupied by individuals under 40 years, 40-64 years, and 65+ years (bottom). Data based on COVID Patient Hospitalization Surveillance (COPHS) through 02/18.

COVID-19 Reported Cases by Race/Ethnicity. Figure 10 shows the number of reported cases by race/ethnicity from March through the present.

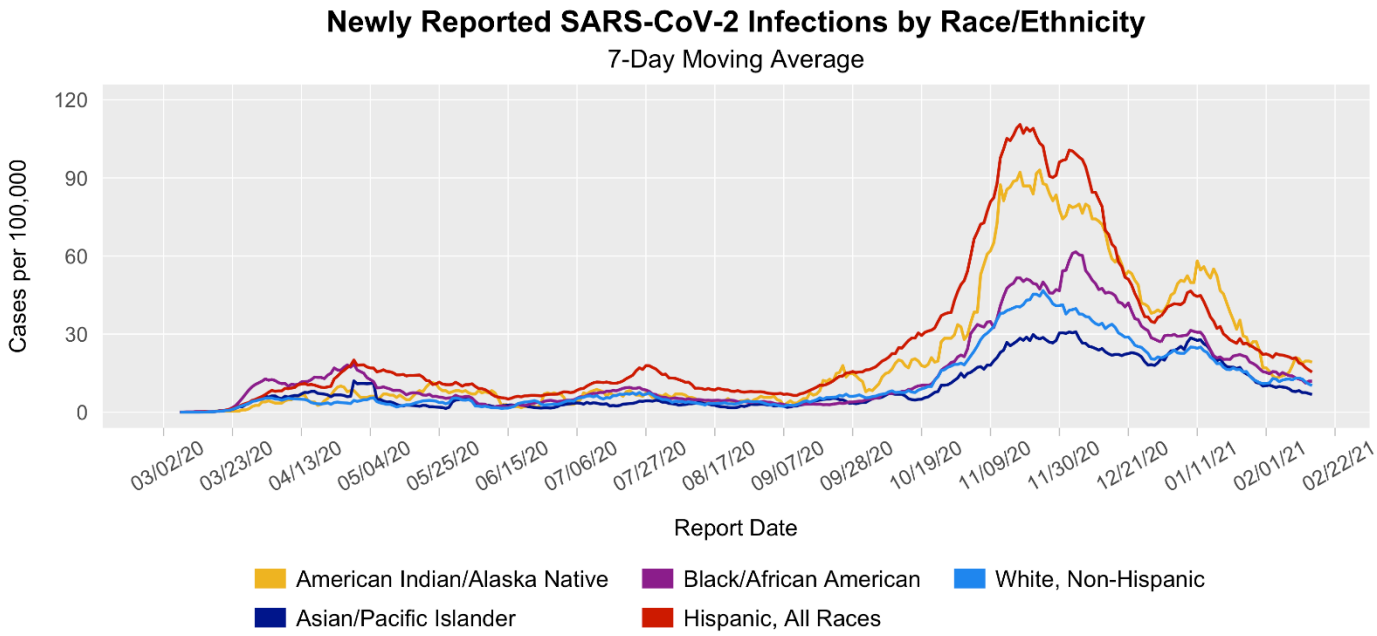


Figure 10 (above). Distribution of 7-day moving average of newly reported SARS-CoV-2 infections by race and ethnicity in Colorado. Reported cases are based on CDPHE data and shown by report date. Cases per 100,000 were obtained by standardizing weekly reported race-specific case counts to the race/ethnicity distribution of the state of Colorado gathered from the CDPHE COVID-19 Case Summary Dashboard. These standardized estimates combine Asian and Native Hawaiian/Pacific Islander races and exclude Other/Unknown races (which account for **21%** of observations over the last two weeks). Data is shown through 02/15 to account for lags in collection of race/ethnicity data for reported cases.

Mobility

To investigate the impact of mobility on COVID-19 transmission, we analyze time away from home using SafeGraph mobile device tracking data. Figure 10 displays daily hours away from home from January 01, 2020 to February 11, 2021 in the Denver metro area (Adams, Arapahoe, Boulder, Broomfield, Denver, Douglas, and Jefferson counties) as well as the rest of Colorado. The faint lines display the daily data while the thick lines represent a smoothed average of the data over time. We also include estimates of the mean daily population-weighted temperature over time from gridMET to explore the relationship between weather and mobility. Figure 11 shows that statewide time away from home dramatically decreased in March, 2020 when the pandemic began. Time away from home gradually increased as the weather warmed and restrictions were relaxed in the summer. As the weather cooled and cases rose in the state, time away from home fell through December, but is currently increasing, especially in the non-metro areas. To enhance privacy, SafeGraph excludes Census Block Group (CBG) information if fewer than five devices are observed on any day. SafeGraph determines a device's CBG of residence by calculating the most common evening location over the past six weeks.

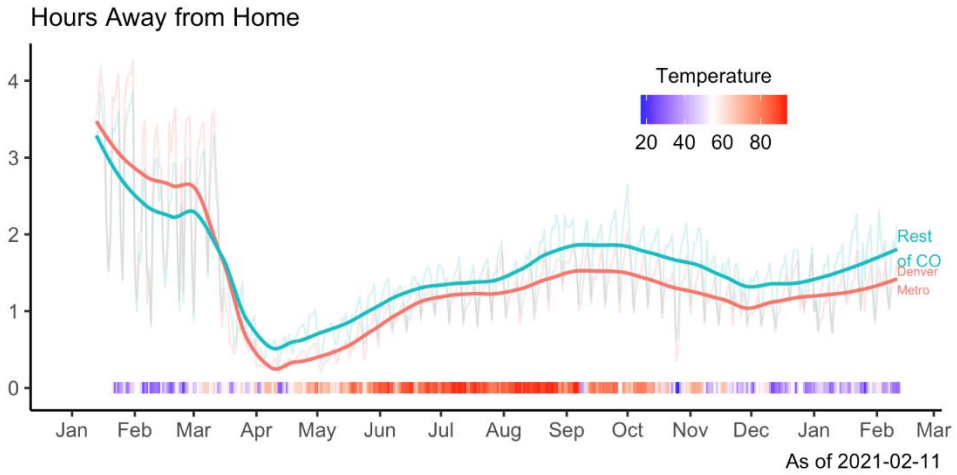


Figure 11 (above). Daily hours away from home (SafeGraph) is averaged across census block groups within the two regions. The faint lines show the daily data, and the thick lines represent a smoothed average over time. The ribbon below the time away from home displays the population-weighted mean daily temperature across the state from gridMET.

