

The Current State of COVID-19 in Colorado

02/03/2021

Prepared by the Colorado COVID-19 Modeling Group

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Summary

- The effective reproduction number is < 1 , while transmission control has increased slightly to 79% from 77% last week.
- Infection prevalence has declined but remains high at 1 in 149. Prevalence is just below the April peak levels.
- Regionally: Infections are estimated to be increasing in the Central Mountains and West Central Partnership regions but declining in the others. We estimate that more than 1 in 100 people are infectious in the South Central, Southeast, and West Central Partnership Regions.
- On the current trajectory, statewide hospital demand and cases will continue to decline. It will be more than two months 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 vaccine is being rolled out.
- If the B.1.1.7 variant spreads rapidly in Colorado, high levels of transmission control and/or vaccination will be critical to avoiding another large surge in hospital demand. Thresholds for care capacity would not be reached under bounding scenarios of variant penetration and reduced transmission control.
- Time away from home is increasing in non-metro regions.

Snapshot of Current SARS-CoV-2 Transmission in Colorado Based on COVID-19 Hospitalization Data Through 02/01

Effective reproduction number: 0.8. *Infections are decreasing.*

Estimated prevalence of infections: Approximately 670 of every 100,000 Coloradoans or 1 in every 149 Coloradans are currently infectious. *The estimated infection prevalence is lower than last week.*

Estimated number of infections to date: Approximately 25% of the Colorado population has been infected to date.

Estimated current level of transmission control: 79% for the period of 01/03 to 01/19. *There is an approximate 79% 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 at least 450, including 150 patients in the ICU, if we remain on the current trajectory at 79% 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 02/01.

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.

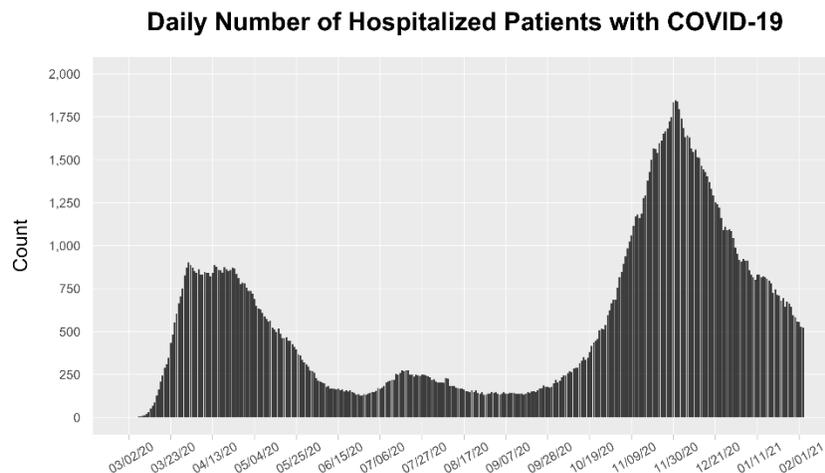


Figure 1 (above). Daily count of hospitalized COVID-19 cases through 02/01. The time series of COVID-19 hospitalizations in Colorado is based on hospitalization data provided by CDPHE through 4/07/2020 and the EMResource hospital census of COVID-19 hospitalizations starting 4/08/2020 (EMResource hospital 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 79% (95% CI: 77.4%, 80.1%). This estimate is for the period 01/03 to 01/19, given the timespan between infection and hospitalization.

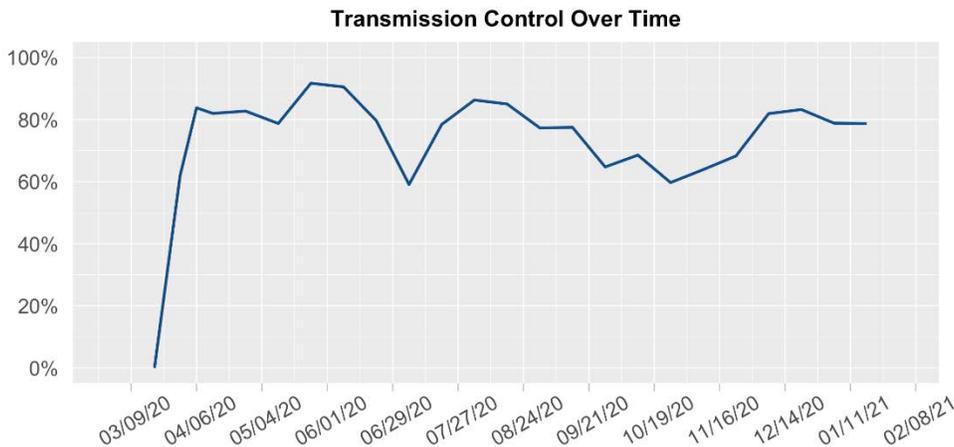
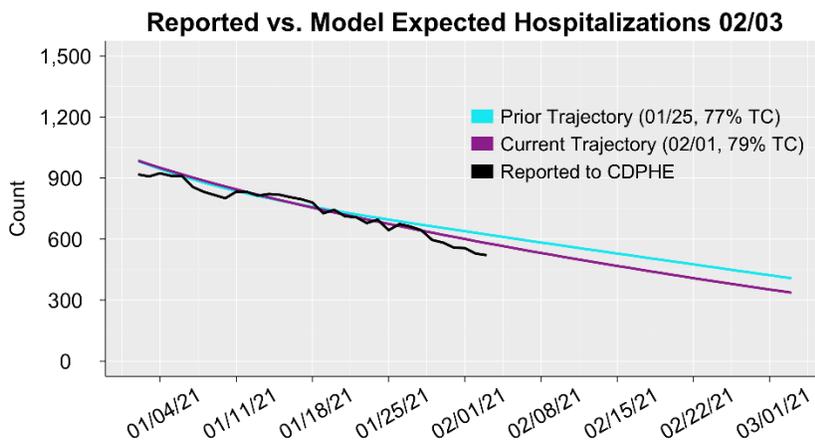


Figure 2 (above). The estimated transmission control value for each two-week period since the beginning of the epidemic. On the graph, the value is shown for the mid-point of each two-week period. Transmission control is estimated using model fitting approaches to align model output with COVID-19 hospitalizations.

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.



521 Active COVID-19 Hospitalizations as of Wednesday, 02/03

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 vaccination phase 1B on schedule, as described in the long-term projections section.

The Effective Reproduction Number

The effective reproduction number (R_e) 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 R_e is 0.8 (95% CI: 0.75, 0.84). Due to the lag between infections and hospitalizations, this estimate of R_e reflects the spread of infections occurring on approximately 01/19. 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 (R_e) 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 (02/01)	Estimate One Week Prior (01/25)	Estimate Two Weeks Prior (01/18)
Estimate of R_e , Approach 1*	0.80 (0.75, 0.84)	0.86 (0.79, 0.93)	0.83 (0.78, 0.87)
Estimate of R_e , Approach 2*	0.8	0.87	0.83

*Estimates are based on hospitalization data through the date listed. Due to the lag between infection and hospitalization, 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.

