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

- Hospitalizations are increasing. Avoiding challenging peaks in infections and hospital demand over the next three months will require a substantial increase in the level of transmission control. The window to improve transmission control is over the next several weeks to assure that critical care capacity is not stressed. In most scenarios for the next few months, Colorado will exceed the April peak in hospitalizations.
- The magnitude and timing of reductions in transmission will determine the severity of COVID-19 in Colorado in the months ahead.
- We are at a critical moment

Snapshot of current SARS-CoV-2 transmission in Colorado

- Effective reproductive number: 1.5 (95% confidence interval 1.16, 1.85). *Hospitalizations are increasing rapidly*
- Estimated prevalence of infections: Approximately 344 (95% CI: 187, 599) of every 100,000, or 1 in 292 Coloradans are currently infectious. *The estimated prevalence is higher than last week.*
- Estimated number of infections to date: Approximately 8.4% (95% confidence interval: 8.2, 8.7) of the population has been infected to date.
- Estimated current level of transmission control: 67% for the period of 09/28 to 10/06. *There is an approximate 67% 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 contact rates (Transmission control = 58%), and contact rates are increasing among individuals over 65 (Transmission control = 73%).
- There is substantial regional variation at present with local public health association (LPHA) regions of concern including Central, East Central, Northeast, and South Central LPHA regions.

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

- If we remain on the current trajectory, we will soon exceed the April peak and will approach ICU hospital capacity in January. Increases in contacts over the holidays will accelerate growth in cases and ICU hospital capacity may be exceeded in December or January.

- The magnitude and timing of reductions in transmission will determine the severity of COVID-19 in Colorado in the months ahead.

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.

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 10/19/2020. We use these estimates to generate projections of the potential future course of SARS-CoV-2 in Colorado. These include near-term projections based on the current estimated trajectory, projections that consider the impact of further relaxation of transmission control levels, as well as projections that examine the potential impact of increased contact rates over the Thanksgiving to New Year holidays.

The report this week transitions to using the new "transmission control" parameter that provides an estimate of the collective impact of all policies and behaviors on the spread of SARS-CoV-2. This parameter is an overall measure of the percent reduction in transmission-relevant contacts and has the advantage of requiring fewer assumptions in our model. We have previously used the term "transmission reduction" for this parameter.

We use the transmission control (TC) model to generate estimates of the effective reproductive number, 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 uses both hospitalization and case data for parameter estimation.

Model Updates This Week

Transmission control. We have fully transitioned to the transmission control model. Our model previously included a social distancing parameter in addition to separate parameters describing mask wearing and self-isolation of infected individuals. Social distancing as a parameter in the model is different from what social distancing means colloquially. In our previous model, "social distancing" included behavior, policy, contact tracing and all reductions in transmission not accounted for based on our assumptions about case isolation and mask wearing. The estimate of social distancing was sensitive to the assumptions made about mask wearing and isolation. Moreover, impacts of contact tracing not captured by the self-isolation parameter were likely obscured by the social distancing estimates.

The new model replaces social distancing, mask wearing and self-isolation parameters with an overall TC parameter. This TC parameter is the percent decrease in effective contacts between infected and susceptible individuals compared to pre-pandemic behavior. This parameter captures ALL behavioral and policy changes in response to the SARS-CoV-2 pandemic including mask wearing, physical distancing, improved ventilation, working from home, contact tracing (including both isolation and quarantine), moving activities outside, seasonal impacts on transmission. This approach has the advantage of requiring fewer assumptions. For example, in the SD model we had assumed mask wearing

jumps from 70 to 90% on July 16, the date of the statewide mask order – an assumption that becomes unnecessary with the new model. For clarity, we refer to this new model parameterization as the TC model. We refer to the model with social distancing, mask wearing and self-isolation as the SD model.

Currently, given the proportion of susceptible people remaining in the population, TC levels under 78.5% will lead to increasing infections and Re > 1, whereas if contact rates are reduced such that transmission control is over 78.5%, infections will flatten or decrease.

Uncertainty. Given that our estimates of TC and current Re are subject to substantial uncertainty, we are visualizing uncertainty now using 95% Confidence Intervals (95% CI). We calculate the 95% CI using Markov Chain Monte Carlo methods and sample from the distribution of possible parameter estimates we fit each week. 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, this gives us a 95% CI for TC, R_e, and current prevalence.

Current COVID-19 hospitalizations and model fit

Figure 2 shows 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 9/28 to 10/06, is 67%. We note that due to the approximately 13-day lag between infection and hospitalization, we are currently only able to estimate social distancing and TC through 10/06.

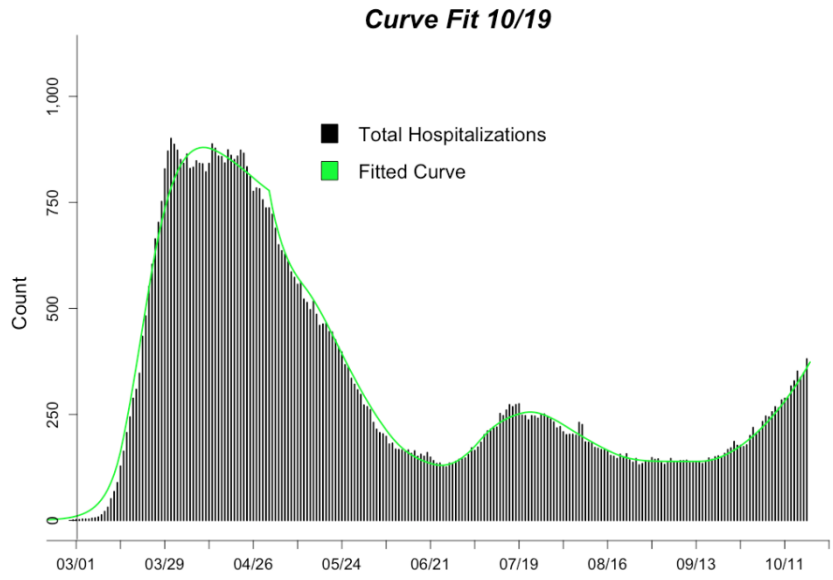


Figure 2. Current model fit (green line) to count of hospitalized COVID-19 cases (black lines) using the age-structured SEIR model – the SD model. Hospitalized COVID-19 cases are from CDPHE reported COVID-19 hospitalizations and EMResource (EMR) hospital census data provided by CDPHE.

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 of which are similar. 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 in these external estimates reflect those in our estimates.

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

	Current Estimate (10/19)	Estimate one week ago (10/12)	Estimate two weeks ago (10/05)
Estimate of Re, approach 1, TC model*	1.48 (1.16, 1.85)	1.51	1.49
Estimate of Re, approach 2, TC model*	1.51	1.59	1.27
Estimate from RT-Live	1.19 (0.93, 1.41)	1.06	1.00
covid-19-projections.com	1.04 (0.87, 1.24)	1.04	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 6th. 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.

