The Current State of COVID-19 in Colorado

04/07/2021

Prepared by the Colorado COVID-19 Modeling Group

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Summary

- Based on data through 4/05, we estimate that transmission control has remained at 68%, the same as last week. The effective reproductive number remains above 1 at 1.08 indicating growth of infections. Approximately one in 196 people in Colorado are currently infectious, an increase from lows in March of about 1 per 350.
- The benefits of vaccination continue to be realized. We estimate that approximately 30% of Coloradans are currently immune due to vaccination and/or prior infection. Of those 65+, approximately 75% are immune, but the decline of hospitalizations in those 70+ has paused.
- We conducted a statistical analysis of the potential impact of a full move of the Colorado COVID-19 Dial to Level Green and used these estimates to project COVID-19 hospitalizations and deaths in Colorado under different policy and behavior change scenarios.
- The modeling results indicate that delaying policy changes, whether at the state or local level, until mid-May, vs. mid-April, will prevent large numbers of deaths and hospitalizations.
- If vaccinations continue as planned, modeling results suggest that by mid-May policy changes could be made at the state or local levels that would relax restrictions without major increases in hospitalizations or COVID-19 deaths. Policy measures to control transmission should be continued for the next month, whether at the state or local public health agency level. By mid-May, Coloradans might be able to relax some of the behaviors that have been so critical in controlling the state's epidemic.
- Variant growth, the future trajectory, and how policy changes will impact behaviors are major sources of uncertainty. Rapid growth of the B.1.1.7 variant, as is happening now, or increases in hospitalizations would signal a need for caution in adopting further policy changes in the next few weeks.
- Mobility is reaching its highest levels since the start of the pandemic.

Snapshot of Current SARS-CoV-2 Transmission in Colorado Based on COVID-19 Hospitalization Data Through 04/05

Effective reproduction number: 1.08. *Infections are increasing.*

Estimated prevalence of infections: Approximately 510 of every 100,000 Coloradans or 1 in every 196 Coloradans are currently infectious.

Estimated percent of the population immune: Approximately 30% of Coloradans are immune due to vaccination or prior infection.

Estimated percent of the population vaccinated: Approximately 31% of Coloradans have received at least one dose of a SARS-CoV-2 vaccine.

Introduction

We used our age-structured SEIRV (susceptible-exposed-infected-recovered-vaccinated) model and real-time COVID-19 hospital census, vaccination, and case data to characterize the current status of the COVID-19 epidemic in Colorado. We use 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 vaccine roll out, spread of variants of concern and transmission control measures. These include estimates of hospital needs, infections, and deaths under these different scenarios.

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. Links to model details are provided in the appendix at the end of this report.

The estimates presented in this report are based on hospitalization census data through 04/05 and vaccination data through 04/04.

Model Updates

Model updates implemented this week.

- **Vaccine Efficacy.** Based on evidence from the recent CDC MMWR report, we are now modeling the Pfizer/Moderna vaccines to be 80% effective 14 days after the first dose.
- **Hospitalizations and Deaths Among the Vaccinated.** For the past two weeks, we have halved the projected number of COVID-19 hospitalizations in the 65+ age group in our projections to account for high efficacy of the vaccine in protecting against severe COVID-19. Examination of recent hospitalization data indicates we should discontinue this practice (appendix Figure A2). We continue to assume vaccinated individuals age 65+ have almost no mortality.
- **Variants of Concern.** Colorado now has a mix of variants of concern. We updated our variant of concern scenarios to better reflect the status of the major variants of concern in Colorado. These scenarios account for different transmissibility and virulence of the different variants. We include two scenarios – one where the B.1.1.7 variant becomes dominant, and another where the B.1.427/B.1.429 becomes dominant. Recent sequencing data suggests B.1.1.7 is more likely to become the dominant variant.

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 shows that the epidemic curve is now starting to turn upwards.

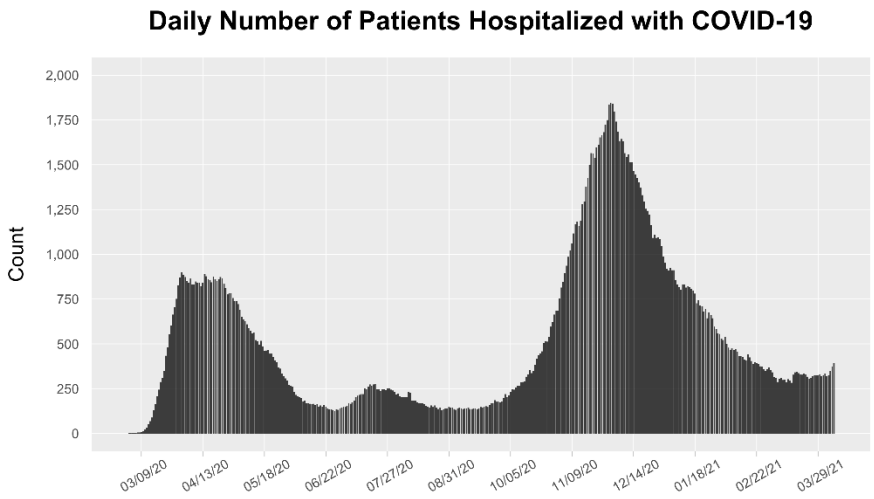


Figure 1 (above). Daily count of hospitalized COVID-19 cases through 04/05. The time series of COVID-19 hospitalizations in Colorado is based on hospitalization data provided by CDPHE through 4/07/2020 and the EMResource hospital census of COVID-19 hospitalizations starting 4/08/2020 (EMResource hospital 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 on slowing the spread of infections from infected to susceptible individuals. 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 2020 (Figure 2). Transmission control is estimated by aligning model output to hospitalization data using model-fitting approaches.

Our current estimate of transmission control is 68%. This estimate is for the period 03/13 to 03/23, given the lag between infection and hospitalization. The trajectory of transmission control has been downward for several months.

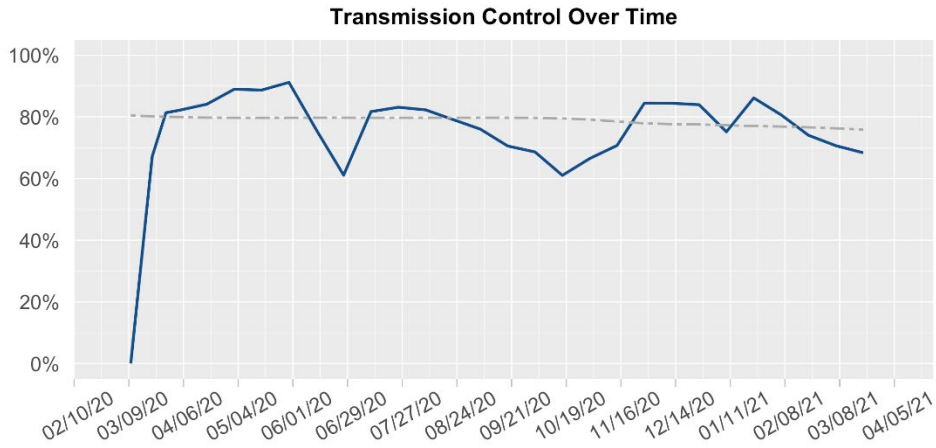


Figure 2 (above). The estimated transmission control value for each two-week period since the beginning of the epidemic. On the graph, the value is shown for the mid-point of each two-week period. Transmission control is estimated using model fitting approaches to align model output with COVID-19 hospitalizations. The grey dashed line indicates the estimated value of transmission control 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. We note that in the days since the model was fit, hospitalizations have trended upwards above the projected curve (black line), suggesting transmission control now may be lower than estimated on April 5. COVID-19 hospitalizations should be watched closely in the days ahead.

