The Current State of COVID-19 in Colorado

01/20/2021

Prepared by the Colorado COVID-19 Modeling Group

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Summary

- The effective reproductive number is 0.83, while transmission control has dropped to 78% from 82% two weeks ago.
- Infection prevalence remains high at 1 in 115.
- On the current trajectory, hospital demand and cases will continue to decline, but about three months are needed for hospital demand and infection prevalence to reach levels comparable to last summer.
- The slowed decline in infections may be due to a holiday bump or changes in policy implemented in the new year.
- If the B.1.1.7 variant spreads as rapidly in Colorado as in the United Kingdom, high levels of transmission control and/or vaccination will be critical to avoiding another large surge in hospital demand.
- Scenarios incorporating vaccines show that in the near-term, the most cases and deaths will be prevented by keeping transmission control at high levels (~80%).

Snapshot of Current SARS-CoV-2 Transmission in Colorado Based on COVID-19 Hospitalization Data Through 01/18

Effective reproduction number: 0.83 (95% CI: 0.78, 0.87).

Infections are decreasing.

Estimated prevalence of infections: Approximately 870 (95% CI: 798, 946) of every 100,000 Coloradoans or 1 in every **115** Coloradans are currently infectious.

The estimated infection prevalence is slightly lower than last week.

Estimated number of infections to date: Approximately 24% (95% CI: 23.9%, 24.1%) of the Colorado population has been infected to date.

Estimated current level of transmission control: 78% (95% CI: 77.1%, 79.7%) for the period of 12/20 to 01/05.

There is an approximate 78% 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 approximately 600, including 194 patients in the ICU, if we remain on the current trajectory at 78% 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, vaccination, and frequency of the variant SARS-CoV-2 from the United Kingdom. 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 **01/18.**

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.

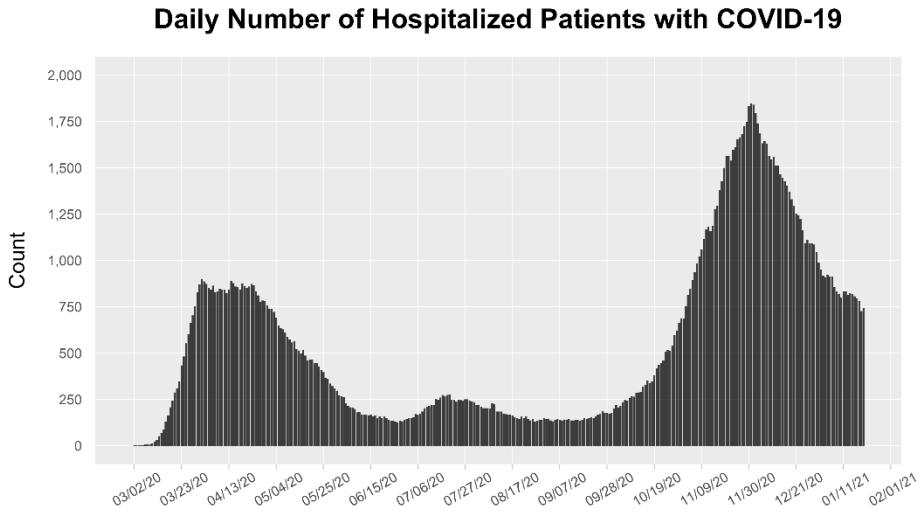

Figure 1 (above). Daily count of hospitalized COVID-19 cases through 01/18. The time series of COVID-19 hospitalizations in Colorado is based on hospitalization data provided by CDPHE through 4/07/2020 and the EMResource hospital census of COVID-19 hospitalizations starting 4/08/2020 (EMResource hospital 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 78% (95% CI: 77.1%, 79.7%). This estimate is for the period 12/20 to 01/05, given the timespan between infection and hospitalization.

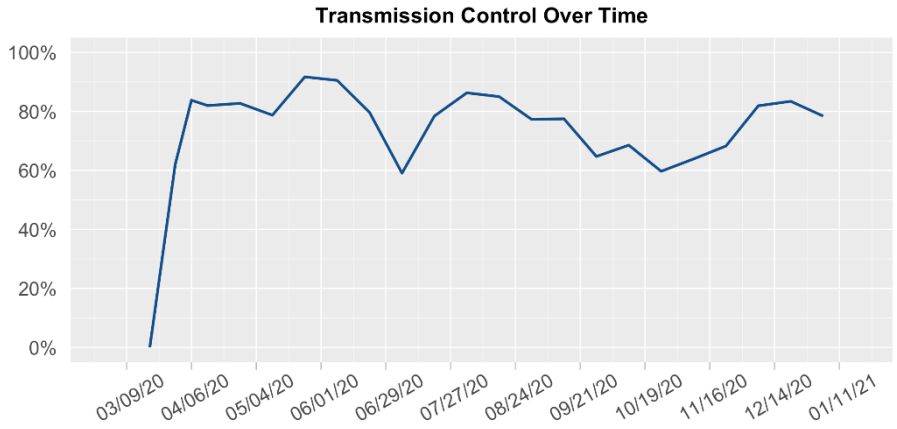

Figure 2 (above). The estimated transmission control value for each two-week period since the beginning of the epidemic. On the graph, the value is shown for the mid-point of each two-week period. Transmission control is estimated using model fitting approaches to align model output with COVID-19 hospitalizations.

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.

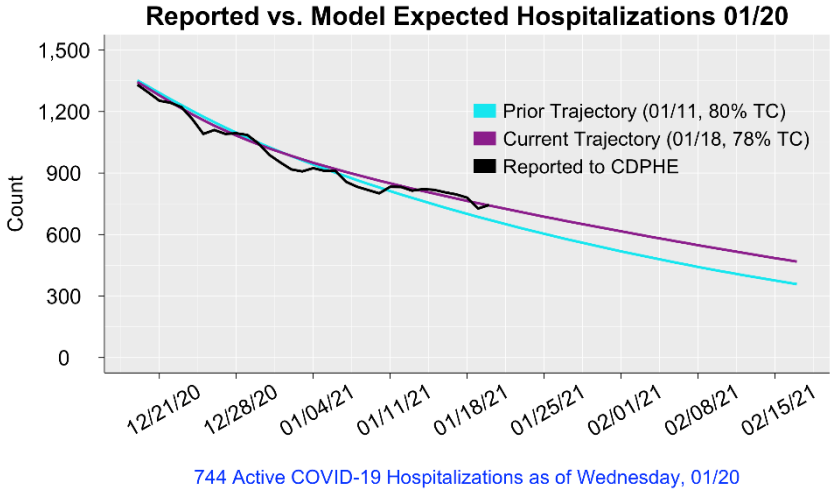

Figure 3 (above). The projected course of COVID-19 hospitalizations if Colorado were to remain on the current estimated trajectory (purple line) or on the trajectory estimated one week prior (turquoise line). Each trajectory is generated assuming Colorado rolls out vaccination phase 1B on schedule, as described in the long-term projections section.