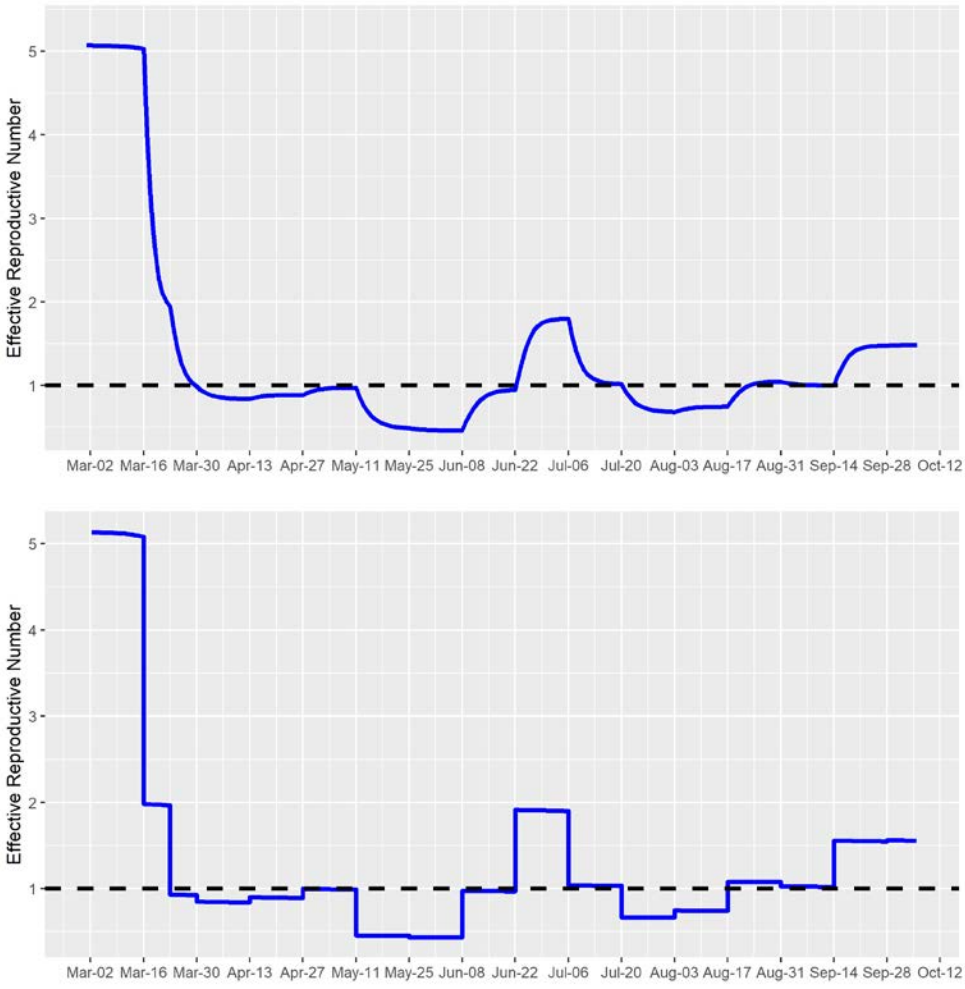


Figure 3. The effective reproductive number using approach 1 (top) and approach 2 (bottom) based on the TC model.

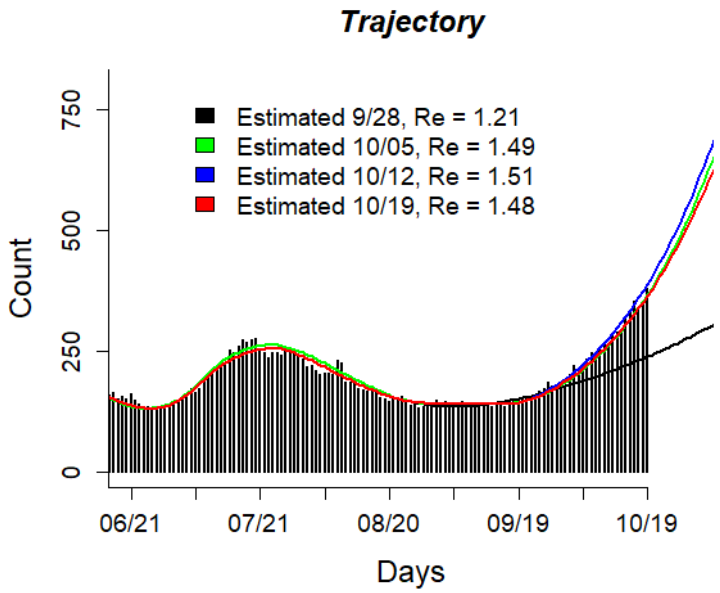


Figure 4. The projected trajectory of COVID-19 hospitalizations if Colorado remains on the current estimated trajectory (red line), the trajectory estimated one week prior (blue line), and the trajectory estimated two weeks prior (green line). Each trajectory is generated assuming transmission control levels remain at the estimated levels: current estimate (10/19) 67% based on the period 9/28 to 10/06, one-week prior estimate (10/12) 66% based on the period 9/13 to 9/29 (blue line), two-week prior estimate (10/05) 67% based on the period 9/13 to 9/22 (green line), three-week prior estimate (9/28) 74% based on the period 9/01 to 9/15 (black 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 TC 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 an infected individual will be symptomatic and require hospital care, as well as estimates about length of hospital stay, which vary over time, all variables of which we assume varies by age.

We estimate that approximately 490,000 (95% CI: 478,000, 505,000) people in Colorado, or 8.4% (95% CI: 8.2, 8.7) of the population have been infected to date.

We estimate that there are approximately 20,000 (95%CI: 11,000, 35,000) infectious individuals in Colorado at present: approximately 344 (95% CI: 187, 599) of every 100,000 Coloradoans or 1 in every 292 people (95% CI: 530, 167).

Comparing observed to model-estimated infections, we can estimate that approximately 44% 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.