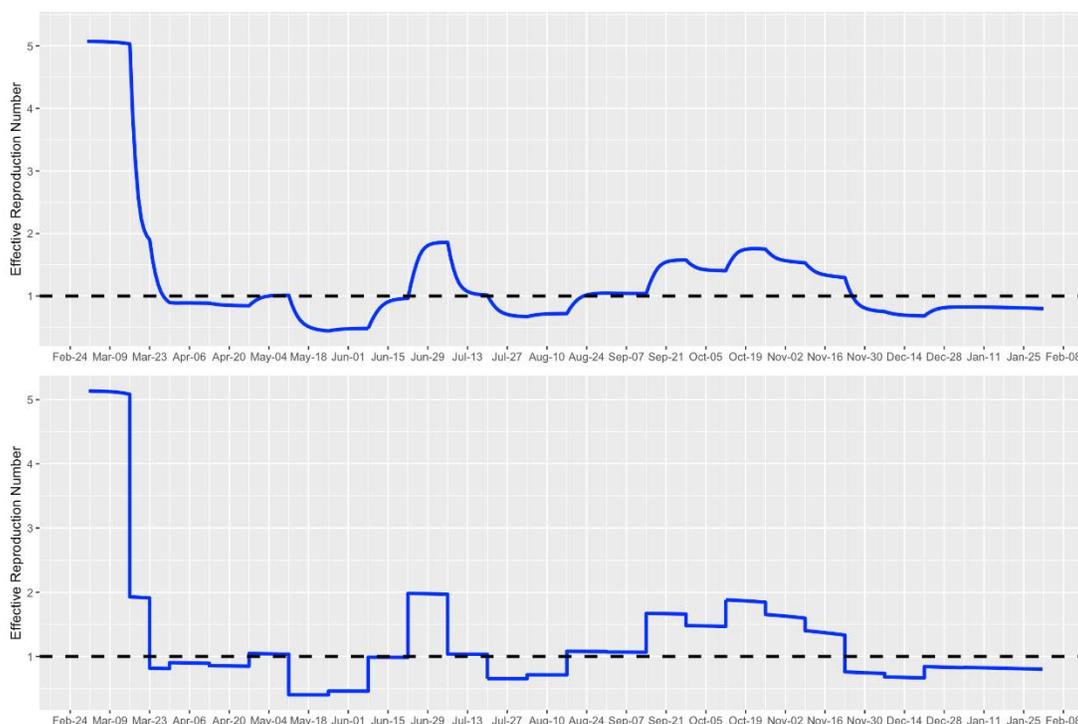


Figure 4 (above). Estimates of the effective reproduction number over time, using approach 1 (top) and approach 2 (bottom) based on the TC model.

Infection Prevalence

Infection prevalence provides an estimate of the proportion of the population that is currently (as of 02/01) 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 01/03 to 01/19) remains at the estimated value through 02/01. 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 39,300 (95% CI: 36,200, 41,900) infectious individuals in Colorado at present (02/01): approximately 670 (95% CI: 620, 720) of every 100,000 Coloradans or 1 in every 149 people (95% CI: 139, 161).

Figure 5 illustrates the estimated infection prevalence over time.

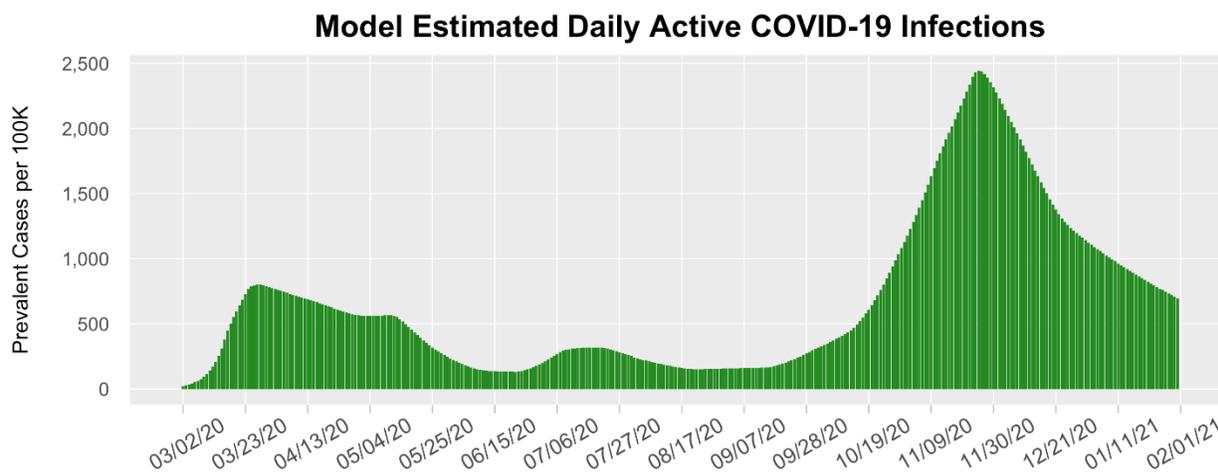


Figure 5 (above). Estimated daily number of people who are infectious and infected with SARS-CoV-2 (point prevalence). Estimate is shown per 100,000 population. The number of infectious individuals is inferred using the model and based on hospitalizations.

Case Detection

Comparing observed to model-estimated infections, **we estimate that approximately 31% of infections were detected by state surveillance systems, including both asymptomatic and symptomatic infections in the two week period from 01/09 to 01/22 (Figure 6).**

