The current state of COVID-19 in Colorado and projected course of the epidemic in the coming weeks

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Prepared by the Colorado COVID-19 Modeling Group
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Summary

- COVID-19 hospitalizations have been increasing since late June.
- The estimated effective reproductive number has increased over the past two weeks and is now at the highest estimated value since late March. Social distancing has declined since May.
- Collectively, these data indicate that the trajectory of SARS-CoV-2 transmission in Colorado has changed over the past two months, from a curve of declining infections in May to a curve of increasing infections (Figure 3). Our most recent model results suggest the rate of increase has changed from slow growth to a more rapid increase in cases. There is still uncertainty about the rate of increase. The estimates will be more certain as we track the rate of increase over the next week.
- If Colorado remains on the current estimated trajectory, we expect to exceed intensive care unit (ICU) capacity in early September. If social distancing continues to decline, we could exceed hospital capacity in late August. Under these scenarios, without additional interventions or changes in social distancing, demand could greatly exceed hospital capacity.
- If social distancing is increased or other interventions to reduce transmission are implemented, the projected growth in infections and hospital demand is slower and, depending on the efficacy of these interventions, ICU capacity is reached in the fall or not at all.

Current state of COVID-19 in Colorado

As before, 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 reduce the spread of the SARS-CoV-2 virus. Modeling methods are detailed here, (see documentation tab). These estimates are based on hospitalization data through 7/14/2020.

Figure 1 shows COVID-19 hospitalizations (black bars) and the green line shows the current model fit to the data. COVID-19 hospitalizations have increased, and this is reflected in the estimated effective reproductive number. The effective reproductive number is above 1, indicating a growth in infections (Table 1). The reproductive number increased over the past two weeks and is now at the highest estimated value since late March (Figure 2). Table 1 provides estimates we generated using two

different methods. Both estimates are well above 1 and higher than our estimates from last week. 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). These estimates are lower, but above 1.
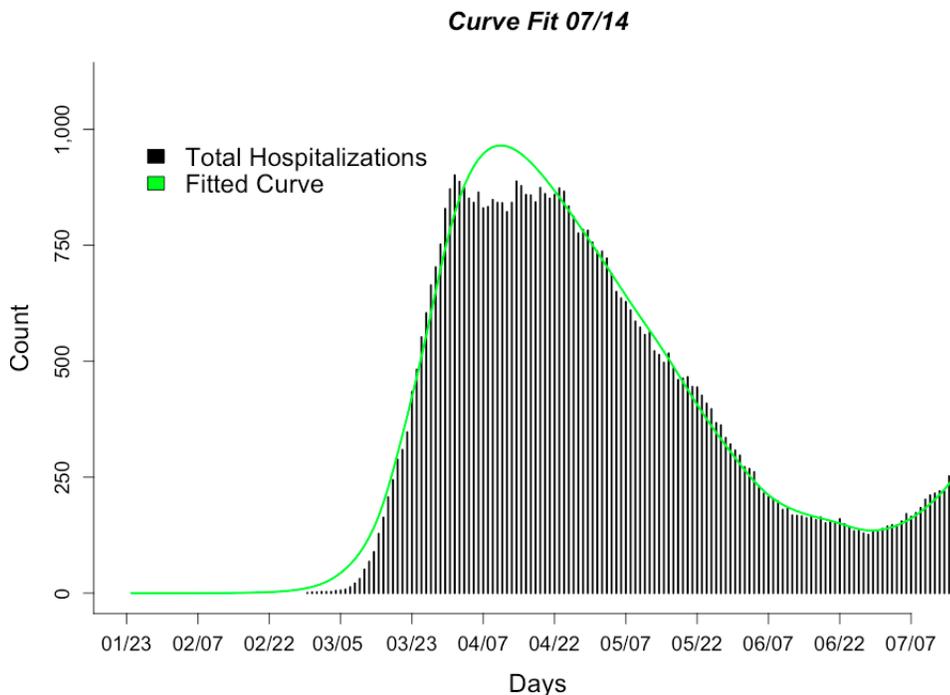
Figure 1. Current model fit (green line) to count of hospitalized COVID-19 cases (black lines) using the age-structured SEIR model. Hospitalized COVID-19 cases are from CDPHE reported COVID-19 hospitalizations and EMResource (EMR) hospital census data provided by CDPHE.

