The Current State of COVID-19 in Colorado

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Prepared by the Colorado COVID-19 Modeling Group

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Summary

- Based on data through 06/28, hospitalizations continue to decline statewide.
- The effective reproductive number is 0.77 indicating decreasing transmission.
- An estimated 1 in every 390 people in Colorado are currently infectious.
- Approximately 54% of the Colorado population is estimated to be immune to SARS-CoV-2. This estimate accounts for estimated infections, vaccine doses, and vaccine efficacy.
- Based on recent Delta variant growth in Colorado, we estimate that ~90% of cases could be due to the variant by the end of June. The Delta variant is more infectious (high certainty), and vaccines provide modestly lower protection against infection (high certainty) compared to Alpha (B.1.1.7).
- The course of the pandemic varies across the state. Areas with higher vaccination rates are seeing fewer SARS-CoV-2 cases, hospitalizations, and deaths. Areas where infection prevalence is high and/or infections are flat or increasing are regions with some of the lowest vaccine uptake rates in the state.
- Interventions to promote vaccinations can reduce the occurrence of severe COVID and hospital demand if contact rates increase and/or seasonal affects accelerate transmission.

Snapshot of Current SARS-CoV-2 Transmission in Colorado Based on Data Through 05/10

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

Estimated prevalence of infections: Approximately 260 of every 100,000 Coloradans or 1 in every 390 Coloradans are currently infectious.

Estimated percent of the population immune: Approximately 54% of Coloradans are immune due to vaccination or prior infection.

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 06/28 and vaccination data through 06/27.

This report focuses on state-wide trends. A report on the regional variability in infections, hospitalizations and vaccinations across Colorado is provided at: https://www.colorado-data.org/regional-epidemic-models

Model Updates

Model updates implemented since our last report on May 12.

Demographic updates. Previously, we used estimates from the US Census for Colorado in 2016, accounting for population growth evenly across all age groups. We are now using updated estimates from the Colorado Demography Office for 2020 which better account for the aging of baby boomers. The changes in our model are as follows:

- The population of the 0-19 age group has decreased from 1,513,005 to 1,413,638.
- The population of the 20-39 age group has increased from 1,685,869 to 1,701,344.
- The population of the 40-64 age group has decreased from 1,902,963 to 1,820,564.
- The population of the 65+ age group has increased from 738,958 to 877,662.
- The total population of Colorado has decreased from 5,840,795 to 5,813,208.

These updates lead to changes in the estimates of the percent vaccinated and immune, particularly in the 65+ population.

Delta Variant. The model has been updated to include the Delta variant (B.1.617.2). For the purpose of the model we assume:

1. The Delta variant is 1.5 times more infectious as the Alpha variant (B.1.1.7). Both the CDC and Public Health England have stated that the Delta variant is more infectious than Alpha (B.1.1.7). Current evidence suggests Delta is 1.4 to 1.9 times more

infectious than Alpha (Allen et al; Sonabend et al). This equates to Alpha being more than twice as infectious as the wild-type strains of 2020.

2. Infection with the Delta variant leads to 10% more breakthrough infections among the vaccinated. Both the CDC and Public Health England have stated that it is likely that vaccines confer modestly less protection against symptomatic infection with the Delta variant.
3. The Delta variant has grown rapidly in Colorado, and currently accounts for over 75% of infections. This is based on data provided by CDPHE and the growth of the variant observed elsewhere. Details on projected variant growth are provided in the appendix.

There is uncertainty as to whether the Delta variant increases risk of hospitalizations and death compared to Alpha (Public Health England Risk Assessment). A recent study from Scotland suggests that infection with the Delta variant is associated with an increased risk of hospitalization compared to infection with Alpha (Sheikh et al). However, this finding has not yet been replicated. For now, Delta is assumed to have the same virulence as Alpha in the model.

The science is evolving rapidly, and we will continue to update the model to reflect the latest information about the Delta variant.

Describing Vaccination and Immunity in Colorado

With vaccination well underway in Colorado and with the majority of the state's population vaccinated, we are tracking progress of vaccination closely. Two distinct indicators of vaccination progress are provided in this report: how many people are vaccinated and how many people are immune. The percent vaccinated is estimated based on the number of vaccine doses administered. The immunity calculation is more complex and accounts for vaccine doses, vaccine effectiveness and estimated prior infections using our SEIRV model.

Percent vaccinated. Vaccination levels can be described in several ways. The percentage of the entire population that is vaccinated includes those eligible and those not eligible (right now, children under 12 years of age are not eligible to be vaccinated). The percentage of the eligible population that is vaccinated includes only those eligible (right now, including those 12 years of age and older). The percent vaccinated can also be described by age (e.g., the percent vaccinated that are 65+). Each of these measures are useful for public health purposes – helping track progress toward immunization targets and identify gaps in vaccine coverage. We note that at present, our percent vaccinated numbers are slightly lower than those provided by the state as we do not yet include in our data vaccinations delivered by Federal facilities, such as the Veterans Administration.

Percent immune. The modeling team estimates the percentage of the state's population that is immune to SARS-CoV-2 accounting for prior infections and vaccinations. Calculation of that percentage is more complicated than describing the percentage of the population

that is vaccinated. To estimate the percentage of the population that is immune, we use the SEIRV model and daily vaccination figures from the Colorado Department of Public Health and Environment (CDPHE). The estimate accounts for 1) the number of people who have been infected with SARS-CoV-2 over time and who have retained immunity; 2) the number of people vaccinated; and 3) vaccine efficacy. The modeling team provides an overall estimate of the percent immune as well as estimates of immunity by age-group. As immunity grows, the spread of infections slows.