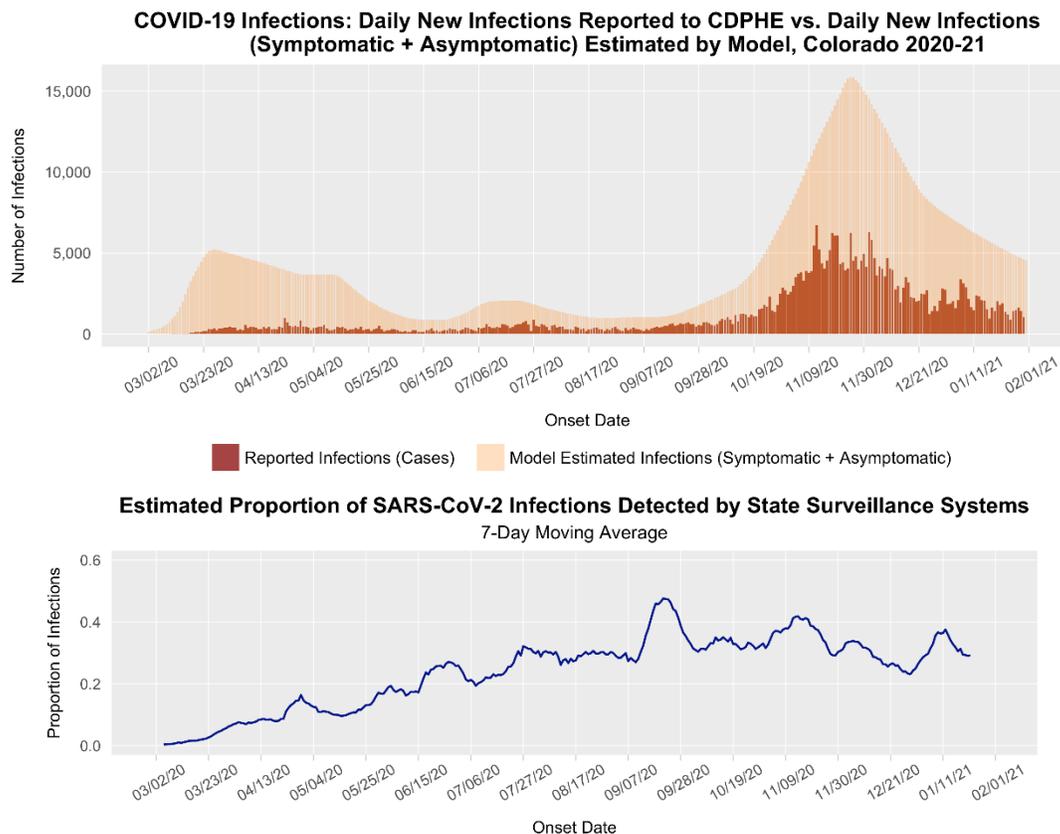


Figure 6 (above). Estimated daily number of new (incident) SARS-CoV-2 infections based on the SEIR model (light orange graph) and reported cases (dark orange graph) over time shown in the top panel. Lower panel shows the 7-day moving average of the estimated proportion of SARS-COV2 infections that are 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 01/22 to account for typical lags between symptom onset and case report.

Cumulative Infections

As more people develop immunity, due to vaccination or prior infection, the spread of infections slows because infectious individuals are less likely to encounter individuals who are still susceptible to infection. The estimated cumulative number of infections provides an estimate of the percent of the population that may be immune, although we still do not know how long immunity lasts after an infection. As a vaccine becomes available and our understanding of SARS-CoV-2 immunity changes, these estimates will be updated.

The cumulative number of infections is estimated using our age-structured SEIR model fit to hospitalization data. As with our prevalence estimates, these estimates are generated by assuming the most recent transmission control parameter estimate remains at the estimated value through 02/01. These estimates are sensitive to model assumptions, including assumptions about the probability an infected individual will be symptomatic and require hospital care, as well as assumptions about length of hospital stay, which varies over time; all of the above are variables that we assume vary by age.

We estimate that approximately 1,472,000 (95% CI: 1,465,000, 1,477,000) people in Colorado, or 25.2% (95% CI: 25.1%, 25.3%) of the population, have been infected with SARS-CoV-2 to date (02/01).

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 7 shows the 7-day moving average of reported new SARS-CoV-2 infections by age group.

People under age 40 account for 57% of reported SARS-CoV-2 cases in the two weeks between 01/11 and 01/25.

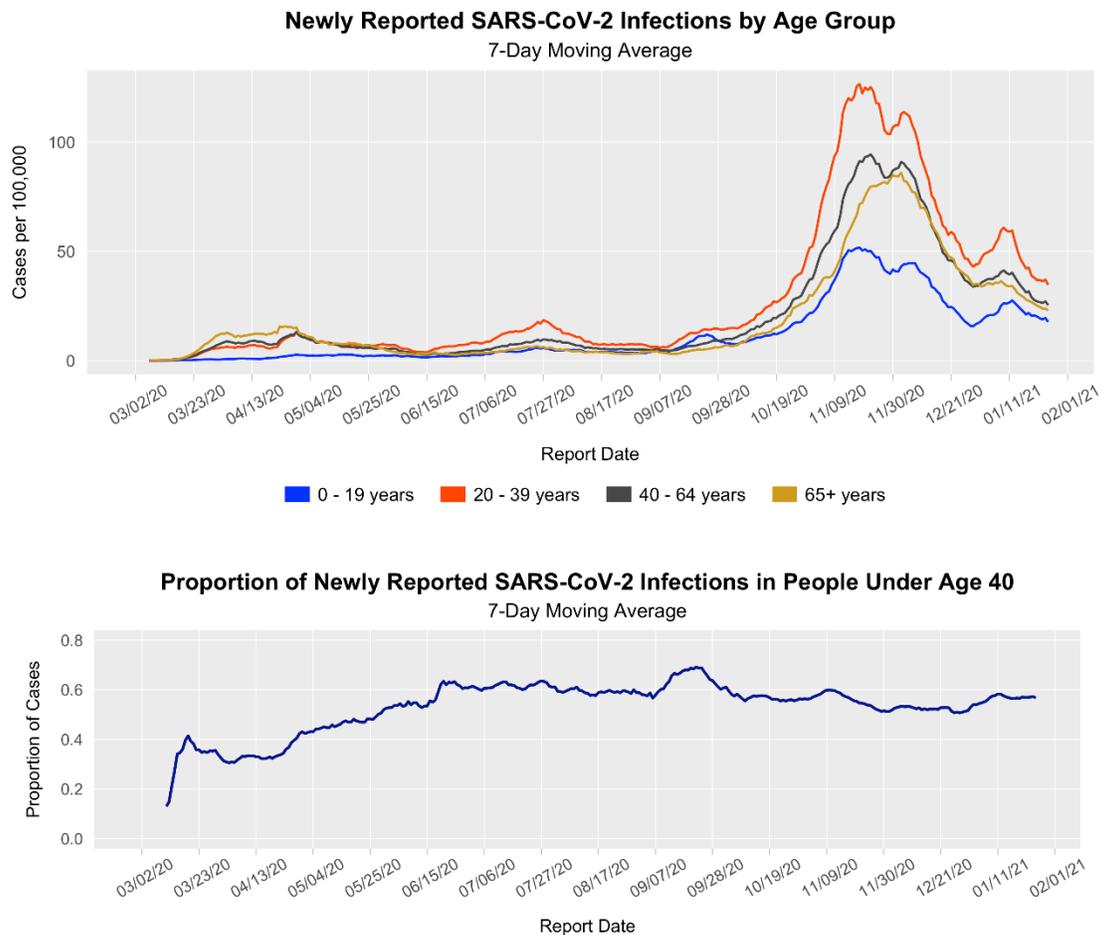


Figure 7 (above). Distribution of 7-day moving average of newly reported SARS-CoV-2 infections by age group (top) and the proportion of all cases among individuals under 40 (bottom). Reported cases are based on CDPHE data and shown by report date. Incident cases per 100,000 were obtained by standardizing 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 01/25, to account for typical lags in collection of age data for reported cases.

COVID-19 Hospitalizations by Age Group. Figure 8 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 01/25.

People under age 40 account for **13%**, people age 40 to 64 account for **37%**, and people age 65+ account for **50%** of COVID-19 hospital utilization over the two weeks between 01/12 and 01/25.