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

	Current estimate		Estimates from last week	
	Estimate	Notes	Estimate	Notes
Our estimate of Re, approach 1*	1.78	Fit to data through 7/14/2020	1.26	Fit to data through 7/07/2020
Current of Re, approach 2*	1.61	Fit to data through 7/14/2020	1.37	Fit to data through 7/07/2020
Estimate from RT-Live	1.12	As of 7/14/2020	1.04	As of 7/07/2020
covid-19-projections.com	1.03	As of 7/14/2020	1.05	As of 7/07/2020

*Because of the 13-day lag between infection and hospitalization, on average, our current estimate reflects transmission up to approximately July 1, estimates from last week reflect transmission up to approximately June 24. Approach 1 uses model output to estimate the average number of new cases generated by existing cases, accounting for the latent period and duration of infectiousness. The second method uses the model structure to estimate the dominant eigenvalue for a matrix describing population flows across the model compartments.
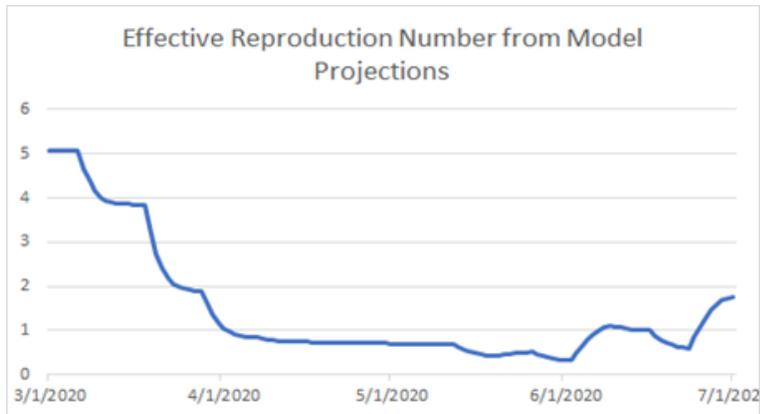
Figure 2. The effective reproductive number estimated from our model output, corresponding with approach 1 in Table 1.

Table 2 provides values for model parameters including social distancing estimated by the model from mid-March through the present. The social distancing parameters describe reductions in the contact rate a measure of how rapidly infections spread from person to person.

Social distancing has been declining since May, meaning the rate of contact between infectious and susceptible individuals is increasing. We estimate that social distancing was approximately 87% in May, after the whole state transitioned to Safer at Home (5/9 to 5/26), and then dropped to 66% in June (5/27 to 7/1). Our most recent estimate of social distancing, for the period 6/21 to 7/1, is 41%. This indicates social distancing has declined over the month of June. We note that due to the approximately 13-day lag between infection and hospitalization, we are currently able to estimate social distancing through late June. Hence, the model results do not reflect the closure of bars on 7/1 or gatherings and travel related to the July 4th holiday.

Collectively, these data indicate that the trajectory of SARS-CoV-2 transmission in Colorado has changed over the past two months, from a path of declining infections in May to a path of increasing infections now (Figure 3). Our most recent model fit suggests the rate of increase has changed from slow growth to a more rapid increase in cases. We discuss the implications of this for hospital capacity in the next section.
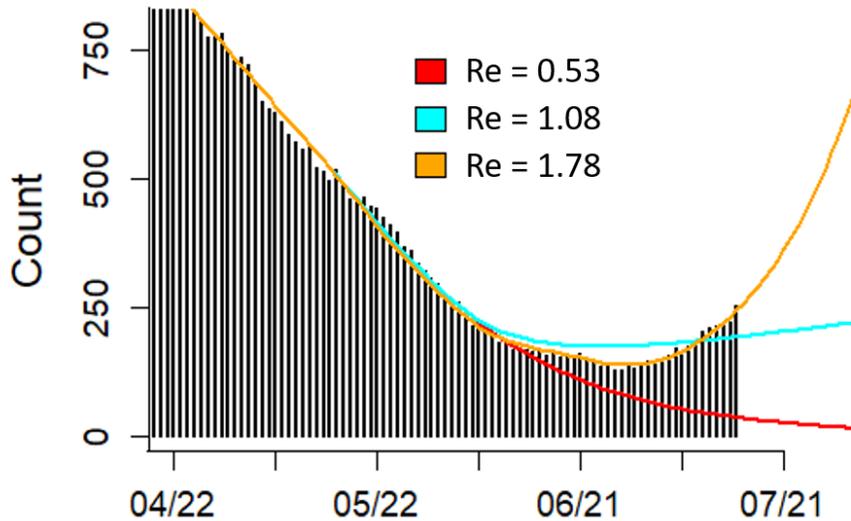
Figure 3. The projected trajectory of the COVID-19 hospitalizations if Colorado social distancing levels remained at levels seen in May after the full state transition to Safer at Home (5/9-5/26, 89%, red line), in June (5/27 - 7/1, 66%, blue line), or at present estimated levels (6/21-7/1, 41%, yellow line).