Thus, the figures on the percentage vaccinated and the percentage immune are different and complementary. We caution against direct comparison of the estimated percentage immune to SARS-CoV-2 to the percentage vaccinated.

Model Fit

We assess model fit by comparing the model-estimated number of hospitalizations to actual hospitalizations. We show 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 (Figure 1). For reference, a line showing the estimated trajectory one-week prior is also shown. A figure showing hospitalizations and model fit since the beginning of the pandemic is provided in the appendix.

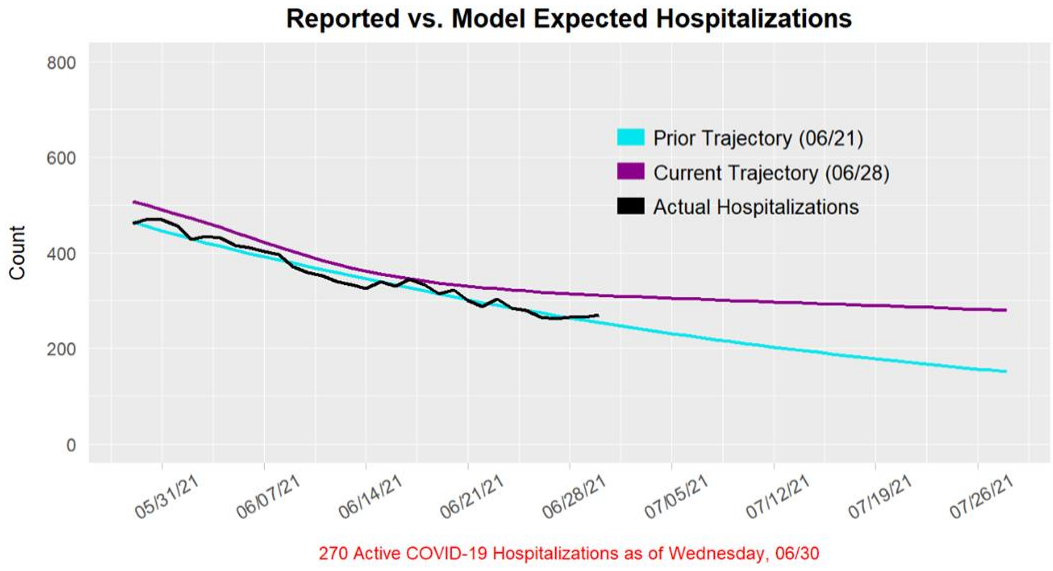

Figure 1. The projected course of COVID-19 hospitalizations if Colorado were to remain on the current estimated trajectory (purple line) or on the trajectory estimated one week prior (turquoise line). Each trajectory is generated assuming Colorado rolls out vaccines on schedule, as described in the long-term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

The Effective Reproduction Number

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

Our current estimate of Re is 0.77. Due to the lag between infections and hospitalizations, this estimate of Re reflects the spread of infections occurring on approximately 06/15.

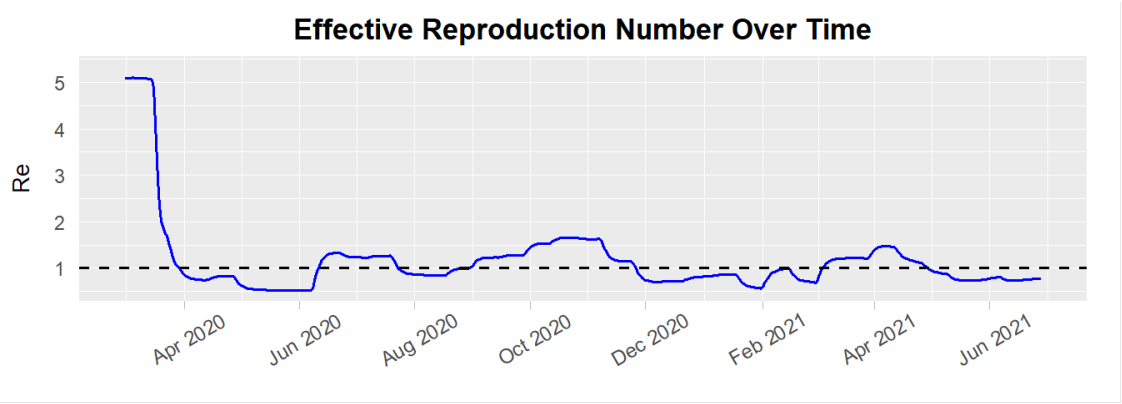

Figure 2. Estimates of the effective reproduction number over time.

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 06/05 to 06/15) remains at the estimated value through 06/28. 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 approximately 260 of every 100,000 Coloradoans or 1 in every 385 people are infectious in Colorado as of 06/28.