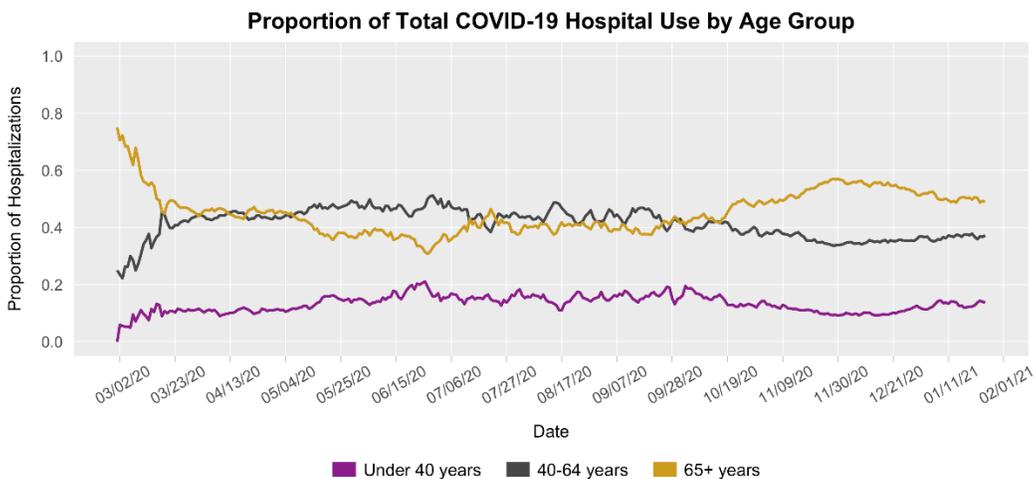
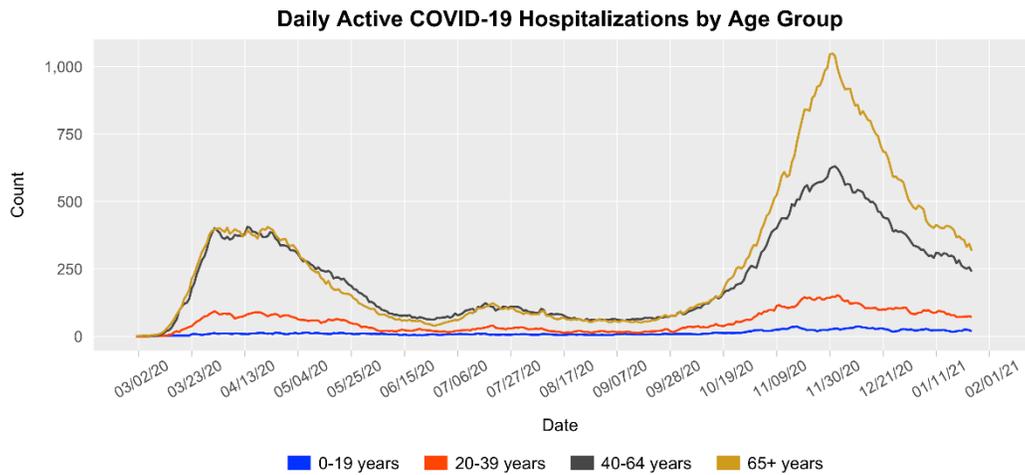


Figure 8 (above). The number of individuals hospitalized with COVID-19 by age group from March through the present (top) and the proportion of COVID-19 hospital beds occupied by individuals under 40 years, 40-64 years, and 65+ years (bottom). Data based on COvid Patient Hospitalization Surveillance (COPHS) through 01/25.

COVID-19 Reported Cases by Race/Ethnicity. Figure 9 shows the number of reported cases by race/ethnicity from March through the present.

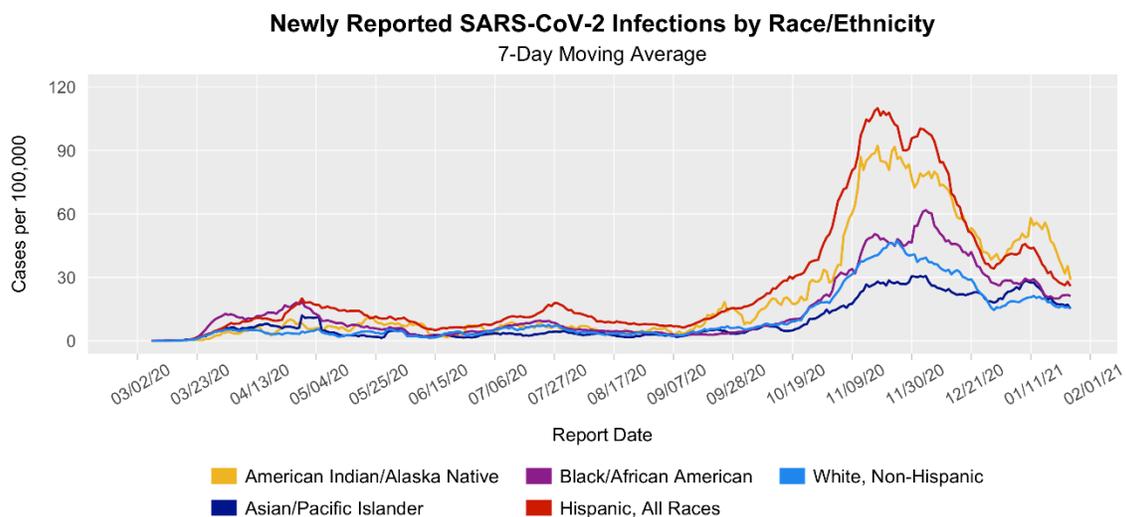


Figure 9 (above). Distribution of 7-day moving average of newly reported SARS-CoV-2 infections by race and ethnicity in Colorado. Reported cases are based on CDPHE data and shown by report date. Cases per 100,000 were

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 23% of observations over the last two weeks). Data is shown through 01/25 to account for lags in collection of race/ethnicity data for reported cases.

Mobility

Because SARS-CoV-2 spreads when people mix with others, we track measures of population mobility. We analyze time away from home using [SafeGraph](#) mobile device tracking data.¹ Figure 10 displays daily hours away from home from January 01, 2020 to January 28, 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 10 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.

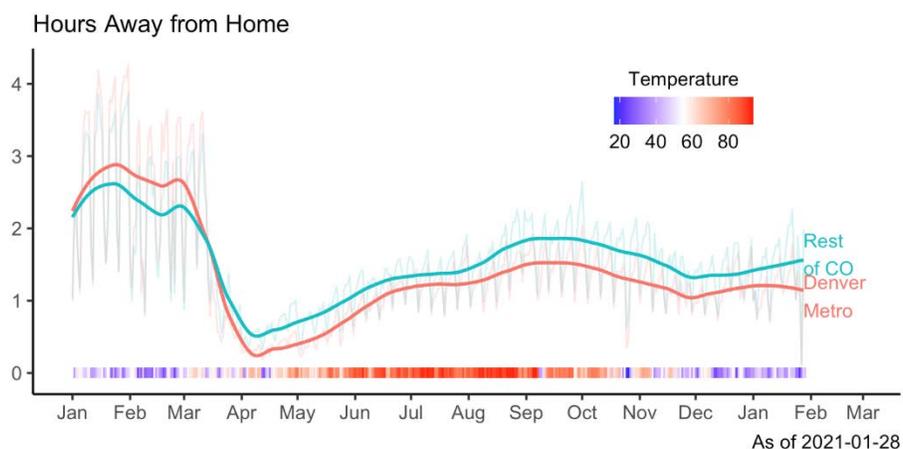


Figure 10 (above). Daily hours away from home ([SafeGraph](#)) is averaged across census block groups within the two regions. The faint lines show the daily data, and the thick lines represent a smoothed average over time. The ribbon below the time away from home displays the population-weighted mean 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 of the epidemic curve and accounting for uncertainty in our current estimated trajectory (Figure 11). **In two weeks on 02/15, there is a 50% chance that at least 450 patients will be hospitalized with COVID-19, including 150 patients in the ICU, if we remain on the current trajectory.**

¹ To enhance privacy, SafeGraph excludes 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.