Table 2. Estimated model parameters based on fitting our model output of total hospitalizations to reported hospitalizations in Colorado.

	Range of possible values	Fitted value	Fit using data through
Social distancing*			
Phase 1. Estimated social distancing from mid-March until the start of the stay at home order, modeled as 3/17 - 3/25	10 – 70%	50%	06/24
Phase 2. Estimated social distancing during the state-wide stay at home order, modeled as 3/26 to 4/26	50 – 99%	79%	06/24
Phase 3. Estimated social distancing during the transition to state-wide Safer at Home, modeled as 4/27 to 05/08†	50 – 99%	80%	06/24
Phase 4. Estimated social distancing during early state-wide Safer at Home, modeled as 05/09 to 05/26†	50-99%	87%	06/30
Phase 5. Estimated social distancing during Safer at Home as more businesses re-open, 5/27-present†	50-99%	66%	07/14
Estimated current social distancing level, after 6/21	50-99%	41%	07/14
Mask wearing			
Percent of individuals wearing masks, 4/4 to 4/27		50%	Assumed¶
Percent of individuals wearing masks, 4/27 to present		70%	Assumed¶
Case isolation			
Decrease in infectious - symptomatic contact rate due to self-isolation by symptomatic after March 5 (dividing by 0.57 gives proportion that self-isolate) **	0.1 - 0.8††	0.44	06/24
Case detection			
Proportion of cases detected over the last 14 days			
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

*The social distancing parameter estimates the percent decrease in effective contacts between susceptible and infectious individuals. This parameter accounts for social distancing policies intended to avoid contact altogether (e.g., through workplace and school closures) as well as policies and individual behaviors to reduce potential contact with the virus (e.g., maintaining at least 6 feet of distance between people outside of one's household, and handwashing).

†Social distancing estimated weekly and averaged over time period of interest.

¶Given the difficulty in disentangling the effect of mask wearing from social distancing in decreasing transmission, we cannot fit this parameter at this time. Survey data suggests current levels of mask wearing are approximately 70% [1].

**Self-isolation by symptomatic cases is assumed to occur 1 day after the onset of infectiousness and decrease the 67% of contacts that typically occur outside of the home. This parameter jointly accounts for the percent of symptomatic individuals that self-isolate and the imperfect decline in contacts. Dividing the value in the table by 0.57 gives the proportion of symptomatic individuals that self-isolate.

††The range of potential parameter values for case isolation [2] and 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 here.

What do we project for the coming months?

We used the age-structured SEIR model fit to the parameters described in Table 2 to project the expected number of total hospitalizations and need for critical care beds in the coming months. Projections are generated assuming we remain on the current trajectory set by the current level of social distancing, and also for a set of scenarios that model changes in social distancing starting in early July. All of these scenarios assume social distancing remains at the projected level indefinitely.

If Colorado remains on the current estimated trajectory, we expect to exceed ICU capacity for people with COVID-19 in early September (Figure 4 and Table 3). If social distancing declines below current values (to 30% or 35%), we could exceed ICU capacity in late August. Under these scenarios, without additional interventions or changes in social distancing, demand could greatly exceed hospital capacity.

If social distancing increased in recent weeks to 55% or 65%, growth is slower. Under the 55% social distancing scenario, ICU capacity is reached in November. This slow rate of growth may provide time for hospitals to prepare additional surge capacity. Under the 65% scenario, hospital capacity is not expected to be exceeded.

