The current state of COVID-19 in Colorado

10/28/2020

Prepared by the Colorado COVID-19 Modeling Group

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Summary

- Hospitalizations are increasing on the same upward curve. Avoiding challenging peaks in infections and hospital demand over the next three months will require a substantial and rapid increase in transmission control. The window to improve transmission control is over the next few weeks to avoid levels of infection that could strain health care facilities.
- On the current trajectory, Colorado will probably exceed the April peak in hospitalizations (N=900) by approximately November 10th and reach ICU capacity for COVID-19 (N=1800) in early to mid-January. If contacts increase over the holidays, ICU capacity could be exceeded in December.
- The magnitude and timing of reductions in transmission will determine the severity of COVID-19 in Colorado in the months ahead.

Snapshot of current SARS-CoV-2 transmission in Colorado

- Effective reproductive number: 1.57 (95% confidence interval 1.47, 1.70). *Hospitalizations are increasing rapidly*
- Estimated prevalence of people with infections: Approximately 457 (95% CI: 434, 473) of every 100,000, or 1 in 219 Coloradans are currently infectious. *The estimated prevalence is higher than last week.*
- Estimated number of infections to date: Approximately 8.7% (95% CI: 8.6, 8.7) of the population has been infected to date.
- Estimated current level of transmission control: 65% for the period of 09/28 to 10/13. *There is an approximate 65% reduction in total transmission-relevant contacts, inclusive of reductions due to contact tracing, self-isolation, mask wearing, and all other policy and behavioral changes compared to compared to a situation with transmission uncontrolled.*
- Using an extended modeling approach that includes case data, we estimate transmission control varies significantly by age group, with significant decreases in control levels among all ages over the last month. Individuals aged 20-39 have the highest infectious contact rates (Transmission control = 60%), and contact rates have increased among individuals over 65 (Transmission control = 76%).
- There is substantial regional variation at present with local public health agency (LPHA) regions of concern South Central, East Central, Central, and the Metro region. In the Metro Area, hospitalizations are increasing rapidly in all counties.

Snapshot of the potential future trajectory of SARS-CoV-2 in Colorado

- If we remain on the current trajectory of the epidemic curve, we will soon exceed the April peak, within two weeks, and will approach ICU hospital capacity in January. Increases in contacts over the holidays will likely accelerate growth in case numbers and ICU hospital capacity may be exceeded in December.
- The longer the state remains on the current trajectory, the greater the change in transmission control needed to keep hospital demand below capacity.

Additional notes

- We have added methods to better quantify uncertainty in our estimates. Estimates of prevalence, the effective reproductive number, and the percent of the Colorado population infected are now presented with confidence intervals, describing statistical uncertainty.
- We have added a near-term forecast with uncertainty estimates to provide estimated numbers of cases and hospital needs in the next two weeks if we continue on the current trajectory. Long-term, scenario-based projections are also provided to evaluate what might happen in the months ahead.

Introduction

We used our age-structured SEIR 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. These estimates are based on hospitalization data through 10/26/2020. We use these estimates to generate projections of the potential future course of SARS-CoV-2 in Colorado. 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 increases in transmission control as well as increased contact rates over the Thanksgiving to New Year holidays.

These estimates are based on a transmission control model (referred to as the transmission control (TC) model). We use this model to generate estimates of the effective reproductive number (R_E), to show the current trajectory of hospitalizations, to project the potential trajectory of hospitalizations under different scenarios, and to estimate the variability in transmission control by age group, using a new modeling approach that incorporates both hospitalization and case data for parameter estimation.

Model Updates This Week

Uncertainty. Given that the estimates of TC and current Re are subject to substantial uncertainty, we are visualizing uncertainty now using 95% Confidence Intervals (95% CI) in estimating TC and other measures at present, and for showing uncertainty in the two-week forecasts of hospitalizations and ICU need using established methods [1, 2]. We calculate the 95% CIs using Markov Chain Monte Carlo methods and sample from the distribution of possible parameter estimates we fit each week. Restating in less technical terms, we run thousands of repeats of the model, introducing some statistical variation into the model's variables. This gives us a range of possible parameter estimates for the last three TC parameters. When we run the model, carrying out the range of TC estimates, we produce a 95% CI for TR, R_e, and current prevalence.

With regard to the technical approach, uncertainty in the projections is obtained by fitting all 16 transmission control parameters since March 1st and the date of initial infection using a hybrid optimization approach initially using a particle swarm followed by a weighted nonlinear least squares-based Levenberg-Marquardt constrained optimization algorithm. An estimated covariance matrix was computed via parametric sensitivity computations. A multivariate normal distribution was created via using the parameters estimates (as means) and the approximate covariance matrix. The predictions were generated via sampling parameters from the multivariate normal distribution and 10% of the resulting solutions are shown in the figures.

Current COVID-19 hospitalizations and model fit

Figure 2 provides COVID-19 hospitalizations (black bars) and the green line shows the current model fit to the data using the TC method. Table A1 provides values for model parameters for the TC approach. Our most recent estimate of TC, for the period 10/05 to 10/13, is 65%. We note that due to the approximately 13-day lag between infection and hospitalization, we are currently only able to estimate social distancing and transmission control through 10/13.

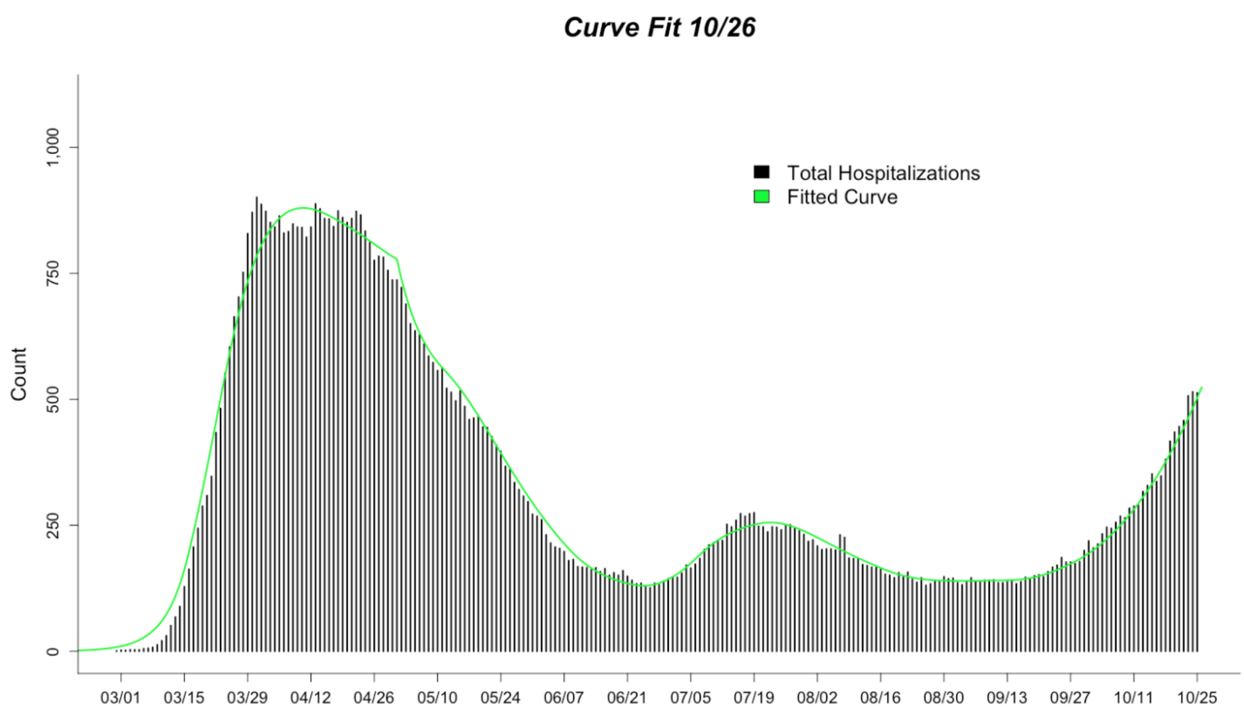


Figure 2. Current model fit (green line) to count of hospitalized COVID-19 cases (black lines) using the age-structured SEIR model. Hospitalized COVID-19 cases are from CDPHE reported COVID-19 hospitalizations and EMResource (EMR) hospital census data provided by CDPHE.

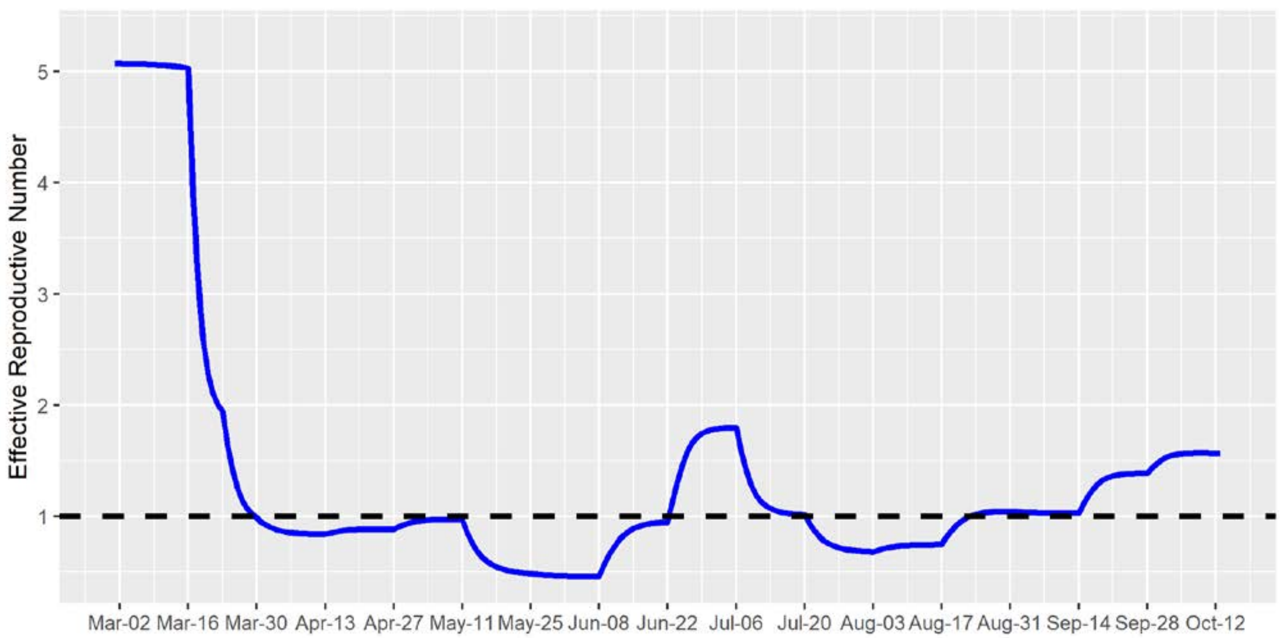
The effective reproductive number

The estimated effective reproductive number is shown in Table 1 and Figure 3. Table 1 provides estimates we generated using two different methods, both yielding similar values. We also provide values from two external groups that use different data and methods (RT-Live uses SARS-Cov-2 case data and covid-19-projections.com uses mortality data). Trends over time in these external estimates reflect our estimates, although the values are different.

