

Findings on the COVID-19 epidemic in Colorado to date and projections for future scenarios of social distancing

Prepared by the COVID-19 Modeling Group

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Introduction

This is one of a series of reports providing updated estimates of the course of the COVID-19 pandemic in Colorado and projections of the COVID-19 in Colorado for a range of scenarios. Previously, we have provided a description of the model that is being used, along with projections of the course of the epidemic under various social distancing scenarios ([April 6, 2020 COVID-19 Modeling Report](#)). Over time, the model has been refit to the accumulating data to gauge the effectiveness of the interventions taken to increase social distancing.

This report provides in part 1 an updated estimate of the degree of social distancing that has been achieved; that estimate is key to predicting the immediate course of the epidemic in Colorado and to determining the baseline of suppression from which any relaxation of distancing measures would take place. In part 2, the report provides projections of the future course of the epidemic under a range of scenarios including relaxing of social distancing, mask wearing, improved case detection and containment, and recommendations that high-risk populations maintain high levels of social distancing. Since the prior report, the Governor has broadened requirements for use of masks and they are being used widely by the public. This report also addresses the potential efficacy of masks.

Part 1. The Current Status of the COVID-19 Epidemic in Colorado

Summary/Key Findings

- Measures taken to date, including those taken on March 17 and March 26, have slowed the COVID-19 epidemic in Colorado and there is indication of a downturn indicative that the curve is “bending.” Assuming social distancing is maintained at current levels, we expect to see declines in hospital demand in coming days.
- Social distancing in mid-March reduced population mixing (“the contact rate”) by an estimated 65% with a further reduction to at least 75% following the March 26 stay-at-home order.
- If these successful interventions are continued, it is likely that most Coloradans remain susceptible to infection (i.e., uninfected) with the SARS-CoV-2 virus.