We will be monitoring hospitalizations closely in the days ahead to better assess the level of social distancing in early July and the implications for hospital demand in the months ahead. Additionally, we will be generating projections of the potential impact of transmission-reducing interventions implemented in the coming weeks. If policy changes are implemented in the days ahead, they may have immediate effects on the acquisition of new infections. However, it will take several weeks to see impacts on hospital demands as hospitalizations today are due, on average, to transmission events occurring two weeks prior.
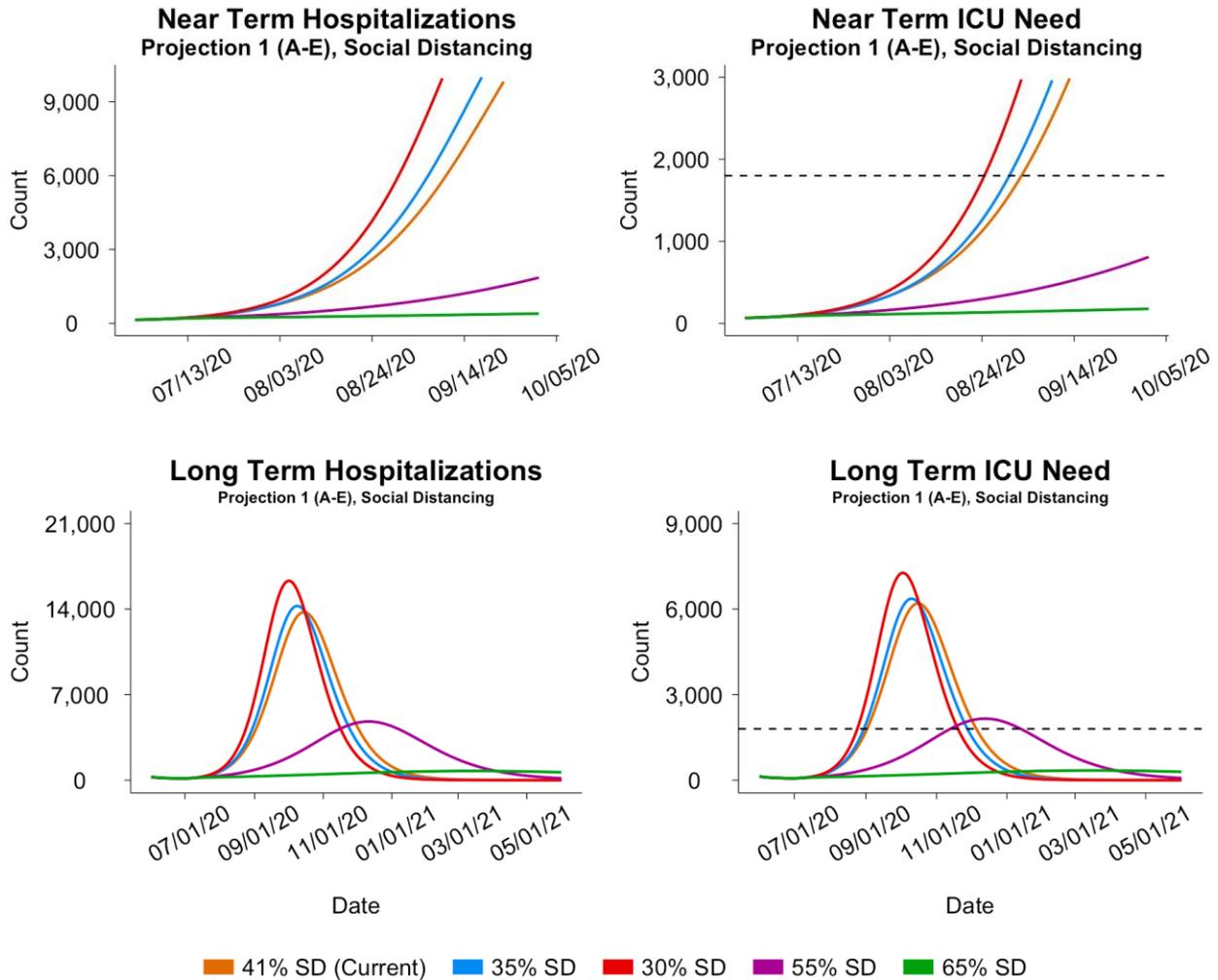
Figure 4. Projected hospital and intensive care (ICU) demand in the near term (top panel) and long-term (bottom panel) if we remain on our current estimated trajectory (orange line) and for four different social distancing scenarios. Based on CDC recommendations, in the 65%, 55%, 35% and 30% scenarios half of older adults are assumed to practice high levels of social distancing (80%). Mask wearing and case isolation are assumed to remain at current levels. In the 65%, 55%, 35% and 30% scenarios, current parameter estimates are used through 7/3, and social distancing is changed on 7/4 to the scenario values.