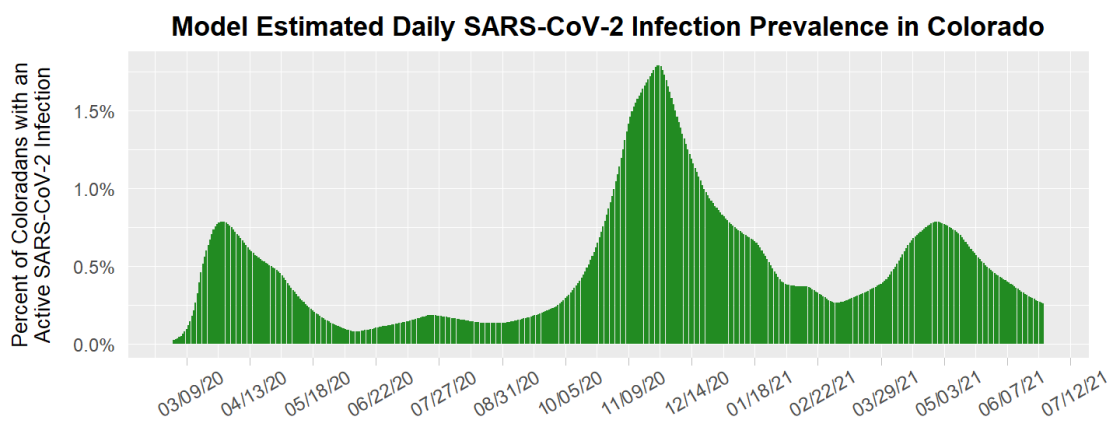

Figure 3. Estimated daily number of people who are infectious and infected with SARS-CoV-2 (point prevalence). Estimate is shown per 100,000 population. The number of infectious individuals is inferred using the model and based on hospitalizations.

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. Transmission control is estimated by aligning model output to hospitalization data using model fitting approaches. The most recent model update allows us to estimate two values of transmission control. We can estimate the level of transmission control due to policies and behaviors (TC_{pb}). This is the level of transmission were there no variants of concern in Colorado. We estimate TC_{pb} as 86%. We can also estimate transmission control that accounts for policies, behaviors, and variants (TC). This value accounts for the proportion of total infections presumed to be caused by B.1.1.7 (Alpha), B.1.427/429, and B.1.617.2 (Delta) variants. The difference between TC_{pb} and TC represents the consequences of the more transmissible variants versus the previously circulating strains.

Our current estimate of effective transmission control due to policy, behaviors, and variants is 71%. This estimate is for the period 06/05 to 06/15, given the lag between infection and hospitalization. We estimate TC_{pb} is 86%, meaning that variants diminish transmission control by 15%..

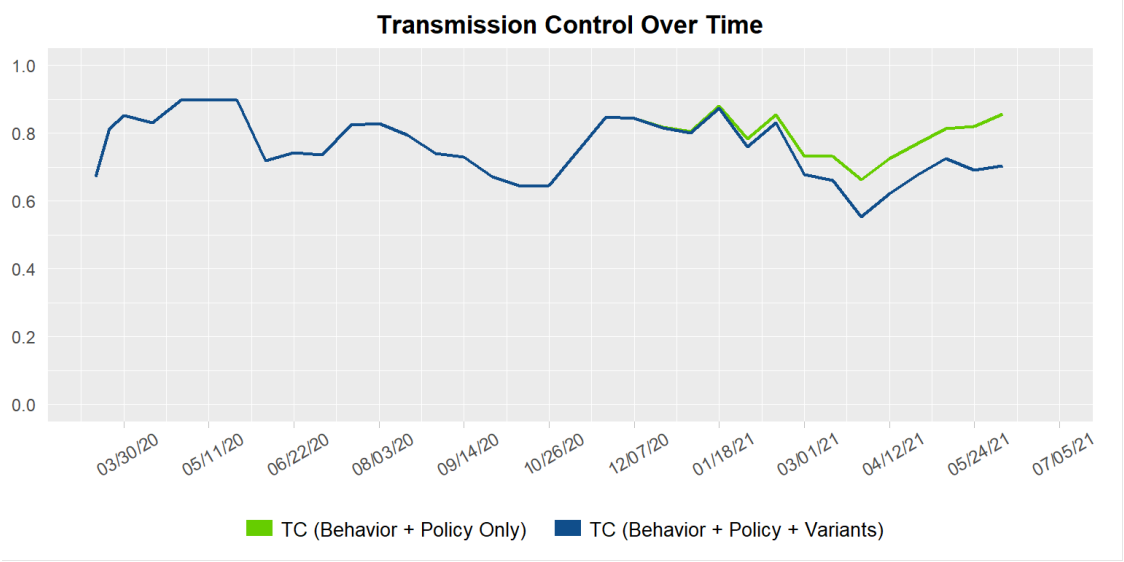

Figure 4. The estimated transmission control value for each two-week period since the beginning of the epidemic due to behavior and policy only (green line) and the estimated transmission control accounting for behavior, policy, and variants (blue line). On the graph, the value is shown for the mid-point of each two-week period. Transmission control is estimated using model fitting approaches to align model output with COVID-19 hospitalizations.

Population Immunity

People 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).

We estimate the proportion of the population immune using our age-structured SEIR model and data on vaccinations in Colorado provided by CDPHE (Figures 5 and 6). 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. We assume all individuals who receive first doses of two-dose vaccines received second doses on schedule. 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. Our estimates account for overlap between the vaccinated population and those with immunity due to prior infection. We note that the percent of the population immune to the Delta variant is likely lower than the estimates

provided here due to modest reductions in vaccine protection against infection with the Delta variant.

We estimate that approximately 3,098,000 people in Colorado, or 54% of the Colorado population, are currently immune to SARS-CoV-2 as of 06/28.