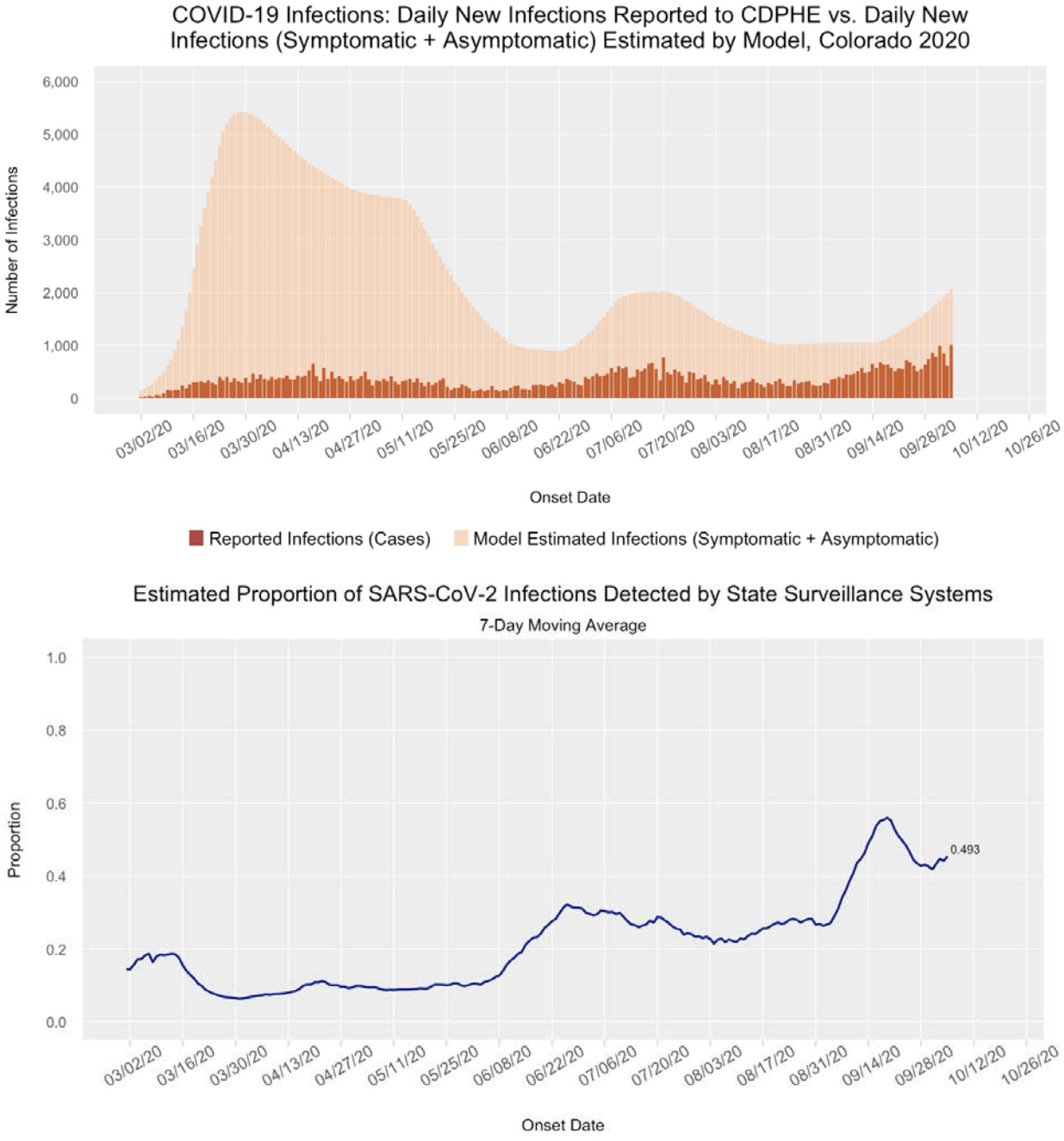


Figure 6. Estimated daily number of new (incident) SARS-CoV-2 infections based on the SEIR model (light orange graph) and reported cases (dark orange graph) over time shown in the top panel. Lower panel shows the 7-day moving average of the estimated proportion of SARS-COV2 infections that are being 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 10/06, 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%.

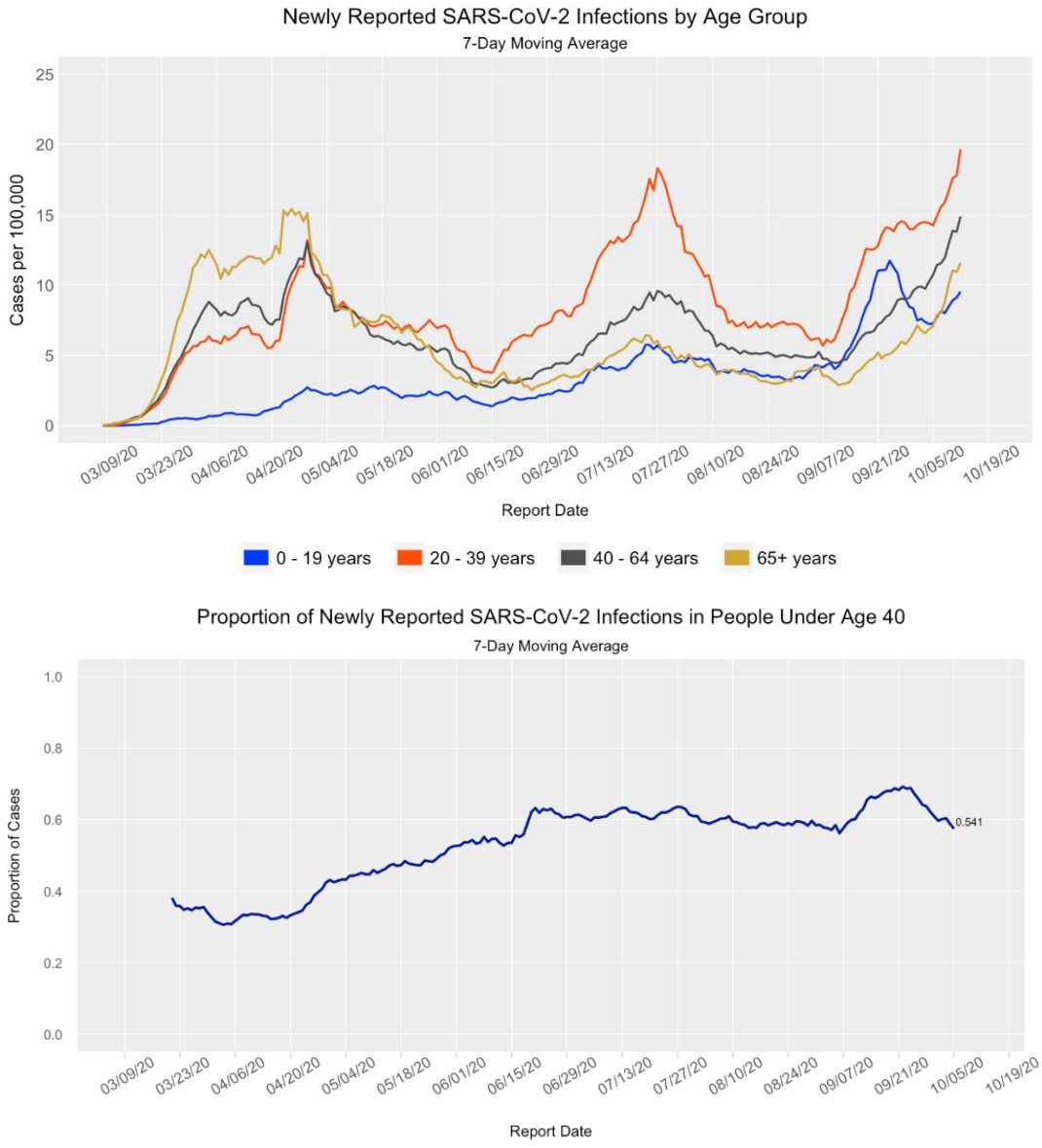


Figure 7. Distribution of 7-day moving average of newly reported SARS-CoV-2 infections by age group (top) and the proportion of all cases among individuals under 40 (bottom). Reported cases are based on CDPHE data and shown by report date. Incident cases per 100,000 were obtained by standardizing weekly 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 10/06/2020, 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 COPHS hospital census records. Currently, individuals age 40-64 account for the greatest COVID-19 hospital use. People under 40 account for approximately 17% of COVID-19 hospital use.