Table 3. Comparison of the projected date that ICU capacity is reached, the date ICU demand peaks and the estimated number of ICU beds needed at the peak, at the estimated current trajectory and scenarios at different levels of social distancing. Based on CDC recommendations, in the 65%, 55%, 35% and 30% scenarios half of older adults are assumed to practice high levels of social distancing (80%). Mask wearing and case isolation are assumed to remain at current levels.

	Date ICU Capacity Reached*	Date of ICU Peak	ICU Need at Peak**
Current trajectory (1A)	9/3/2020	10/16/2020	6,200
Social distancing at 35% (1B)	8/31/2020	10/10/2020	6,400
Social distancing at 30% (1C)	8/25/2020	10/3/2020	7,300
Social distancing at 55% (1D)	11/14/2020	12/12/2020	2,200
Social distancing at 65% (1E)	N/A	4/12/2020	430

*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.

Changes in the age-distribution of cases and hospitalizations over time

The number of reported SARS-CoV-2 infections in young adults (20-39 years) has increased over the month of June followed by an increase in infections in middle-aged adults (40-64 years) and there is a recent increase in reported infections in children (0-19 years) (Figure 5). Infections in older adults (age 65+) remain low relative to the other age groups. People under 40 comprise over half of recent reported SARS-CoV-2 infections.
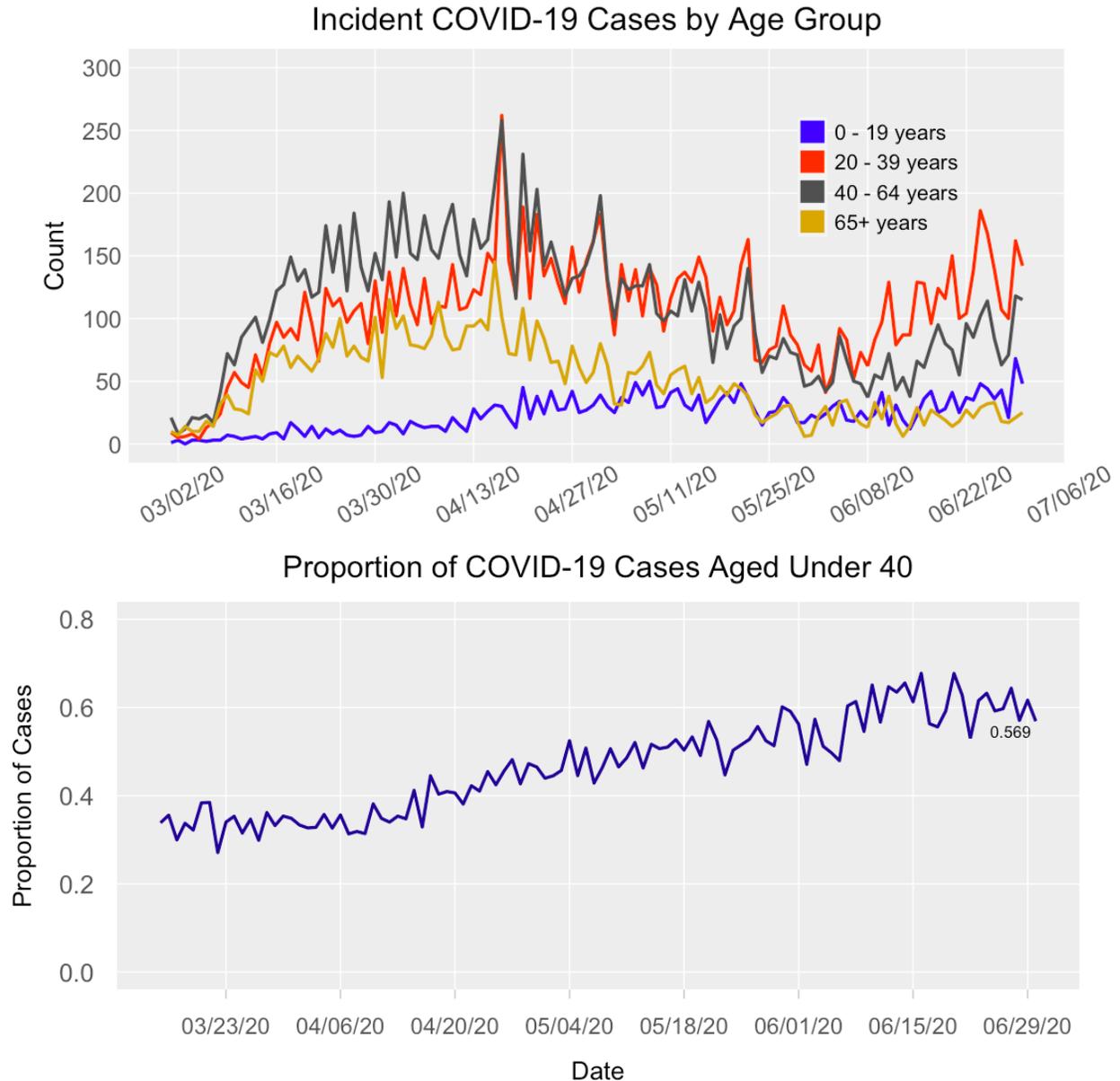
Figure 5. Distribution of reported SARS-CoV-2 cases by age group from CDPHE case report data from the March 2020 through two weeks prior to current day. Incident cases (top) and the proportion of all cases among individuals under 40 (bottom).