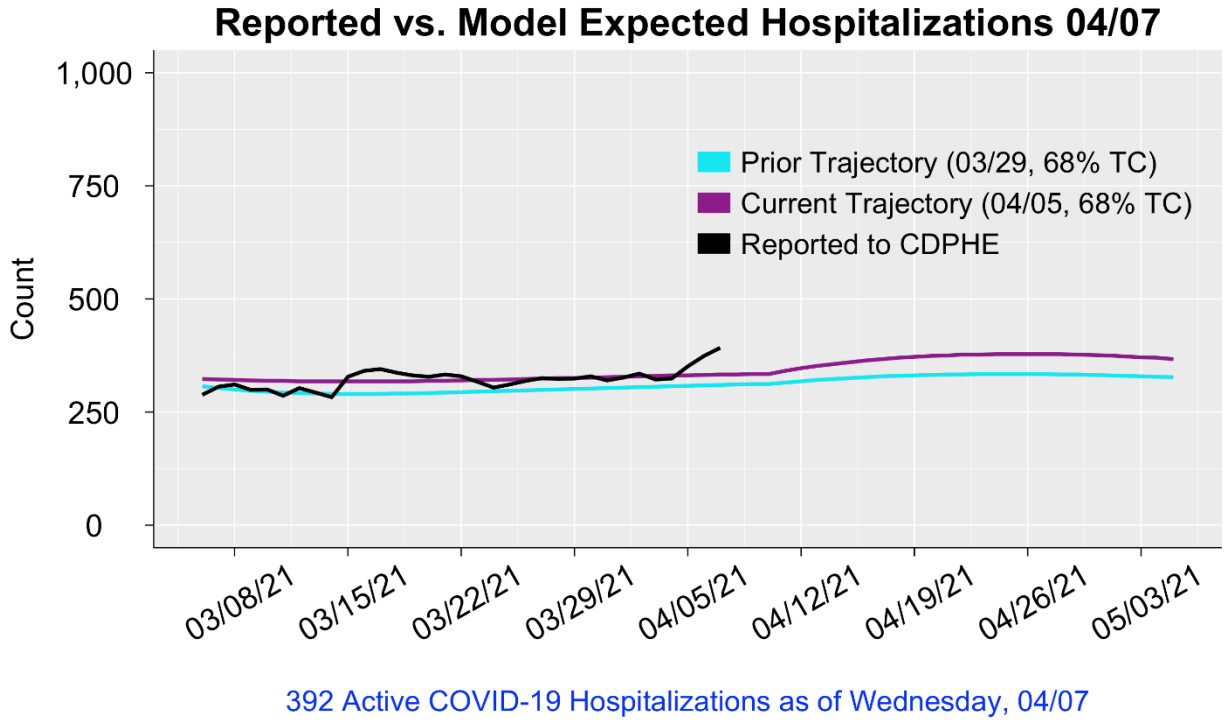


Figure 3 (above). The projected course of COVID-19 hospitalizations if Colorado were to remain on the current estimated trajectory (purple line) or on the trajectory estimated one week prior (turquoise line). Each trajectory is generated assuming Colorado rolls out vaccines on schedule, as described 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 one, infections are decreasing. When the effective reproduction number is above one, 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 1.08. Due to the lag between infections and hospitalizations, this estimate of Re reflects the spread of infections occurring on approximately 03/23. The estimated values of the reproduction number since March 2020 are shown in Figure 4.

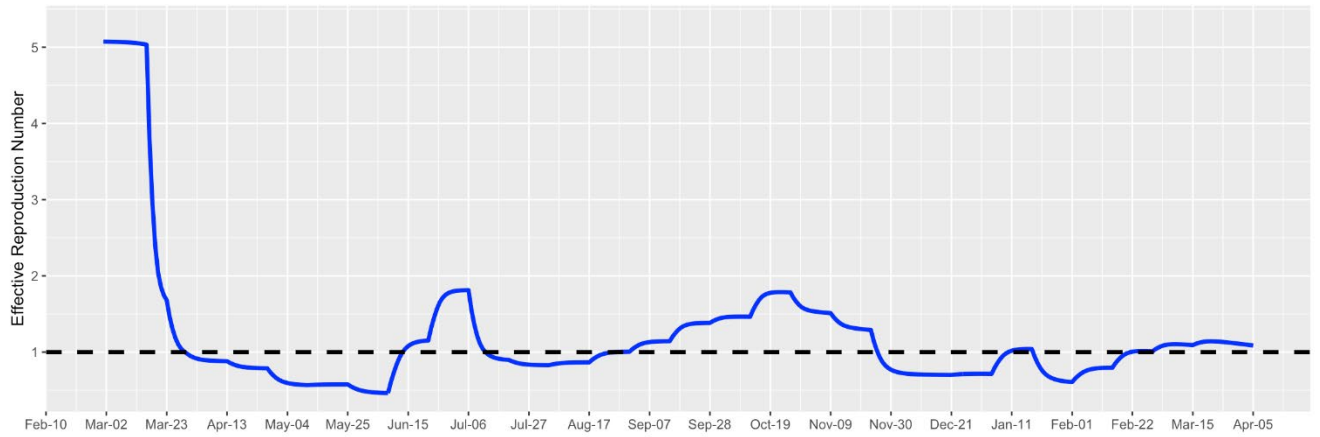


Figure 4 (above). Estimates of the effective reproduction number over time.

Infection Prevalence

Infection prevalence provides an estimate of the proportion of the population that is currently 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 not detected by the Colorado Electronic Disease Reporting System (CEDRS).

These estimates are generated using the model by assuming the most recent transmission control parameter (estimated for the period 03/13 to 03/23) remains at the estimated value through 04/05. 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 by age.

We estimate that there are approximately 29,700 infectious individuals in Colorado at present (04/05): approximately 510 of every 100,000 Coloradoans or 1 in every 196 people. The estimated infection prevalence since March 2020 is shown in Figure 5. It rose progressively over the month of March.

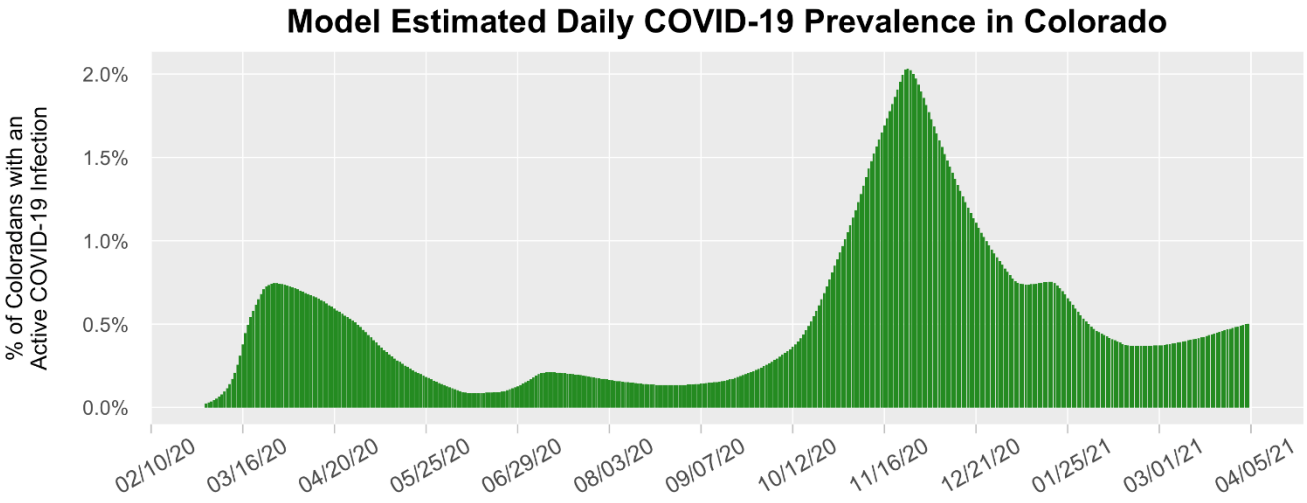


Figure 5 (above). Estimated daily number of people who are infectious and infected with SARS-CoV-2 (point prevalence). Estimate is shown per 100,000 population. The number of infectious individuals is inferred using the model and based on hospitalizations.

Case Detection

Comparing observed to model-estimated infections, **we estimate that approximately 36% of infections were detected by state surveillance systems, including both asymptomatic and symptomatic infections in the two-week period from 03/13 to 03/26** (Figure 6).