Table 1. Current and prior estimates of the effective reproductive number (Re) in Colorado.

	Current Estimate (10/26)	Estimate one week ago (10/19)	Estimate two weeks ago (10/12)
Estimate of Re, approach 1, TC model*	1.57 (1.47, 1.70)	1.48 (1.16, 1.85)	1.51
Estimate of Re, approach 2, TC model*	1.66	1.51	1.59
Estimate from RT-Live	1.23 (0.96, 1.45)	1.19 (0.93, 1.41)	1.06
covid-19-projections.com	1.04 (0.87, 1.24)	1.04 (0.87, 1.24)	1.04

*Our estimates are based on hospitalization data through the date listed. Estimates from the external sites are extracted on the day listed. Because of the 13-day lag between infection and hospitalization, on average, our current estimate reflects transmission up to approximately October 13th. Approach 1 uses TC 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 TC model structure to estimate the dominant eigenvalue for a matrix describing population flows across the model compartments.



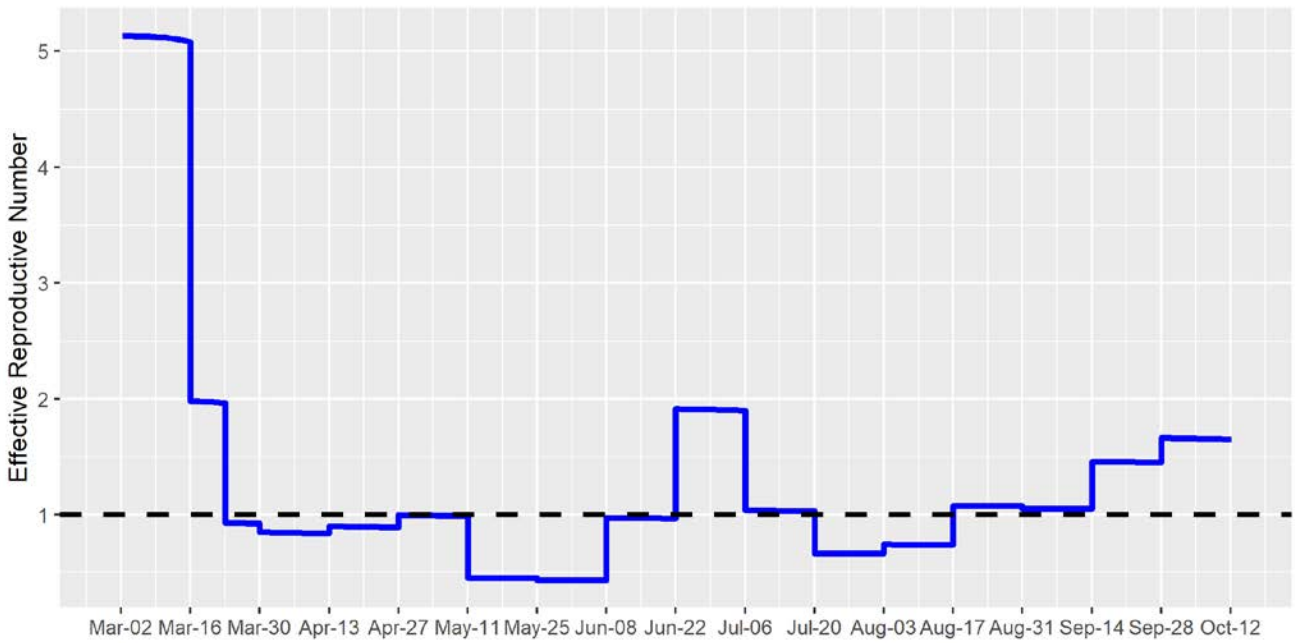


Figure 3. The effective reproductive number using approach 1 (top) and approach 2 (bottom) based on the TC model.

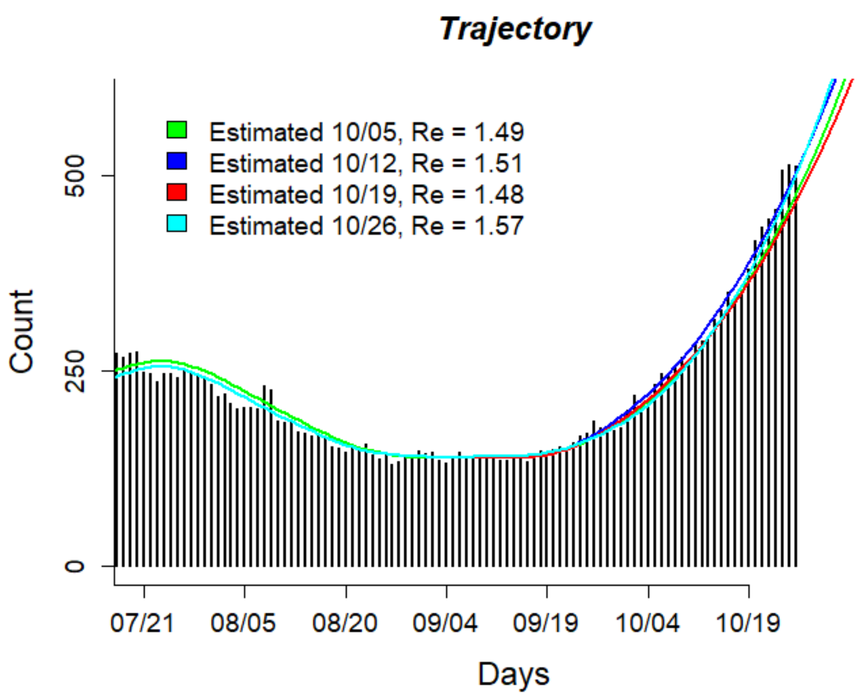


Figure 4. The projected trajectory of COVID-19 hospitalizations if Colorado remains on the current estimated trajectory (cyan line), the trajectory estimated one week prior (red line), and the trajectory estimated two weeks prior (blue line). Each trajectory is generated assuming transmission control levels remain at the estimated levels: current estimate (10/26) 65% based on the period 9/28 to 10/13, one-week prior estimate (10/19) 67% based on the period 9/28 to 10/06, two-week prior estimate (10/12) 66% based on the period 9/13 to 9/29 (blue line), three-week prior estimate (10/05) 67% based on the period 9/13 to 9/22 (green line). Note that the estimation

periods overlap as we re-estimate parameters each week and use the past approximately 10 days to estimate the most recent transmission control parameter.

The estimated cumulative and current number of infections in the population

We use the TC model to estimate the cumulative number of infections to date and the approximate number of infectious individuals in the population. Given the characteristics of SARS-CoV-2 and of COVID-19, many infections are not detected by surveillance systems – the estimates provided here are intended to provide an approximation of the total number of infections, as well as the proportion detected by the Colorado surveillance system. These estimates are sensitive to model assumptions, including assumptions about the probability that an infected individual will be symptomatic and require hospital care, as well as estimates about length of hospital stay, which vary over time and also by age.

We estimate that approximately 507,000 (95% CI: 503,000, 511,000) people in Colorado, or 8.7% (95% CI: 8.6, 8.7) of the population have been infected to date.

We estimate that there are approximately 27,000 (95%CI: 25,000, 28,000) infectious individuals in Colorado at present: approximately 457 (95% CI: 434, 473) of every 100,000 Coloradoans or 1 in every 219 people (95% CI: 234, 209). Figure 5 illustrates the relationship between COVID-19 hospitalizations and the estimated number of infectious individuals at any given point in time. The number of infectious individuals is approaching the March/April peak. This implies that the probability of encountering an infected person in the population is higher than it was at any point this summer.