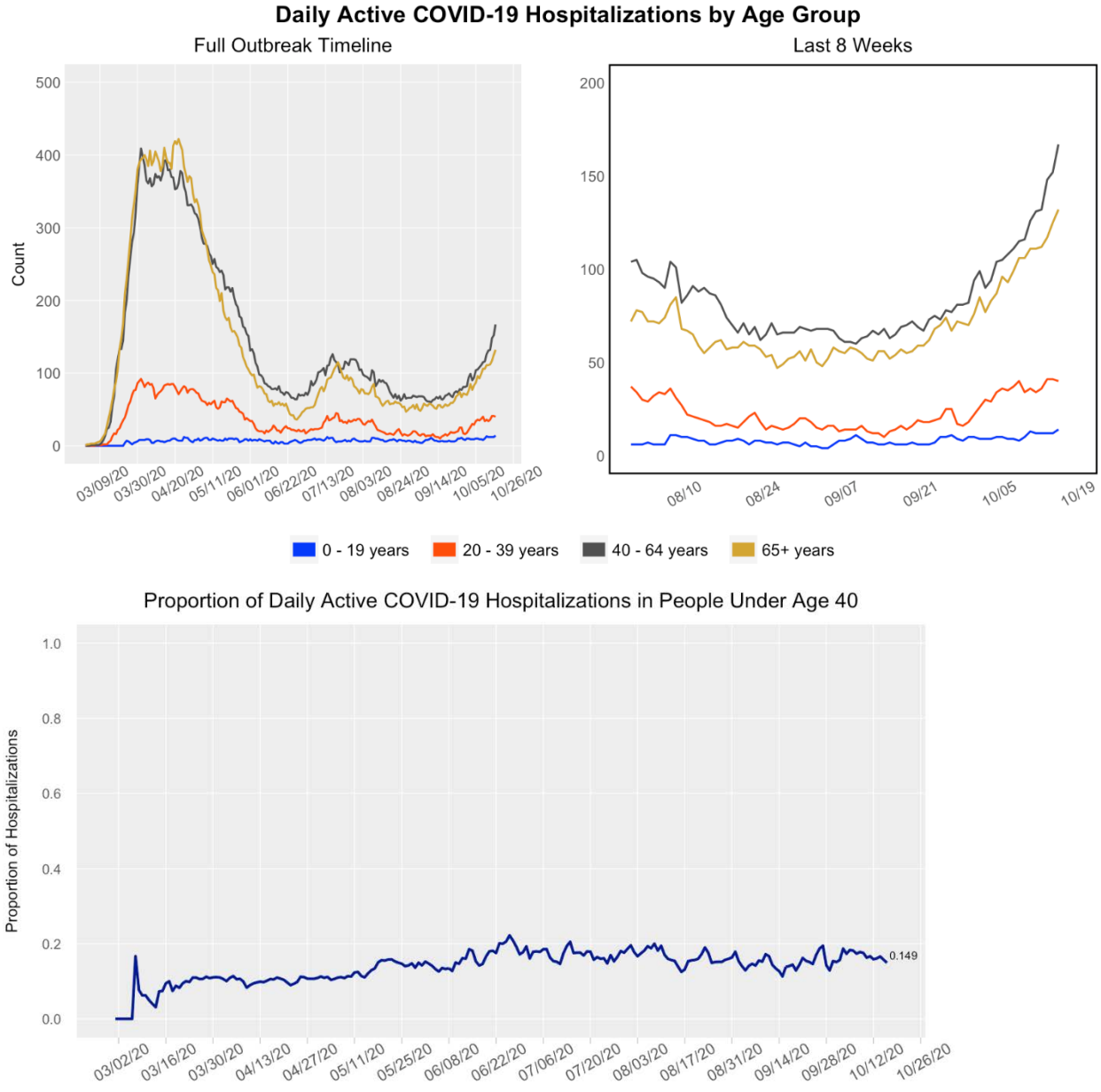


Figure 8. The number of individuals hospitalized with COVID-19 by age group from March through the present (top) and the proportion of COVID-19 hospital beds occupied by individuals under age 40. Data based on COVID Patient Hospitalization Surveillance (COPHS).

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.

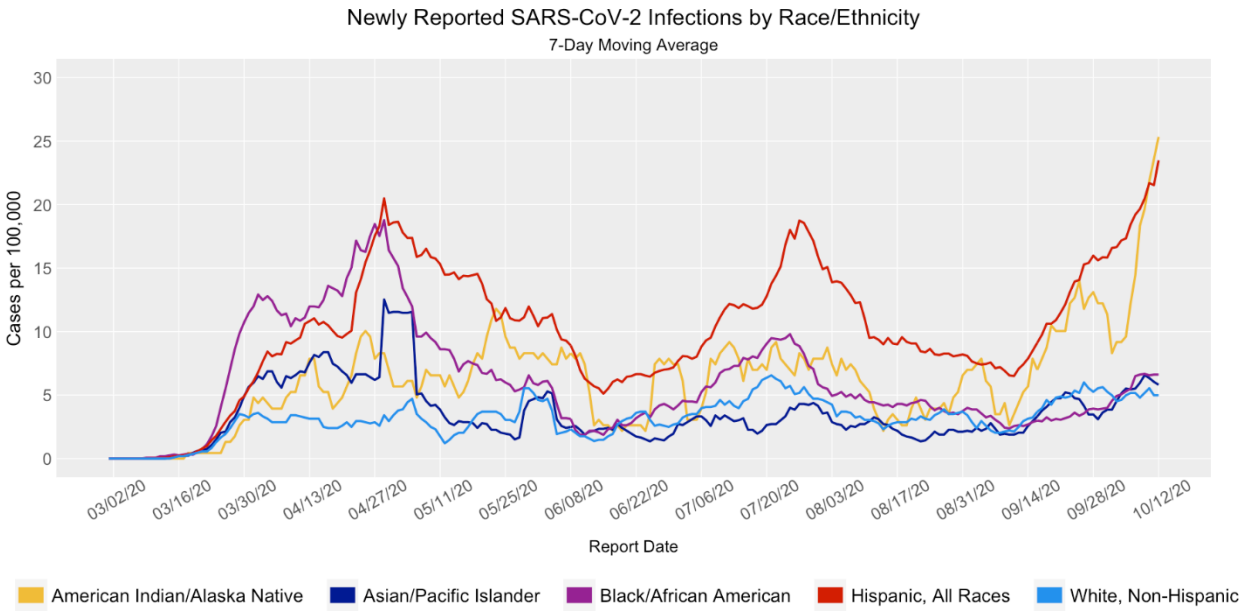


Figure 9. Distribution of 7-day moving average of newly reported SARS-CoV-2 infections by race and ethnicity in Colorado. Reported cases are based on CDPHE data and shown by report date. Cases and hospitalizations per 100,000 were obtained by standardizing weekly reported race-specific case and hospitalization 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 29% 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 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= 58%). In all other individuals, cases have increased recently, leading to a decreased estimate of transmission control (TC = 74%, 66%, and 73% for individuals under 20, 40-64, and 65+ respectively).