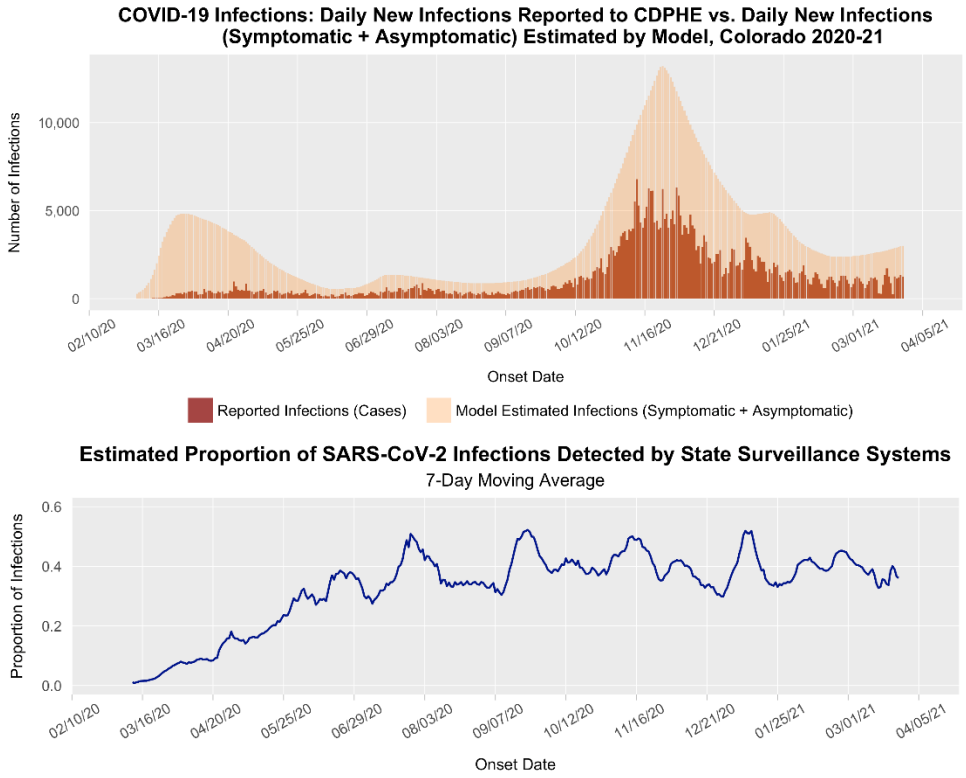


Figure 6 (above). Estimated daily number of new (incident) SARS-CoV-2 infections based on the total estimated by the SEIR model (light orange graph) and reported cases (dark orange graph) over time shown in the top panel. Lower panel shows the 7-day moving average of the estimated proportion of SARS-COV2 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 03/26 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 from March 2020 through the present, estimated using our age-structured SEIR model and data on vaccinations in Colorado provided by CDPHE. Figure 8 shows the proportions of this immunity by age group. This estimate of population immunity has two components. It accounts for the proportion of people estimated to be immune due to vaccination (yellow line), and the proportion of people estimated to be immune due to either vaccination or prior infection (blue line). In the model, the two-dose vaccines are assumed be 80% effective at preventing infections 14 days after the first dose, and 90% effective one week

after the second dose. Vaccination data by age are provided by CDPHE and we assume all individuals who receive first doses also received second doses on schedule. This estimate 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. This means people who were infected early in the pandemic may no longer be immune to infection unless they have been vaccinated. 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 1,765,000 people in Colorado, or 30% of the Colorado population, are currently immune to SARS-CoV-2 as of 04/05.

Projecting forward, Figure 9 shows theoretical herd immunity thresholds and the projected proportion of the population estimated to be immune through vaccination or prior infection at 70% transmission control through early July 2021.

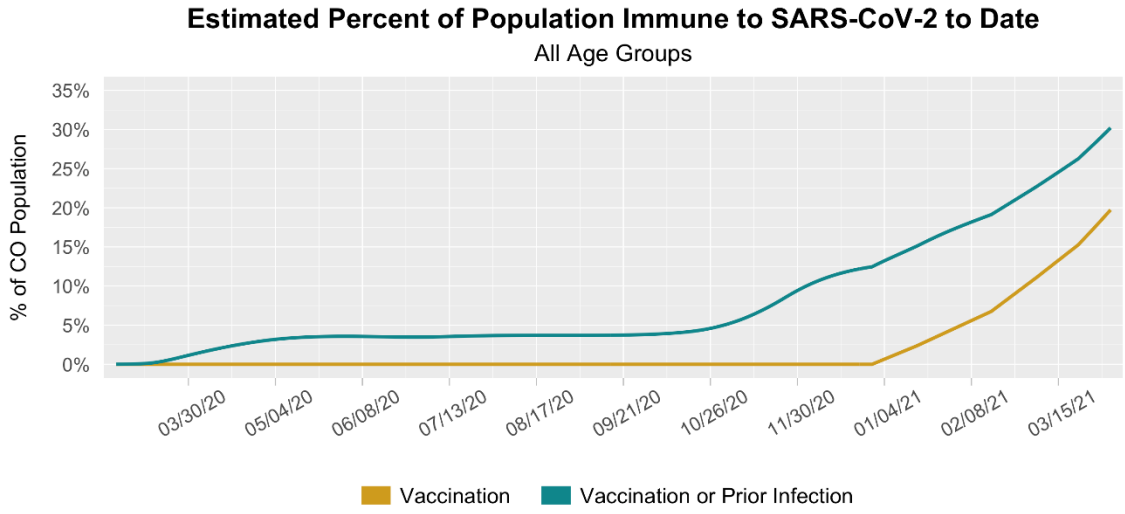


Figure 7 (above). Estimated percent of the population in Colorado assumed to be immune to SARS-CoV-2 due to infection and/or vaccination through 04/05.