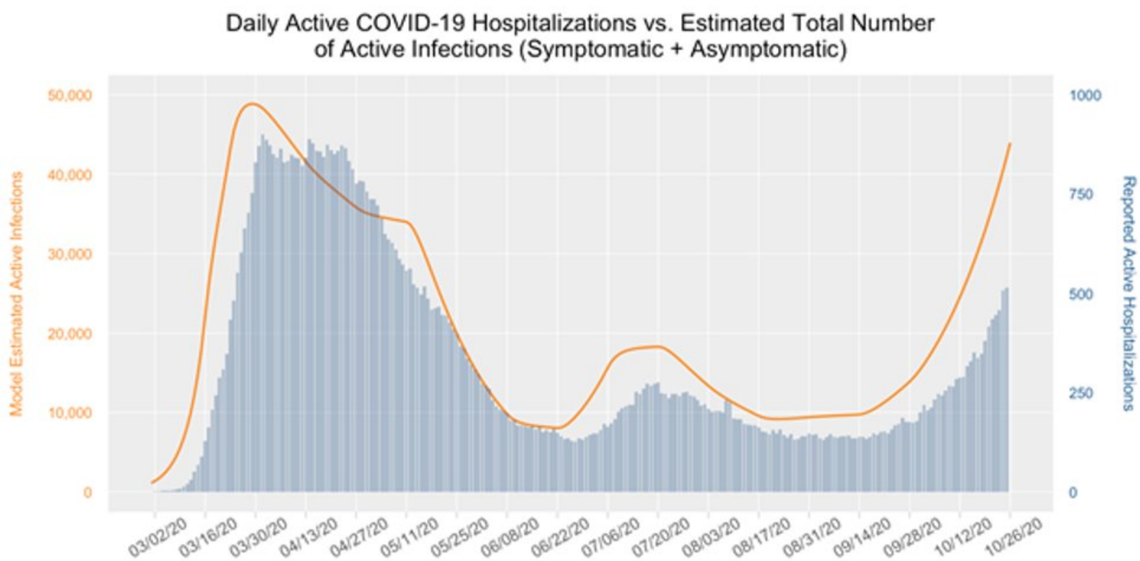
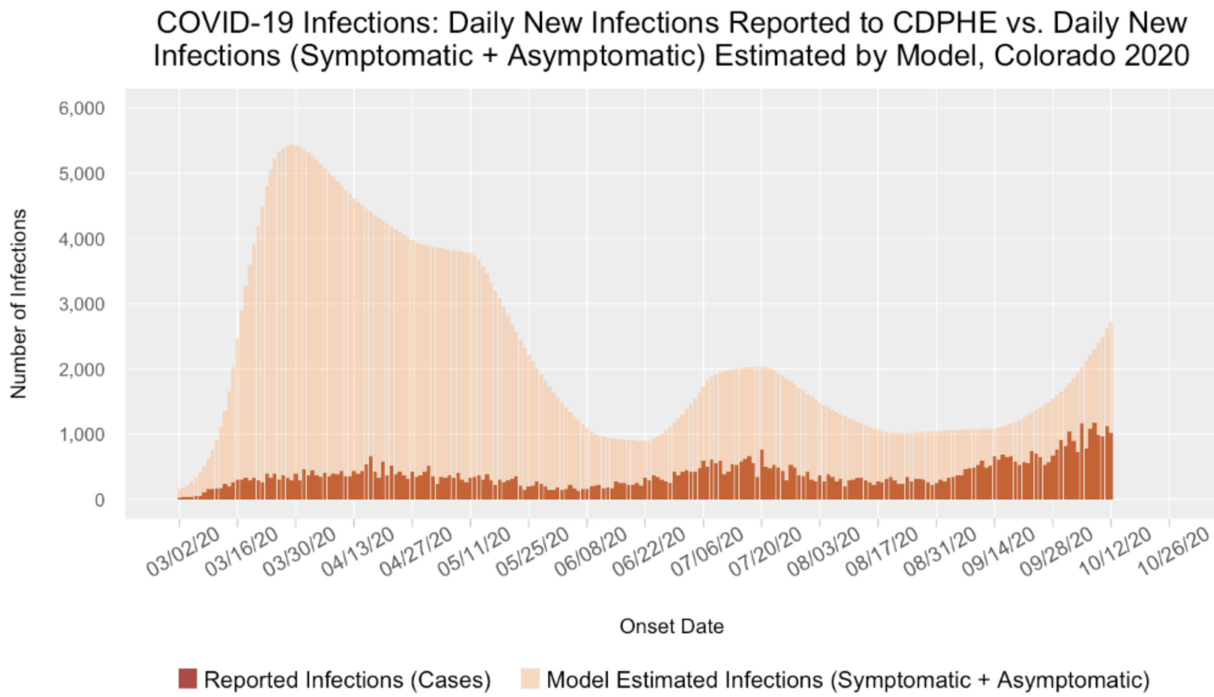


Figure 5. Estimated daily number of people who are infectious and infected with SARS-CoV-2 (point prevalence), as shown on the orange line, and the number of COVID-19 hospitalizations (blue bars). The number of infectious individuals is inferred using the model and based on hospitalizations.

Comparing observed to model-estimated infections, we estimate that approximately 46% of infections in the past two weeks were detected, including both asymptomatic and symptomatic infections. Note that our estimate of proportion of infections detected over time has decreased substantially as a result of the new model fit to shortened hospital length of stay duration.



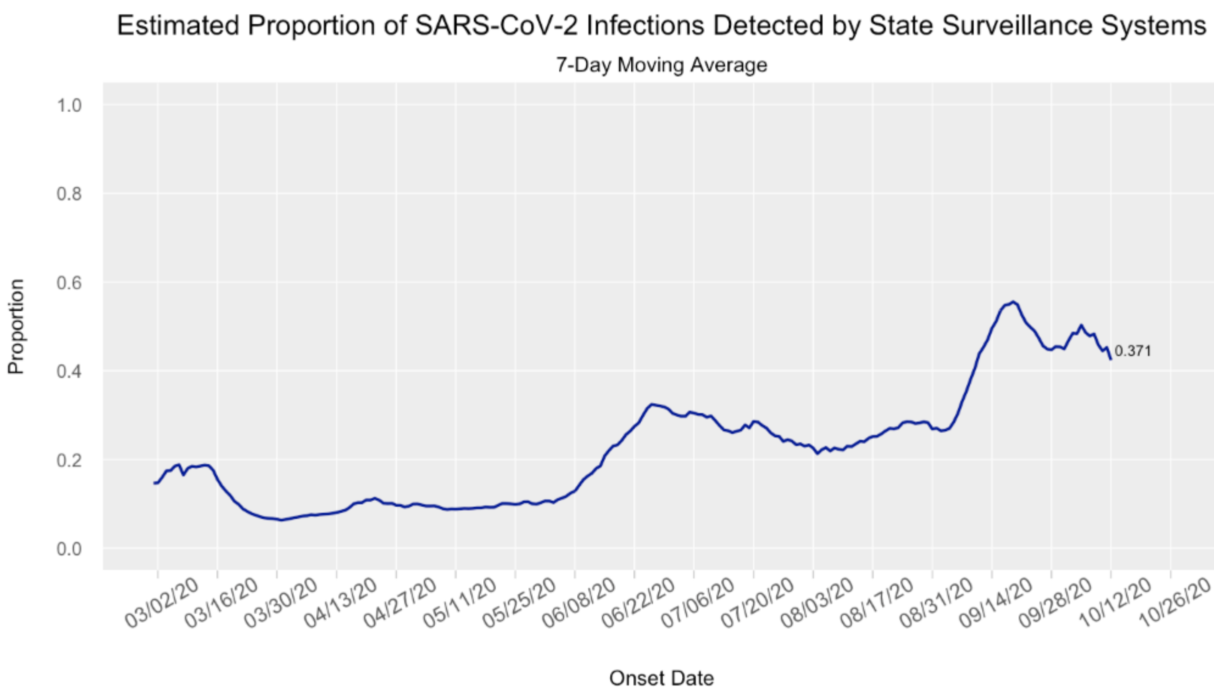
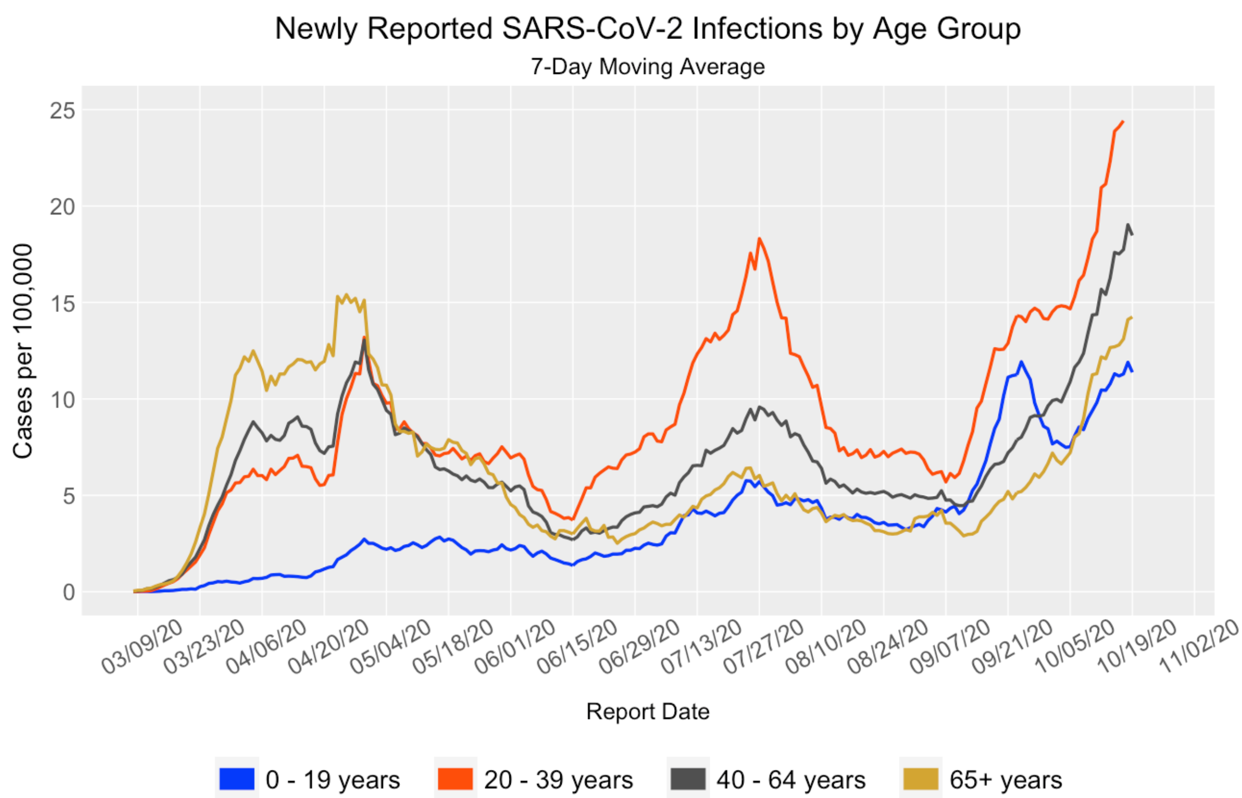


Figure 6. Estimated daily number of new (incident) SARS-CoV-2 infections based on the SEIR model (light orange graph) and reported cases (dark orange graph) over time shown in the top panel. Lower panel shows the 7-day moving average of the estimated proportion of SARS-COV2 infections that are being 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 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 10/13 to account for typical lags between symptom onset and case report.