Near-Term Forecast

We generated estimated hospital and ICU demand over the next two weeks assuming Colorado remains on the current trajectory and accounting for uncertainty in our current estimated trajectory (Figure 12). **In two weeks on 03/09, there is a 50% chance that approximately 314 patients will be hospitalized with COVID-19, including 102 patients in the ICU, if we remain on the current trajectory.**

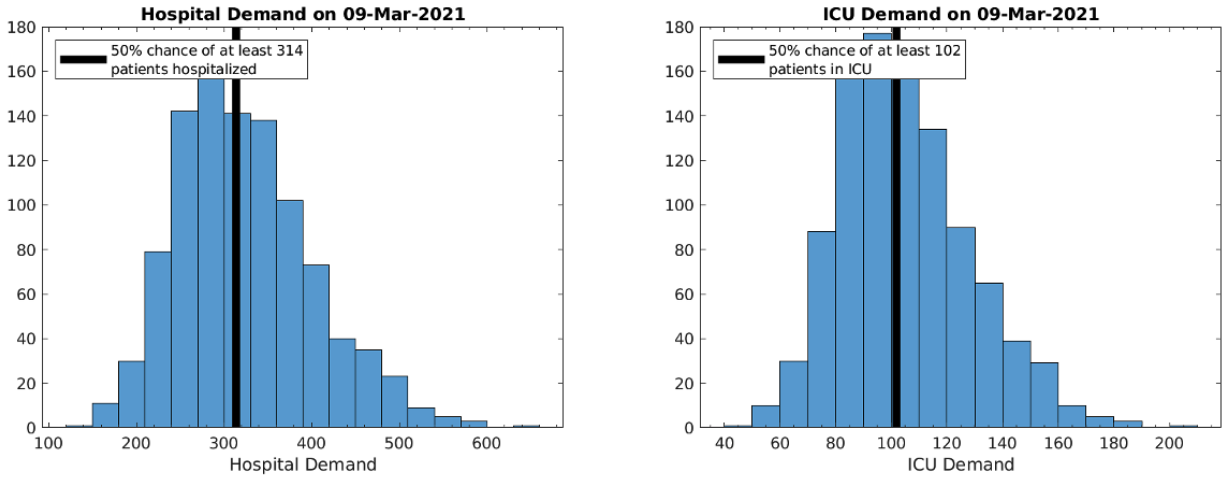


Figure 12 (above). Probability distribution of the number of hospitalized COVID-19 patients (left) and COVID-19 patients requiring ICU care (right) in two weeks if Colorado remains on the current trajectory These estimates account for vaccination under Vaccine Scenario I, but do not account for the B.1.1.7 variant. Estimates are based on 10,000 simulated runs of the model, with 1,000 of those runs randomly selected for visualization.

Long-Term Projections

We generate projections of future infections, hospital demand and deaths under different vaccine rollout strategies given different levels of transmission control and the B.1.1.7 variant. The potential impacts of the variant depend on the initial level of transmission control, and the spread of the more infectious variant can lead to an apparent decrease in transmission control without changes in policy or behavior. There is considerable uncertainty about how policies and behaviors over the last few weeks will influence the course of the epidemic, how rapidly the B.1.1.7 will spread in Colorado, and how rapidly the vaccine will be administered.

Vaccination. In our projections, we investigate the impact of two potential vaccine rollout strategies as well as differences in vaccine uptake.

- **Vaccine scenario I.** Under this strategy, approximately 40% of the Colorado population receives at least a first dose of a vaccine by 06/01. This includes an approximately 25% increase in the availability of the Pfizer and Moderna vaccines starting March 1st as well as the introduction of the Johnson & Johnson single-dose vaccine on March 1st. [Details: From 03/01-06/01, vaccinate 127,108 individuals weekly with the Pfizer or Moderna vaccines and 45,000 individuals weekly with the Johnson & Johnson vaccine.]
- **Vaccine scenario III.** Under this scenario, 70-89% of the Colorado population receives at least a first dose of a vaccine by 06/01. This includes and approximately 35% increase in the availability of the Pfizer and Moderna vaccines starting March 1st, and twice the amount of Johnson & Johnson vaccine starting March 1st. Starting April 15th, the Pfizer and Moderna vaccine supply more than doubles and the AstraZeneca two-dose vaccine is introduced. [Details: From 03/01-04/15, vaccinate 135,108 individuals weekly with the Pfizer or Moderna vaccines and from 04/15-07/01, increase to 235,108 weekly through the federal pharmacy program. From 03/01-07/01, vaccinate 90,000 individuals weekly with the Johnson & Johnson vaccine. From 04/15-07/01, vaccinate 22,500 individuals weekly with the AstraZeneca vaccine.]

For each scenario we model a maximum of either 70% or 80% uptake in each age group. Vaccination rates in the projections occur at current age-specific rates which currently prioritizes the oldest age groups. Once the oldest age groups are vaccinated up to the threshold, vaccine is then allocated to the next oldest age group (Details of the vaccine allocation are provided in Appendix Table A3).

We note that in the Vaccine III scenario, if we assume 70% uptake by age group, there is unused vaccine on June 1st.