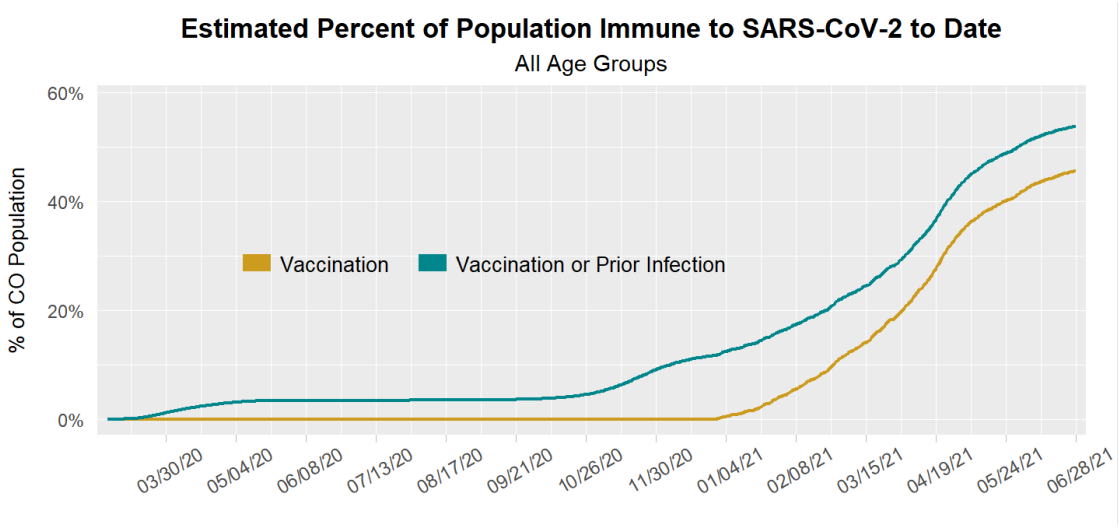

Figure 5. Estimated percent of the population in Colorado assumed to be immune to SARS-CoV-2 due to infection and/or vaccination through 06/28.

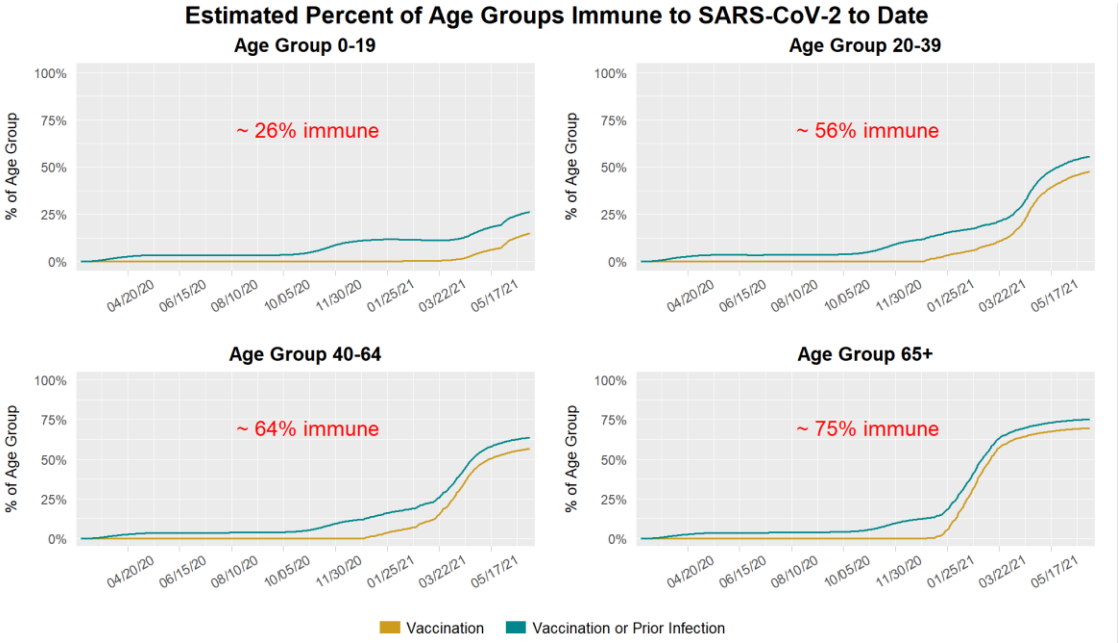

Figure 6. Estimated percent of each age group in Colorado assumed to be immune to SARS-CoV-2 due to infection and/or vaccination through 06/28.

Mobility

To investigate the impact of mobility on COVID-19 transmission, we analyze time spent away from home using aggregated mobile device data. Figure 7 displays daily % of time spent away from home from November 1st, 2019 to the present for Colorado.

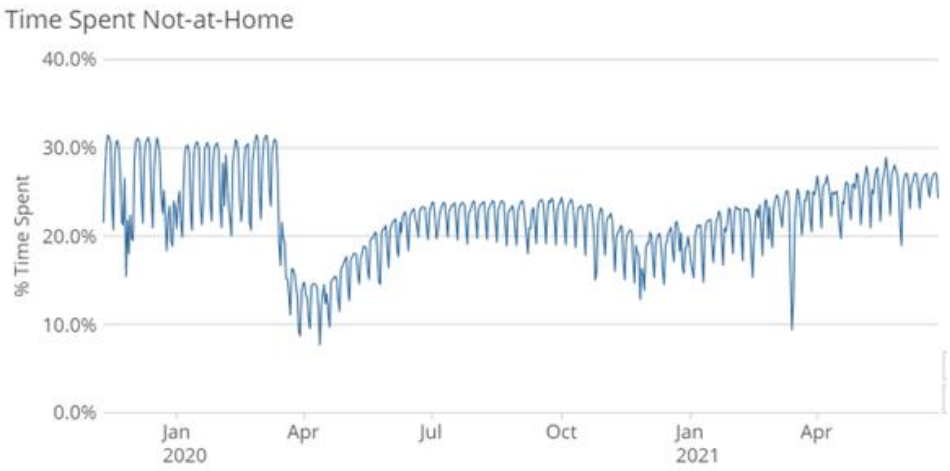

Figure 7. Daily % of time spent not at home from November 2019 to present.