The distribution of reported infections and hospitalizations by age, race and ethnicity

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. Recent reports of new cases are highest for those aged 20 - 39. The average proportion of COVID-19 cases in people under age 40 over the last two weeks is approximately 57%.



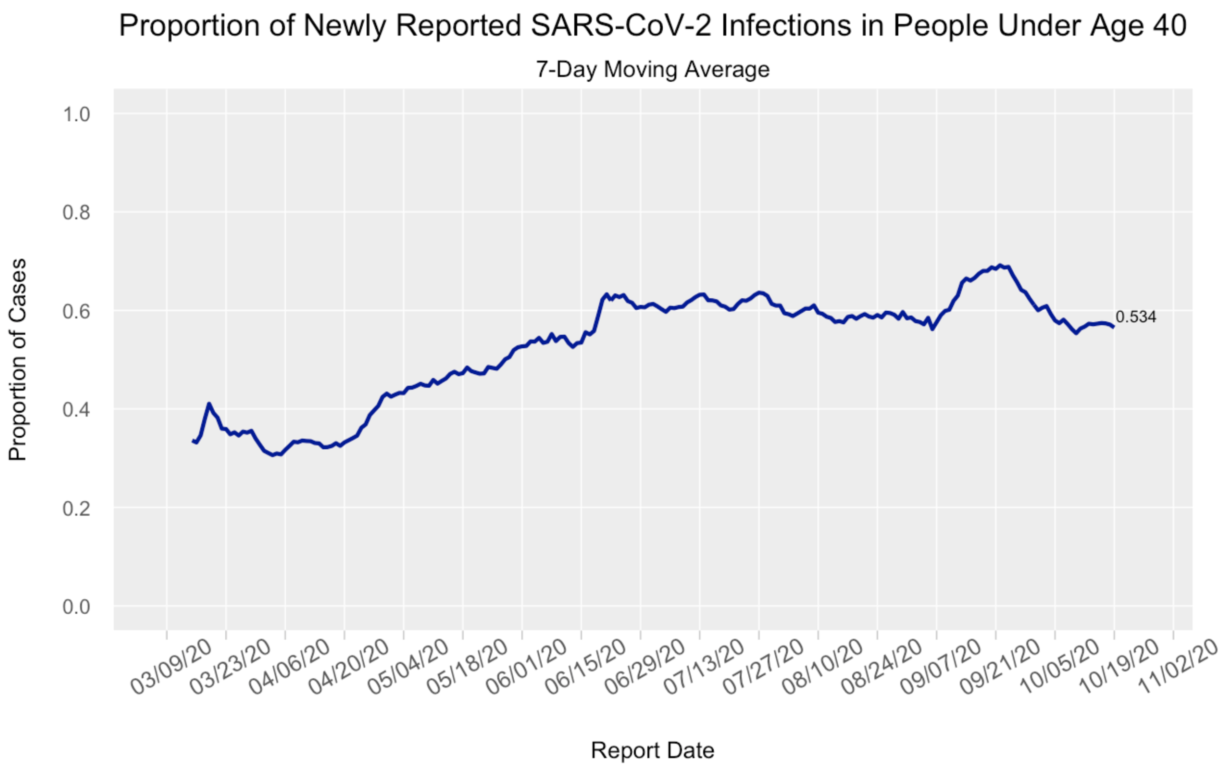
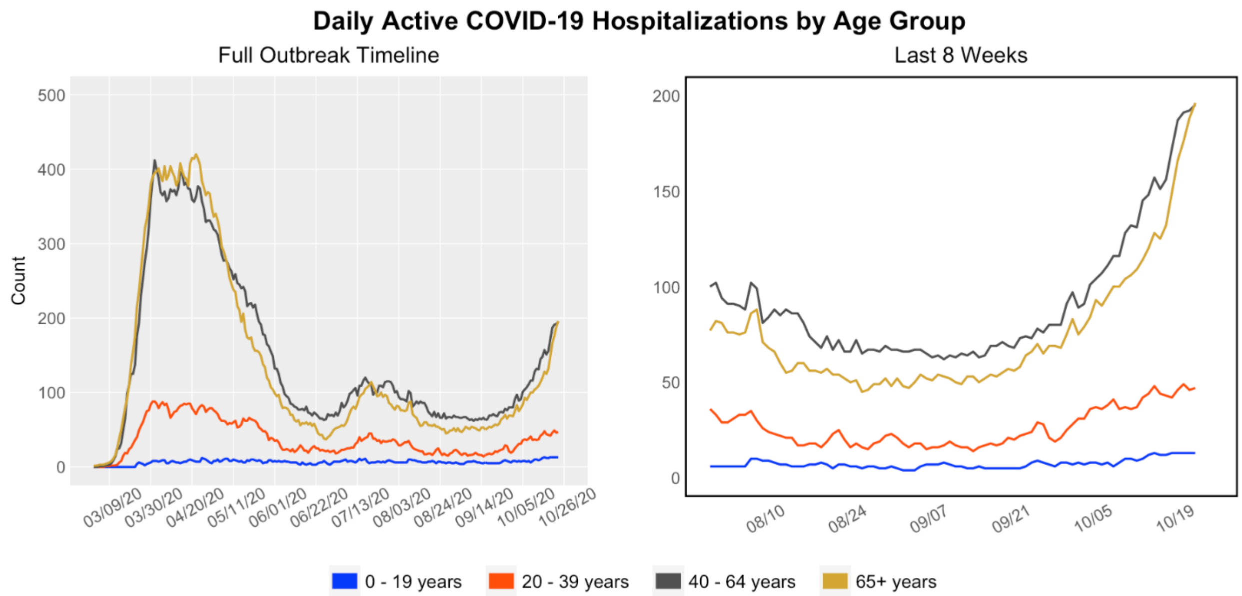


Figure 7. Distribution of 7-day moving average of newly reported SARS-CoV-2 infections by age group (top) and the proportion of all cases among individuals under 40 (bottom). Reported cases are based on CDPHE data and shown by report date. Incident cases per 100,000 were obtained by standardizing weekly 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 10/19/2020, to account for typical lags between case report and data updates.

COVID-19 hospitalizations by age group. Figure 8 shows the number of individuals hospitalized with COVID-19 by age group from March through the present. This is based on COvid Patient Hospitalization Surveillance (COPHS) hospital census records. Currently, individuals age 40-64 account for the greatest COVID-19 hospital use. People under 40 account for approximately 15% of COVID-19 hospital use.



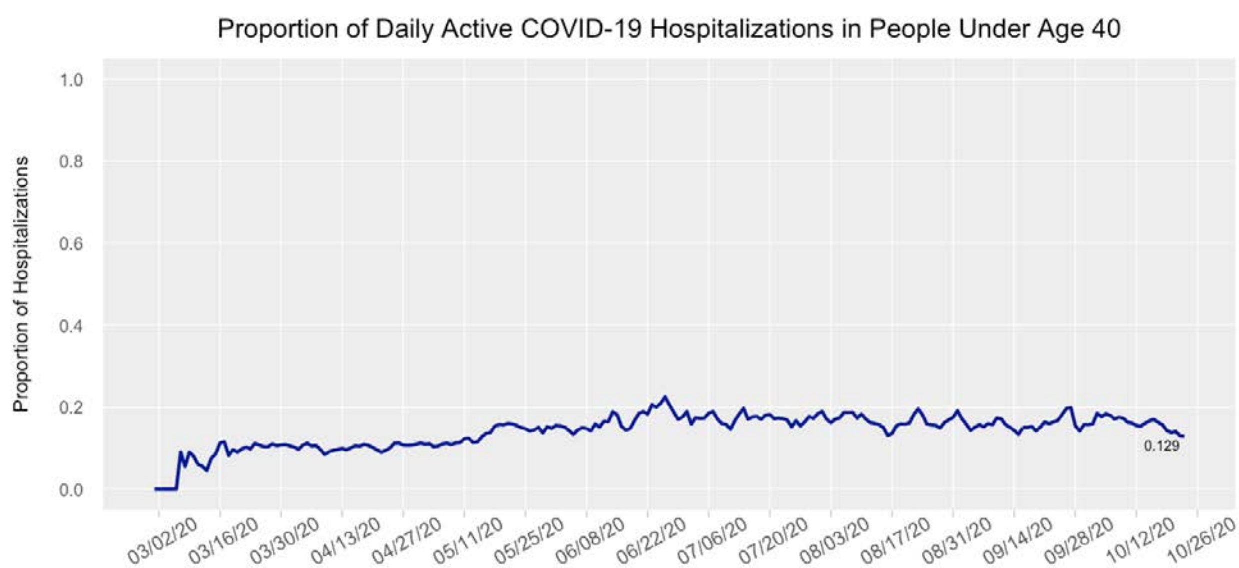


Figure 8. The number of individuals hospitalized with COVID-19 by age group from March through the present (top) and the proportion of COVID-19 hospitalized patients under age 40. Data based on COvid Patient Hospitalization Surveillance (COPHS).

COVID-19 reported cases by race/ethnicity. Figure 9 shows the number of reported cases by race/ethnicity from March through the present. Hispanic populations continue to be disproportionately impacted.