In regards to vaccination, we take into consideration the following:

- We assume all individuals who receive a first dose of a two-dose vaccine (Pfizer, Moderna, or AstraZeneca) receive a second dose on schedule.
- In the model, we represent the efficacy of single and double doses by assuming that among individuals who receive any two-dose vaccine (Pfizer, Moderna, or AstraZeneca), a collective 33% of individuals enter the vaccinated compartment (indicating complete immunity) 14 days after the first dose, and an additional 57% of individuals enter the vaccinated compartment (indicating complete immunity) 32 days after the first dose for a total of 90% of individuals achieving complete immunity through vaccination.
- In the model, we represent the efficacy of the Johnson & Johnson vaccine by assuming that a collective 72% of individuals receiving this vaccine will enter the vaccinated compartment (indicating complete immunity) 28 days after dosing.
- We assume that individuals will be vaccinated regardless of prior infection history. Any individual can receive a vaccine, although vaccination is assumed to have no effect on individuals currently infected.

Transmission Control. Scenarios were developed to examine the potential impact of decreases in transmission control. The scenarios include a reduction of transmission control to 70% and 60% on Friday, 02/26, in comparison to remaining on the current trajectory. Changes in transmission control occur when people have more contacts which can be due to changes in policy and/or behavior.

New Variants. The current scientific evidence indicates that the new B.1.1.7 variant is approximately 50% more infectious than the currently circulating variants. In the United Kingdom, the variant spread rapidly and is estimated to be causing over 90% of new infections. Recent CDC models as well as genomic surveillance in the US suggest that the variant may rapidly become the dominant strain in the US. In light of this, the B.1.1.7 variant scenario has been updated to model rapid growth of the variant in Colorado, akin to the growth in of the variant in the UK. In addition, there is emerging evidence that the B.1.1.7 variant causes more severe disease. The New and Emerging Respiratory Virus Threats Advisory Group, NERVTAG, concluded "it is likely that infection with VOC B.1.1.7 is associated with an increased risk of hospitalization and death compared to infection with non-VOC viruses" (NERVTAG 02/11/2021). Based on these reports, in the B.1.1.7 scenario, we make the following assumptions:

- The variant is assumed to be 1.5 times more infectious than current circulating variants.
- The amount of variant in the Colorado population is assumed to be 2% on 2/9. In reality, we do not know the true fraction of cases caused by the B.1.1.7 variant in Colorado.
- The variant is assumed to follow an S-shaped logistic growth curve such that the variant comprises 50% of infections by mid-March and approaches the maximum of 95% in mid-May. In reality, we do not know how quickly the variant will spread in Colorado.
- Infection with B117 variant confers a 1.4-fold increased risk of hospitalization and a 1.4-fold increased risk of death among those hospitalized for those age 40+
- Infection with B117 variant confers a 1.7-fold increase in the risk of death among cases not hospitalized and age 40+
- The impact of the variant is modeled as a decrease in transmission control due to both the infectiousness of the variant and the distribution of the variant (e.g. the proportion of all infections due to the variant).

We note that the science is evolving rapidly, and several variants of concern have been identified in the US. We are monitoring this closely and will adapt these scenarios as the science evolves and more information is available on the distribution of these variants.

Hospital Demand on the Current Trajectory. Figure 13 shows the range of estimated hospital and ICU demand in four weeks, on 03/23. Figure 14 shows long-term projections of estimated hospitalizations and cumulative mortality on our current trajectory under Vaccine I and 70% uptake, assuming no increase in the presence of B.1.1.7.

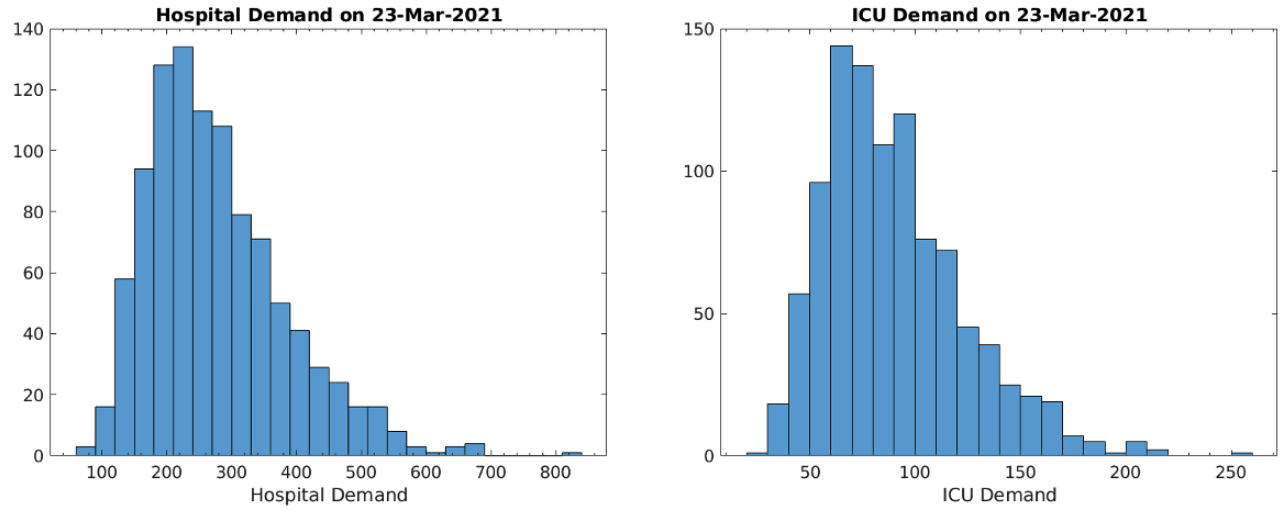


Figure 13 (above). Probability distribution of the number of hospitalized COVID-19 patients (left) and COVID-19 patients requiring ICU care (right) in four weeks if Colorado remains on the current trajectory. These estimates account for vaccination under Vaccine I, but do not account for the B.1.1.7 variant. Estimates are based on 10,000 simulated runs of the model, with 1,000 of those runs randomly selected for visualization.