The Effective Reproduction Number

The effective reproduction number (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 0.83. Due to the lag between infections and hospitalizations, this estimate of Re reflects the spread of infections occurring on approximately 01/05. 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. We also include estimates from RT-Live, an external source that calculates the reproductive number using reported SARS-CoV-2 cases and testing data. Note that the confidence interval for RT-Live is an 80% CI around the mean point estimate.

	Current Estimate (01/18)	Estimate One Week Prior (01/11)	Estimate Two Weeks Prior (01/04)
Estimate of Re, approach 1, TC model*	0.83 (0.78, 0.87)	0.76 (0.70, 0.82)	0.70 (0.67, 0.72)
Estimate of Re, approach 2, TC model*	0.83	0.77	0.71
Estimate from RT-Live	0.95 (0.73, 1.12)	0.98 (0.74, 1.14)	1.09 (0.86, 1.29)

*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.

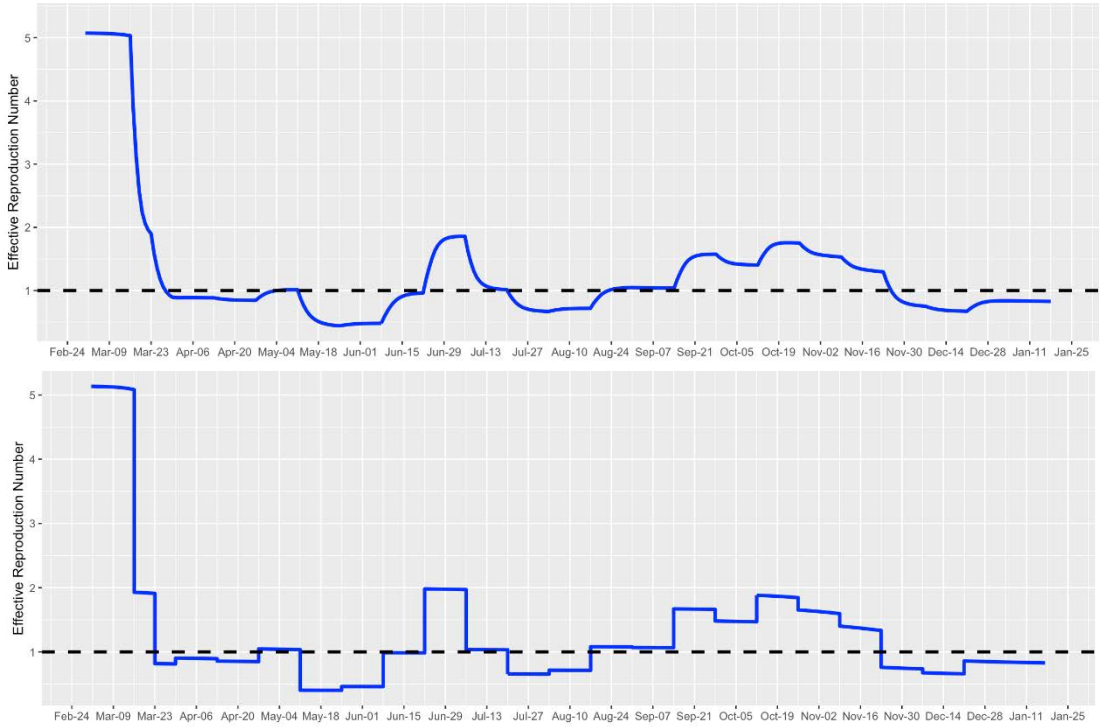

Figure 4 (above). Estimates of the effective reproduction number over time, using approach 1 (top) and approach 2 (bottom) based on the TC model.

Infection Prevalence

Infection prevalence provides an estimate of the proportion of the population that is currently (as of 01/18) 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 12/20 to 01/05) remains at the estimated value through 01/18. 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 50,700 (95% CI: 46,619, 55,258) infectious individuals in Colorado at present (01/18): approximately 870 (95% CI: 798, 946) of every 100,000 Coloradoans or 1 in every 115 people (95% CI: 106, 125).

Figure 5 illustrates the estimated infection prevalence over time.

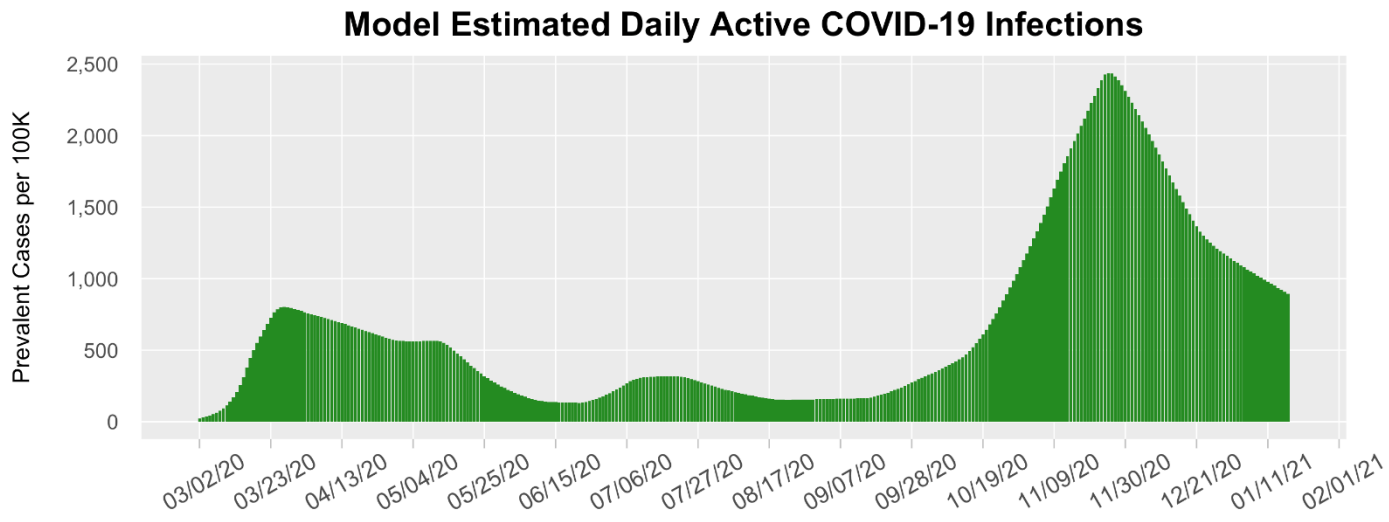

Figure 5 (above). Estimated daily number of people who are infectious and infected with SARS-CoV-2 (point prevalence). Estimate is shown per 100,000 population. The number of infectious individuals is inferred using the model and based on hospitalizations.