Vaccinations

We conducted three analyses to examine the impact and reach of COVID-19 vaccinations in Colorado. First, we examined the relationship between the percent of the population vaccinated and the number of reported cases and severe COVID by region. Second, we looked at the distribution of vaccines by age and region. Third, we generated projections to estimate the potential impact of low vs. high vaccine uptake this summer.

Vaccinations vs. Reported cases and hospitalizations and deaths. Counties with a higher percentage of the population fully immunized have fewer COVID-19 cases, hospitalizations, and deaths (Figure 8).

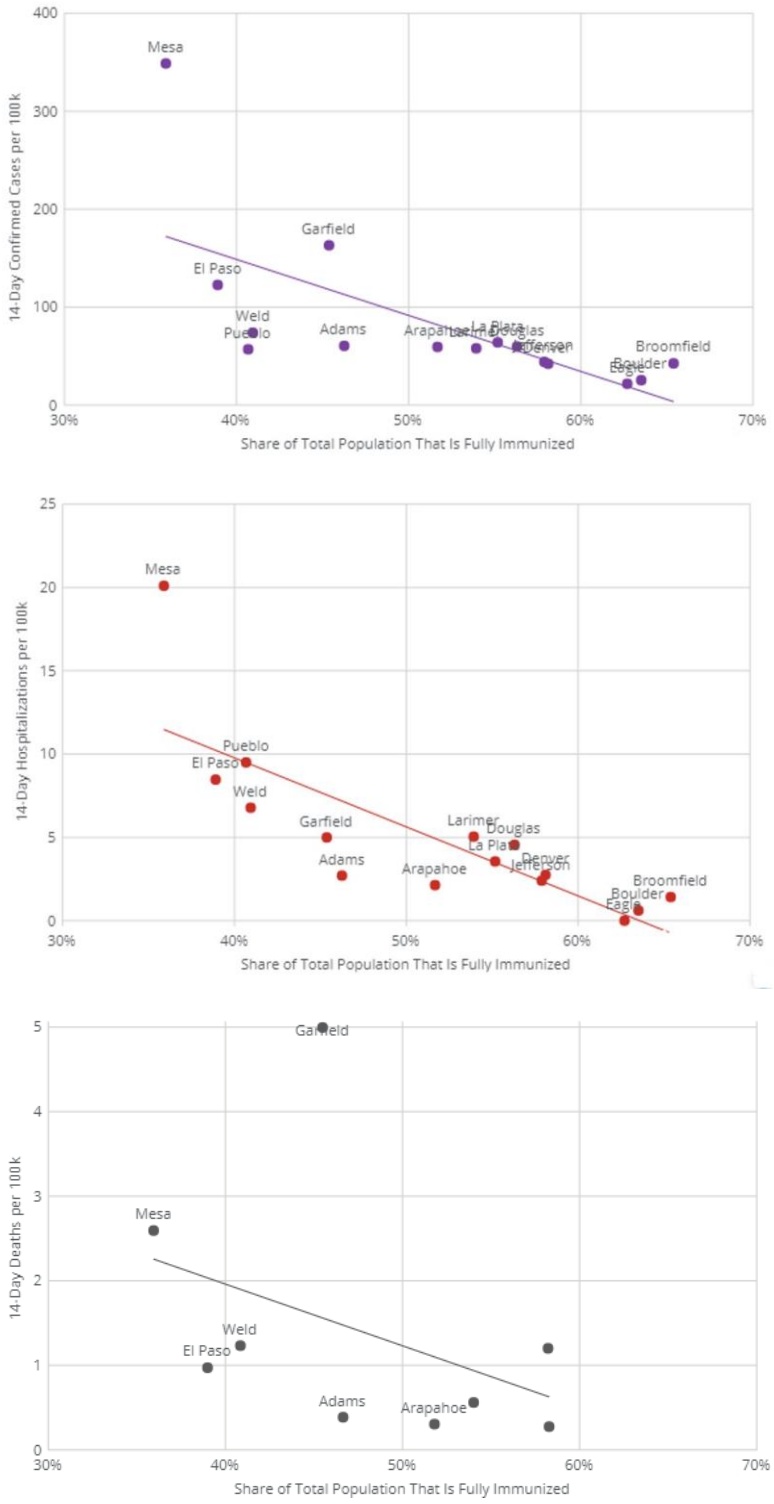

Figure 8. Relationship between the percent of population fully immunized in the 15 counties in Colorado with the largest population and COVID-19 cases per 100,000 (top), COVID-19 hospitalizations per 100,000 (middle), and COVID-19 deaths per 100,000 (bottom). Based on vaccination data provided by CDPHE through 06/27/2021.

Differences in vaccinations by age and region. There are substantial differences in the percent of the population vaccinated by region and by age group (Figure 9). Generally, vaccination is lowest in the 12-19 year-old age group and highest among those 65+. The Metro and Central Mountains LPHA regions have the highest percent vaccinated in the state, whereas vaccinations are lowest in the East Central Region. Both the Southeast and East Central LPHA regions have the lowest percent of older populations (age 65+) vaccinated.