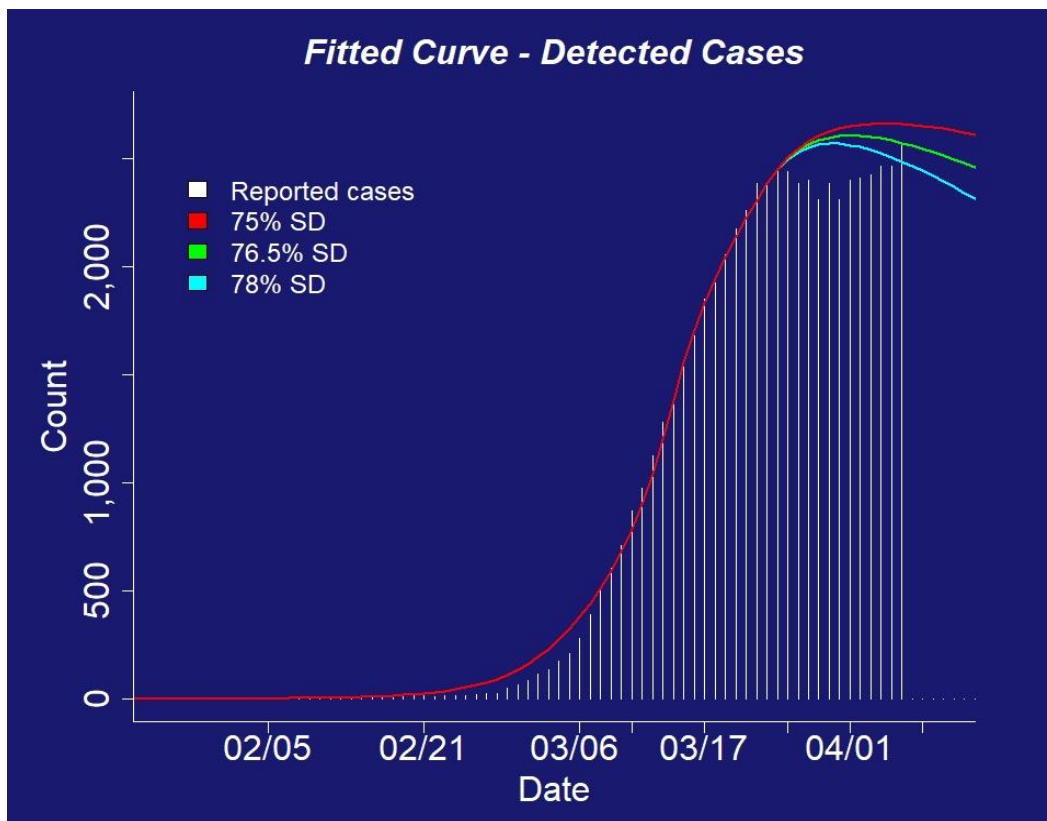
Introduction

To gauge the effectiveness of the social distancing measures implemented on March 17 and further augmented on March 26, the model is fit to the updated daily case counts to estimate the degree of social distancing. The model produces an estimate of the degree of social distancing achieved. The model and the underlying assumptions are as before (See Methods Appendix). The effectiveness of social distancing is modeled as a percent reduction in contact rates, a key driver of the spread of infections between susceptible and infected individuals. For example, “45% social distancing” is modeled as a 45% reduction in the contact rate from its starting point prior to any interventions. The case counts and the model findings show that following the March 26 state-wide stay at home order has greatly slowed the rise of the epidemic curve (Figure 1). The figure shows how the case counts rose and have now flattened, reflecting effective social distancing in the range of 75-80 percent.

Results

We estimate that the social distancing interventions implemented as of March 26 have led to an approximately 75% to 78% reduction in the contact rate based on reported case data through April 16th (Figure 1). This should be viewed as the collective impact of all social distancing measures that were in place as of March 26 – including both the statewide stay at home order and prior interventions. Public awareness and concern about COVID-19 during this period may have also contributed to the observed reduction in contact rates. These results suggest the number of cases for the current wave of infections has peaked (see Results in Context, below) and will decline with the continuation of social distancing at current levels.

Figure 1. Reported cases of COVID-19 in Colorado, shown by symptom onset date, and the estimated number of reported cases under social distancing that reduced the contact rate by 75% (red line), 76.5% (green line) and 78% (blue line).



We also update our prior estimate of the effectiveness of the first wave of social distancing interventions, estimating an approximately 65% reduction in the contact rate among people (Table 1). We note that this is a larger reduction than estimated previously using reported COVID-19 data through March 31 ([April 6, 2020 COVID-19 Modeling Report](#)). In our model, we assigned the first wave of interventions to a single start date of March 17. In reality, these interventions were implemented over a longer period, corresponding with a general rise in awareness and concern about COVID-19 with associated changes in behavior, and the closure of a number of retail establishments and educational institutions. For this reason, we think the most important estimate with regard to the current trajectory

of the COVID-19 epidemic in Colorado is the estimated collective effectiveness of social distancing from March 26 forward.

Table 1. Model parameters estimated by fitting our model to Colorado COVID-19 surveillance data through April 16. Additional parameter estimates provided in the Methods Appendix.

	Range of possible values and sources	Fitted value
Estimated effectiveness of social distancing		
Effectiveness of social distancing interventions implemented in mid-March (modeled with a start date of March 17), assessed 3/17 - 3/25	0.1 - 0.7 (see text)	65%
Effectiveness of social distancing interventions implemented as of March 26	0.5 – 0.95	Best fit within the range of 75 – 78%

Results in context – Flattening vs. bending (or “squashing”) the curve

These findings set the context for considering the next steps with regard to social distancing. The goal of the measures taken has been as to “flatten” and “bend” the epidemic curve. “Flattening the curve” is intended to slow down the rate of infection, such that the peak occurs later and is lower than what would have happened without interventions. At higher levels of social distancing, we see something different from “flattening the curve.” In these scenarios, contact rates are greatly to such an extent that the growth rate of the epidemic falls, and cases begin to decline. In essence, the basic reproductive number, the number of new infections directly generated by an infected person, on average, is quickly reduced below 1. This current report suggests that the curve is, indeed, bending. This is good news for now, but this success means that we still have a large susceptible population, creating the potential for future peaks. Bending the curve buys us time, for example, allowing hospitals to increase bed and ventilator capacity for the later surge in cases. This means it is essential to develop a plan for the next phase of the COVID-19 epidemic that controls case numbers to protect public health and assure that the health care system is not overwhelmed in the future.