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 12/26 to 01/08 (Figure 6).**

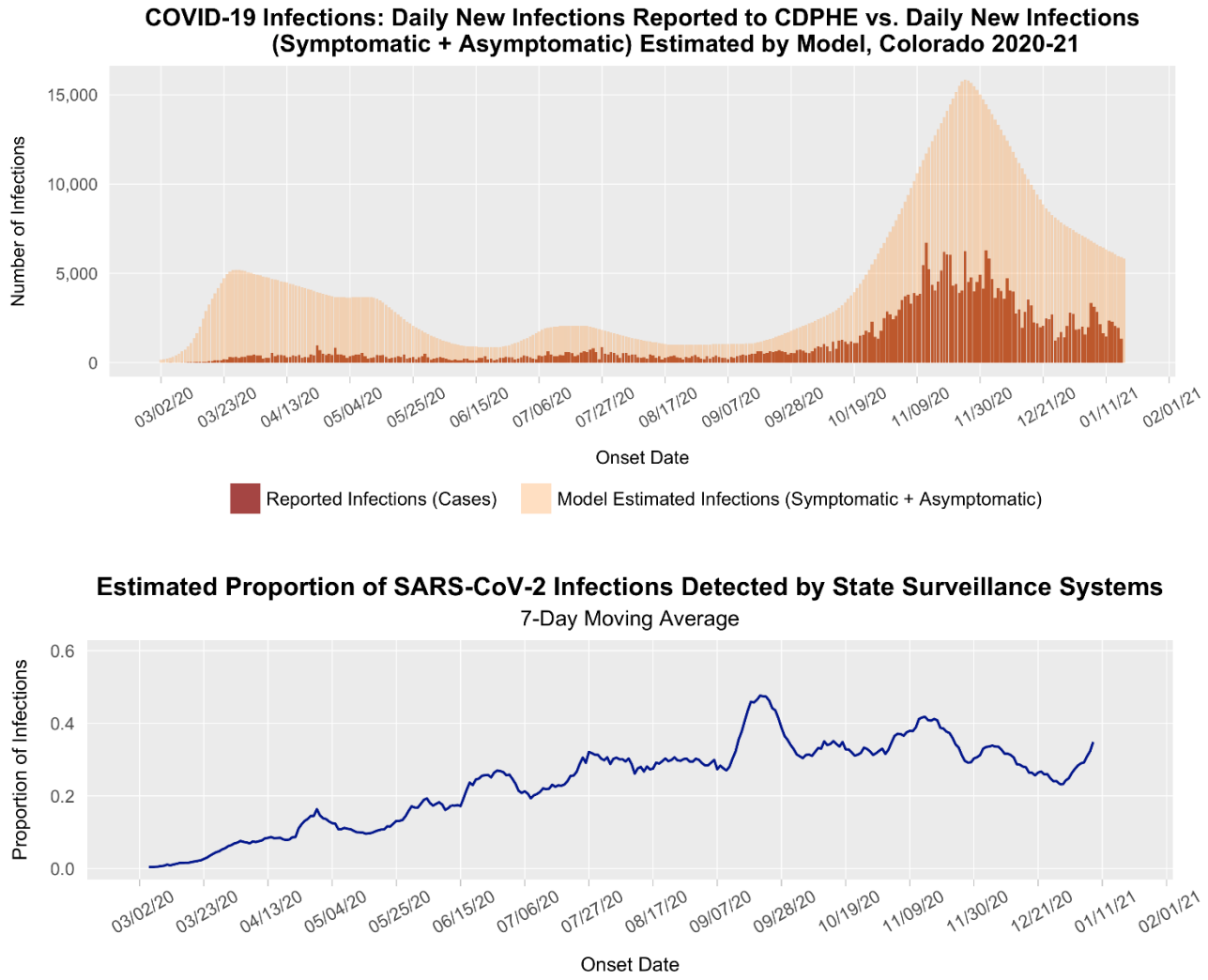

Figure 6 (above). Estimated daily number of new (incident) SARS-CoV-2 infections based on the SEIR model (light orange graph) and reported cases (dark orange graph) over time shown in the top panel. Lower panel shows the 7-day moving average of the estimated proportion of SARS-COV2 infections that are 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 01/08 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 that 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 01/18. 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 1,400,000 (95% CI: 1,397,139, 1,410,540) people in Colorado, or 24% (95% CI: 23.9%, 24.1%) of the population, have been infected to date (01/18).

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 56% of reported SARS-CoV-2 cases in the two weeks between 12/28 and 01/11.