Over the past month, people under 40 have been accounting for a growing proportion of hospitalizations (Figure 6). In recent weeks, this trend has shifted as older populations are now accounting for a growing proportion of hospitalizations. This is not surprising given the recent increase in infections in people age 40-64. Currently, people under 40 account for approximately 25% of new hospitalizations.

Incident COVID-19 Hospitalizations by Age

Proportion of COVID-19 Hospitalizations Aged Under 40
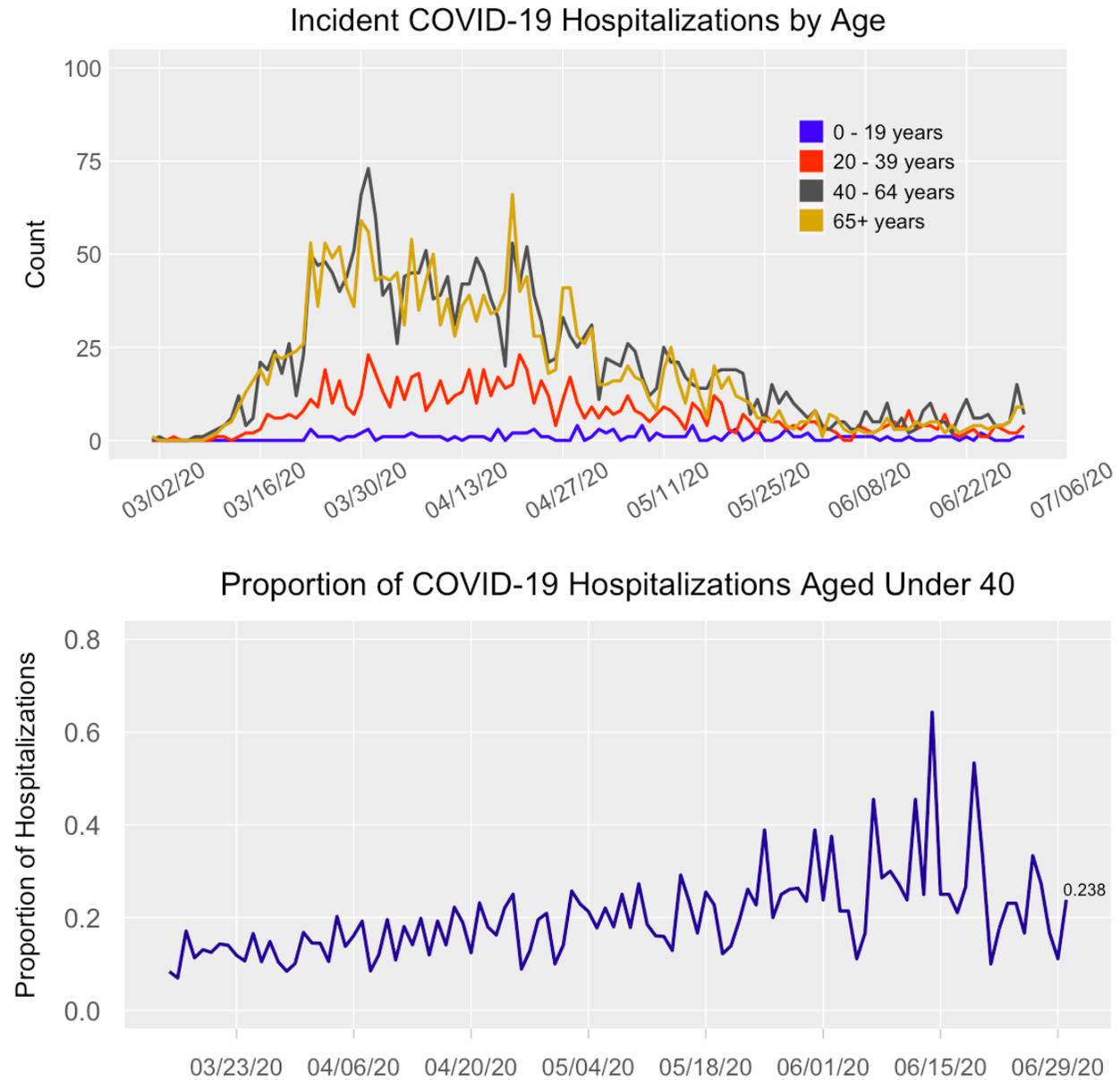
Figure 6. Distribution of new (incident) COVID-19 hospitalizations by age (top) and the proportion of hospitalizations occurring among individuals under 40 (bottom), based on CDPHE case data from March 2020 through two weeks prior to current day.

Proportion of infections detected

We use our model output of the total number of new infections per day, compared to reported SARS-CoV-2 cases in Colorado to estimate the proportion of infections reported to state surveillance systems.

We estimate the proportion of infections detected has increased from a low in early April, corresponding with the first peak in infections (Figure 7). We estimate that approximately 43% of infections were detected in past two weeks, including both asymptomatic and symptomatic infections.