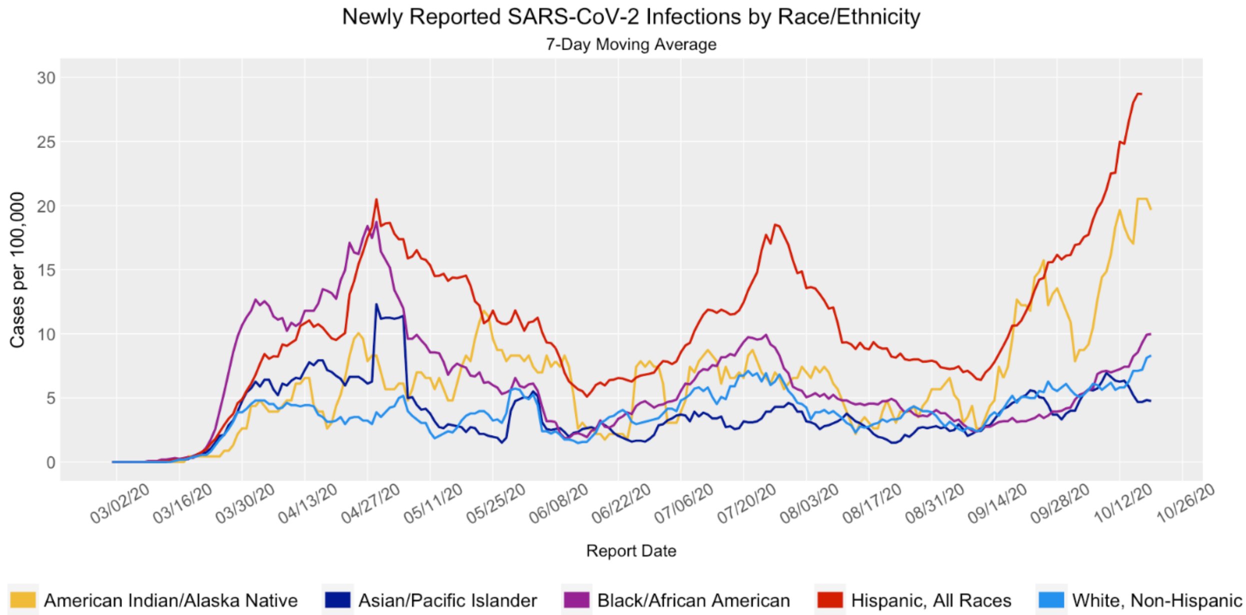


Figure 9. Distribution of 7-day moving average of newly reported SARS-CoV-2 infections by race and ethnicity in Colorado. Reported cases are based on CDPHE data and shown by report date. Cases and hospitalizations per 100,000 were obtained by standardizing weekly reported race-specific case and hospitalization 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 31% of observations over the last two weeks).

Using age-specific case data to estimate 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 Colorado Electronic Disease Reproting System (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 6)) 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. Transmission control levels have decreased among all age groups over the past month. Individuals aged 20-39 have the highest contact rates currently (TC= 60%). In all other individuals, cases have increased recently, leading to a decreased estimate of transmission control (TC = 74%, 68%, and 76% for individuals under 20, 40-64, and 65+ respectively).

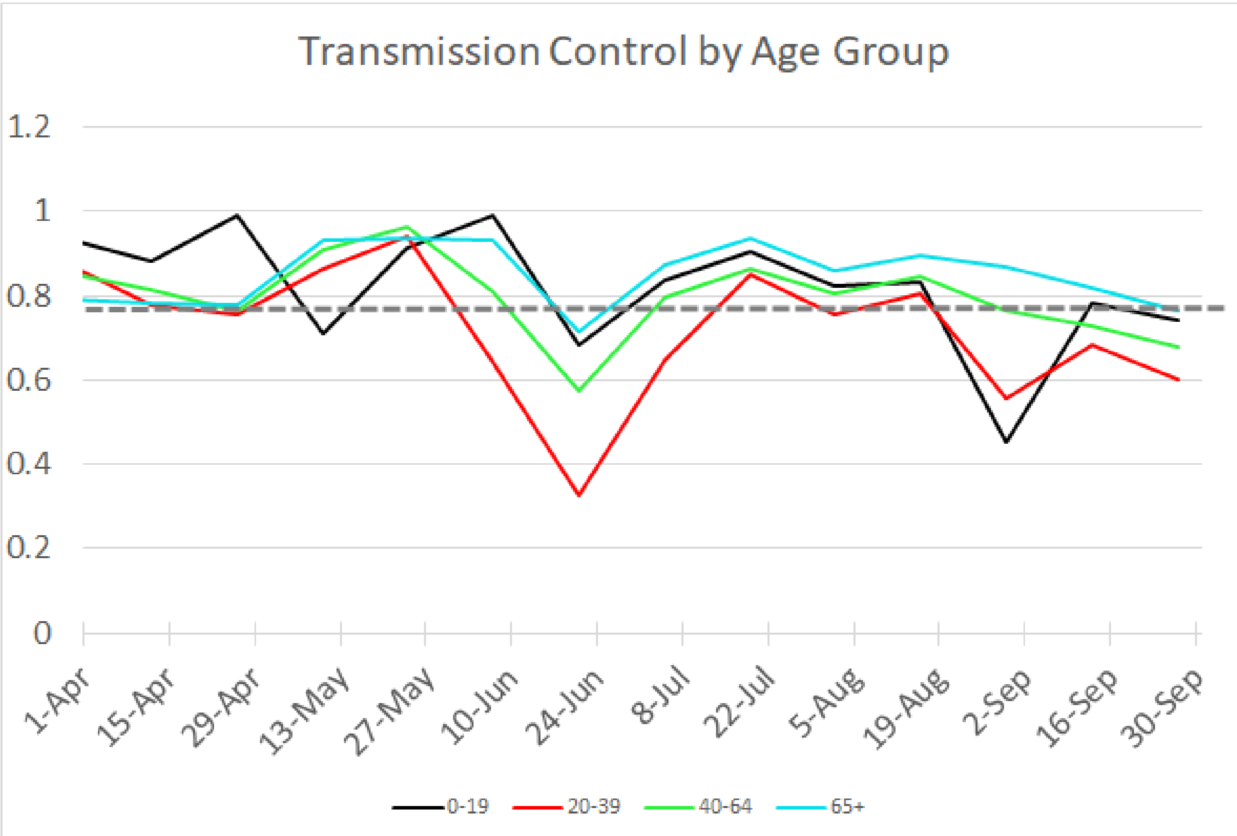


Figure 10. Estimates of transmission control by age plotted over time. Transmission control values are plotted at the time period for which they begin, as the last period for which transmission control is estimated is 9/28 – 10/13, the point on the graph is plotted at 09/28. Grey dashed line indicates threshold value of transmission control = 78%.

Near-term forecast

We generated estimated hospitalizations and ICU need over the next two weeks assuming we remain on the current trajectory and accounting for uncertainty, as described above, in our current estimated trajectory (Figure 11, bottom). The mean estimate shows the number of hospitalizations crossing 900 on ~November 10th; however, there is a chance that figure of 900 hospitalizations could be reached as early as November 8th. These estimates are based on 10,000 simulated runs, with 1,000 of those runs randomly selected for visualization.

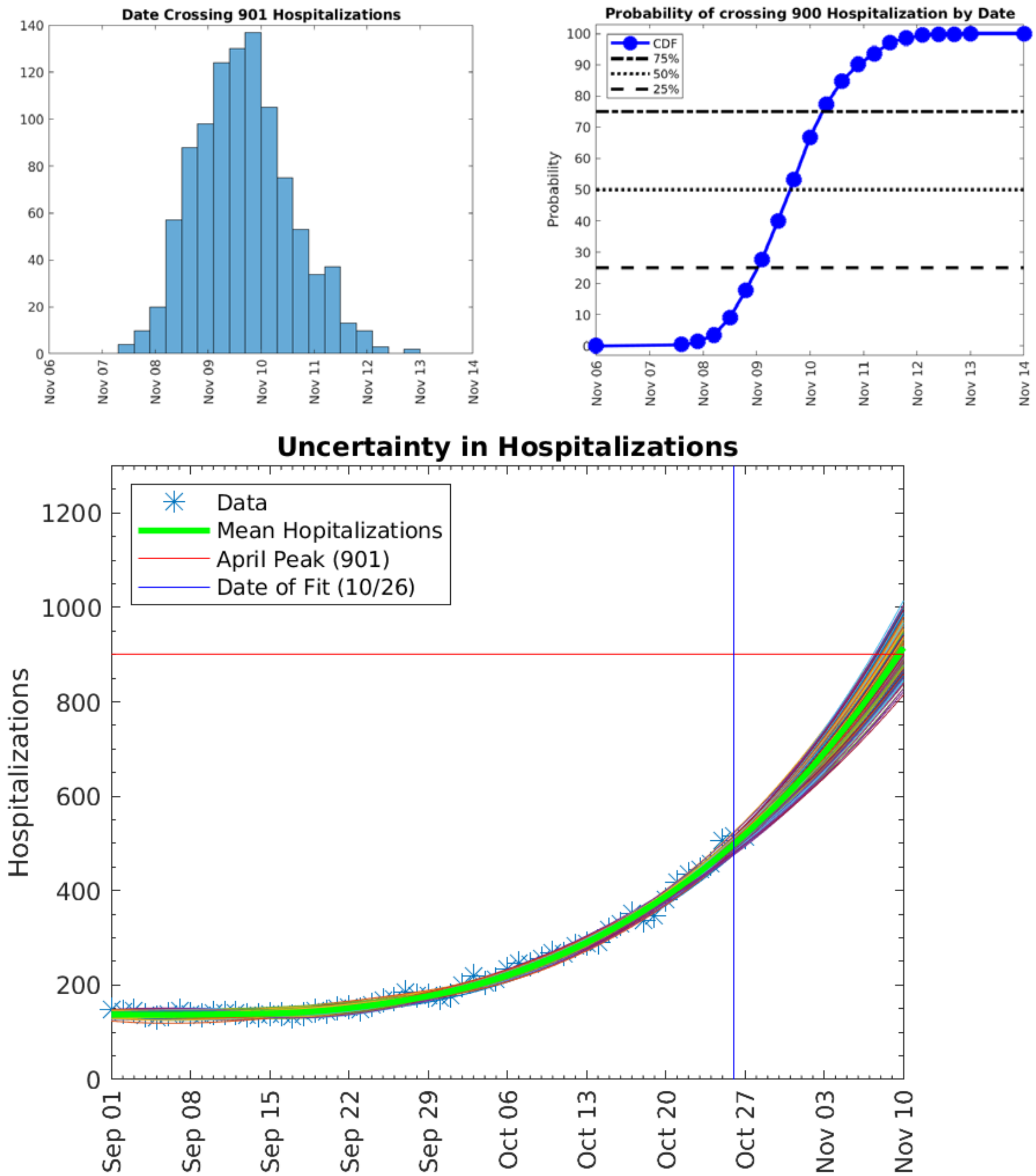


Figure 11. Distribution of likely timing for crossing previous hospitalization peak (901 hospitalizations) (top) and estimated daily count of total hospital demand (bottom) if we remain on the current trajectory (solid line, 65% for the period 9/28 – 10/13). Additional lines show the range of uncertainty in our current trajectory.