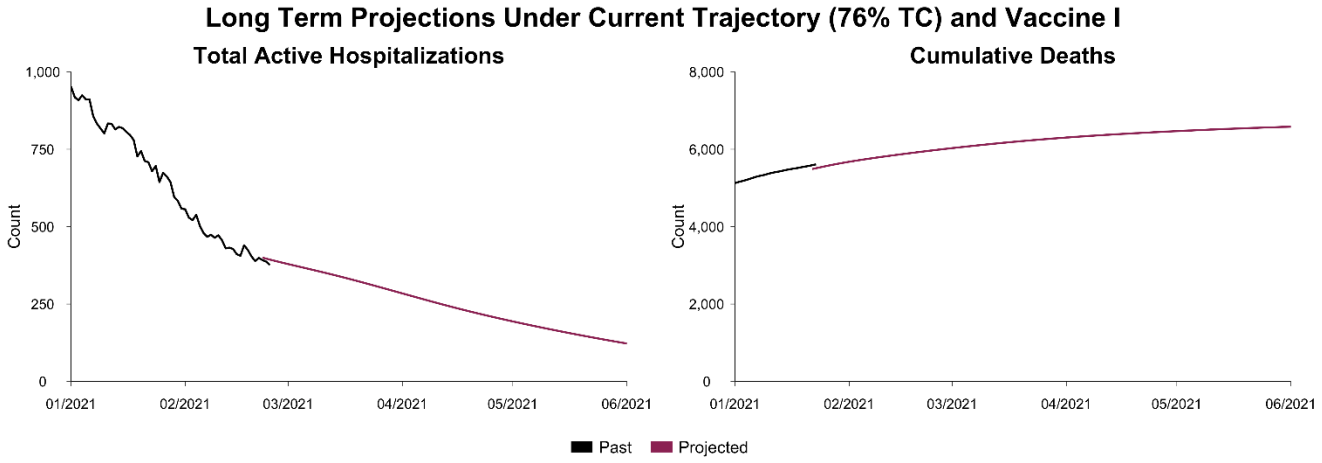


Figure 14 (above). Projected total number of patients actively hospitalized for COVID-19 (left) and projected cumulative deaths through early June 2021, assuming transmission control remains at the current levels (76% TC) indefinitely. Black lines indicating historical data reflect observed hospitalizations reported in EMR and observed cumulative deaths gathered from the CEDRS line list provided by CDPHE. Observed deaths are shown through 01/23 to account for lags in reporting.

Hospital Demand and Cumulative Mortality Under Vaccine I with Immediate Changes to Transmission Control. Figure 15 shows the projected active hospitalizations and cumulative deaths through early June 2021, if Colorado remains on its current trajectory (76% TC) or switches to 70% or 60% indefinitely on Friday, 02/26 under Vaccine Strategy I. This projection does not account for a potential increase in the B.1.1.7 variant.

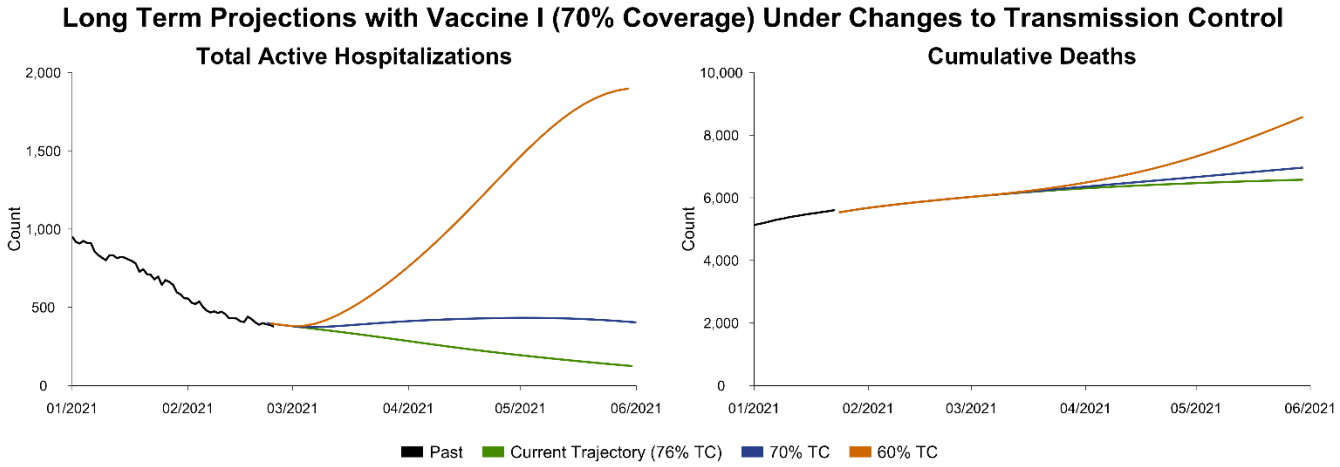


Figure 15 (above). Projected active hospitalizations and cumulative deaths through early June 2021, assuming Colorado remains on its current trajectory (76% TC) as indicated by the green lines, or switches to 70% TC (blue lines) or 60% TC (orange lines) beginning Friday, 02/26. Black lines indicating historical data reflect observed hospitalizations reported in EMR and observed cumulative deaths gathered from the CEDRS line list provided by CDPHE. Observed deaths are shown through 01/23 to account for lags in reporting. These projections assume 70% uptake of the vaccine by age group.

Hospital Demand and Cumulative Mortality at 70% Transmission Control with 70% or 80% Vaccine Coverage. Figure 16 shows the projected active hospitalizations and cumulative deaths through early June 2021, if Colorado switches to 70% indefinitely on Friday, 02/26, comparing Vaccine Strategies I and III. Within each strategy, the impacts of 70% and 80% vaccine coverage levels are compared. This projection does not account for an increase in B.1.1.7.