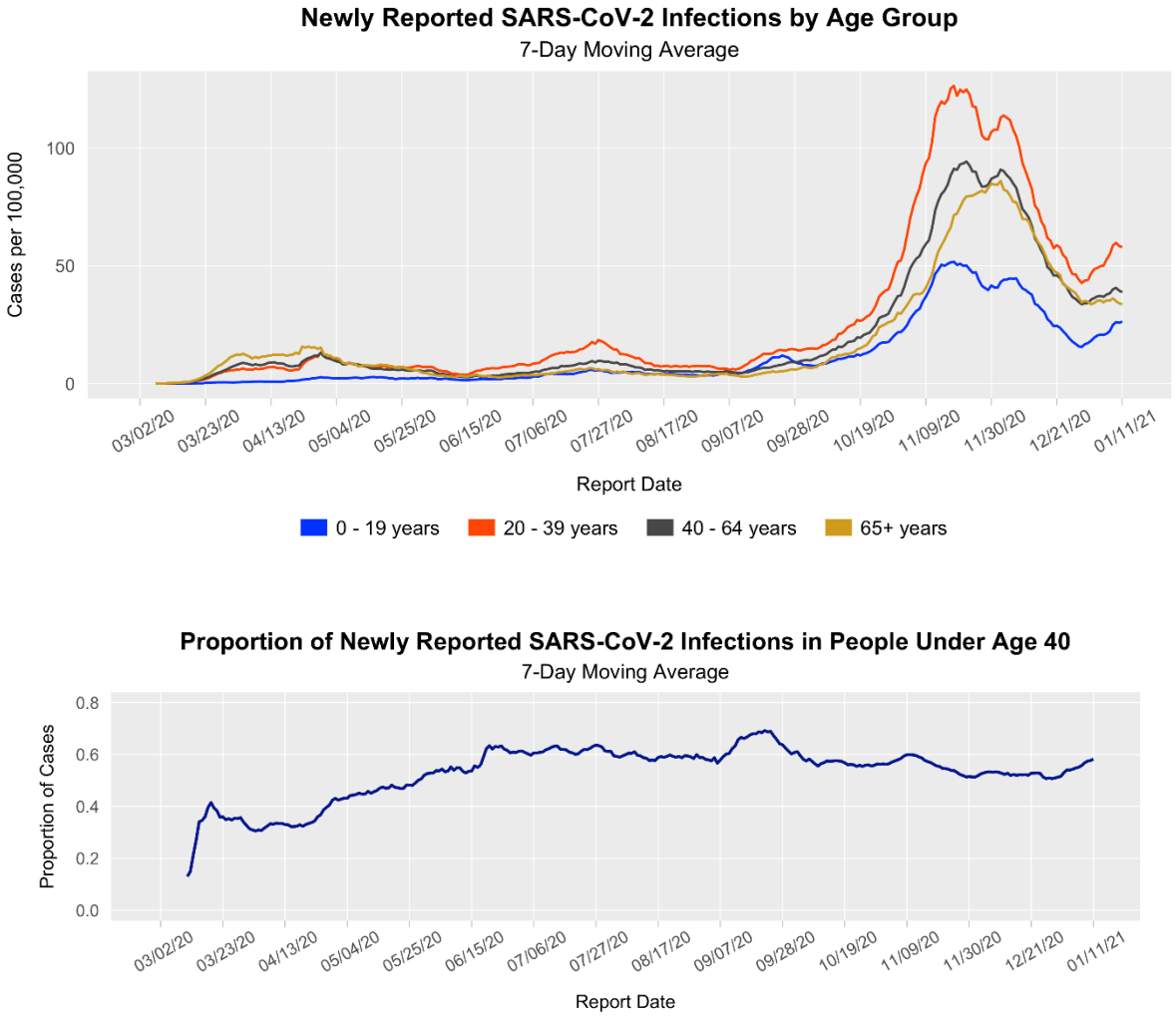

Figure 7 (above). Distribution of 7-day moving average of newly reported SARS-CoV-2 infections by age group (top) and the proportion of all cases among individuals under 40 (bottom). Reported cases are based on CDPHE data and shown by report date. Incident cases per 100,000 were obtained by standardizing 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 01/11, 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 01/11.

People under age 40 account for **13%**, people age 40 to 64 account for **37%**, and people age 65+ account for **51%** of COVID-19 hospital use over the two weeks between 12/29 and 01/11.