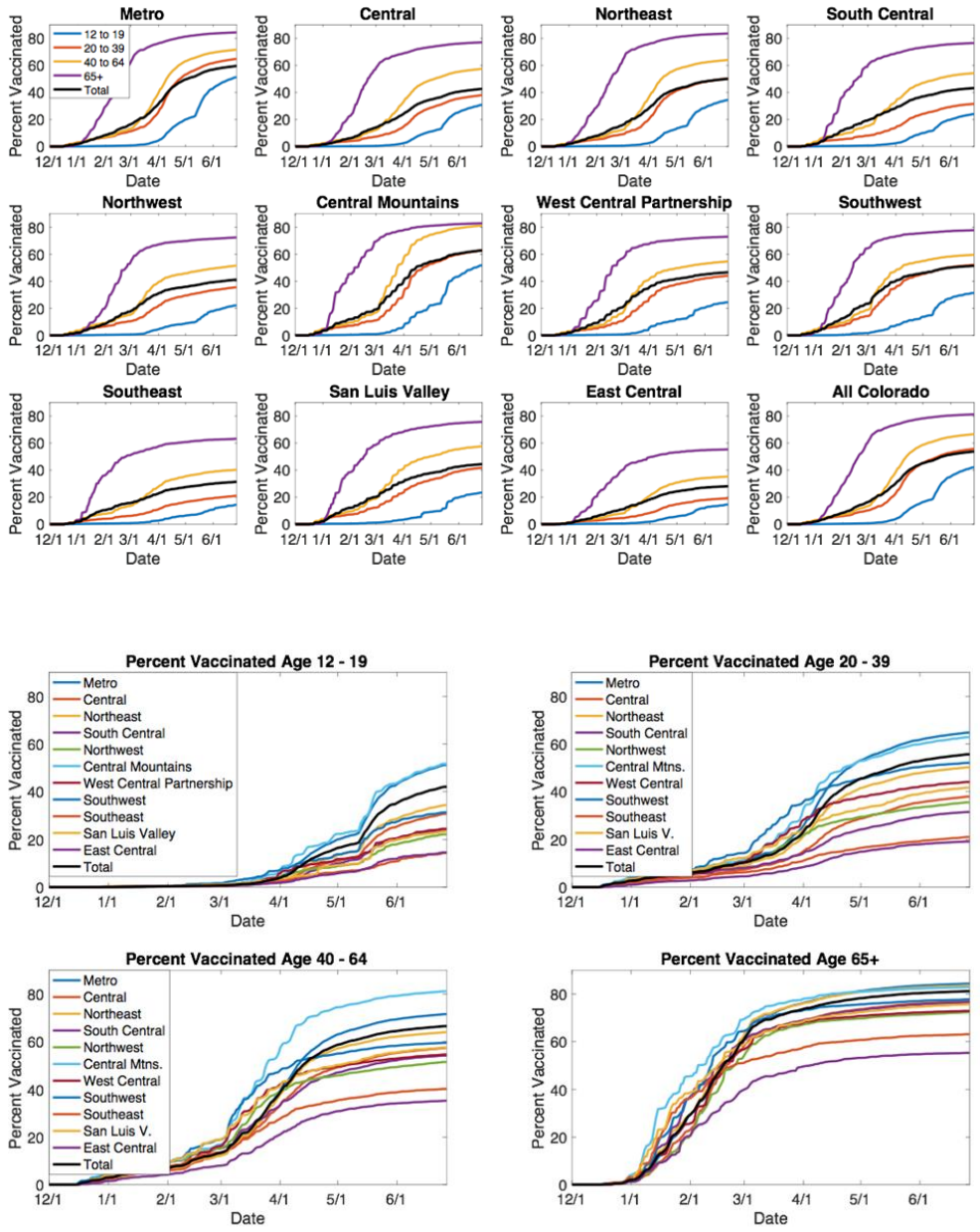

Figure 9. The percent of the population vaccinated with at least one dose over time by age group and region. Based on vaccination data provided by CDPHE through 06/27/2021.

Projections: what is the projected impact of increasing vaccinations over the summer to reach 80% of eligible vaccinated with at least 1 shot by Labor Day?

We used the SEIRV model, based on the most recent fit to generate estimates of the number of people hospitalized with COVID-19 in the months ahead for three different vaccine scenarios in order to gage the potential impact of continued or increase vaccination efforts in Colorado this summer. We used recent vaccination data to generate three vaccination scenarios:

1. Current trajectory. In this scenario, Colorado continues along current trends and approximately 67% of the eligible population in Colorado (age 12+) is vaccinated with at least 1 shot by Labor Day. This is based on recent trends by age with vaccinations declining weekly.
2. Aggressive vaccinations. In this scenario, 80% of the eligible population in Colorado is vaccinated with at least 1 shot by Labor Day. Reaching this target will require a substantial increase in vaccination rates for all age groups.
3. Worst case scenario. In this scenario, vaccinations drop rapidly in the weeks ahead and approximately 63% of eligible vaccinated with at least 1 shot by Labor Day.

Our vaccination estimates do not currently include vaccinations provided by federal agencies such as the Veteran's Administration and thus are underestimates of the true number of people vaccinated. We are working to incorporate these numbers in our estimates.

In order to generate projections, we need to make assumptions about the level of transmission control (independent of vaccinations) in the months ahead. We generated projections assuming transmission control remains at current levels or decreases by 5-7% on July 2, based on recent trends. Such drops might occur because of a more transmissible strain, a return to school and workplaces, and the end of a possible suppression of the virus during the summer.

If transmission control remains at current levels, vaccinating an additional 10% of the population will not have an immediate major impact on the occurrence of severe COVID-19 in the population, or hospital demand (Figure 10). In fact, the distinction between the three different vaccination scenarios is not visible because the hospital projection lines overlap. If transmission increases modestly (-5%), high vaccination leads to lower vaccination demand. The distinction between the aggressive and worst-case vaccination scenarios are greatest under the 7% decline in transmission control scenario.

We expect that transmission control could decrease in the months ahead due to resumption of pre-pandemic activities, opening schools and businesses, as well as due to any seasonal impact that suppresses transmission in the summer. If transmission control were to decline, higher levels of vaccination in the Colorado population would lower

hospital demand and prevent severe COVID-19, compared with lower levels. Attaining high vaccination rates now can prevent the most severe consequences of SARS-CoV-2 in the future. Given the large disparities in vaccine uptake across the state, we anticipate that areas of Colorado with low vaccination will be areas of concern in the months ahead.