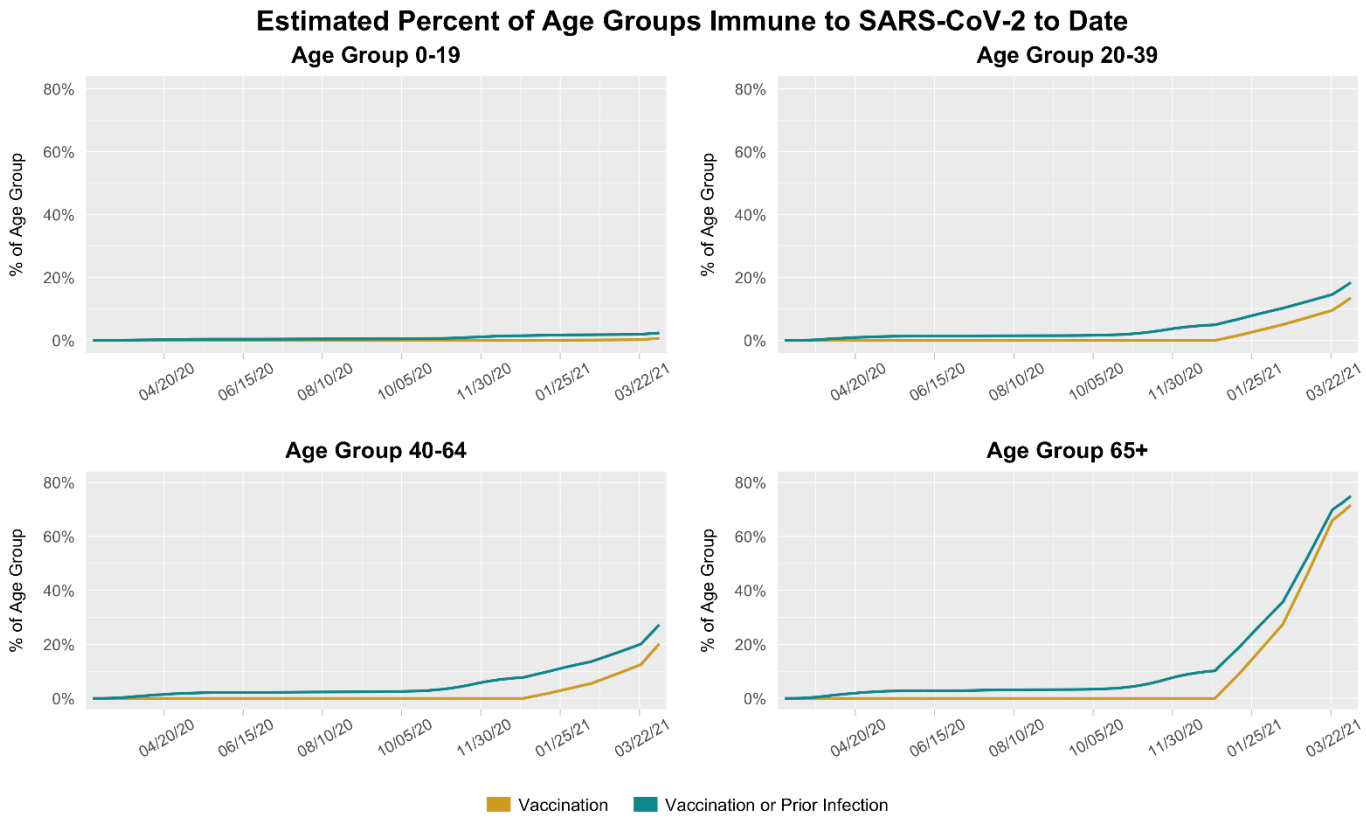


Figure 8 (above). Estimated percent of each age group in Colorado assumed to be immune to SARS-CoV-2 due to infection and/or vaccination through 04/05.

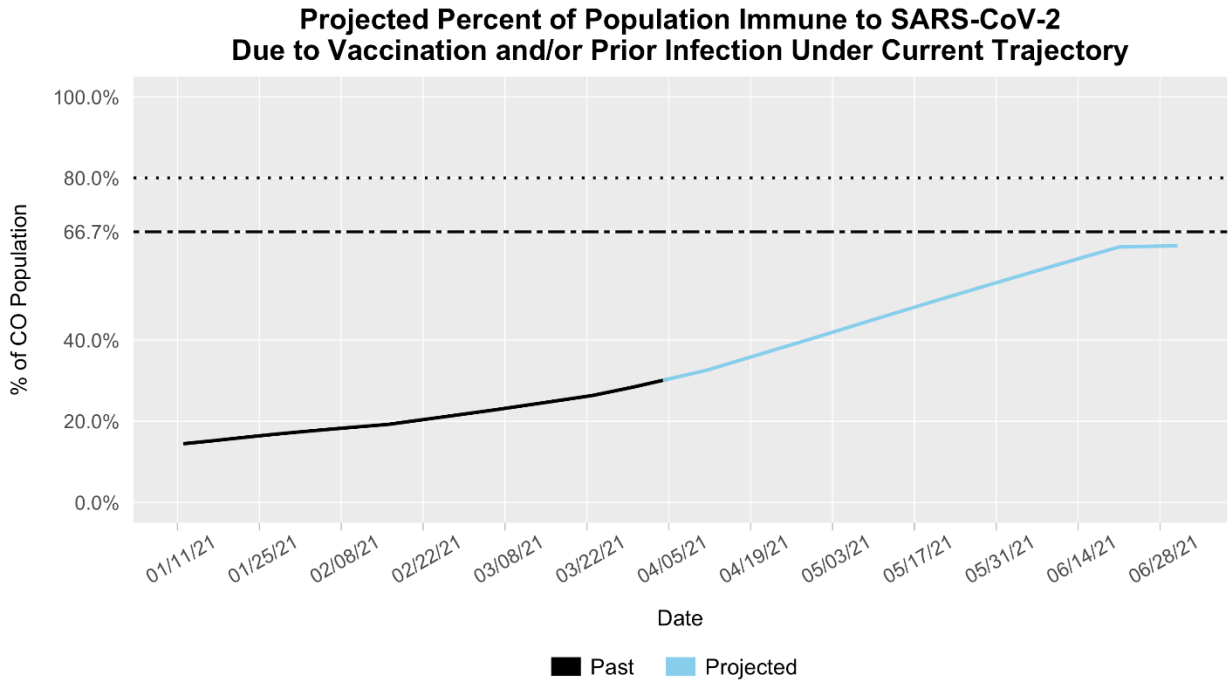


Figure 9 (above). Estimated percent of the population immune due to vaccination and/or prior infection under current vaccination projections, assuming transmission control switches to 70% indefinitely on 04/09. Details of the vaccination rates to date and key assumptions about vaccinations in the future are provided in Appendix Tables A3 and A4. Dashed lines indicate herd immunity thresholds, which are estimated to be at 66.7% at R0 = 3 and 80% at R0 = 5. Currently there is uncertainty regarding the true herd immunity threshold.

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 March 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. 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.

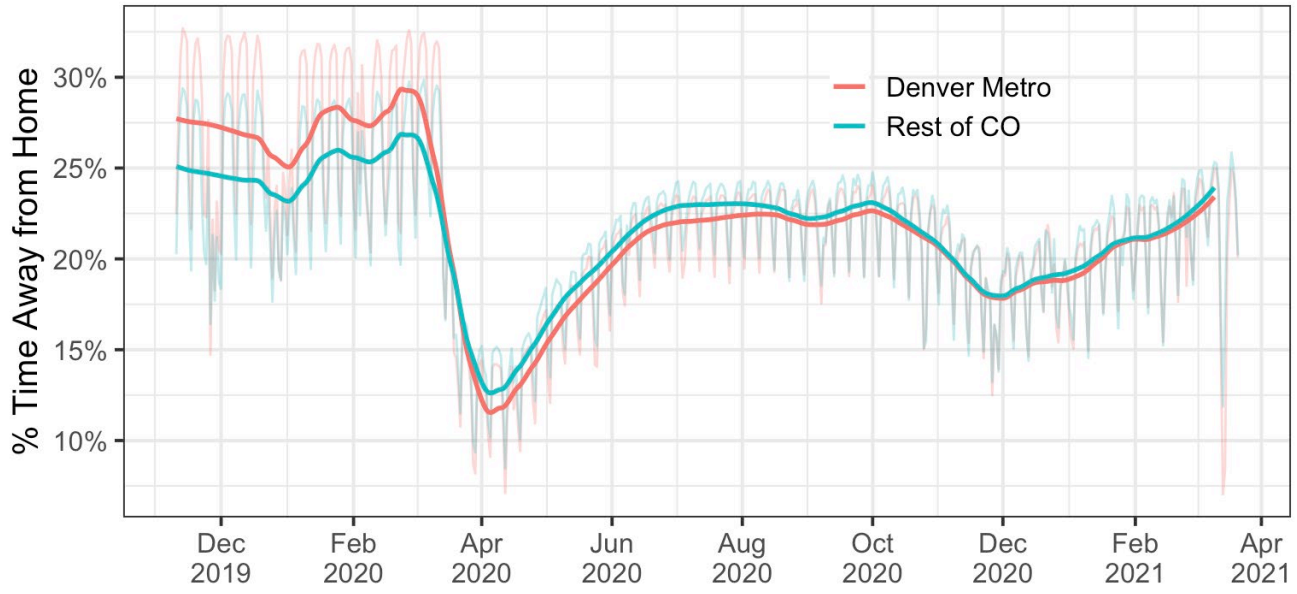


Figure 10 (above). Daily hours away from home (SafeGraph) are averaged across census block groups within the two regions. The faint lines show the daily data, and the thick lines represent a smoothed average over time. The ribbon below the time away from home displays the population-weighted mean daily temperature across the state from gridMET.

Near-Term Forecast of Hospital Demand

We generated estimated COVID-19 hospital demand over the next two and four weeks assuming Colorado remains on the current trajectory and accounting for uncertainty in our current estimated trajectory. **In two weeks on 04/20, we estimate approximately 331 patients will be hospitalized with COVID-19 if we remain on the current trajectory** (Figure 11, left panel). There is greater uncertainty in hospitalizations in four weeks (Figure 11, right panel). We note that the most recent hospital data suggest that the epidemic curve may be on a trajectory that is steeper than that estimated for transmission control at 68% (Figure 3).