Notably, there is a recent modest decline in the estimated proportion of infections detected. It is unclear if this is due to random variation or due to increasing transmission, changing time of delays in receiving test results, or another reason. We will be watching this closely in the coming weeks.
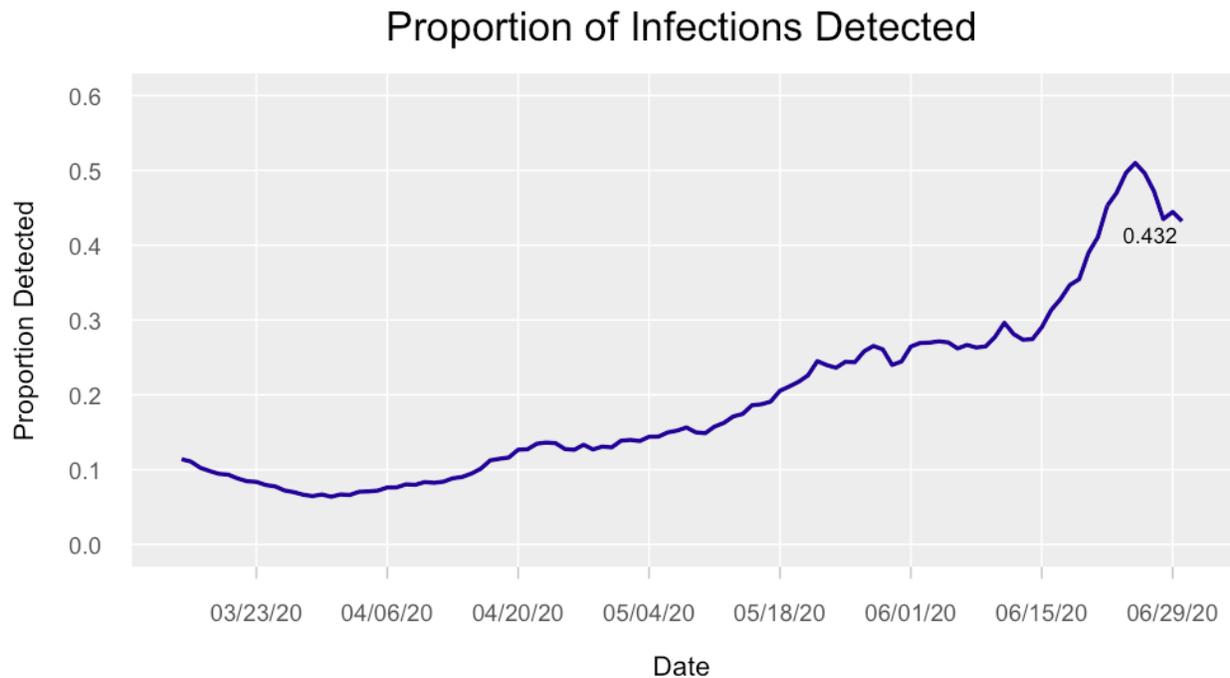
Figure 7. Estimated proportion of SARS-COV2 infections (including both asymptomatic and symptomatic infections) that are being captured by Colorado state surveillance systems, over time. The estimated daily number of new infections is based on SEIR model outputs. The number of cases captured by state surveillance systems is the number of cases reported by CDPHE, using the onset date of symptoms or, if this is not available, the date of report minus 7 days based on typical lags.

Discussion

The above information collectively indicates a distinct change in the course of the SARS-CoV-2 epidemic in Colorado in recent weeks. Hospitalizations are increasing and it appears, if we continue on the current trajectory, we could exceed critical care capacity by early September. It is an open question as to what might explain this change and, importantly, whether we will remain on this trajectory. The course of the epidemic over the next week will provide greater certainty to the model results.

Here we evaluate four possible explanations for the recent shift. First, it is possible that the contact rate in Colorado has increased population-wide due to changes in policy, changes in risk-perception, and/or changes in behavior. Our estimates of the increase in the reproductive number and corresponding changes in social distancing indicate that there is now a growing number of contacts between infected and susceptible individuals leading to new infections.

Second, it is possible that younger populations increased their out-of-household contact rates and became infected at a higher rate than previously, and then spread infections to older populations through household or community contacts. This is supported by the increase in reported infections in people age 20-39 throughout the month of