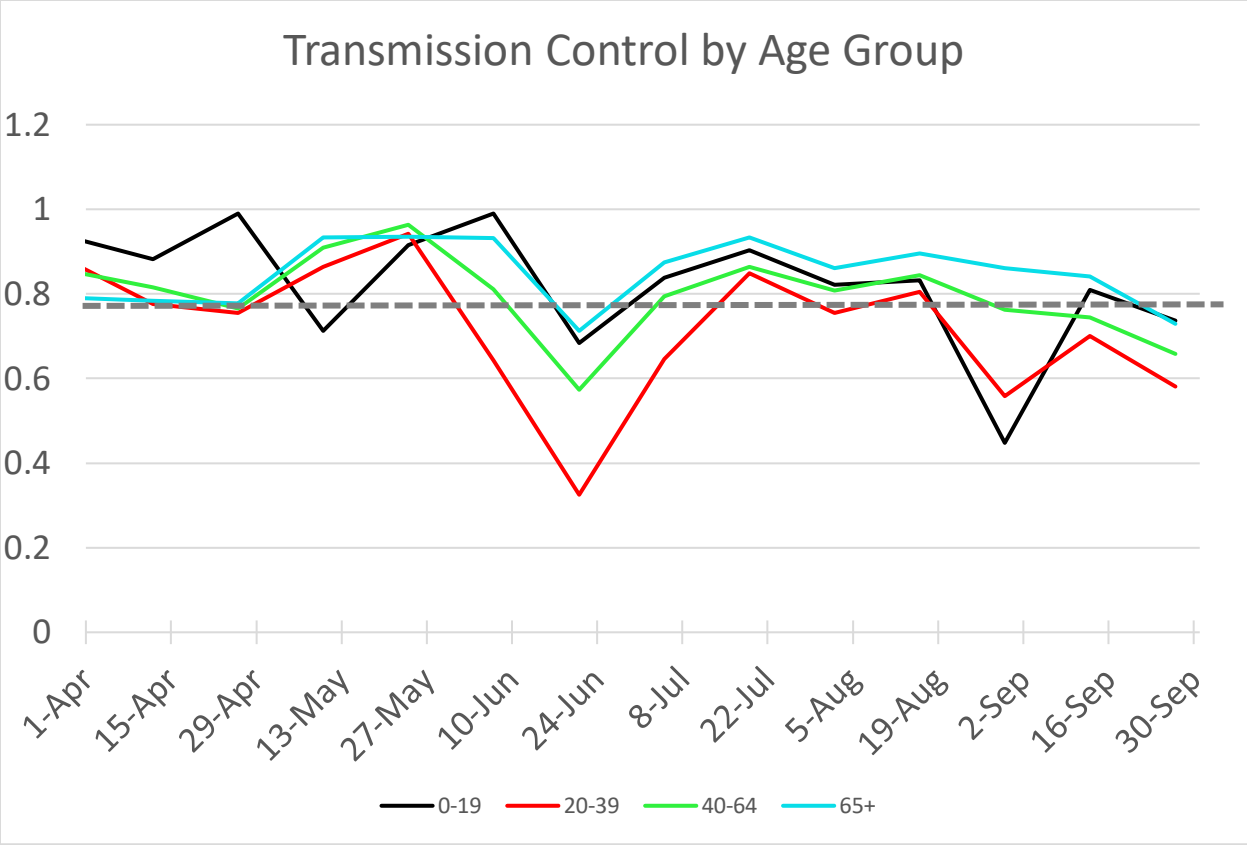


Figure 10. Estimates of transmission control by age plotted over time. Transmission control values are plotted at the time period for which they begin, as the last period for which transmission control is estimated is 9/28 – 10/06, the point on the graph is plotted at 09/28. Grey dashed line indicates threshold value of transmission control = 78%.

Scenario-based projections

Projections were generated to evaluate future cases, 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, TC values are altered from the current trajectory and increased or decreased on 10/16 (Figure 11 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 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.

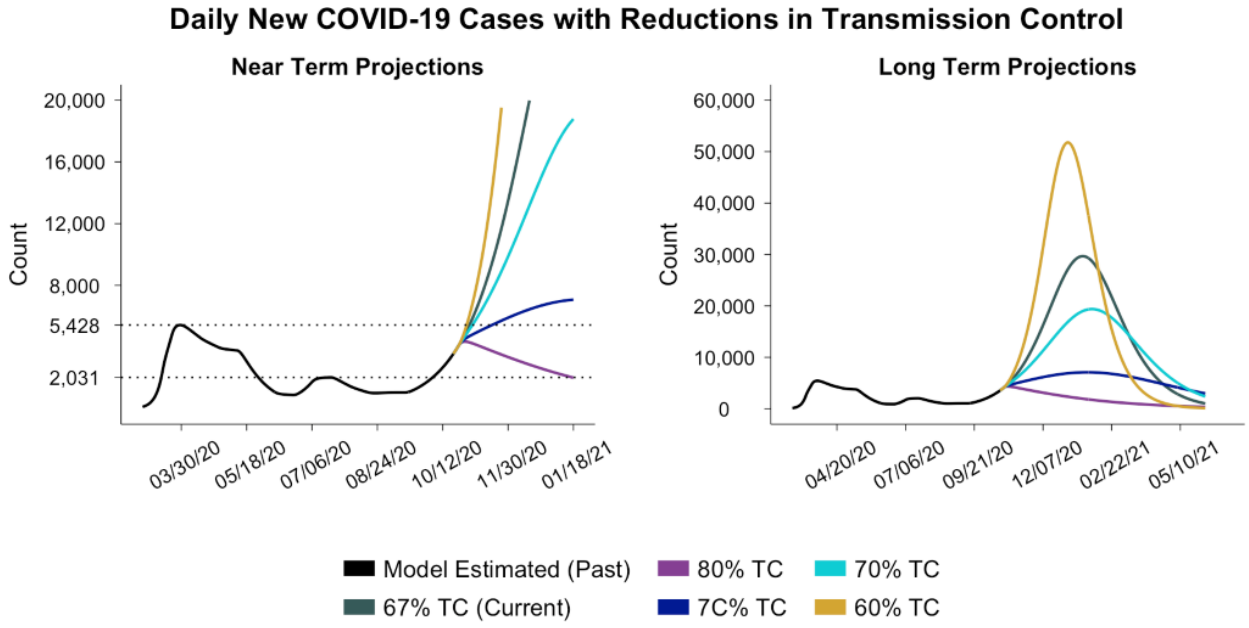
	Date ICU Capacity Reached*	Date of ICU Peak	ICU Need at Peak**	Cumulative cases through 12/31/2020**	Cumulative deaths through 12/31/2020**
Projection set 1: Changes to the current trajectory ¶					
Current trajectory (9/28 – 10/06, TC = 67%)	N/A	01/28/2021	1,500	1,830,000	6,400
TC = 80%	N/A	past	past	810,000	3,500
TC = 75%	N/A	2/03/2021	360	103,000	4,200
TC = 70%	N/A	2/08/2021	960	1,430,000	5,300
TC = 60%	12/20/2020	1/11/2021	2,500	2,920,000	10,700
Projection set 2. Increased contacts over the holidays Holiday scenarios (10% decrease over holidays)**					
Baseline TC = 60%	12/14/2021	1/07/2021	3,200	3,504,000	14,000
Baseline TC = 67%	1/01/2021	1/15/2021	2,200	2,370,000	7,800
Baseline TC = 75%	N/A	1/20/2021	810	1,290,000	4,800
Baseline TC = 80%	N/A	past	past	943,000	3,800