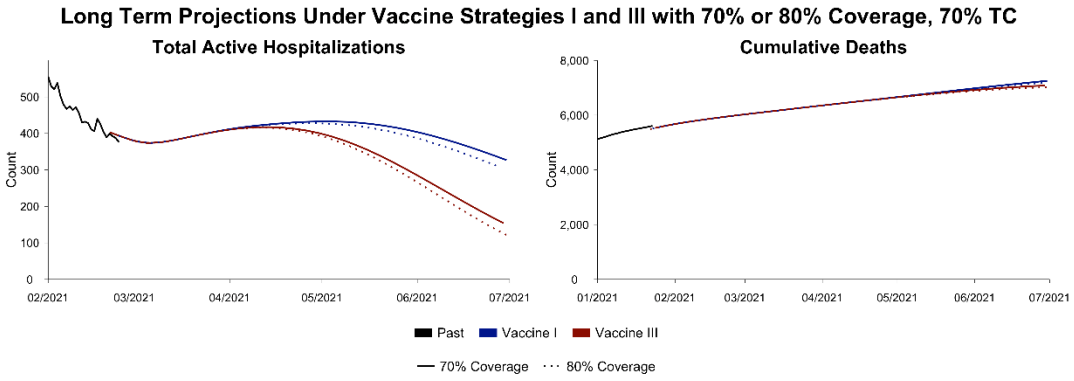


Figure 16 (above). Projected total number of patients actively hospitalized for COVID-19 (left) and projected cumulative deaths through early July 2021, assuming transmission control switches to 70% indefinitely on Friday, 02/26. This projection compares the impacts of Vaccine Strategies I and III under this level of transmission control, and within each vaccine strategy, the impact of 70% age-group coverage and 80% age-group coverage. Black lines indicating historical data reflect observed hospitalizations reported in EMR and observed cumulative deaths gathered from the CEDRS line list provided by CDPHE. Observed deaths are shown through 01/23 to account for lags in reporting.

Hospital Demand and Cumulative Mortality Under B.1.1.7 and Vaccine I with Immediate Changes to Transmission Control. Figures 17 and 18 show the projected active hospitalizations and cumulative deaths through early June 2021, if Colorado remains on its current trajectory (76% TC) or switches to 70% or 60% indefinitely on Friday, 02/26 under a rapid increase in the B.1.1.7 variant. Figure 17 shows projections under vaccine Strategy I and 70% uptake of the vaccine. Figure 18 shows projections under vaccine Strategy III and 70% uptake of the vaccine.

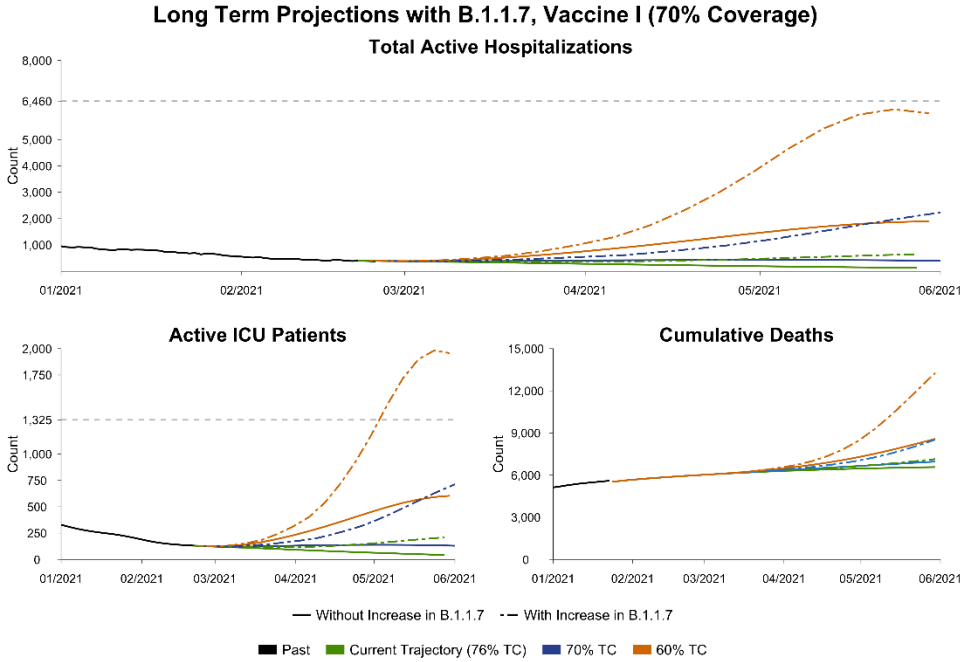


Figure 17 (above). Projected active hospitalizations and cumulative deaths through early June 2021 under Vaccine I, assuming Colorado remains on its current trajectory (76% TC) as indicated by the green lines, or switches to 70% TC (blue lines) or 60% TC (orange lines) beginning Friday, 02/26, comparing the impact of no increase in the prevalence of B.1.1.7 with respect to the wild-type strain (solid lines) and a logistic growth pattern of increase in the prevalence of B.1.1.7 infections with respect to infections with the wild-type strain (dashed lines). Black lines indicating historical data reflect observed hospitalizations reported in EMR and observed cumulative deaths gathered from the CEDRS line list provided by CDPHE. Observed deaths are shown through 01/23 to account for lags in reporting.