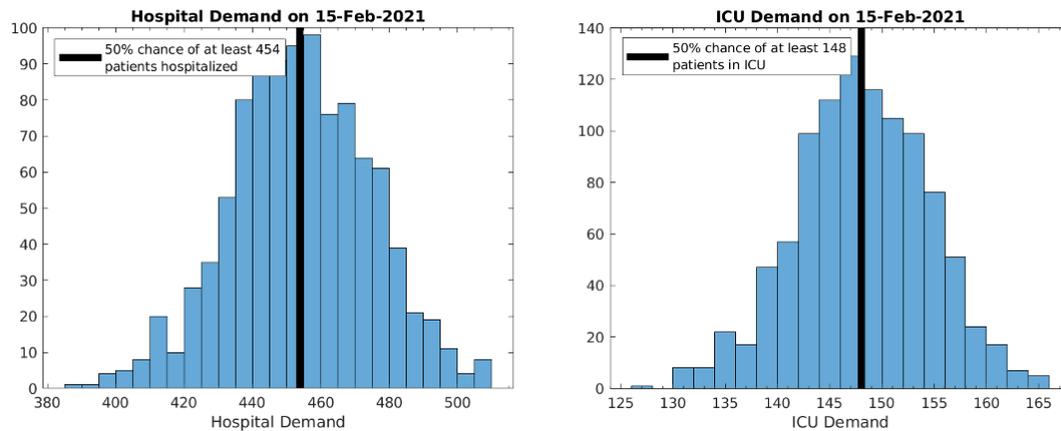


Figure 11 (above). Probability distribution of the number of hospitalized COVID-19 patients (left) and COVID-19 patients requiring ICU care (right) in two weeks if Colorado remains on the current trajectory. These estimates account for vaccination under Vaccine I, but do not account for the B.1.1.7 variant. 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 scenarios 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 all of the projections, vaccinations continue at current age-specific rates through early April until 70% of the population age 65+ are vaccinated and immune. Vaccination continues at the same daily rate after 70% of the 65+ are vaccinated, with vaccines distributed to younger age groups through April 30.

In regards to vaccination, we assume the following:

- We assume all individuals who receive a first dose receive a second dose on schedule.
- In the model, we assume that it takes approximately five weeks from the first dose for individuals to achieve complete immunity.
- Colorado is assumed to have a sufficient supply to administer all vaccines needed for Phase 1B. At present, additional vaccine is required above Colorado's current allocation in order to reach 1B targets.
- We assume that individuals will be vaccinated regardless of prior infection history. In the model, we account for the fact that an estimated 23% of people receiving the vaccine have already recovered from natural infection. This is in line with the estimated number of people infected in Colorado to date.
- Phase 2 is not included in this model given the current uncertainty regarding the target population.

New variant. The current scientific evidence indicates that the new B.1.1.7 variant is more infectious than the currently circulating variants. This increase in infectiousness will lead to more rapid spread of the virus if policy and behavior remain the same. The impact of this increase in transmission can be modeled as a reduction in effective transmission control. In the B.1.1.7 scenario, below we take into consideration the following:

- The variant is assumed to be 1.5 times more infectious than current circulating variants.
- The amount of variant in the Colorado population currently is 2% or less.
- The variant is assumed to account for a growing proportion of SARS-CoV-2 infections in Colorado over time. In the projection, the variant increases, as a proportion of all infections, by 1% per day until it

comprises 50% of all SARS-CoV-2 infections in early March. In reality, we do not know how quickly the variant will spread in Colorado.

- 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).
- There is emerging evidence that the new variant may be more lethal ([NERVTAG Report 1/22](#)). The current projections do not account for any increased risk of hospitalization or death due to the B.1.1.7 variant.

Hospital Demand on the Current Trajectory. Figure 12 shows the range of estimated hospital and ICU demand in four weeks, on 03/01.

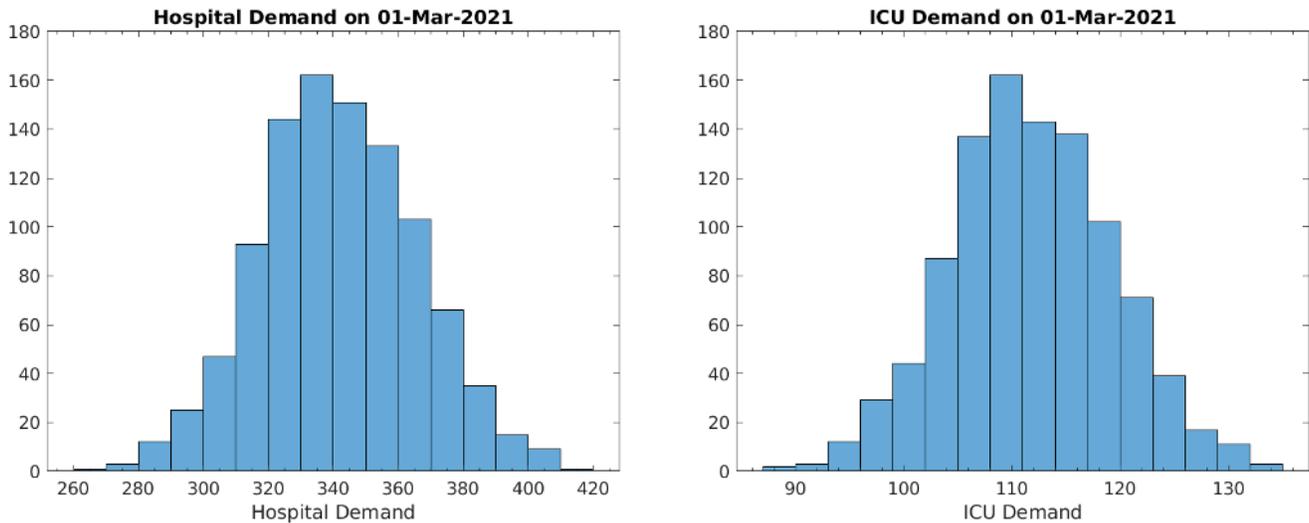


Figure 12 (above). Probability distribution of the number of hospitalized COVID-19 patients (left) and COVID-19 patients requiring ICU care (right) in four weeks if Colorado remains on the current trajectory. These estimates account for vaccination under Vaccine I, but do not account for the B.1.1.7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

Hospital Demand and Cumulative Mortality on the Current Trajectory. Figure 13 shows the projected active hospitalizations and cumulative deaths through early June 2021, if Colorado remains on its current trajectory (79% TC). This projection does not take into account an increase in B.1.1.7. We note that our projections are underestimating current COVID-19 deaths. An update is in process.