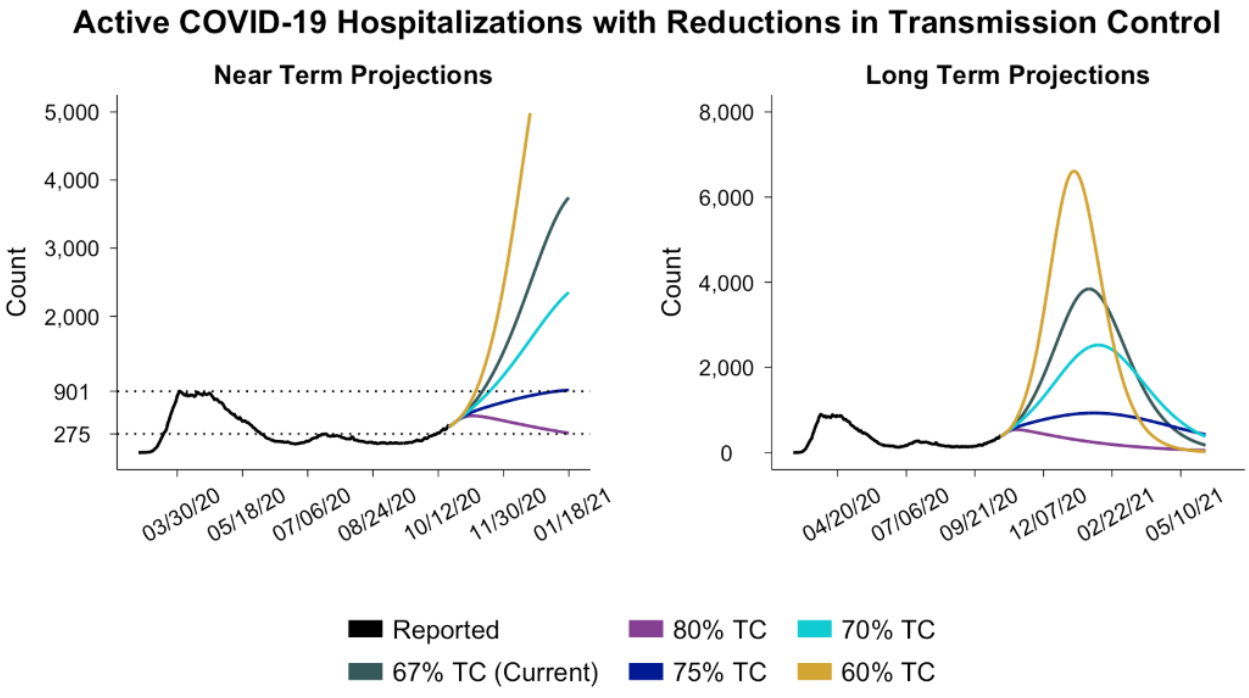
*ICU capacity for COVID-19 patients is estimated to be 1800 in Colorado, a figure provided by the Colorado Department of Public Health and the Environment.

**Estimates are rounded to two significant figures.

¶ Intervention are modeled assuming TC levels remain at the current estimated level until 10/23, 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 10/23 and then switch to indicated value at 10/23. 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.