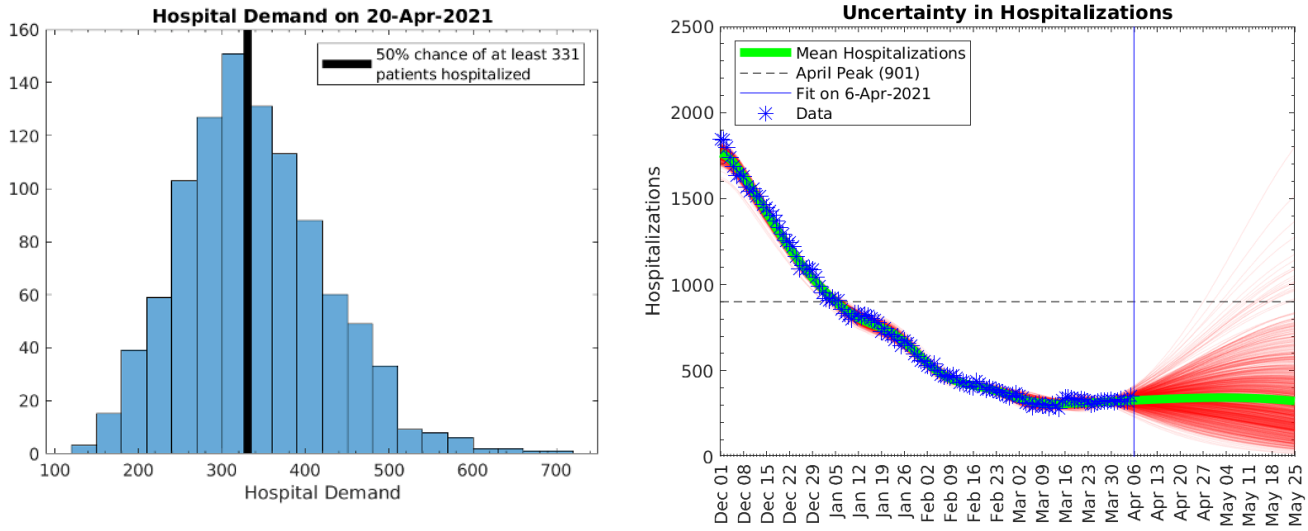


Figure 11 (above). Probability distribution of the number of hospitalized COVID-19 patients in 2 weeks if Colorado remains on the current trajectory (left) and uncertainty in the COVID-19 hospital demand over the next four weeks (right). Estimates are based on 10,000 simulated runs of the model, with 1,000 of those runs randomly selected for visualization.

Long-Term Projections

We generated projections of future hospital demand under current transmission control and vaccine rollout strategies, using scenarios in which county dial policies are lifted April 15th and May 15th with and without other changes in policy and behavior. We consider these scenarios in the context of either the B.1.1.7 or B.1.427/429 variant as the dominantly circulating strain.

Vaccination. We model vaccine rollout based on vaccination projections provided by CDPHE. We model a maximum of 90% uptake in individuals over 65, and 80% uptake in each other age group. Vaccination rates in the projections occur at current age-specific rates which currently prioritizes the oldest age groups. Individuals under the age of 15 are assumed not to receive any vaccine. Once the oldest age groups are vaccinated up to the threshold, vaccine is then allocated to the next oldest age group. We assume all individuals who receive a first dose of a two-dose vaccine (Pfizer, Moderna) receive a second dose on schedule. Vaccine allocation scenarios run through June 1st. Note that under the assumptions of 80% uptake among younger individuals and no vaccination of children under 15, we run out of people to vaccinate in late-May. Details of the vaccination rates to date and key assumptions about vaccinations in the future are provided in Appendix Tables A2 and A3.

Variants of Concern. In late 2020, two new variants of concern (VOC) emerged in the United States—B.1.1.7, which emerged in the United Kingdom and was first reported in the United States in Colorado, and B.1.427/429, first reported in California. The current scientific evidence indicates that both variants are more infectious than other currently circulating variants and the US CDC classifies both as "variants of concern." The spread of the more infectious variants can lead to an increase in infections, hospitalizations, and deaths without changes in policy or behavior. In the United Kingdom, the B.1.1.7 variant spread rapidly and is estimated to be causing over 90% of new infections. The B.1.427/429 variants also appear to be growing rapidly, particularly in the western United States (US CDC, Deng et al 2021). The B.1.1.7 variant is likely also more virulent and more lethal. 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). At present, there not strong evidence that B.1.427/429 is more virulent (Science, 02/23/2021). We also note that two additional variants of concern have not been identified in Colorado: B.1.351

and P1 at the original drafting of this report. We are monitoring the variant situation closely and note that both variants have now been documented in Colorado as of the release of this report.

In our projections, we assume the following:

- B.1.1.7 is 1.5 times more infectious and B.1.427/429 is 1.2 times more infectious than currently circulating variants.
    - Variants of concern follow a logistic growth curve, comprising 30% of SARS-Cov-2 infections in Colorado as of 3/14 and over 50% of infections by early April. Variants of concern approach a maximum of 95% of infections in early June.
    - We generate two scenarios. In one, B.1.1.7 outpaces growth of B.1.427/429 by a 2:1 ratio (this is the B.1.1.7 becomes dominant scenario). In the other B.1.427/429 outpaces growth of B.1.1.7 by a 2:1 ratio (this is the B.1.427/429 becomes dominant scenario). Recent data suggest the former may be closer to reality but there remains uncertainty regarding how the variants will spread.
    - Infection with the B.1.1.7 variant confers a 1.4-fold increased risk of hospitalization, a 1.4-fold increased risk of death among those hospitalized, and a 1.7-fold increased risk of death among those not hospitalized for those age 40+. Infection with the B.1.427/429 variant confers no additional risk of hospitalization or death.
    - The impact of the variants is modeled as a decrease in transmission control due to both the infectiousness of the variants and the distribution of the variants (e.g., the proportion of all infections due to the variants).

We note that the science is evolving rapidly. We are monitoring this situation closely and will adapt these scenarios as the science evolves and more information is available on the distribution of these variants.

Analysis of Potential Impact of Policy Changes. We previously conducted a statistical analysis to estimate the potential impact of a statewide mask requirement and the dial on COVID-19 case growth, and used these estimates to inform model projections. The analysis of the mask requirement is conducted at the state level and includes US states. The dial is a Colorado specific policy, so we use data from Colorado counties to analyze the impact of the dial. We follow the methods described in Guy et al. (2021) and estimate a population-weighted linear regression with state (county) and day fixed effects (detailed methods available upon request). Specifically, we quantify the impact of the mask requirement and dial policy on the log growth rate of cases. We then translate the regression coefficients measuring the effect on case growth to transmission control. This translation allows us to compare the effect sizes of the policy and project the epidemic curve into the future.

We find that implementing the mask requirement increased TC by approximately 4% points (± 2% points), while rescinding the mask requirement decreases TC by 4% points (± 3% points) (see Table 1). We find that the Colorado dial policy increased TC. The dial levels correspond to increasing restrictions on business operations and gatherings. Increasing the dial rating to blue (relative to the green reference level) is associated with a 3% points (± 3% points) increase in TC, while a move to red is associated with nearly a 9% points (± 4% points) increase in TC (see Table 2). To quantify the effect of the policy on future TC, we calculated a population-weighted average of the change in dial level over the past 4 months. The average impact over that period is approximately 7% points (± 3% points).