Scenario-based projections

Projections were generated to evaluate future hospital and ICU need under an array of hypothetical scenarios.

- The first set of scenarios shows the potential impact of theoretical changes to the current trajectory
- The second set of scenarios considers the potential impact of increased population mixing and more social contacts over the holidays

Projection set 1. Changes to the current trajectory.

In these scenarios, transmission control values are altered from the current trajectory and increased or decreased on 10/30 (Figure 12 and Table 2).

Projections show that at the current level of contact rates we could see substantial growth in cases in the months ahead, and ICU capacity of 1800 beds for people with COVID-19 would be expected to be exceeded in January.

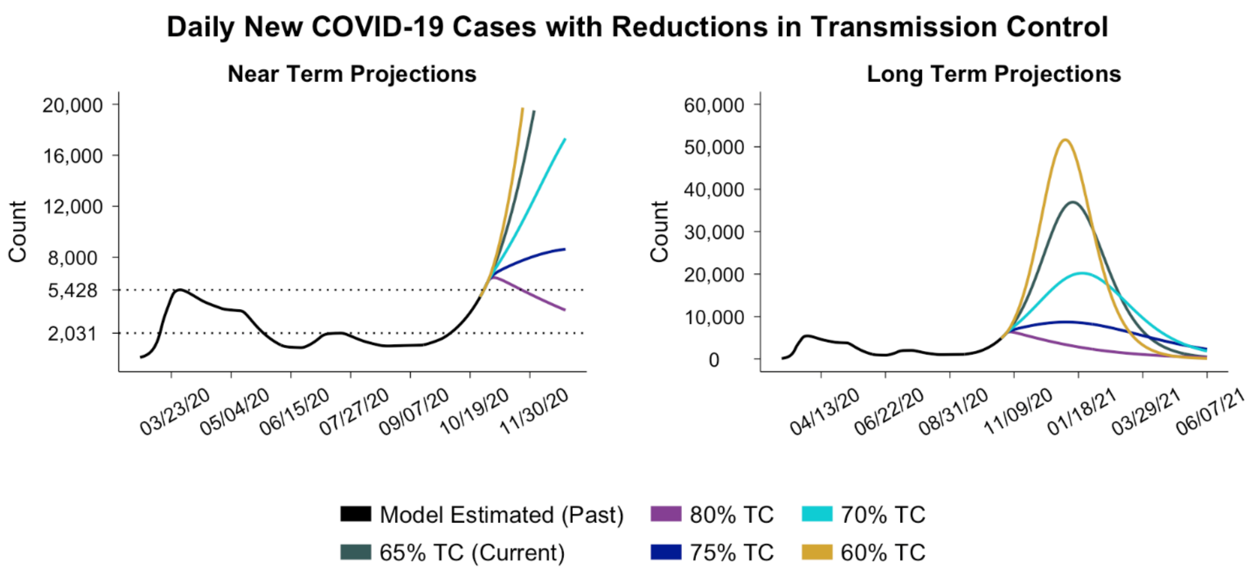
Table 2. Comparison of the projected date that ICU capacity is reached, the date ICU demand peaks, the estimated number of ICU beds needed at the peak, and the cumulative COVID-19 deaths at different levels of social distancing.

	Date ICU Capacity Reached*	Date of ICU Peak	ICU Need at Peak**	Cumulative cases through 12/31/2020**	Cumulative deaths through 12/31/2020**
Projection set 1: Changes to the current trajectory¶					
Current trajectory (9/28 – 10/13, TC = 65%)	1/19/2021	1/19/2021	1,800	2,250,000	7,600
TC = 60%	12/20/2020	1/11/2021	2,500	2,940,000	10,800
TC = 70%	N/A	1/30/2021	1,000	1,590,000	5,900
TC = 75%	N/A	1/12/2021	430	1,180,000	4,800
TC = 80%	N/A	past	past	938,000	4,000
Projection set 2. Increased contacts over the holidays assuming 10% relative decrease over holidays**					
Baseline TC = 65% (current)	12/23/2020	1/12/2021	2,600	2,840,000	10,000
Baseline TC = 60%	12/14/2020	1/7/2021	3,200	3,520,000	14,100
Baseline TC = 75%	N/A	1/16/2021	960	1,502,000	5,400
Baseline TC = 80%	N/A	1/11/2021	450	1,130,000	4,500
Projection set 3. Increased contacts over the holidays with					

scenarios assuming 20% relative decrease in TC over holidays)**					
Baseline TC = 65% (current)	12/16/2020	1/8/2021	3,400	3,480,000	13,400
Baseline TC = 60%	12/10/2020	1/5/2021	3,900	4,064,000	17,500
Baseline TC = 75%	N/A	1/14/2021	1,800	2,006,000	6,500
Baseline TC = 80%	N/A	1/13/2021	1,020	1,464,000	5,100

*ICU capacity for COVID-19 patients is estimated to be 1800 in Colorado, a figure provided by CDPHE.
**Estimates are rounded to two significant figures.
¶ Interventions are modeled assuming social TC levels remain at the current estimated level until 10/30, at which point it changes to the indicated value. These scenarios do not account for any additional changes in contacts over the holidays.

** Holiday scenarios assume TC values remain at current level until 10/30 and then switch to indicated value at 10/30. Transmission control values remain at indicated value until 11/20, at which point they decrease by a relative 10% reduction. The decreased value remains until January 3rd, when the TC level switches back to the indicated baseline TC value.