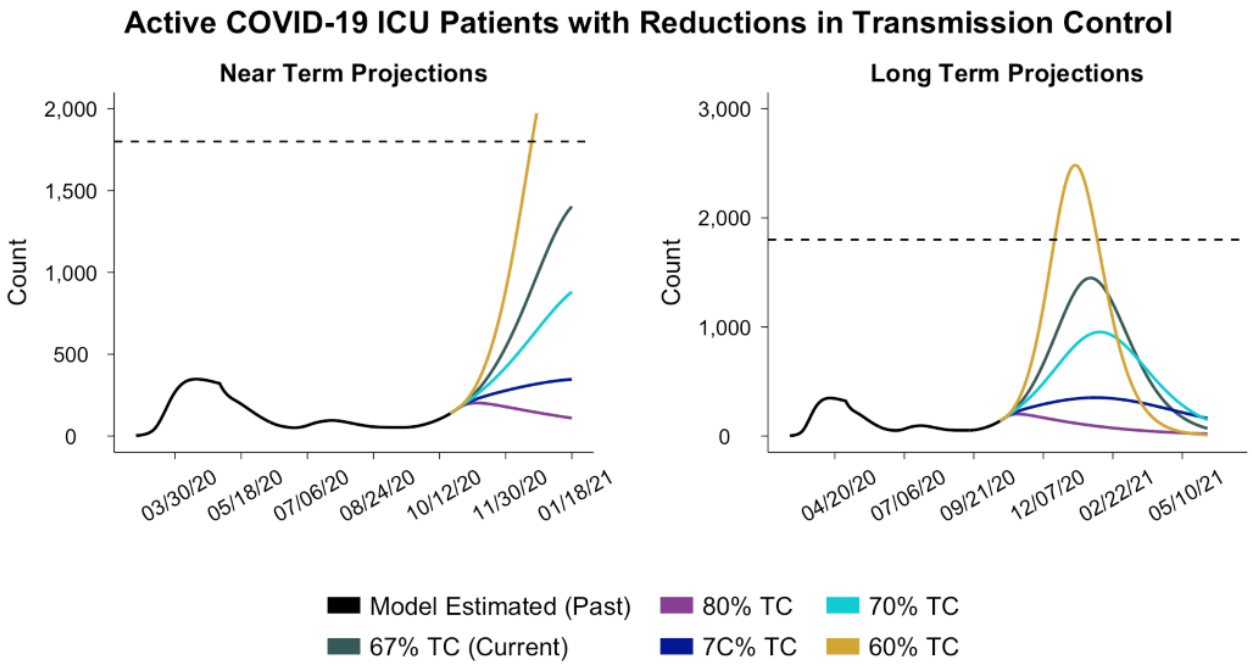


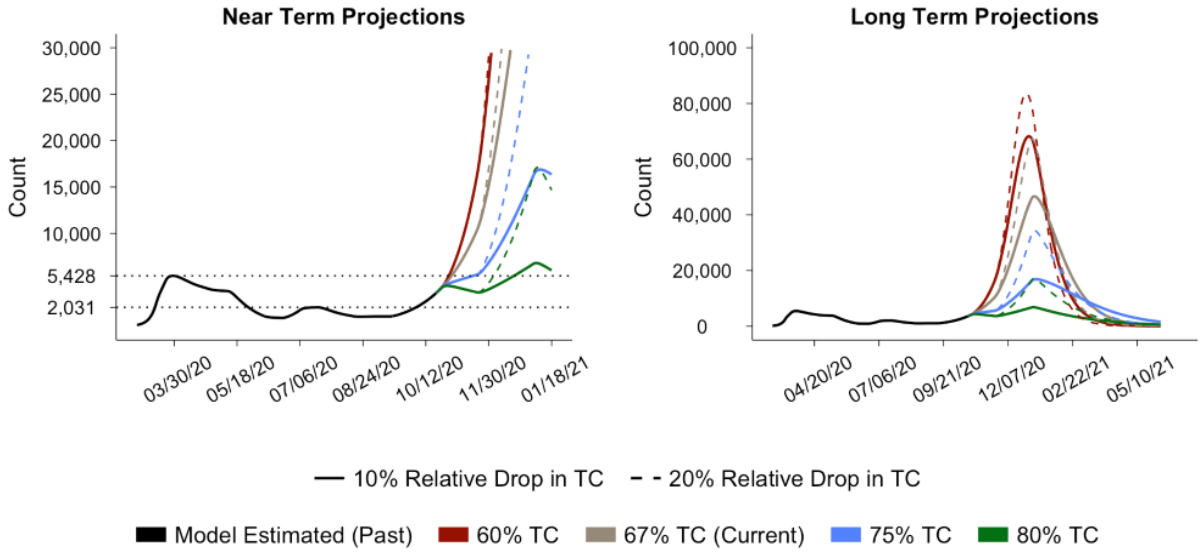
Figure 11. Projected daily count of new infections (top), hospitalizations (middle) and ICU need (bottom) varying levels of transmission control, assuming TC remains at current levels (67%), or switches to 80, 75, 70, or 60% on 10/23. Dotted lines on the new infections plot indicate the number of new infections estimated during the April and July peaks. Dotted lines on the ICU need plot indicate estimate ICU capacity = 1,800.

Projection set 2. Decreases in TC levels during the holiday season

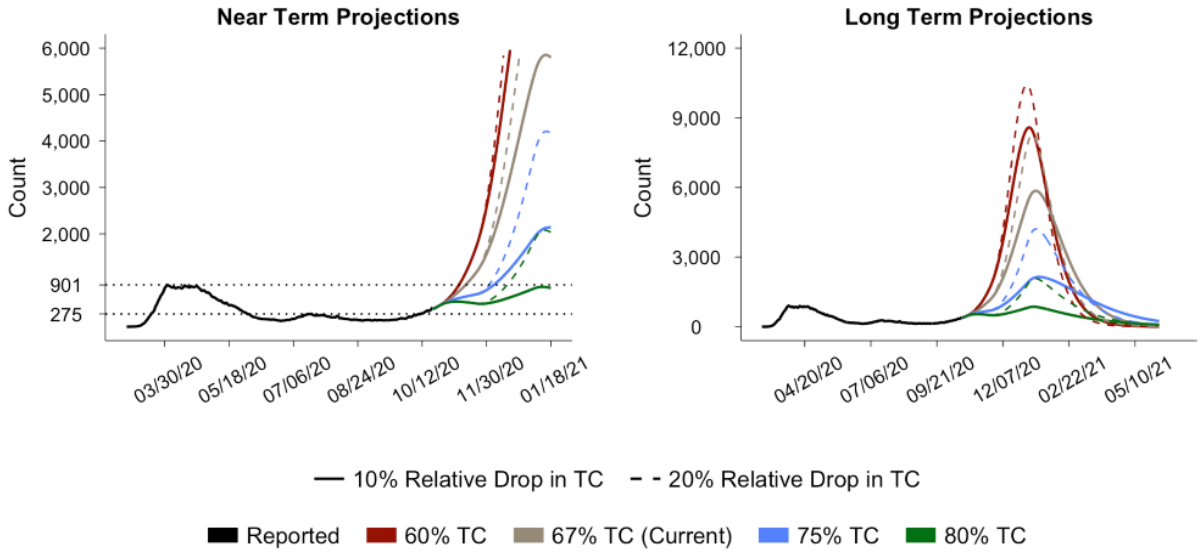
Given the recent rise in cases around the Independence Day (TC = 60%) and Labor Day holidays, we generated preliminary scenarios to evaluate the potential impact of theoretical increased social contacts over winter holidays. These scenarios assume contact rates increase starting the Friday before Thanksgiving, 11/20/2020, and lasts 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 in which transmission control levels increase to 75% or 80%, stay the same (66%) or when TC levels are decreased to 65%, or 60% on 10/23. 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 12 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



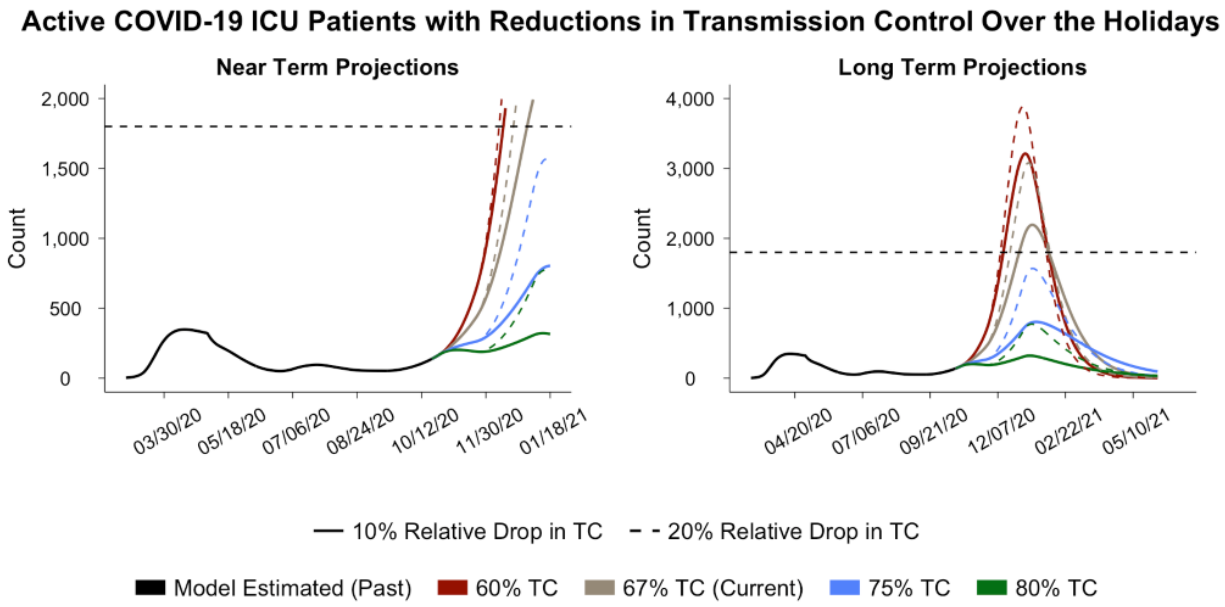


Figure 12. Projected daily count of new infections (top), hospital demand (middle), and intensive care (ICU) demand (bottom) in the near term (left) and long term (right), with a 10% relative decrease in TC levels over the winter holidays shown in solid lines and a 20% relative decrease in transmission control levels over the holidays shown in dotted lines. Model assumes TC level remains at ~ current levels (67%), or switches to 80, 75, or 60% on 10/23. Decreases in TC 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 within Colorado, with some regions (South Central, East Central, Central, Northeast) seeing marked increases in hospitalizations and high reproductive numbers (Figure 14), while other regions (West Central Partnership, San Luis Valley, Northwest) are stable or declining.