Scenarios accounting for possible changes in behavior and policy. Since these analyses were generated, there has been evidence of behavioral change (e.g., Figure 10) as well as proposed and current changes in policies related to SARS-CoV-2. It is possible that changes in policy leads to altered risk perceptions, which also lead to changes in behavior. To provide a range of estimates on how both policy and behavior changes may impact the future trajectory, we simulate six scenarios:

1. Remain on current trajectory (68%)
2. Removal of the dial. Because the dial has been in place since September, our estimate is the impact of moving all counties to green. Modeled as a 7% reduction in TC statewide. Based on aforementioned data analysis.
3. Modest behavior / policy changes leading to a 5% reduction of TC statewide.
4. Major behavior / policy changes leading to a 10% reduction of TC statewide.
5. Remove dial and modest behavior / policy changes, leading to a 12% reduction in TC statewide.
6. Remove dial and major behavior / policy changes, leading to a 17% reduction in TC statewide.

These projections are simulated for both variant scenarios. They are modeled taking effect April 15th and May 15th. Transmission is assumed to follow the current trajectory (68% TC) until the changes take effect.

Projections: Current Trajectory. Figure 12 shows estimated hospitalizations through early July 2021, if Colorado remains on the current trajectory (68% TC), accounting for both variant growth scenarios.

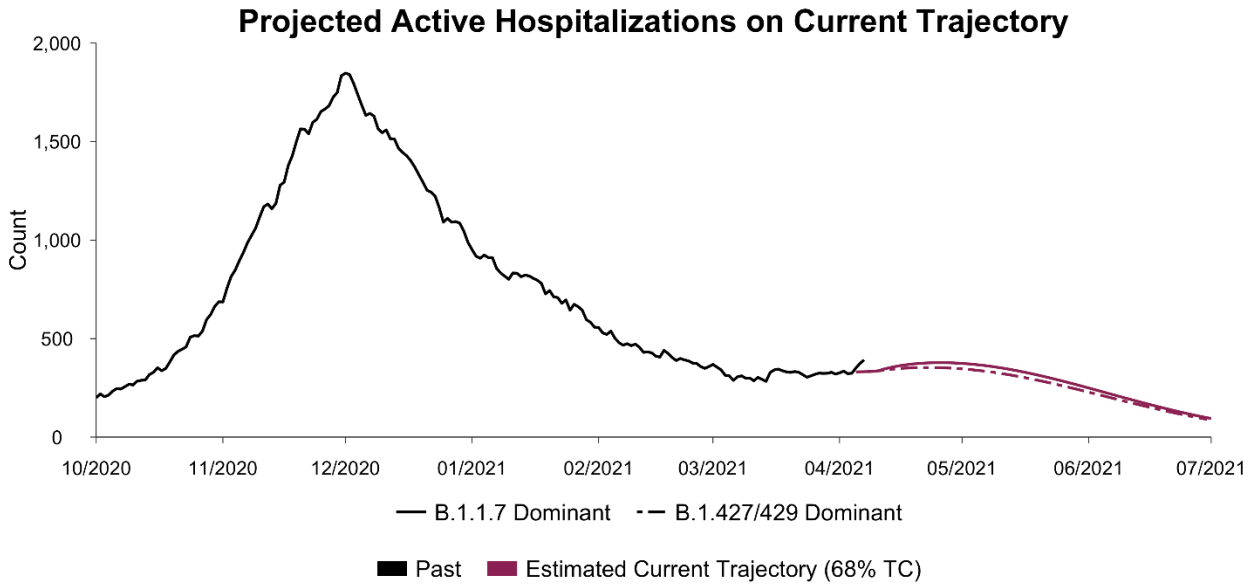


Figure 12 (above). Projected total number of patients actively hospitalized for COVID-19 through early July 2021, assuming transmission control remains at the current level (68% TC) indefinitely. Black lines indicating historical data reflect observed hospitalizations reported in EMR, to include the December peak. This projection accounts for variant growth in which B.1.1.7 becomes dominant (solid lines) and B.1.427/429 becomes dominant (dashed lines).

Projections: Changing policies and behavior on April 15th or May 15th. Figure 13 shows the projected COVID-19 hospitalizations through early July 2021 for the six scenarios. Figure 14 shows the projected additional deaths for these policy change scenarios. In these projections, we assume Colorado remains on its current trajectory (68% TC) until April 15th or May 15th, at which the changes occur (in reality, changes may occur more gradually). Estimates are provided for the two variant growth scenarios. Detailed estimates are provided in Appendix Table A4.

These projections illustrate several points. First, delaying policy changes until mid-May will prevent large numbers of deaths and hospitalizations. Moreover, delaying policy changes until mid-May, will allow for more options in terms of the number and magnitude of changes that could be pursued without a major increase in hospitalizations and deaths. If the dial is removed in April and this change is paired with either people adopting more risky behavior or additional policy changes, there could be a surge in COVID-19 hospitalizations that approaches the December peak. Clear communication regarding the continued risks of infection through mid-May, particularly among those

not yet vaccinated will be important. The uncertainty of the current trajectory, variant growth and the statistical analysis means there are large uncertainties regarding the impact of these policies. If the COVID-19 hospitalizations increase substantially in the days ahead, the impacts of changes in behavior and policy could be larger than shown here.

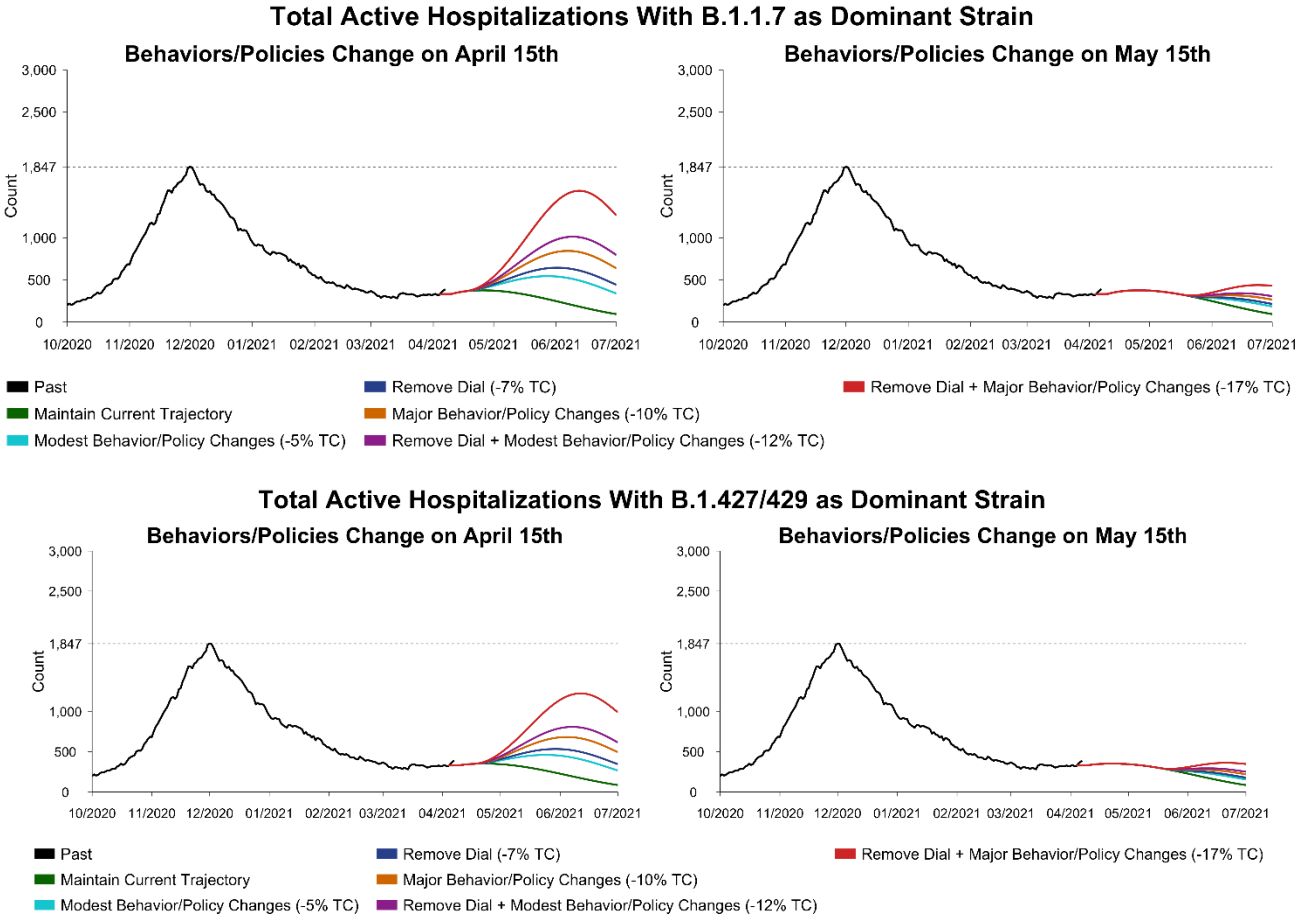


Figure 13 (above). Projected COVID-19 hospitalizations through early July 2021 if changes to policy and/or behavior occur on April 15 (left panels) or May 15 (right panels) and for variant growth scenarios where B.1.1.7 becomes dominant (top) or B.1.427/429 becomes dominant (bottom). In these scenarios, it is assumed Colorado remains on its current estimated trajectory (68% TC) until April 15 or May 15. Black lines indicating historical data reflect observed hospitalizations reported in EMR since October 2020. Horizontal dashed line indicates December 2020 peak in COVID-19 hospital demand.