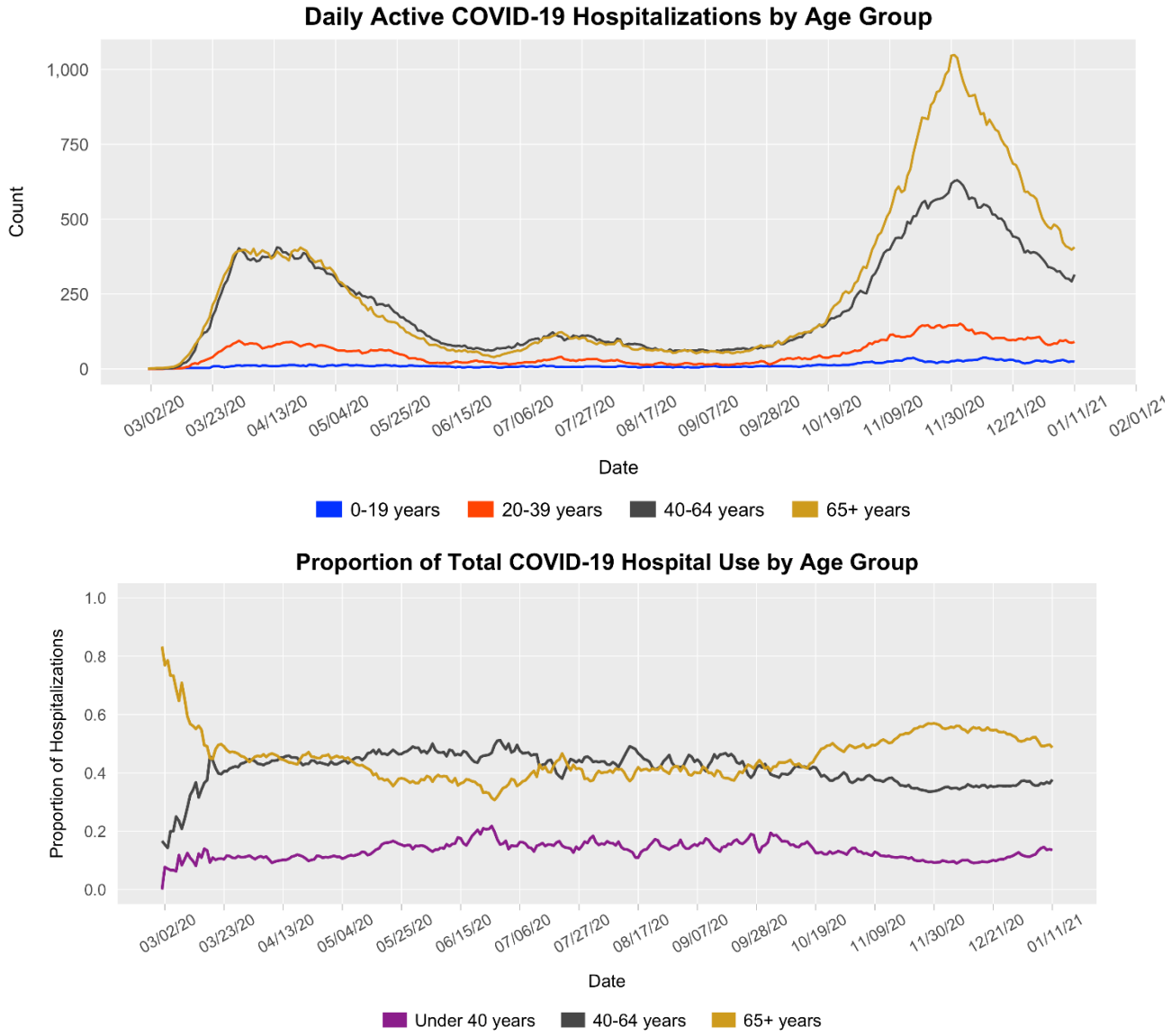

Figure 8 (above). The number of individuals hospitalized with COVID-19 by age group from March through the present (top) and the proportion of COVID-19 hospital beds occupied by individuals under 40 years, 40-64 years, and 65+ years (bottom). Data based on COVID Patient Hospitalization Surveillance (COPHS) through 01/11.

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

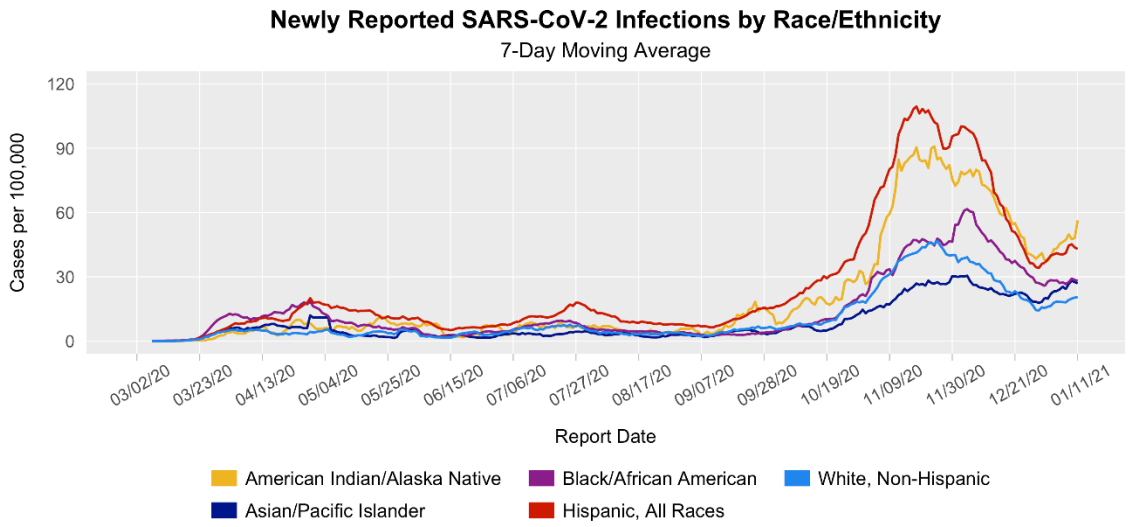

Figure 9 (above). Distribution of 7-day moving average of newly reported SARS-CoV-2 infections by race and ethnicity in Colorado. Reported cases are based on CDPHE data and shown by report date. Cases per 100,000 were obtained by standardizing weekly reported race-specific case counts to the race/ethnicity 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 **25%** of observations over the last two weeks). Data is shown through 01/11 to account for lags in collection of race/ethnicity data for reported cases.

Estimating Transmission Control Behaviors by Age

Due to the variation in behavior by age and the increase in cases seen among younger age groups, we estimate how transmission control varies by age group. We use CEDRS case data presented in Figure 7 to fit age-group specific levels of transmission control. We make the following assumptions about detection rate: We take the probability of detection from the overall model, calculated by comparing daily model estimated infections to reported infections (Figure 10) as a time series (daily time-step), and fit observed CEDRS case data to age-specific estimated infections over time. To account for age-specific differences in detection rate, we fit parameters for age-differences in detection rate to hospitalization data and then refit the TC parameters to case data.

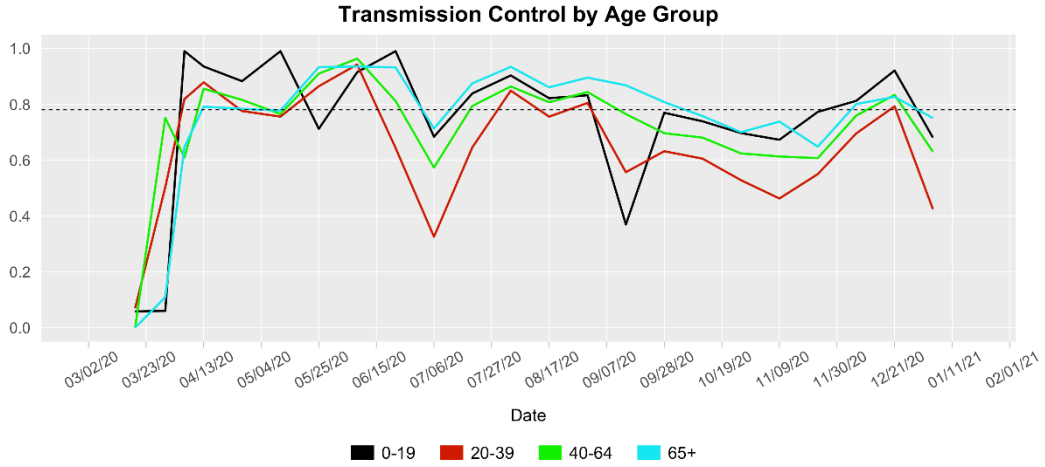

Figure 10 (above). Estimates of transmission control by age plotted over time. Transmission control values are plotted at the midpoint of the corresponding time period. As the last period for which transmission control is estimated is 12/20-01/05, the point on the graph is plotted at 01/04. Grey dashed line indicates threshold value of transmission control = 78%, at which Re = 1.