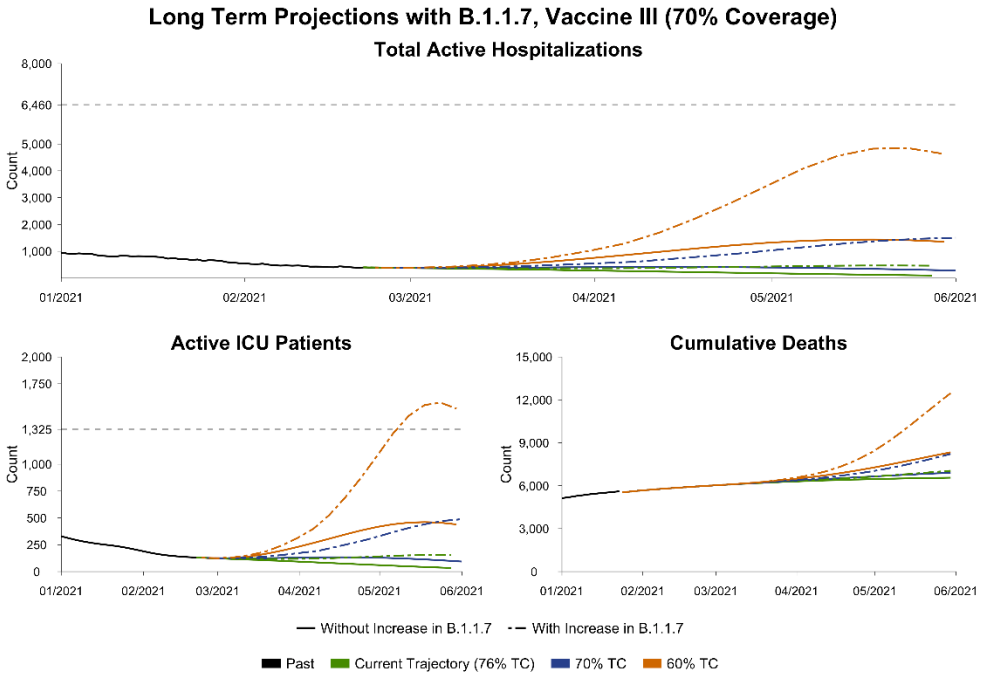


Figure 18 (above). Projected active hospitalizations and cumulative deaths through early June 2021 under Vaccine Strategy III, assuming Colorado remains on its current trajectory (76% TC) as indicated by the green lines, or switches to 70% TC (blue lines) or 60% TC (orange lines) beginning Friday, 02/26, comparing the impact of no increase in the prevalence of B.1.1.7 with respect to the wild-type strain (solid lines) and a logistic growth pattern of increase in the prevalence of B.1.1.7 infections with respect to infections with the wild-type strain (dotted lines). Black lines indicating historical data reflect observed hospitalizations reported in EMR and observed cumulative deaths gathered from the CEDRS line list provided by CDPHE. Observed deaths are shown through 01/23 to account for lags in reporting.

Table 2 (below). Comparison of the projected date that ICU surge capacity is reached, the date that ICU demand peaks, the estimated number of ICU beds needed at the peak, and the cumulative COVID-19 deaths at different levels of transmission control.

	Date ICU Capacity Reached*	Date of ICU Peak	ICU Need at Peak	Cumulative Infections Through 06/01/21**	Cumulative Deaths Through 06/01/21**	Deaths Between 02/22 and 06/01/21**
70% Vaccine Coverage						
Vaccine I						
Without B.1.1.7 Increase						
Current	NA	past	551	1,790,000	6,580	630
70% TC	NA	past	551	2,010,000	6,990	1,040
60% TC	NA	06/03/21	606	2,950,000	8,730	2,780
With B.1.1.7 Increase						
Current	NA	past	551	2,010,000	7,200	1,250
70% TC	NA	06/24/21	837	2,640,000	8,740	2,790
60% TC	05/03/21	05/26/21	1,986	4,460,000	13,800	7,850
Vaccine III						
Without B.1.1.7 Increase						
Current	NA	past	551	1,780,000	6,560	610
70% TC	NA	past	551	1,950,000	6,930	980
60% TC	NA	past	551	2,700,000	8,440	2,490
With B.1.1.7 Increase						
Current	NA	past	551	1,930,000	7,090	1,140
70% TC	NA	past	551	2,400,000	8,360	2,410
60% TC	05/08/21	05/23/21	1,576	3,940,000	12,900	6,950
80% Vaccine Coverage						
Vaccine I						
Without B.1.1.7 Increase						
Current	NA	past	551	1,790,000	6,580	630

	Date ICU Capacity Reached*	Date of ICU Peak	ICU Need at Peak	Cumulative Infections Through 06/01/21**	Cumulative Deaths Through 06/01/21**	Deaths Between 02/22 and 06/01/21**
70% TC	NA	past	551	2,000,000	6,970	1,020
60% TC	NA	06/01/21	582	2,940,000	8,620	2,670
With B.1.1.7 Increase						
Current	NA	past	551	2,000,000	7,160	1,210
70% TC	NA	06/23/21	781	2,620,000	8,590	2,640
60% TC	05/04/21	05/25/21	1,923	4,440,000	13,400	7,450
Vaccine III						
Without B.1.1.7 Increase						
Current	NA	past	551	1,780,000	6,550	600
70% TC	NA	past	551	1,950,000	6,890	940
60% TC	NA	past	551	2,680,000	8,280	2,330
With B.1.1.7 Increase						
Current	NA	past	551	1,930,000	7,020	1,070
70% TC	NA	past	551	2,380,000	8,170	2,220
60% TC	05/09/21	05/22/21	1,508	3,910,000	12,200	6,250

*ICU bed capacity for COVID-19 patients is estimated to be 1,325 in Colorado, a figure provided by CDPHE.
**Deaths estimated from the model include deaths both inside the hospital (ICU and non-ICU) and outside the hospital. Due to lags in reporting that can take up to 28 days, the model may overestimate the number of actual deaths reported by this date. Estimates for cumulative cases and deaths are rounded to three or two significant figures.

When Will Infection Prevalence Return to Prior Low Levels?