June and the more recent increase in infections and hospitalizations in people over 40. The reported infection data show that infections in older adults (age 65+) thus far remain low, which is encouraging as older populations are more likely to have severe symptoms and die from COVID-19. This should be monitored closely in the weeks ahead. We are evaluating modeling approaches that will allow us to better account for historical age differences in social distancing.

Third, it is possible that some of Colorado's out of state visitors arrive in the state infectious, and may transmit the virus during contact with Colorado residents (Figure 8). Indeed, many visitors to the state come from counties currently experiencing surges in infection rates. These potentially infectious visitors are not counted in the modeled population, and effectively increase the rate of transmission.

Lastly, it is possible that the recent uptick in hospitalizations is due to random chance. Our projections are sensitive to what has happened in the last few weeks and our current estimate of social distancing spans a 10-day window. There is far less statistical noise in the daily COVID-19 hospitalization census compared to case counts (see Figure 1 vs. Figure 5), but there is day to day variability which may be impacting our estimates. Given that the estimated change in social distancing is so large, random variation is unlikely to fully explain the recent change in the estimated trajectory.

Given the implications of our current projections, we will monitor the data closely and re-fit again in the coming days in order to assess whether Colorado's epidemic will remain on the current trajectory.

Figure 8. Out of state visits to Denver County on July 11, 2020. Thicker import lines indicate greater number of visits. Color of the import lines indicates the estimated incidence of infection in the location of origin based on data from the New York Times [5].

Additional Resources

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.

References

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5.   https://github.com/nytimes/covid-19-data.