Long Term Projections Under Current Trajectory (79% TC)

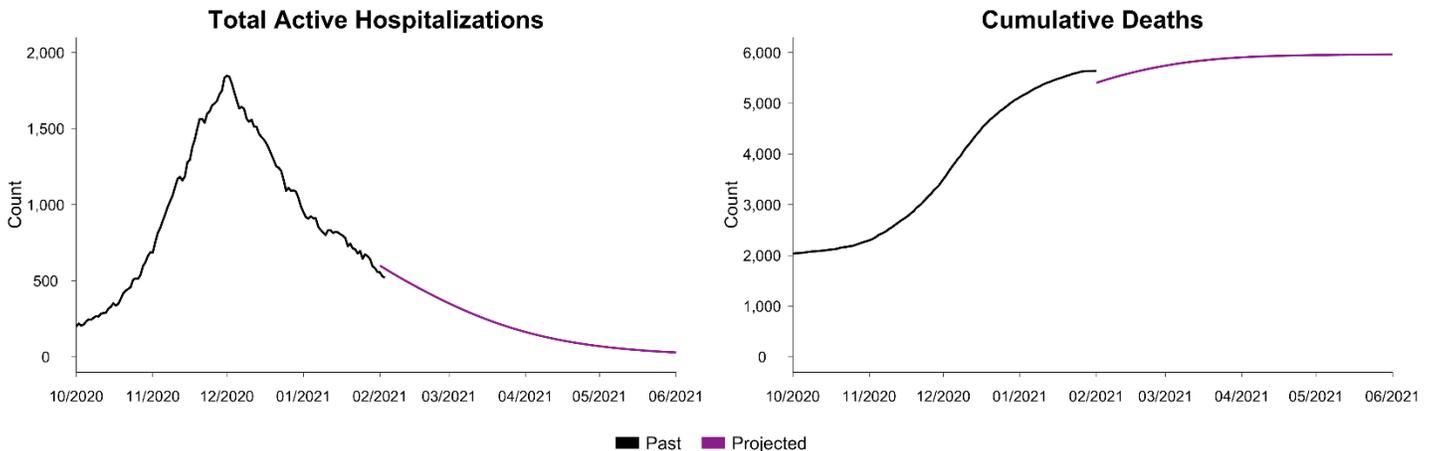


Figure 13 (above). Projected total number of patients actively hospitalized for COVID-19 (left) and projected cumulative deaths through early June 2021, assuming transmission control remains at the current levels (79% TC)

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.

Hospital Demand and Cumulative Mortality on the Current Trajectory or Immediate Changes to Transmission Control. Figure 14 shows the projected active hospitalizations and cumulative deaths through early June 2021, if Colorado remains on its current trajectory (79% TC) or switches to 70% or 60% indefinitely on Friday, 02/05.

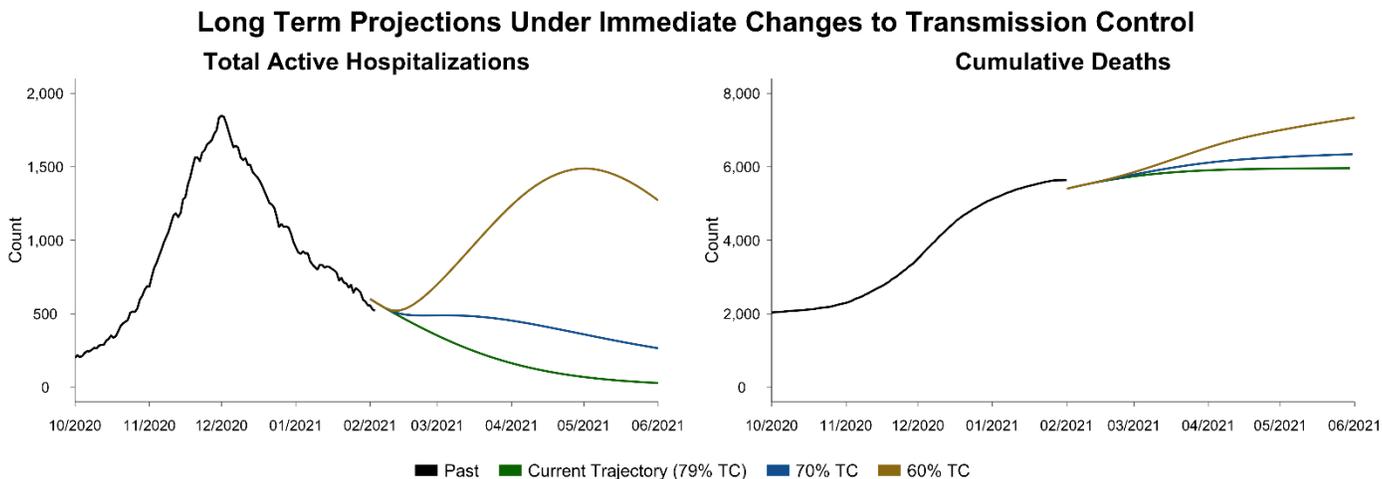


Figure 14 (above). Projected active hospitalizations and cumulative deaths through early June 2021, assuming Colorado remains on its current trajectory (79% TC) as indicated by the green lines, or switches to 70% TC (blue lines) or 60% TC (gold lines) beginning Friday, 02/05. Black lines indicating historical data reflect observed hospitalizations reported in EMR and observed cumulative deaths gathered from the CEDRS line list provided by CDPHE.

Hospital Demand and Cumulative Mortality on the Current Trajectory, With and Without an Increase in the B.1.1.7 Variant. Figure 15 shows the projected active hospitalizations and cumulative deaths through early June 2021, if Colorado remains on its current trajectory (79% TC), with the impact of an increase in the presence of the B.1.1.7 variant in the state of Colorado. In our model, we assume that the prevalence of the variant in Colorado will increase in a linear fashion reaching 50% of all infections by early March. This means that of all active COVID-19 infections at this time, half will be with the wild-type strain and half will be with the B.1.1.7 variant. In reality, we do not know how quickly more infectious variants will increase.

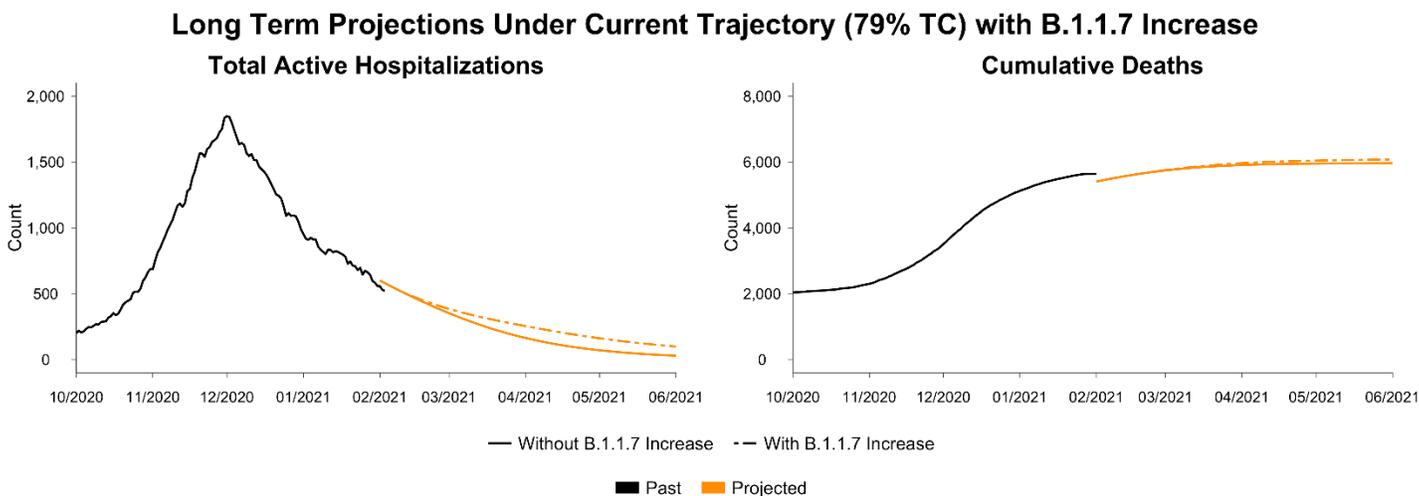


Figure 15 (above). Projected active hospitalizations and cumulative deaths through early June 2021, assuming Colorado remains on its current trajectory (79% TC) comparing the impact of no increase in the prevalence of