In order to facilitate decision-making around policy changes such as the reopening of businesses to full occupancy, we estimated the projected prevalence of active COVID-19 infections through July 2021, assuming we remain on the current trajectory. Figure 19 shows that if we remain on the current trajectory, infection prevalence will decline. On the current trajectory, infection prevalence will reach the summer low point (143 per 100,000) on approximately 06/11/2021. If transmission control drops in the weeks ahead, prevalence will decline more slowly.

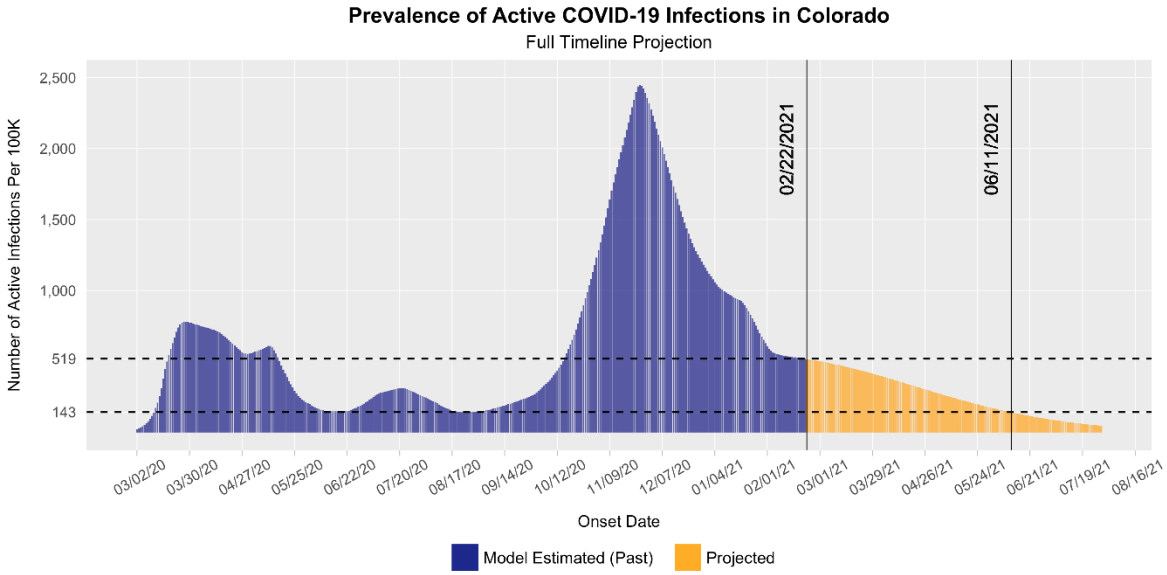


Figure 19 (above). Estimated daily number of people who are infectious and infected with SARS-CoV-2 (point prevalence). Estimate is shown per 100,000 population. The number of infectious individuals is inferred using the model and estimates and based on hospitalizations. Horizontal dashed lines indicate the current estimated prevalence of detected and undetected infections, both symptomatic and asymptomatic, as of 02/22, and the summer low point (143 per 100K).

Appendix

Code, Documentation, and Prior Reports

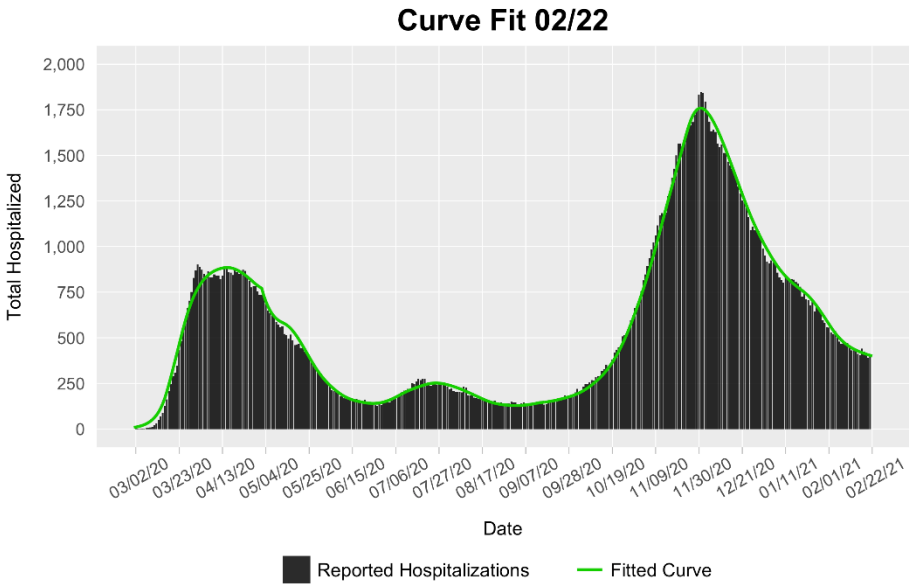
Code for our model is available on GitHub: https://github.com/agb85/covid-19

Documentation for the model can be found at: https://agb85.github.io/covid-19/SEIR%20Documentation.pdf

Prior modeling reports and documentation can be found at: https://agb85.github.io/covid-19/

Regional modeling results can be found at: https://www.colorado-data.org/regional-epidemic-models

Model Fit



Appendix Figure A1 (above). Current model fit (green line) to the count of hospitalized COVID-19 cases (black lines) through 02/22 using the age-structured SEIR model. Hospitalized COVID-19 cases are from CDPHE reported COVID-19 hospitalizations and EMResource (EMR) hospital census data provided by CDPHE.

Appendix Table A1 (below). Estimated model parameters based on fitting our model output of total hospitalizations to reported hospitalizations in Colorado. The new "TC" model includes a single transmission control parameter that accounts for all reduction in effective contacts as a result of all policy and behavior changes to reduce transmission.