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 11). **In two weeks on 02/02, there is a 50% chance that at approximately 600 patients will be hospitalized with COVID-19, including 194 patients in the ICU, if we remain on the current trajectory.**

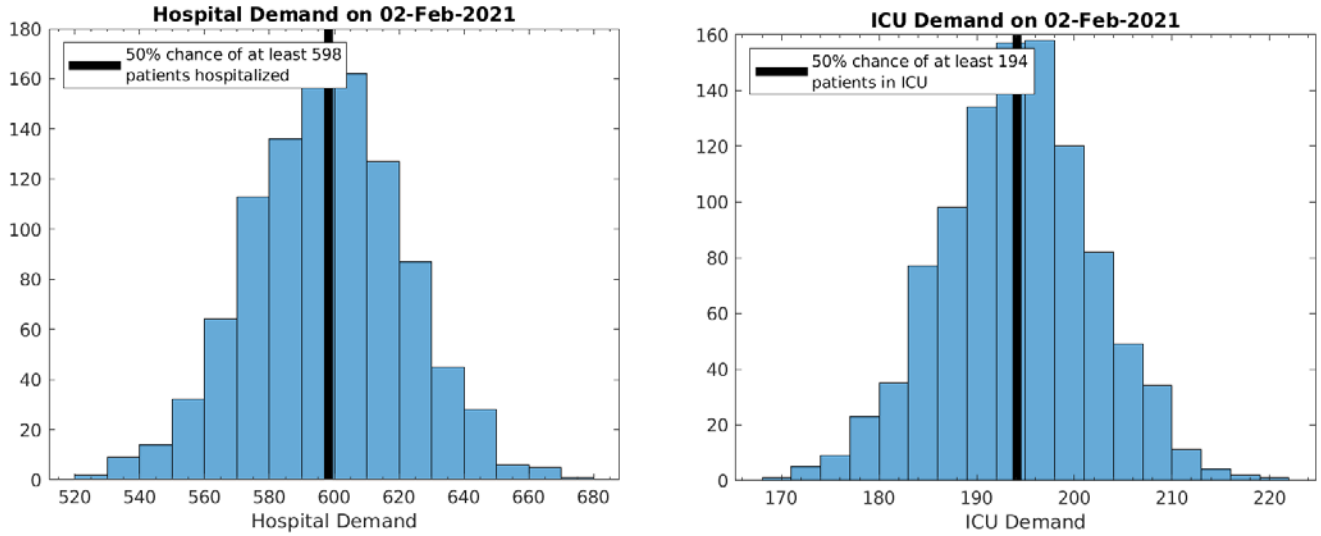

Figure 11 (above). Probability distribution of the number of hospitalized COVID-19 patients (left) and COVID-19 patients requiring ICU care (right) in two weeks if Colorado remains on the current trajectory These estimates account for vaccination, but do not account for the B.1.1.7 variant. Estimates are based on 10,000 simulated runs of the model, with 1,000 of those runs randomly selected for visualization.

Long-Term Projections

We generated projections of future infections, hospital demand and deaths under different scenarios involving changes in policy and behavior impacting transmission control, vaccine rollout and the growth of the B.1.1.7 variant, first identified in the United Kingdom. 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. The vaccination scenario in this projection assumes that 70% of the population age 70+ will be fully vaccinated and immune by mid-March (03/23/2021) as part of Phase 1B. We take into consideration the following:

- We assume all individuals who receive a first vaccine 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 assume 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 and vaccine availability timeline.

New variant. The current scientific evidence indicates that the new variant is more infectious than the currently circulating virus mix ("wild type"), but equally likely to cause an infected person to require hospitalization or to die. Restating, the variant strain is more infectious but not more virulent. 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.

For example, if transmission control due to policy and behavior were 80% with the wild type mix, and the new variant became the source 100% of the infections (an unlikely scenario), transmission control would effectively drop to 70%, assuming the variant is 1.5 times more infectious. Similarly, if transmission due to policy and behavior were 60%, and the new variant became the source of 100% of infections, transmission control would effectively drop to 40%.

For clarity, we refer to transmission control (TC) as the level of transmission control reached by policy and behavior in the absence of the new variant. We refer to variant-adjusted transmission control (TC_a) as the level of actual transmission control due to policy and behavior AND accounting for the assumed mix of B.1.1.7 and wild-type strains (this mix is a weighted average accounting for the infectiousness of the B.1.1.7 variant and the strain mix). Table 2, below, provides estimates of variant-adjusted transmission control (TC_a) at different levels of TC and for different levels of the frequency of the variant in the Colorado population. The impact of the variant on the spread of infections depends on how infectious it is and how rapidly it spreads and displaces the current circulating virus mix.

Table 2 (below). The variant-adjusted level of transmission control (TC_A) at different levels of behavior and policy (TC) and different levels of the frequency of the variant. These estimates of TC_A assume the variant is 1.5 times more infections than the wild-type.

	80% TC	78% TC	70% TC	60% TC
10% variant	79%	77%	69%	58%
20% variant	78%	76%	67%	56%
30% variant	77%	75%	66%	54%
40% variant	76%	74%	64%	52%
50% variant	75%	73%	63%	50%
100% variant*	70%	67%	55%	40%

*It is unlikely we will get to 100% B.1.1.7 variant

In the projection scenarios, the variant is modeled assuming it is 1.5 times more infectious than the current strain mix. It is assumed to comprise 1% of the strain mix on 1/18/21 and then to increase in a linear fashion (by 1% per day) reaching 50% of the strain mix on 3/08/2021. In reality, we do not know how quickly the variant will increase in Colorado.

Transmission control. Projections are generated assuming transmission control (TC) remains on the current trajectory or drops to 70% or 60% on 1/22/21.

Hospital Demand on the Current Trajectory. Figure 12 shows the range of estimated hospital demand in four weeks, on 02/16.

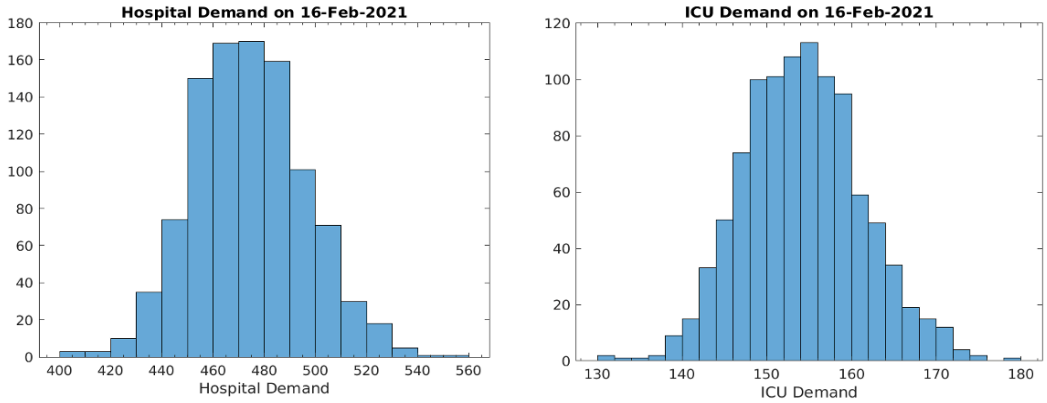

Figure 12 (above). Probability distribution of the number of hospitalized COVID-19 patients (left) and COVID-19 patients requiring ICU care (right) in four weeks if Colorado remains on the current trajectory. These estimates account for vaccination, but do not account for the B.1.1.7 variant. Estimates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

Figure 13 shows the estimated number of infections, COVID-19 hospitalizations and ICU demand for all combinations of vaccine, variant, and transmission control scenarios. Table 3 shows cumulative infections, peak hospital demand and deaths for each scenario.