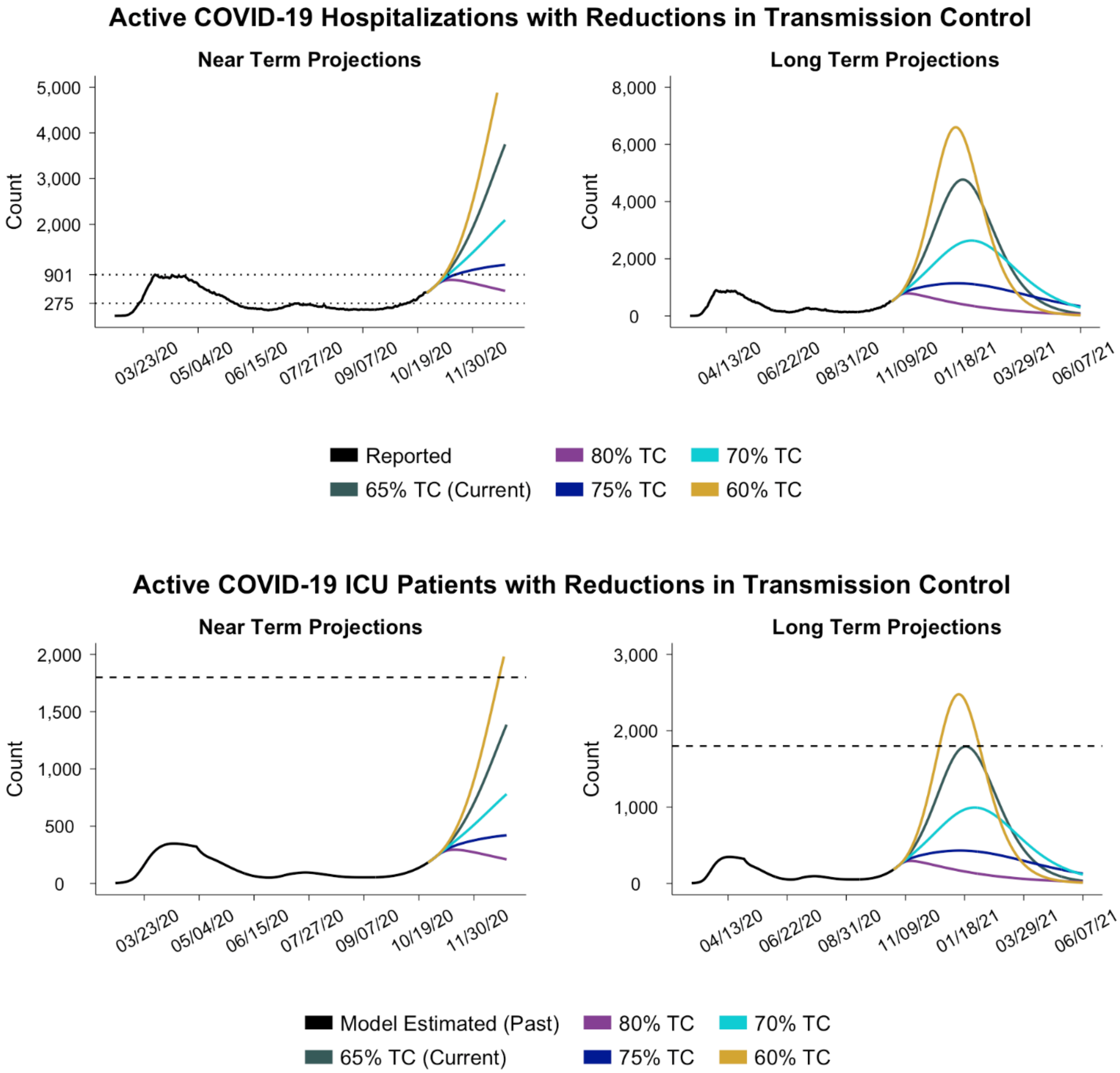


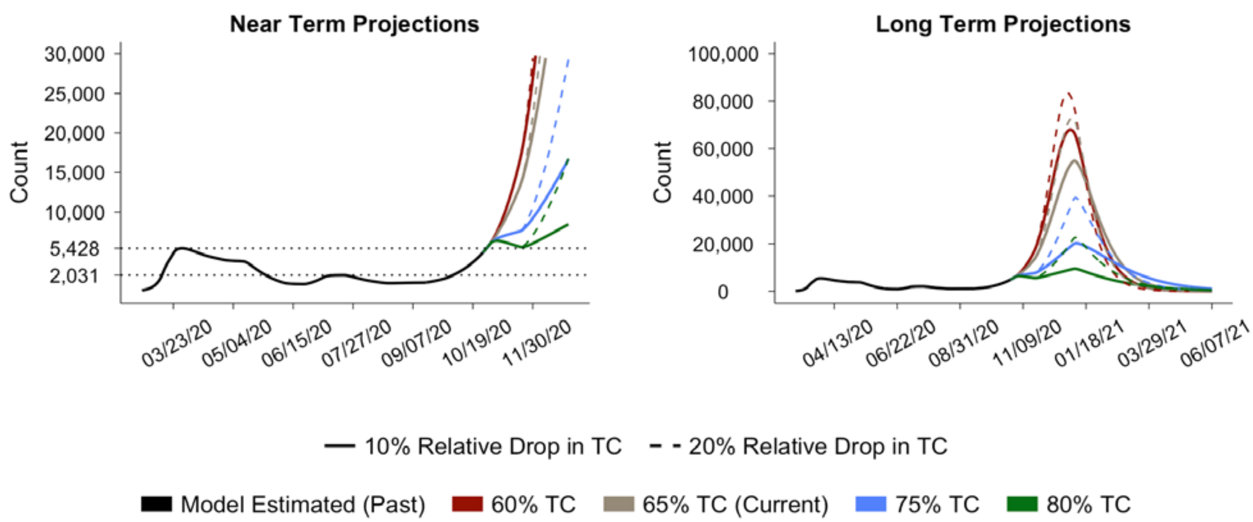
Figure 12. Projected daily count of new infections (top), active hospitalizations (middle) and active ICU patients (bottom) varying levels of transmission control, assuming transmission control remains at current levels (65%), or switches to 80, 75, 70, or 60% on 10/30. Dotted lines on the new infections plot indicate the number of new infections estimated during the April and July peaks. Dotted lines on the ICU need plot indicate estimated ICU capacity for COVID-19 patients of 1,800.

Projection set 2. Decreases in transmission control levels during the holiday season

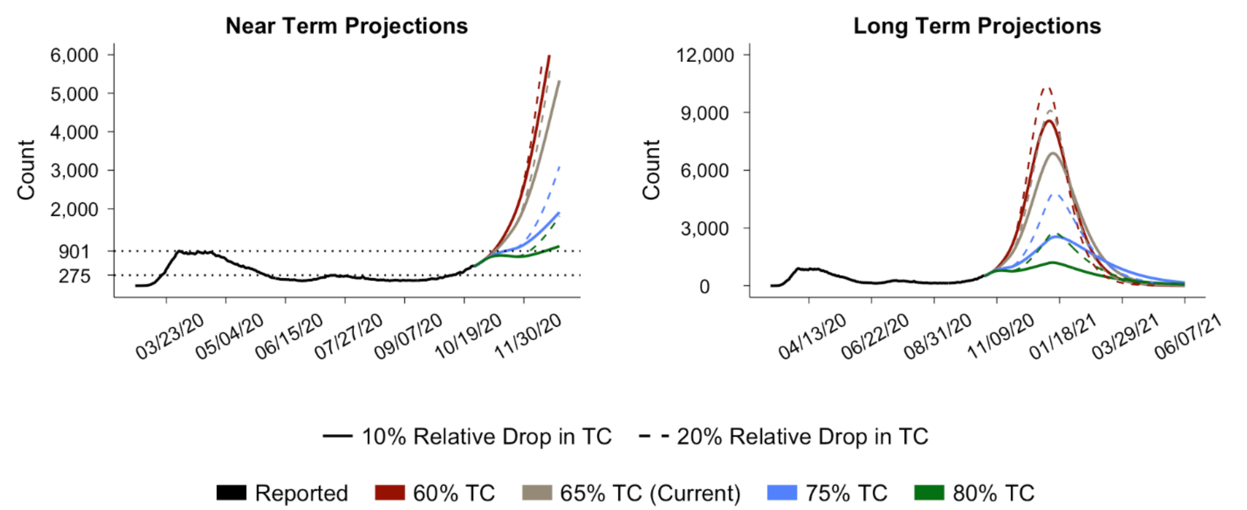
Given the recent rise in cases around the Independence Day (TC = 60%) and Labor Day holidays, we generated preliminary scenarios to evaluate the potential impact of theoretical increased social contacts over winter holidays. These scenarios assume that contact rates increase starting the Friday before Thanksgiving, 11/20/2020, and that the increases last until 1/03/2021. We do not know what the true increase in infectious contacts will be over the holiday season – we modeled 10% and 20% relative decreases in TC levels as preliminary scenarios. We generated projections for five different TC scenarios in the weeks ahead. Scenarios have TC levels increasing to 75% or 80%, staying the same (65%) or with TC levels decreased to 60% on 10/30. This allows us to examine the extent to which the level of infections entering the holiday season impacts the severity of any increase in cases over the holidays.

As shown in Figure 13 and Table 2, a holiday increase in contacts has the potential to lead to an increase in infections and hospital demand. If we remain on the current estimated trajectory, and experience an increase in contacts, ICU capacity could be exceeded in December. This increase will happen more rapidly, and the peak will be higher if we enter the holidays at a higher level of infection. Controlling infections in October and November can reduce the severity of a holiday “bump.”

Daily New COVID-19 Cases with Reductions in Transmission Control Over the Holidays



Active COVID-19 Hospitalizations with Reductions in Transmission Control Over the Holidays



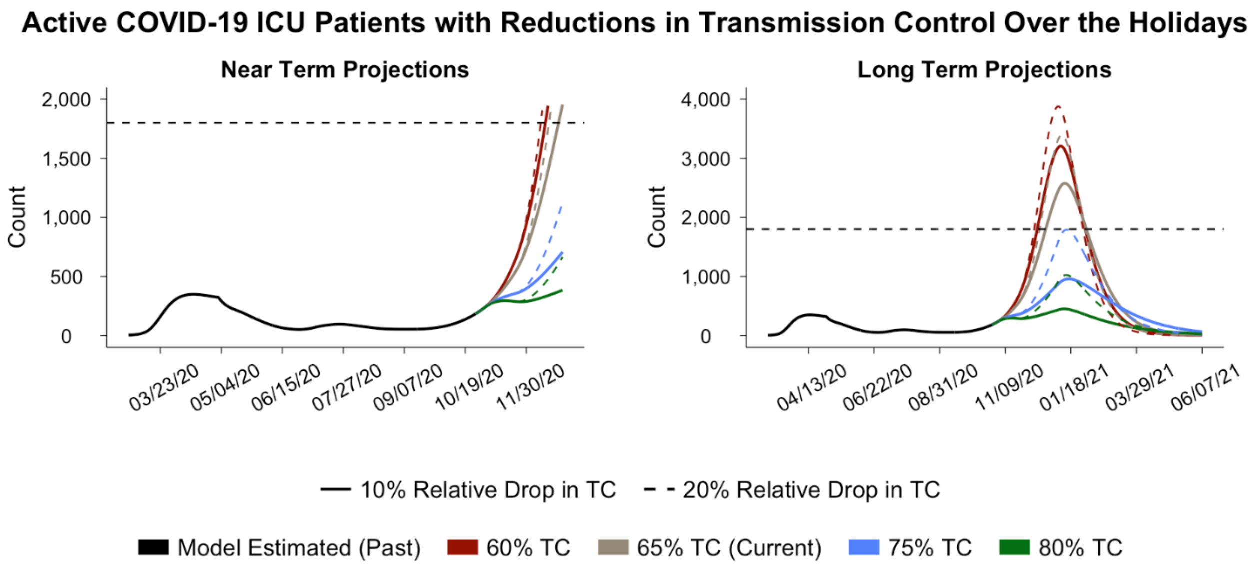
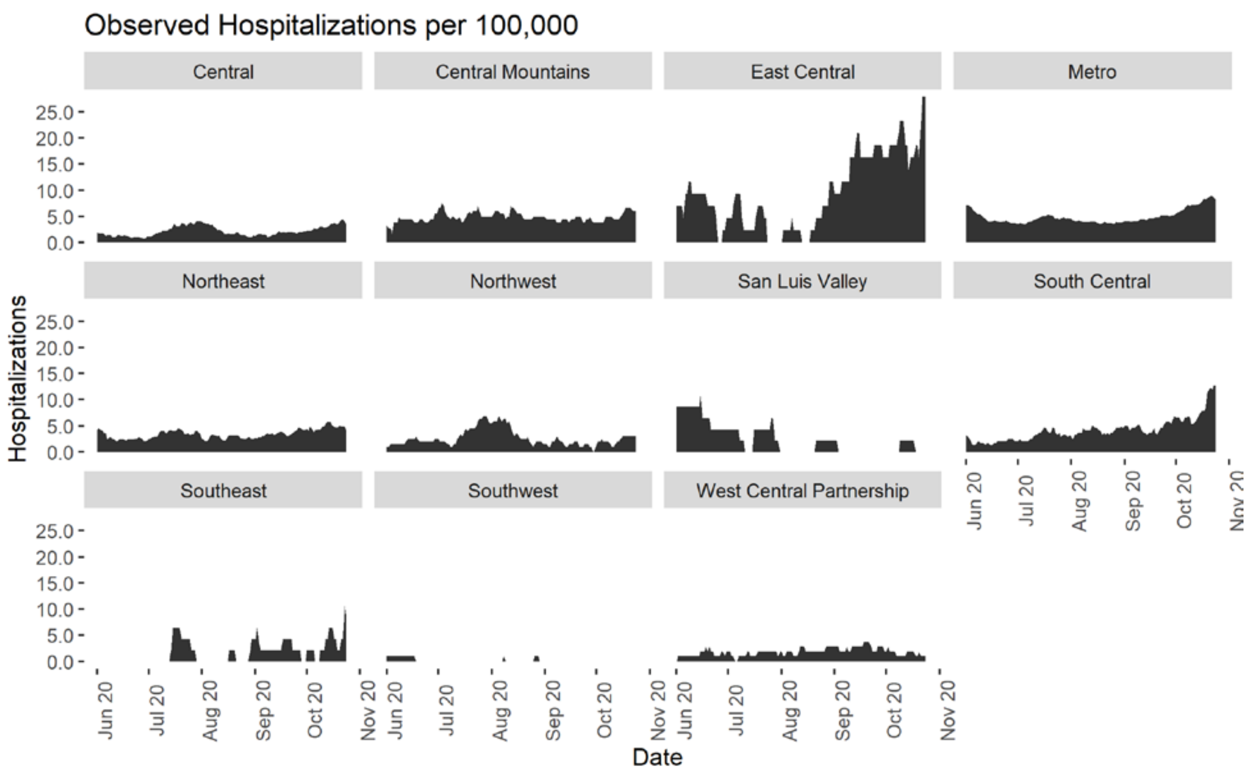