	Range of Possible Values	Fitted Value from TC Model
Estimated current TC level for the period 01/30 to 02/09 *	0-99%	76% (95% CI: 71.6%, 79.9%)
Estimated TC level one week prior for the period 01/17 to 02/01 *	0-99%	83% (95% CI: 81.4%, 85.7%)
Estimated TC level two weeks prior for the period 01/10 to 01/30 *	0-99%	86% (95% CI: 82.5%, 89.4%)
The rate of infection (beta)	0.2 - 0.6**	0.48
Ratio of infectiousness for symptomatic vs. asymptomatic individuals (lambda)	1.0 - 4.0**	1.39

*Two-week transmission control parameters are estimated weekly and averaged over time period of interest.
**The range of potential parameter values for the rate of infectiousness for symptomatic vs. asymptomatic individuals [1, 2] are based on the literature, and for the rate of infection, were obtained from the MIDAS Online COVID-19 compilation of parameter estimates [3].

Data Sources

Appendix Table A2 (below). Data used for this model is collected from a variety of sources. Potential lags in reporting can often result in an artificial decline during the most recent days in a dataset, such as with reported cases. To reconcile this, we have cleaved the source data by a set number of days depending on the degree of lag and the metric used. For example, data measured by onset date is cleaved more aggressively than data measured by report date because reported cases tend to be more up to date than the former.

Data	Description	Source	Download Date	Cleave Date	Additional Notes
Hospitalizations (whole state)	Daily COVID-19 hospitalization census (i.e. snapshot of number of patients in the state currently hospitalized with COVID-19 on a given day)	EMR (CDPHE Emergency Management Resource) Dashboard	02/22	02/22	Data is collected in real time (updated 10am MST daily) and is not cleaved.
Hospitalizations (by age group)	Daily COVID-19 hospitalization census (i.e. snapshot of number of patients in the state currently hospitalized with COVID-19 on a given day) for each age group	COPHS (Covid Patient Hospitalization Surveillance) Resource Utilization Data Output	02/22	02/18	Age groups are 0-19, 20-39, 40-64, and 65+.
Cases detected by state surveillance systems	Daily count of new COVID-19 cases (using onset date)	CEDRS (Colorado Electronic Disease Reporting System) Line List	02/22	02/12	If onset date is missing, an imputed onset date is provided by CDPHE, which is based on true onset dates for the previous two weeks, compiled into a proxy distribution and recalculated weekly.
Reported cases by age and race/ethnicity	Daily count of new COVID-19 cases by age or race/ethnicity (using report date)	CEDRS (Colorado Electronic Disease Reporting System) Line List	02/22	02/15	Age groups are 0-19, 20-39, 40-64, and 65+. Race/ethnicity categories derived from this line list are American Indian/Alaska Native, Asian/Pacific Islander, Black/African American, Hispanic (All Races), Multiple Races (Non-Hispanic), White (Non-Hispanic), and Other/Unknown.
Detected cases by age	Daily count of new COVID-19 cases by age group (using onset date)	CEDRS (Colorado Electronic Disease Reporting System) Line List	02/22	02/08	Used for fitting and estimating age-specific transmission control parameters.
Cumulative deaths	Total deaths among COVID-19 cases to date	CEDRS (Colorado Electronic Disease	02/22	01/23	Used for generating historical and projected estimates of cumulative mortality.

Data	Description	Source	Download Date	Cleave Date	Additional Notes
		Reporting System) Line List			

Vaccination

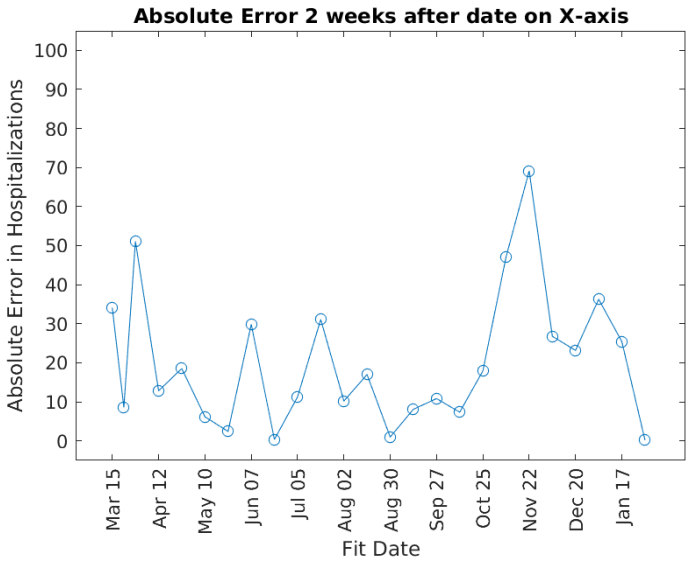
Appendix Table A3 (below). Current assumptions about vaccination rates by age in the model. These assumptions are based on data from CDPHE for vaccination rates by age from December 15th through January 25th and projected forward at the same rate until 70% of individuals age 65+ are vaccinated (estimated to be April 8th). After 70% of individuals age 65+ are vaccinated, vaccination will occur at the same daily rate among younger age groups.

Dates of First Vaccine Dose Administration	Date Moved to Vaccinated Compartment in Model	0-19 Daily Vaccination Rate*	20-39 Daily Vaccination Rate*	40-64 Daily Vaccination Rate*	65+ Daily Vaccination Rate*
12/15 - 02/01	01/16 - 03/05	43	2,089	2,576	4,976
02/01 - 03/01	03/05 - 04/02	58	2,080	3,624	9,019

*First doses administered per day (assuming all people receiving first doses receive second doses on schedule).

Retrospective Accuracy of Projected Estimated Hospitalizations

To assess the accuracy of near-term forecast estimates of COVID-19 hospitalizations, we calculated absolute deviation from the number of hospitalizations reported two weeks after the date of forecast, dating back to the fit conducted on March 15th, 2020.



Appendix Figure A3 (above). Graph showing retrospective accuracy of forecasted hospitalizations with respect to reported hospitalizations 14 days after the forecast date, as denoted on the x-axis. The y-axis represents the absolute difference in the estimated number of hospitalizations on the current trajectory 14 days out minus the observed hospitalizations 14 days out.

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