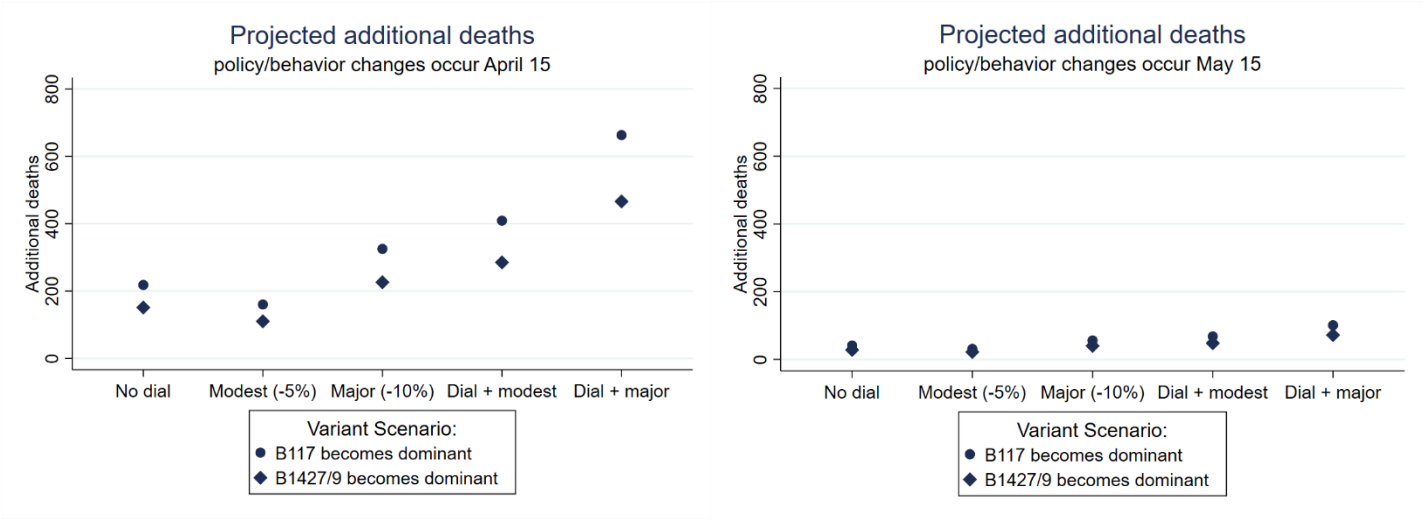


Figure 14 (above). Projected additional deaths from 4/05 to 07/01 for five different policy/behavior change scenarios, implemented on 04/15 and 05/15. We define additional deaths as the difference between the projected number of deaths under the policy/behavior change scenario and the projected number of deaths on the current trajectory and variant growth assumption. In these projections, we assume vaccinated individuals age 65+ have almost no mortality.

Appendix

Code, Documentation, and Prior Reports

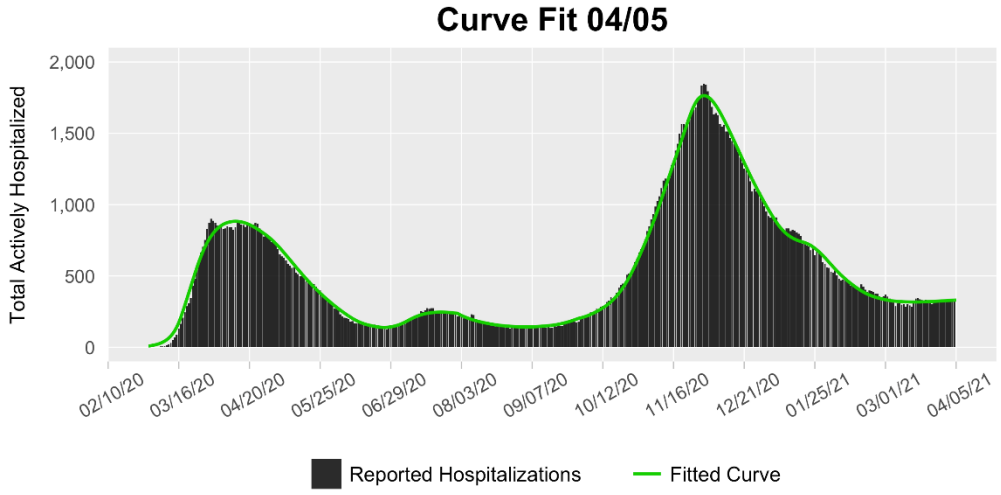
Code for our model is available on GitHub: https://github.com/agb85/covid-19

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

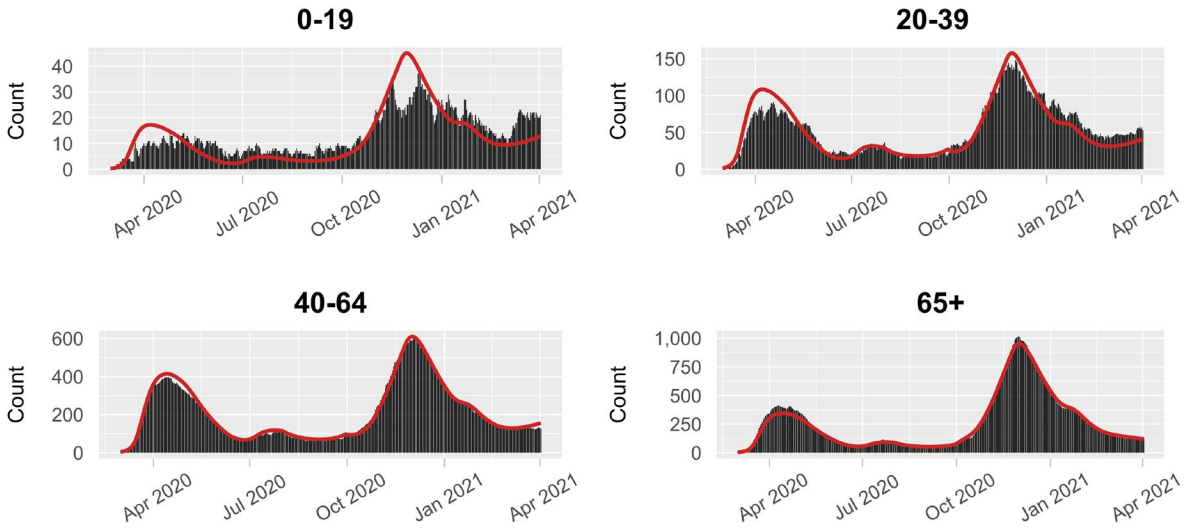
Prior modeling reports and documentation can be found at: https://agb85.github.io/covid-19/

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 04/05 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 Figure A2 (above). Current model fit (red line) to the count of hospitalized COVID-19 patients by age-group (black lines) through 04/05. Age-specific COVID-19 hospitalization data are from COPHS through 4/2, Because EMResources and COPHS do not have the exact same daily count of COVID-19 hospitalizations, COPHS data are scaled to total hospitalizations as reported in EMResources.