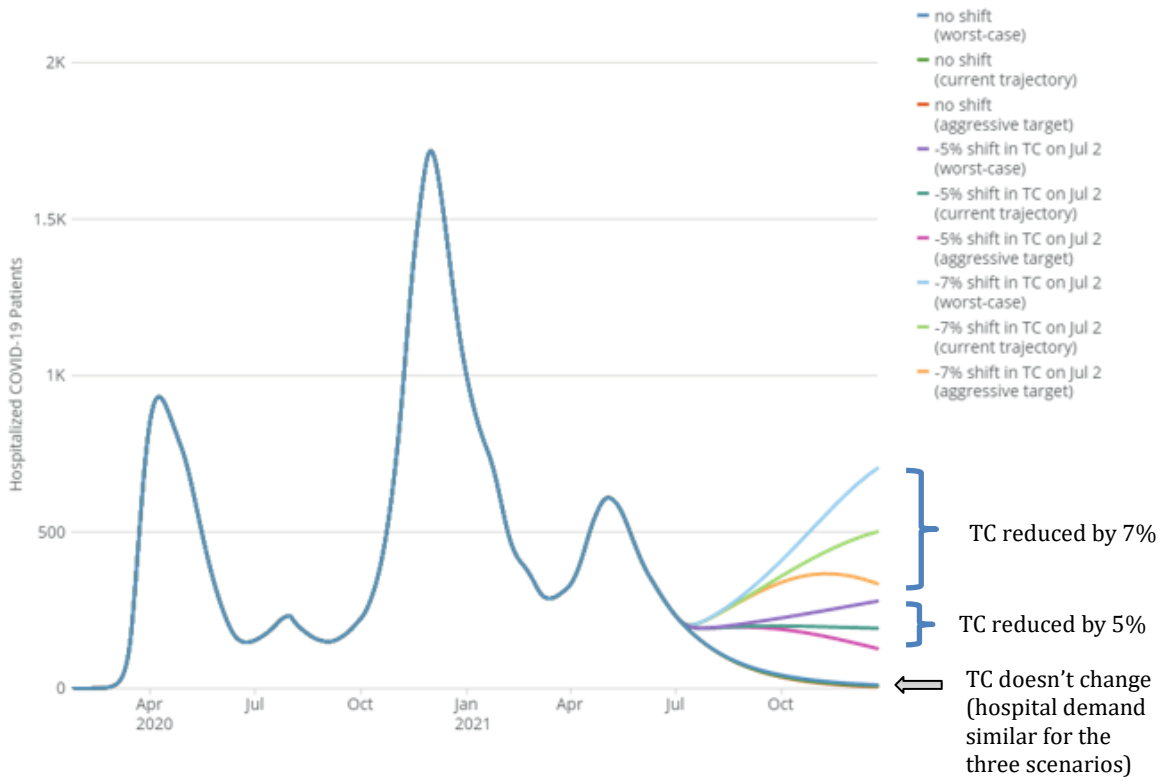

Figure 10. Comparison of COVID-19 hospital demand if transmission control remains at current levels or declines by 5% or 7% on July 2, for three vaccination scenarios: worst case (rapid decline in uptake), current trajectory, and aggressive (80% of eligible vaccinated with first doses by Labor Day).

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

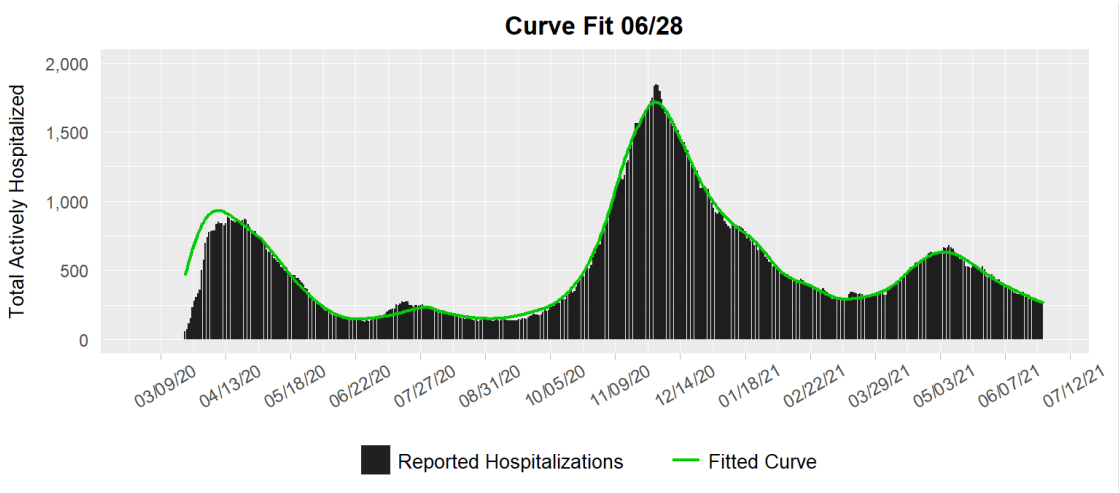

Figure A1. Current model fit (green line) to the number of people hospitalized with COVID-19 (black lines) through 06/28 using the age-structured SEIR model. Hospitalized COVID-19 cases are from CDPHE reported COVID-19 hospitalizations and EMResource (EMR) hospital census data provided by CDPHE.