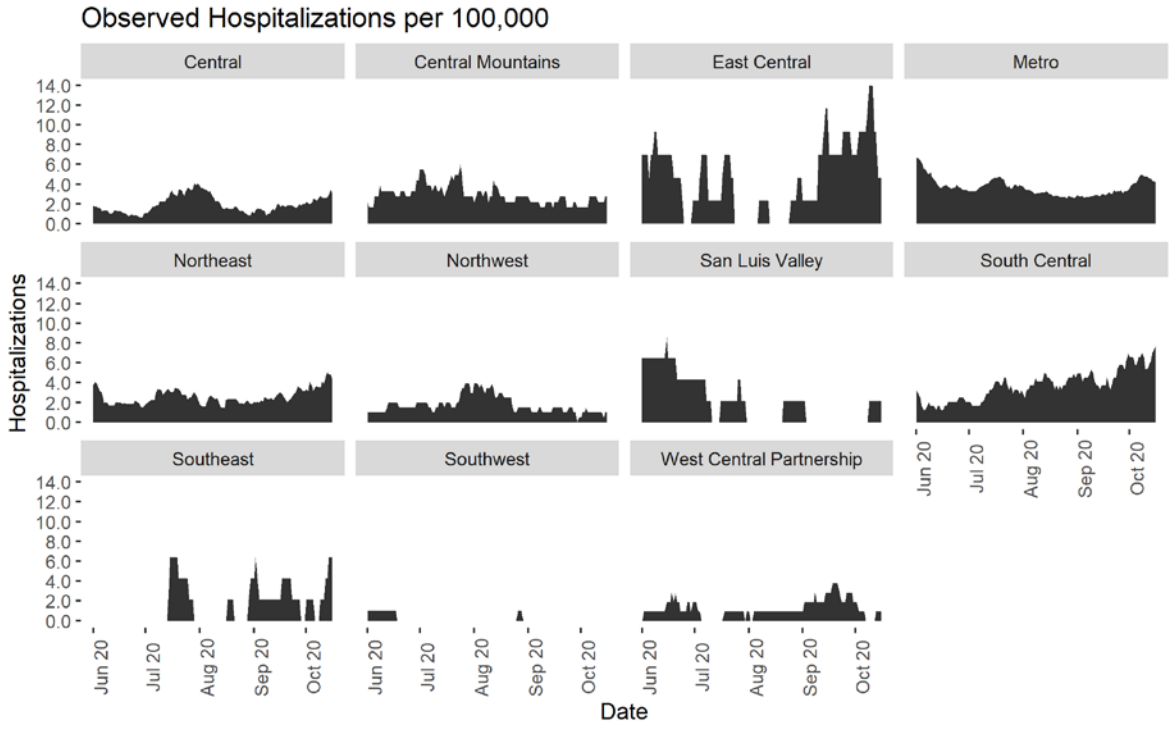


Figure 13. Observed hospitalizations per capita for the 11 LPHA regions in Colorado. Data from COPHS hospital census data up to 10/16/2020. Hospitalizations standardized by population estimates from US Census 2020 projections. Hospitalizations since June 1st, 2020 shown. Note that hospitalizations in the past two weeks may be under-reports of true hospitalizations and underreporting may vary by region.

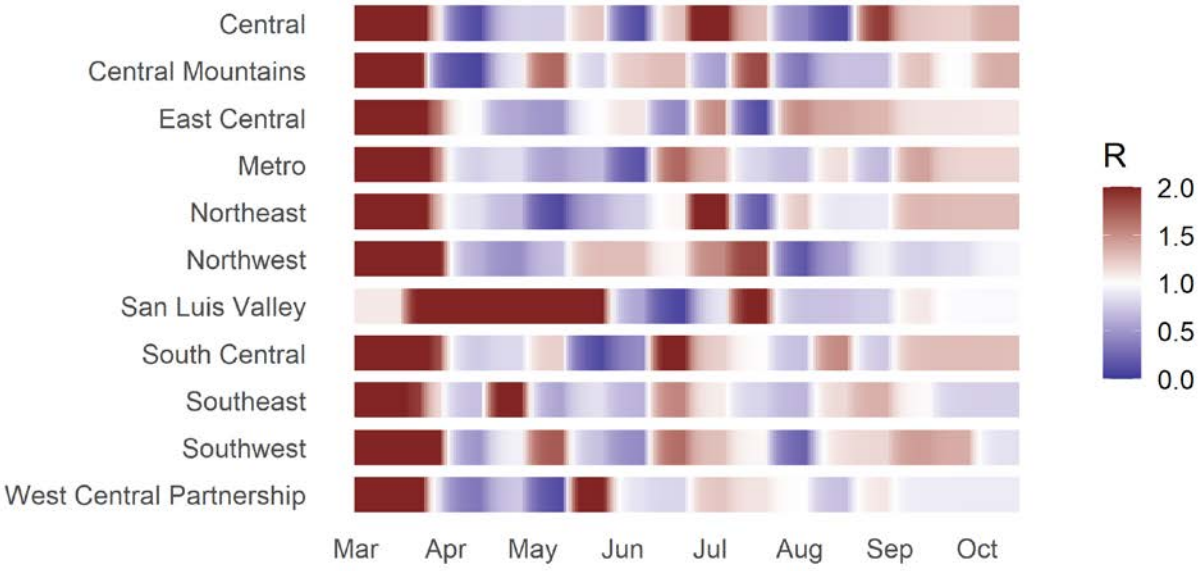


Figure 14. Estimated reproductive number for the 11 LPHA regions in Colorado using COVID-19 hospitalization data through October 8th and SARS-CoV-2 reported case data through October 6th.

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 TC 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 three weeks, 09/13 – 10/06	0-99%	67%	10/19
Estimated current transmission control level, 09/28 – 10/06	0-99%	67% (95% CI: 58%, 75%)	10/19
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 TC parameters are estimated weekly and averaged over time period of interest.
††The range of potential parameter values for the rate of infectiousness for symptomatic vs. asymptomatic individuals [1, 2] are based on the literature, and for the rate of infection, were obtained from the MIDAS Online COVID-19 compilation of parameter estimates [3].

References

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