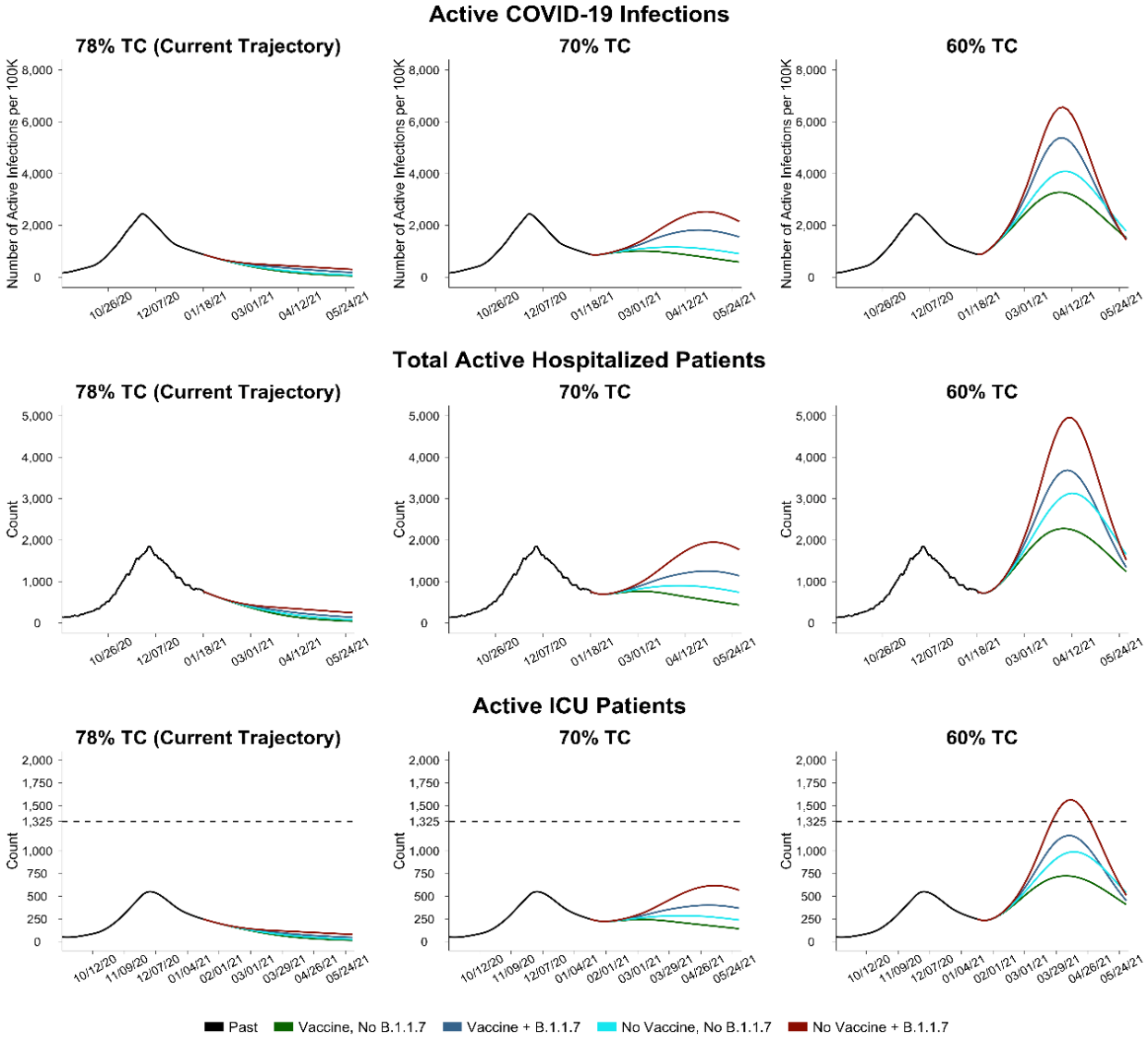

Figure 13 (above). Projected daily active COVID-19 infections per 100,000 population (top), total number of patients actively hospitalized for COVID-19 (middle), and active COVID-19 ICU patients (bottom), assuming TC remains at the current levels (78%) indefinitely (left) or switches to 70% TC (middle) or 60% TC (right) indefinitely beginning Friday, 01/22. This projection compares scenarios with the vaccine with no variant (green line), the combination of the vaccine and the B.1.1.7 variant (blue line), no vaccine and no variant (turquoise line), and the variant with no vaccine (red line). The horizontal dashed line for patients in the ICU indicates capacity limits for critical care (1,325 ICU beds available for COVID-19 patients). Figures on hospital capacity limits are provided by CDPHE.

Table 3 (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 TC.

	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 01/18 and 02/28/21**	Cumulative Deaths Through 06/01/21**
Current (78% TC) and Vaccine	NA	past	552	680,000	5,750	600	6,030
Current (78% TC) and Vaccine + B.1.1.7	NA	past	552	689,000	5,770	620	6,210
Current (78% TC) and No Vaccine	NA	past	552	683,000	5,770	620	6,240
Current (78% TC) and No Vaccine + B.1.1.7	NA	past	552	693,000	5,790	640	6,650
70% TC and Vaccine	NA	past	552	764,000	5,990	840	7,040
70% TC and Vaccine + B.1.1.7	NA	past	552	789,000	6,030	880	7,890
70% TC and No Vaccine	NA	past	552	773,000	6,020	870	8,270
70% TC and No Vaccine + B.1.1.7	NA	05/08/21	619	802,000	6,060	910	10,400
60% TC and Vaccine	NA	04/07/21	726	951,000	6,420	1,270	9,510
60% TC and Vaccine + B.1.1.7	NA	04/09/21	1,172	1,020,000	6,510	1,360	10,900
60% TC and No Vaccine	NA	04/14/21	992	978,000	6,490	1,340	13,200
60% TC and No Vaccine + B.1.1.7	03/26/21	04/11/21	1,566	1,050,000	6,590	1,440	16,800

*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 further reopening of businesses, we estimated the projected prevalence of active COVID-19 infections through May 2021, assuming we remain on the current trajectory. Figure 14 shows that if we remain on the current trajectory, infection prevalence will decline rapidly. However, since infection prevalence is currently relatively high, particularly in comparison to the lowest values of the summer of 2020, 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 01/25/2021 and will reach the summer low point (132 per 100,000) on approximately 04/25/2021. If transmission control drops in the weeks ahead, prevalence will decline more slowly. These estimates account for vaccination, but do not account for the potential consequences of the B.1.1.7 variant.