Part 2. Projected impacts of relaxing social distancing

Summary / Key findings

- Relaxing social distancing carries the risk of a second peak of infections that could potentially exceed current hospital capacity. The more social distancing is relaxed, the sooner we can expect a second peak to occur and hospital capacity approached and possibly exceeded. In addition, the more social distancing is relaxed, the greater the hospital demand at the peak.
- Mask wearing, improved case detection along with timely, effective case containment to prevent further spread of infections, and recommendations that high-risk populations maintain high levels of social distancing will further delay the next peak and reduce the hospital demand at the peak.

- In order to avoid exceeding hospital capacity, relatively high levels of social distancing of around 60% and a combination of complementary interventions will be needed.
- Relaxing social distancing to low levels (such that the contact rate approaches normal levels) now or in early June has the potential to lead us to a severe second wave of infections that exceeds hospital capacity, even if complementary interventions are implemented.
- Protecting vulnerable populations is critical, particularly those above age 60, who represent most of the deaths in Colorado. The need for critical care in this age group is a key driver of health care utilization but needed data on what is occurring in Colorado are lacking.

Introduction

Here, we examine the potential next phase of the COVID-19 epidemic in Colorado. Part 1 of this report indicates the trajectory of the epidemic is bending under aggressive social distancing measures. In this section, we consider the potential impacts of relaxing social distancing in the coming weeks and what additional measures might be taken to avoid a catastrophic second peak of infections. Policy measures intended to re-open businesses or other types of operation will result in an increase in contact rates with a potential to increase the spread of infections. Complementary interventions such as aggressive case detection and containment as well as mask wearing will help to reduce the spread of infections by infected individuals. Strong social distancing by high-risk groups has the potential to prevent infections in these groups, reducing hospital demand.

Specifically, we attempt to address the following priority issues as it relates to the next phase of COVID-19 in Colorado:

1. The projected impact of the degree of relaxation of social distancing at the end of the state-wide stay at home order.
2. The projected impact of complementary interventions including mask-wearing by the general public, efficient case detection and isolation, and recommendations that high-risk populations maintain high levels of social distancing, implemented in parallel with social distancing.
3. The projected impact of a phased reduction in social distancing such that social distancing is initially relaxed at the end of the stay at home order and further relaxed approximately 6 weeks later.

We focus on the projected number of hospitalizations and ICU beds need given the widespread desire to avoid a surge in demand that exceeds hospital capacity. Staying within hospital capacity allows each patient to be treated with dignity, reduces the potential for shortages in personal protective equipment and reduces the potential that health-care workers become infected with the virus. We assume ICU capacity will be 1800 beds in Colorado, accounting for increased ICU need as social distancing is relaxed and elective surgeries are resumed. We use the previously developed and described deterministic age-structured SEIR mathematical model of COVID-19 calibrated to Colorado COVID-19 data to generate projected numbers of hospitalizations and ICU need for a range of scenarios, detailed below. The methods are described in the Appendix.

Scenarios considered (details of each scenario are provided in the text, below)

Scenario A. Partially relax social distancing by the general public.

Scenario B. Partially relax social distancing by the general public plus advise older adults (age>60) to maintain high levels of social distancing.

Scenario C. Partially relax social distancing and promote mask wearing by the public

Scenario D. Partially relax social distancing and pursue aggressive case detection and containment.

Scenario E. Partially relax social distancing, promote mask wearing and pursue aggressive case detection/containment (scenarios A + C + D)

Scenario F. Partially relax social distancing, promote mask wearing, pursue aggressive case detection/containment and recommend older adults maintain high levels of social distancing (scenarios A + B + C + D)

The projected impact of degree of relaxation of social distancing without complementary interventions (Scenario A)

We first modeled relaxation of social distancing to levels ranging from a 35% to 65% reduction in the typical contact rate, assuming this occurred at the end of the stay at home order (starting on 4/27). We refer to these relaxation scenarios, implemented without any complementary interventions, as scenario A. These projections assume that social distancing is maintained at current levels through the end of the stay at home order (4/26).

Relaxing social distancing to low levels (35% or 45%) at the end of the stay at home order is projected to lead to a rapid spike in infections, with ICU capacity expected to be exceeded by late May or early June (Figure 2 and Table 2). At the peak, hospital capacity will be greatly exceeded under these scenarios – the ICU peak is estimated to be 10x capacity at the 35% social distancing scenario (Table 3).