Data Sources

Appendix Table A1 (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	04/05	04/05	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	04/02	03/29	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	04/05	03/26	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	04/05	03/29	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	CEDRS (Colorado Electronic Disease	04/05	03/22	Used for fitting and estimating age-specific

Data	Description	Source	Download Date	Cleave Date	Additional Notes
	age group (using onset date)	Reporting System) Line List			transmission control parameters.
Cumulative deaths	Total deaths among COVID-19 cases to date	CEDRS (Colorado Electronic Disease Reporting System) Line List	04/05	03/06	Used for generating historical and projected estimates of cumulative mortality.

Vaccination

SARS-CoV-2 vaccines became available in Colorado on December 15th, 2020. We use data provided by CDPHE to estimate the number of people vaccinated by age group over time, and to project the allocation of future vaccinations. The allocation of vaccines by age group are described in Table A3.

In regard 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), a collective 80% of individuals enter the vaccinated compartment (indicating complete immunity) 14 days after the first dose, and an additional 10% 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.

Appendix Table A2 (below). Vaccination rates by age to date included in the model. These are based on data from CDPHE on vaccinations to date by age.

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*
Pfizer/Moderna					
12/15 - 02/01	01/16 - 03/05	43	2,089	2,576	4,976
02/02 - 03/08	03/06 - 04/09	79	2,516	4,406	9,469
03/09 - 03/29	04/10 - 04/30	533	5,999	13,817	2,839
Johnson & Johnson					
03/01 - 03/15	03/29 - 04/12	24	497	1,778	456

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*
03/16 - 03/29	04/13 - 04/26	3,321	7,823	0	0

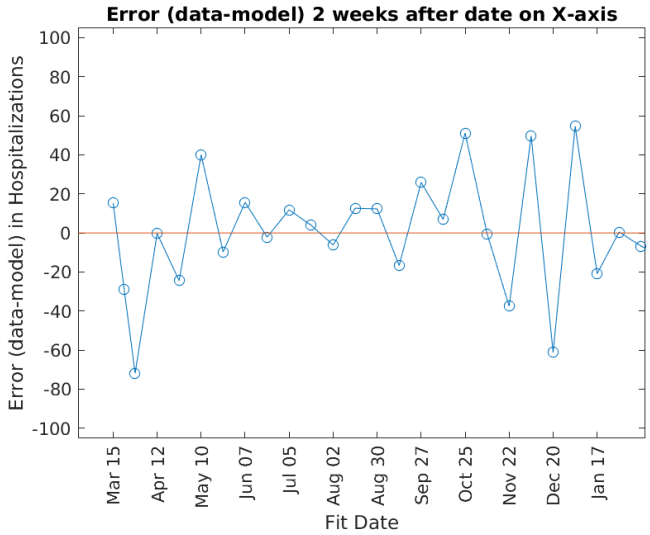
*First doses administered per day for Pfizer/Moderna (assuming all people receiving first doses receive second doses on schedule).

Appendix Table A3 (below). Weekly vaccinations through June 1, based on scenarios provided by CDPHE.

Dates of First Vaccine Dose Administration	Pfizer/Moderna First Doses per Week	Johnson & Johnson Doses per Week
03/01 - 03/08	138,040	19,280
03/09 - 03/15	133,068	19,280
03/16 - 03/28	145,343	67,600
03/29 - 04/04	208,547	84,500
04/05 - 06/01	230,853	101,400

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.

Table A4 (below). Comparison of active COVID-19 hospitalizations and cumulative COVID-19 deaths between 04/05 and 07/01 for different policy and behavior change scenarios occurring on April 15 or May 15. Estimates are show for two different variant growth scenarios, one where B.1.1.7 becomes dominant and another where B.1.427/429 variants become dominant.

	Date of Peak in Active Hospitalizations	Peak Number of Active Hospitalizations Between 04/05 and 07/01*	Cumulative Infections Between 04/05 and 07/01*	Cumulative Deaths Between 04/05 and 07/01*	Deaths 0-39	Deaths 40-64	Deaths 65+
Variant scenario: B.1.1.7 becomes dominant							
Policy/behavior Change 04/15							
Maintain Current Trajectory	04/26/2021	378	195,000	368	12	135	221
Modest Behavior/Policy Changes (-5% TC)	05/28/2021	546	399,000	618	20	217	381
Remove Dial (-7% TC)	06/02/2021	647	477,000	709	23	247	439
Major Behavior/Policy Changes (-10% TC)	06/07/2021	847	620,000	874	29	299	546
Remove Dial + Modest Behavior/Policy Changes (-12% TC)	06/09/2021	1,016	733,000	1,004	34	341	630
Remove Dial + Major Behavior/Policy Changes (-17% TC)	06/13/2021	1,562	1,070,000	1,399	47	467	884
Policy/behavior Change 05/15							
Maintain Current Trajectory	04/26/2021	378	195,000	368	12	135	221
Modest Behavior/Policy Changes (-5% TC)	04/26/2021	378	243,000	414	13	148	252

	Date of Peak in Active Hospitalizations	Peak Number of Active Hospitalizations Between 04/05 and 07/01*	Cumulative Infections Between 04/05 and 07/01*	Cumulative Deaths Between 04/05 and 07/01*	Deaths 0-39	Deaths 40-64	Deaths 65+
Remove Dial (-7% TC)	04/26/2021	378	258,000	428	14	152	262
Major Behavior/Policy Changes (-10% TC)	04/26/2021	378	284,000	450	15	158	277
Remove Dial + Modest Behavior/Policy Changes (-12% TC)	04/26/2021	378	304,000	467	15	163	289
Remove Dial + Major Behavior/Policy Changes (-17% TC)	06/24/2021	440	363,000	516	17	176	322
Variant scenario: B.1.427/429 become dominant							
Policy/behavior Change 04/15							
Maintain Current Trajectory	04/23/2021	354	195,000	313	12	113	188
Modest Behavior/Policy Changes (-5% TC)	05/24/2021	462	363,000	485	19	169	298
Remove Dial (-7% TC)	05/30/2021	536	429,000	550	22	189	339
Major Behavior/Policy Changes (-10% TC)	06/04/2021	684	550,000	666	26	226	414
Remove Dial + Modest Behavior/Policy Changes (-12% TC)	06/07/2021	811	645,000	758	30	255	473
Remove Dial + Major Behavior/Policy	06/12/2021	1,228	937,000	1,038	42	342	654

	Date of Peak in Active Hospitalizations	Peak Number of Active Hospitalizations Between 04/05 and 07/01*	Cumulative Infections Between 04/05 and 07/01*	Cumulative Deaths Between 04/05 and 07/01*	Deaths 0-39	Deaths 40-64	Deaths 65+
Changes (-17% TC)							
Policy/behavior Change 05/15							
Maintain Current Trajectory	04/23/2021	354	195,000	313	12	113	188
Modest Behavior/Policy Changes (-5% TC)	04/23/2021	354	235,000	345	13	122	210
Remove Dial (-7% TC)	04/23/2021	354	248,000	355	14	125	216
Major Behavior/Policy Changes (-10% TC)	04/23/2021	354	270,000	371	14	129	228
Remove Dial + Modest Behavior/Policy Changes (-12% TC)	04/23/2021	354	287,000	383	15	133	236
Remove Dial + Major Behavior/Policy Changes (-17% TC)	06/21/2021	364	338,000	418	16	142	260

*Deaths estimated from the model include deaths both inside the hospital and outside the hospital. To account for the high efficacy of vaccines preventing death, we assume there are essentially no COVID-19 deaths among the vaccinated. We do this by halving the number of deaths in the 65+ age group, the group that accounts for the majority of deaths. This has the effect of assuming all deaths in that age group occur in the unvaccinated in that population (if 90% are vaccinated, and vaccine is 90% effective at preventing spread of infections, approximately 10% of the population remains susceptible due to non-vaccination, another 10% remains susceptible due to the estimated 90% efficacy of the vaccine in preventing the spread of infections. We assume the latter group has no deaths).

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