B.1.1.7 with respect to the wild-type strain (solid lines) and a linear increase in the prevalence of B.1.1.7 up to a total of 50% of all active COVID-19 infections (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.

Infections and Hospital Demand on the Current Trajectory or Under Immediate Changes to Transmission Control, With and Without an Increase in the B.1.1.7 Variant. Figure 16 shows the projected daily active infections, active hospitalizations, and active ICU patients through early June 2021, if Colorado remains on its current trajectory (79% TC) or switches to 70% or 60% indefinitely on Friday, 02/05. Within each level of transmission control, we investigate the impact of an increase in the presence of the B.1.1.7 variant in the state of Colorado. In our model, we assume that the prevalence of the variant in Colorado with respect to the wild-type strain will increase in a linear fashion, reaching 50% of all infections by early March. This means that of all active COVID-19 infections at that time, half will be with the wild-type strain and half will be with the B.1.1.7 variant.

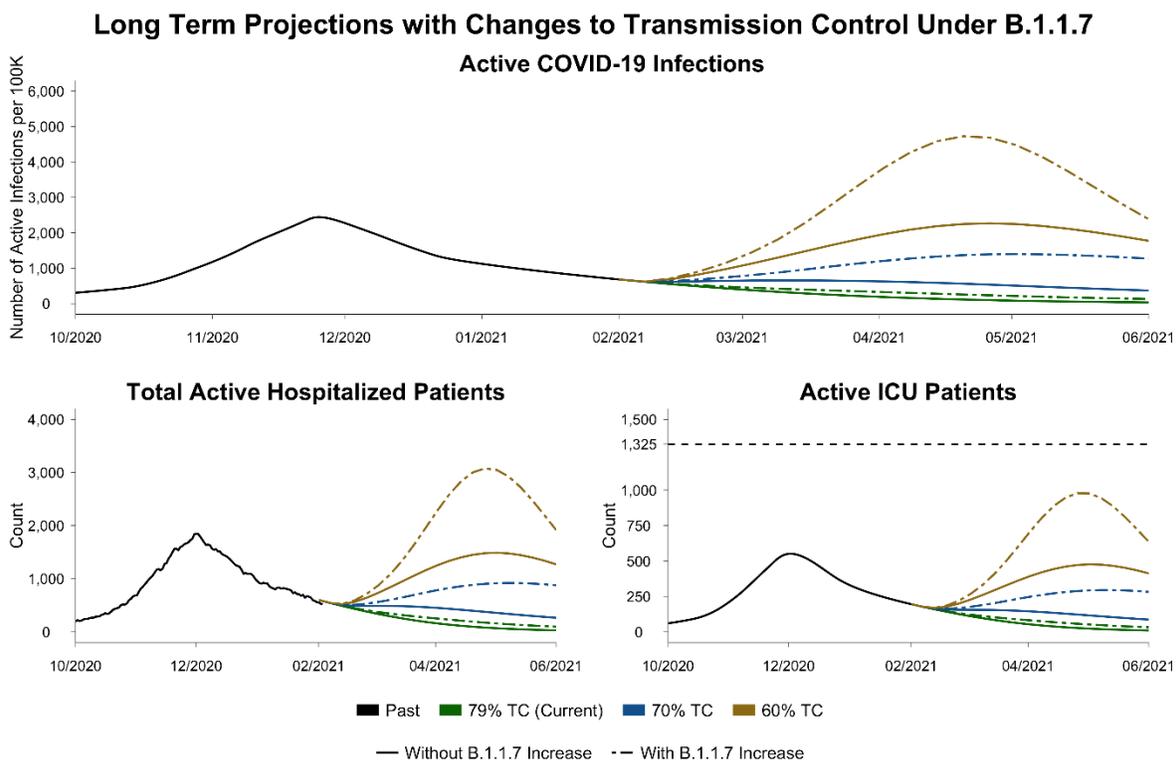


Figure 16 (above). Projected active COVID-19 infections (top), active hospitalizations (bottom left), and active ICU patients (bottom right) through early June 2021, assuming Colorado remains on its current trajectory (79% TC) as indicated by the green lines, or switches to 70% TC (blue lines) or 60% TC (gold lines) beginning Friday, 02/05. Within each level of transmission control, this projection compares the impact of no increase in the prevalence of B.1.1.7 with respect to the wild-type strain (solid lines) and a linear increase in the prevalence of B.1.1.7 up to a total of 50% of all active COVID-19 infections (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.

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 02/28/21**	Cumulative Deaths Through 02/28/21**	Deaths Between 02/01 and 02/28/21**	Cumulative Deaths Through 06/01/21**
Without Increase in B.1.1.7							
Without B.1.1.7, Current Trajectory	NA	past	552	675,000	5,730	330	5,960
Without B.1.1.7, 70% TC	NA	past	552	705,000	5,780	380	6,340
Without B.1.1.7, 60% TC	NA	past	552	754,000	5,830	430	7,340
With Increase in B.1.1.7							
With B.1.1.7, Current Trajectory	NA	past	552	683,000	5,740	340	6,070
With B.1.1.7, 70% TC	NA	past	552	720,000	5,790	390	6,790
With B.1.1.7, 60% TC	NA	04/29/21	982	783,000	5,860	460	8,370

*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 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 May 2021, assuming we remain on the current trajectory. Figure 17 shows that if we remain on the current trajectory, infection prevalence will decline rapidly. However, since infection prevalence is currently so high, contacts will remain risky in the weeks ahead. On the current trajectory, infection prevalence will fall below the spring peak (802 per 100,000) on approximately 02/01/2021 and will reach the summer low point (132 per 100,000) on approximately 04/18/2021. If transmission control drops in the weeks ahead, prevalence will decline more slowly.