Variant distribution

The model includes three variants: Alpha (B.1.1.7); B.1.427/B.1.429; and Delta (B.1.617.2). The distribution of variants over time is based on data provided by CDPHE (Figure A2). We used the CDPHE variant data and information on the growth of the Delta variant elsewhere to project future distribution of the variant (Challen et al). Under our projections, the variant accounts for 90% of infections in the state by July (Figure A3).

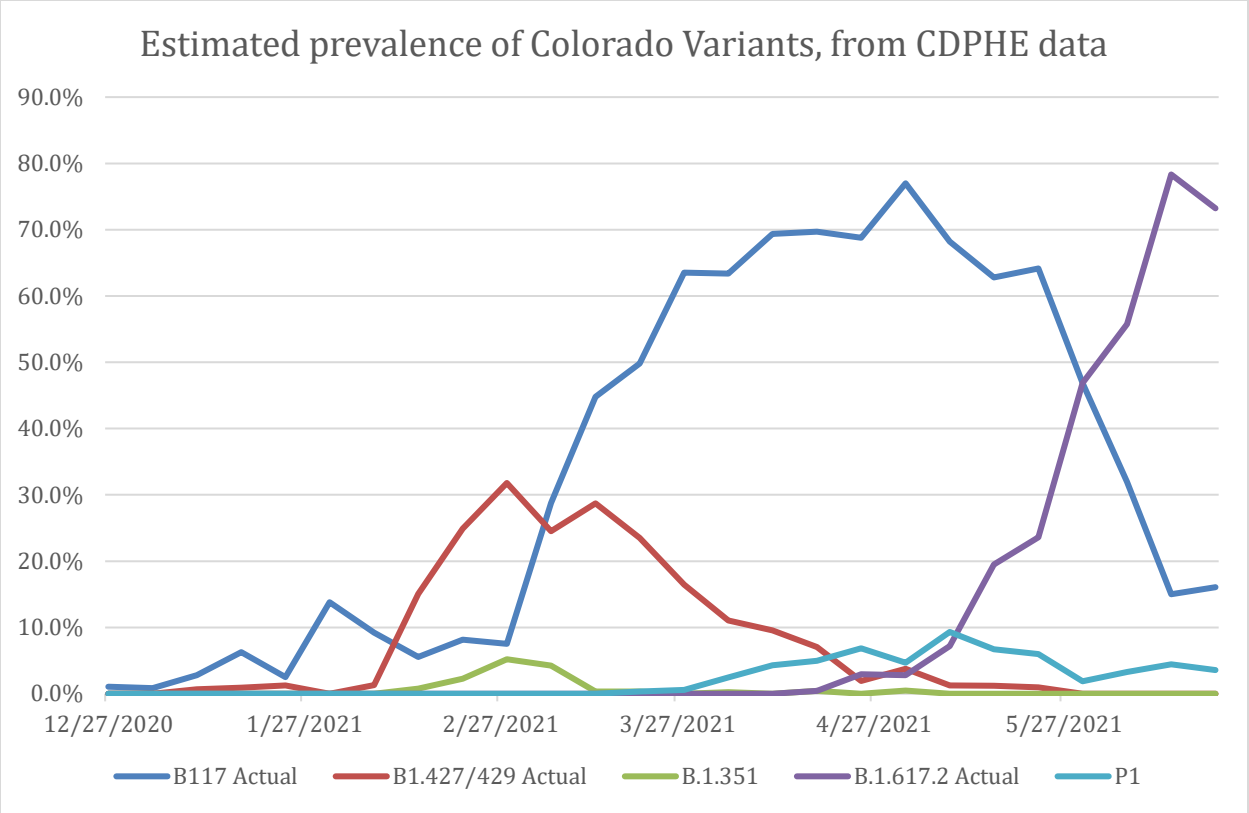

Figure A2. The estimated percent of SARS-CoV-2 infections due to five different variants in Colorado, based on data from CDPHE. The distribution of variants in the model is designed to mirror this distribution.

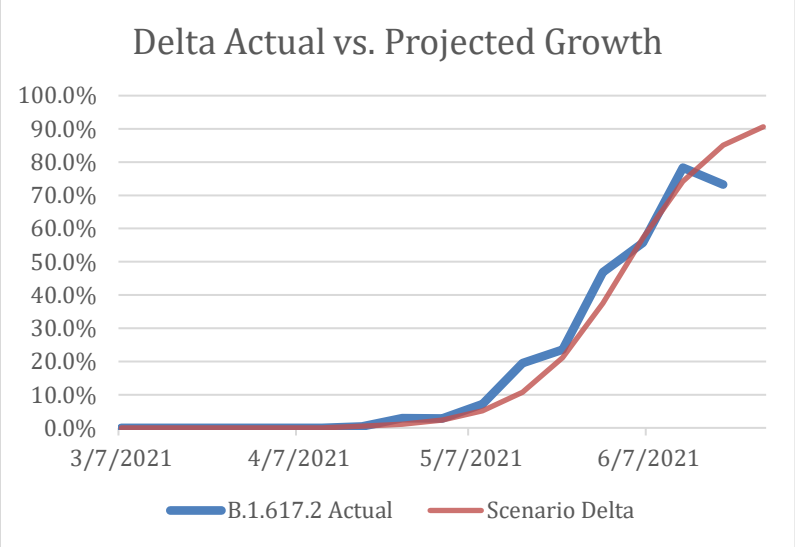

Figure A3. The estimated percent of SARS-CoV-2 infections due to the Delta variants in Colorado, based on data from CDPHE (blue line) and the projected future distribution of Delta variant in Colorado based on recent growth in Colorado and trends observed elsewhere (orange line).