Figure 13. Projected daily count of new infections (top), hospital demand (middle), and intensive care (ICU) demand (bottom) in the near term (left) and long term (right), with a 10% relative decrease in transmission control levels over the winter holidays shown in solid lines and a 20% relative decrease in transmission control levels over the holidays shown in dotted lines. Model assumes transmission control level remains at ~ current levels (65%), or switches to 80, 75, or 60% on 10/30. Decreases in transmission control around the winter holidays is assumed to begin 11/20/2020 and last until 1/03/2021. Dotted lines on the infections and hospitalizations graphs represent the peak model estimated number of infections in April and July and the peak number of hospitalizations, respectively.

Regional Variation in Hospitalizations

There is substantial regional variation in the epidemic within Colorado, with some regions (South Central, East Central, Central, Metro) seeing marked increases in hospitalizations, while other regions (West Central Partnership, San Luis Valley, Northwest) are stable or declining. In the Metro Area, hospitalizations are increasing in all counties (figure 14, bottom).



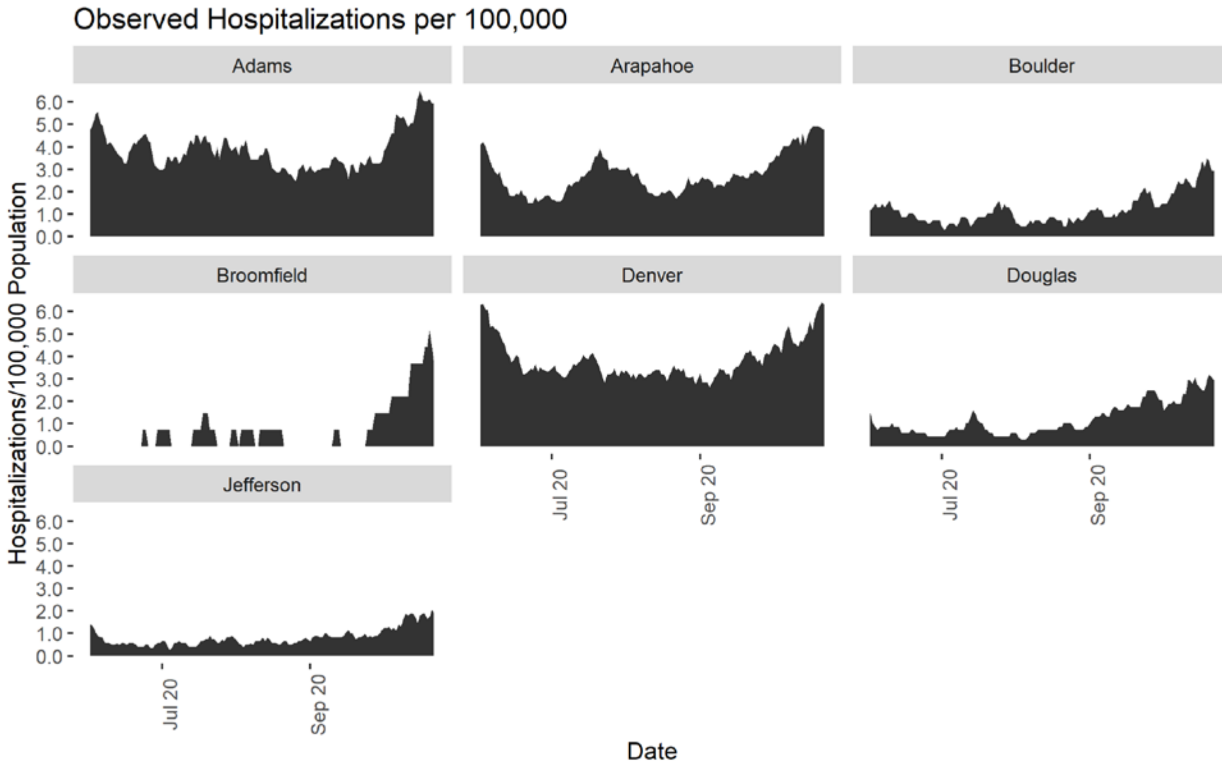


Figure 14. Observed hospitalizations per capita for the 11 LPHA regions in Colorado (top) and for the 7 Metro Denver Counties (Bottom). Data from COPHS hospital census data up to 10/23/2020. Hospitalizations standardized by population estimates from US Census 2020 projections. Hospitalizations since June 1st, 2020 shown. Note that hospitalizations in the past two weeks may be under-reports of true hospitalizations and underreporting may vary by region.

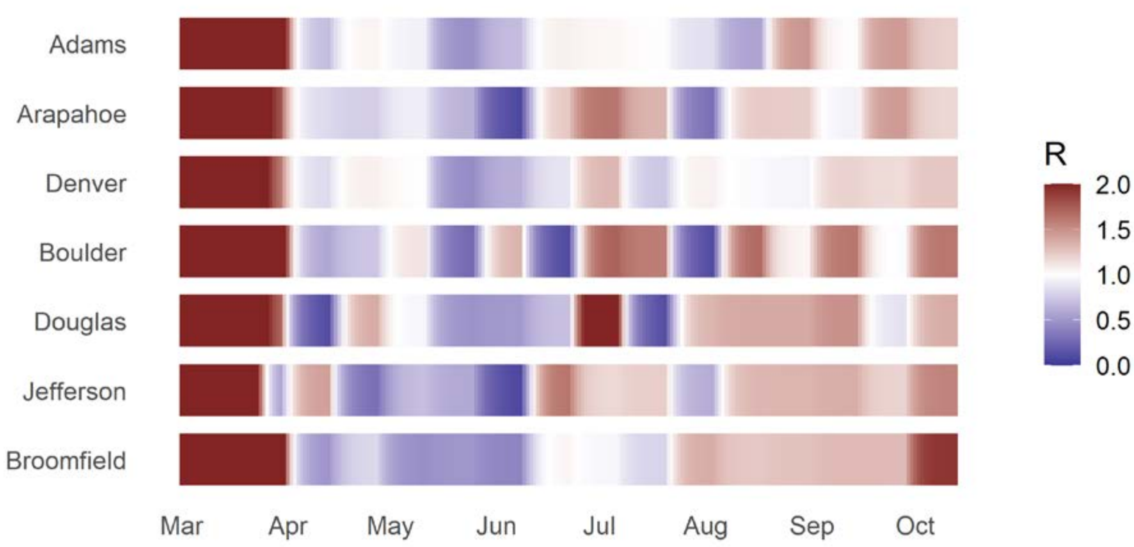


Figure 15. Estimated reproductive number over time for the 7 Metro Denver Counties using COVID-19 hospitalization data through October 16th. The R_e value is indicated by the range of colors, with $R_e = 1$

indicated by white, darker shades of red indicating increasing value above 1, and darker shades of blue indicating decreasing value below 1.

Appendix

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

Model simulations evaluating the potential impact of interventions can be generated using our app: https://cucovid19.shinyapps.io/colorado/. This site also includes detailed documentation of our model. The app is updated weekly to reflect our most recent parameter estimates.

Appendix Table A1. Estimated model parameters based on fitting our model output of total hospitalizations to reported hospitalizations in Colorado. The new "TR" 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, TC model	Fit using data through
Transmission control†			
Estimated transmission control level over past four weeks, 09/13 – 10/13	0-99%	67%	10/26
Estimated current transmission control level, 09/28 – 10/13	0-99%	65% (95% CI: 61%, 71%)	10/26
Transmission parameters			
The rate of infection (beta)	0.2 - 0.6††	0.48	06/24
Ratio of infectiousness for symptomatic vs. asymptomatic individuals (lambda)	1.0 - 4.0††	1.39	06/24

†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 [3, 4] are based on the literature, and for the rate of infection, were obtained from the MIDAS Online COVID-19 compilation of parameter estimates [5].

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