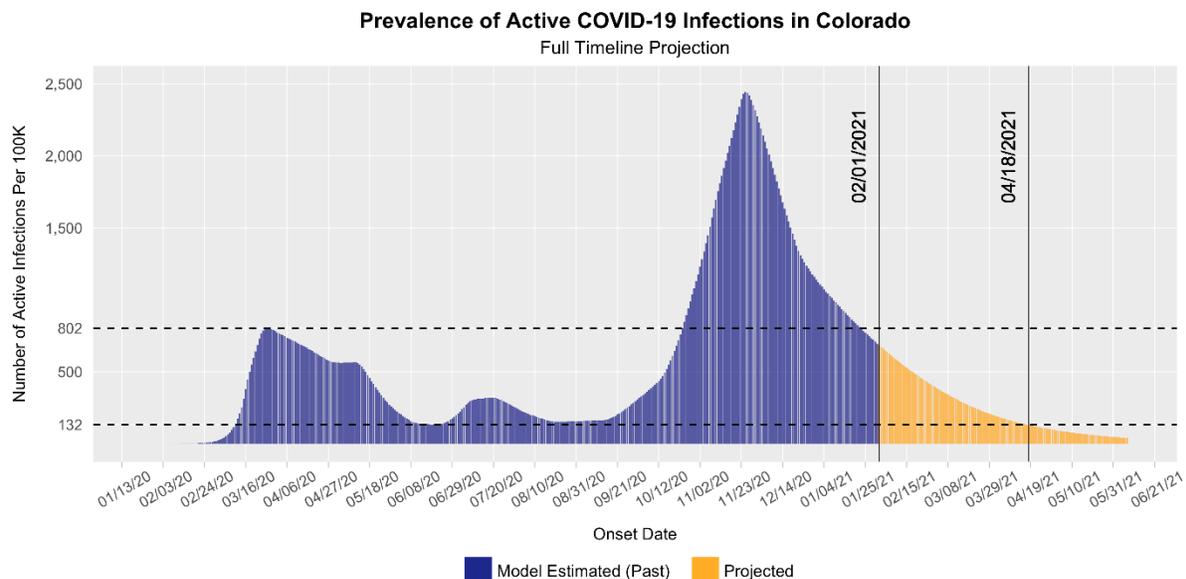


Figure 17 (above). Estimated daily number of people who are infectious and infected with SARS-CoV-2 (point prevalence). Estimate is shown per 100,000 population. The number of infectious individuals is inferred using the model and estimates and based on hospitalizations. Horizontal dashed lines indicate the spring peak (802 per 100K) and summer low point (132 per 100K). Vertical solid lines indicate the approximate dates when projected infection prevalence will drop below these levels, assuming transmission control remains at the current value of 79%.

Appendix

Code, Documentation, and Prior Reports

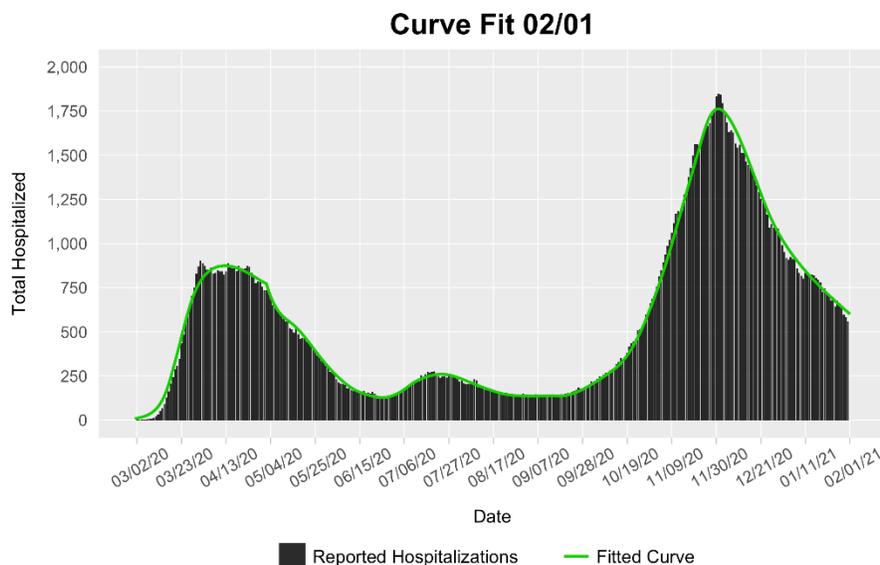
Code for our model is available on GitHub: <https://github.com/agb85/covid-19>

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 02/01 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	Fit Using Data Through
Estimated current TC level for the period 01/03 to 01/19 *	0-99%	79% (95% CI: 77.4%, 80.1%)	2/1/21
Estimated TC level one week prior for the period 01/02 to 01/12 *	0-99%	77%(95% CI: 75.0%, 79.2%)	1/25/21
Estimated TC level two weeks prior for the period 12/20 to 01/09 *	0-99%	78% (95% CI: 77.1%, 79.7%)	1/18/21
The rate of infection (beta)	0.2 - 0.6**	0.48	6/24/20
Ratio of infectiousness for symptomatic vs. asymptomatic individuals (lambda)	1.0 - 4.0**	1.39	6/24/20

*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	02/01	02/01	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	COPHS (Covid Patient Hospitalization Surveillance) Resource Utilization Data Output	01/29	01/25	Age groups are 0-19, 20-39, 40-64, and 65+.

Data	Description	Source	Download Date	Cleave Date	Additional Notes
	day) for each age group				
Cases detected by state surveillance systems	Daily count of new COVID-19 cases (using onset date)	CEDRS (Colorado Electronic Disease Reporting System) Line List	02/01	01/22	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	02/01	01/25	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	02/01	01/18	Used for fitting and estimating age-specific transmission control parameters.

Vaccination

Two vaccines became available in Colorado on December 15th, 2020. Currently (01/04/21) 111,679 doses have been administered, suggesting a vaccination rate of ~37,000 doses a week up to this point. Both vaccines require two doses per individual and are being distributed first to healthcare workers in high-risk settings and other high-risk individuals. Individuals are expected to take ~32 days from time of receipt of first vaccine dose to develop immunity. To account for vaccination in the model, we have added a vaccination compartment to the SEIR model. Assuming health care workers and most other high-risk groups are all over 19, vaccination is modeled beginning in the three older age groups with 37,000 individuals vaccinated per week distributed 1:1:1 between individuals 20-39, 40-64, and 65+. Vaccination is modeled as the number of successfully vaccinated individuals in each age compartment moving directly from the Susceptible to the Vaccinated compartment. Vaccines are assumed to be 90% effective based on early, unpublished, reports. Vaccination rates are expected to increase following the holidays and distribution of vaccines to CVS, so starting January 4th, the number of individuals vaccinated weekly is expected to increase by 8,000 people a week, to 45,000 people per week. Currently vaccine delivery schedules are known through the end of January, but we assume similar levels of vaccine will be delivered through February, for a total of 834,080 doses by the end of February, or 417,040 individuals receiving two doses. We include vaccinations of all vaccines received through the end of February, not knowing how many vaccines will be received after this time. Vaccination is assumed to be transmission blocking when effective. Vaccine-derived immunity is assumed to last ~365 days.

Appendix Table A2 (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 - 01/05	01/16 - 02/06	23	2,358	2,738	1,075
01/05 - 01/25	02/06 - 02/26	59	1,991	2,588	7,467
01/25 - 03/07	02/26 - 04/08	59	1,560	2,053	9,557
03/07 - 04/30	04/08 - 06/01	59	6,338	6,831	0

*Daily rate at which individuals move from the susceptible to vaccinated compartment or achieve immunity (32 days after first dose).

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