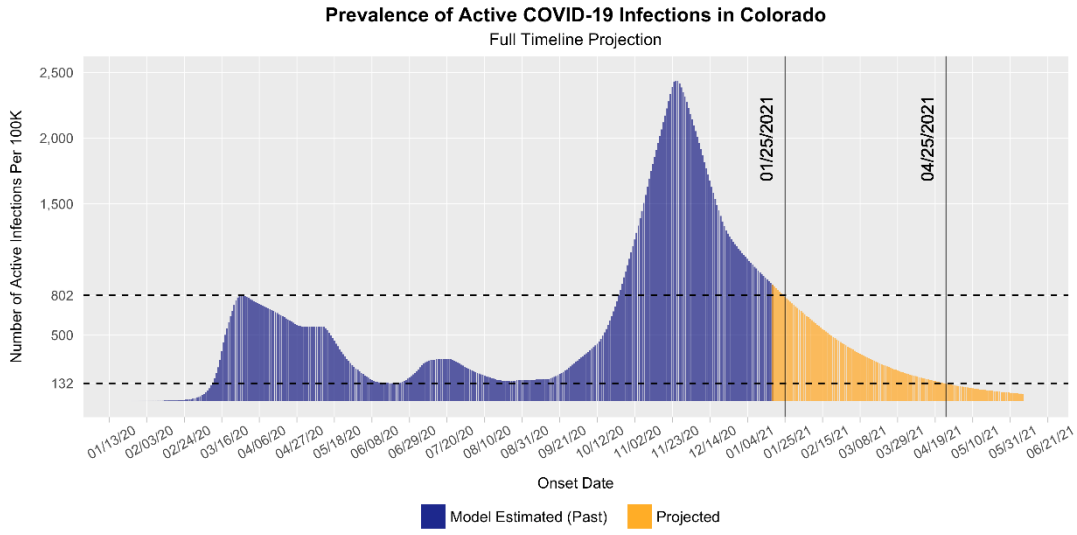

Figure 14 (above). Estimated daily number of people who are infectious and infected with SARS-CoV-2 (point prevalence). Estimate is shown per 100,000 population. The number of infectious individuals is inferred using the model and estimates and based on hospitalizations. Horizontal dashed lines indicate 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 78%.

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/

Model Fit

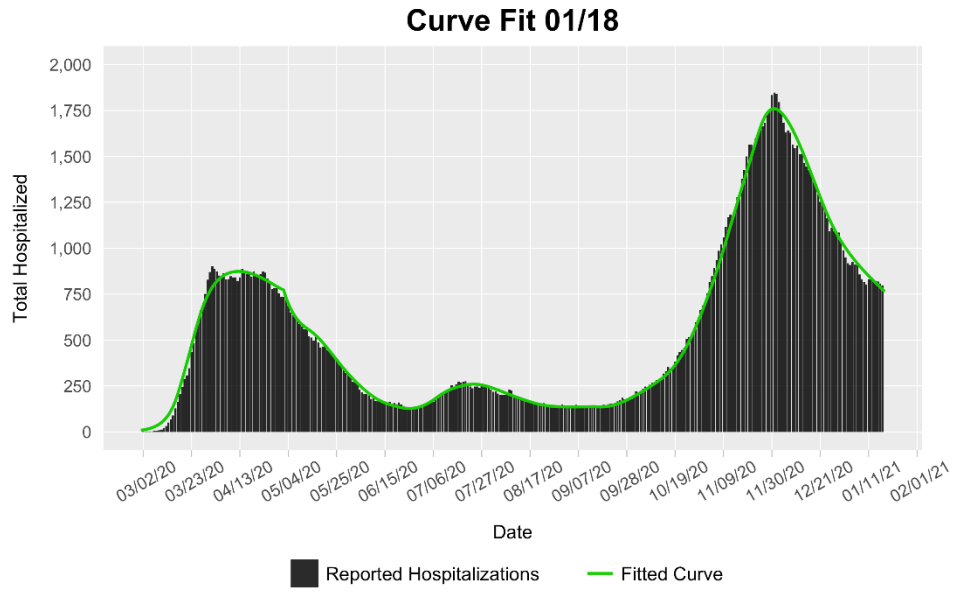

Figure A1 (above). Current model fit (green line) to the count of hospitalized COVID-19 cases (black lines) through 01/18 using the age-structured SEIR model. Hospitalized COVID-19 cases are from CDPHE reported COVID-19 hospitalizations and EMResource (EMR) hospital census data provided by CDPHE.

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 12/20 to 01/05 *	0-99%	78% (95% CI: 77.1%, 79.7%)	1/18/21
Estimated TC level one week prior for the period 12/19 to 12/29 *	0-99%	80% (95% CI: 78.9%, 82.2%)	1/11/21
Estimated TC level two weeks prior for the period 12/06 to 12/26 *	0-99%	82% (95% CI: 81.6%, 83.1%)	1/4/21
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	01/18	01/18	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	01/15	01/11	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	01/18	01/08	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	01/18	01/11	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	01/18	01/04	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 with known age-specific vaccination rates from CDPHE data. 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. Currently vaccine delivery schedules are known through the end of January, but we assume sufficient levels of vaccine to vaccinate 70% of individuals over age 70. 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 A3 (below). Current Assumptions about Vaccination Rates by Age in the Model

Dates of first Vaccination 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	2358	2738	1075
01/05 - 01/15	02/06 - 02/16	33	3372	3915	1537
01/15 - 02/19	02/16 - 03/23	0	0	0	8871

*Number of first vaccinations per day

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