Greater social distancing can lead to a smaller, later peak but ICU capacity is still expected to be exceeded (by late June in 55% social distancing, by late August at 65% social distancing).

Figure 2. Projected hospitalizations (left, including both ICU and non-ICU) and ICU need (right) under relaxed social distancing scenarios implemented on 4/27/20 without complementary interventions (Scenario A). Different colors indicate the different levels of social distancing for the general population.

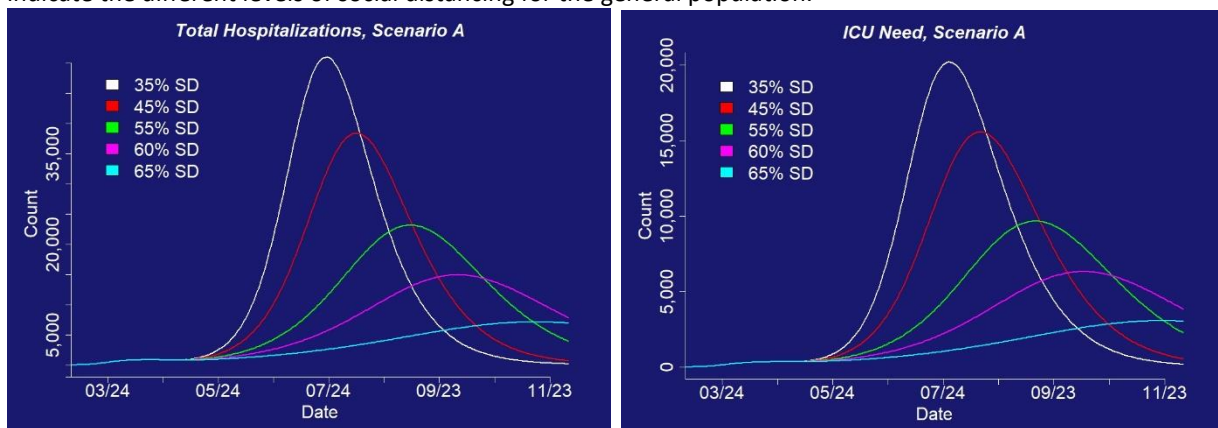


Table 2. Projected date that ICU capacity is reached in Colorado for a range of social distancing scenarios implemented 4/27. Model assumes current levels of social distancing are maintained until the new social

distancing is implemented. ICU capacity is estimated at 1,800 critical care beds. Scenario A considers social distancing by the general public, Scenario B considers the addition of strong recommendations that older adults, who are at highest risk of morbidity, adhere to high levels of social distancing.

	Scenario A	Scenario B
Scenario	Approximate date ICU threshold is reached	Approximate date ICU threshold is reached
Relax to 35% SD	05/29/2020	06/17/2020
Relax to 45% SD	06/06/2020	06/29/2020
Relax to 55% SD	06/21/2020	07/25/2020
Relax to 60% SD	07/09/2020	08/26/2020
Relax to 65% SD	08/26/2020	N/A*

*Capacity is not projected to be exceeded under 65% social distancing by the general public and current levels of social distancing maintained by older populations.

Table 3. Projected timing and magnitude of the peak number of infections and peak number of hospitalizations for an array of social distancing scenarios implemented on 4/27 and maintained indefinitely.

	Peak infections		Peak non-ICU hospitalizations		Peak ICU hospitalizations	
	Num*	Date	Num*	Date	Num*	Date
Scenario A – relax to 35% SD	151,000	07/10/2020	51,000	07/17/2020	20,200	07/21/2020
Scenario A – relax to 45% SD	111,000	07/26/2020	38,400	08/02/2020	15,600	08/07/2020
Scenario A – relax to 55% SD	65,600	08/24/2020	23,200	08/31/2020	9,670	09/06/2020
Scenario A – relax to 60% SD	41,800	09/18/2020	14,900	09/26/2020	6,330	10/02/2020
Scenario A – relax to 65% SD	19,800	10/30/2020	7,140	11/07/2020	3,070	11/13/2020

*Number of infections, non-ICU hospitalizations and ICU hospitalizations at the peak date indicated. Numbers are rounded to three significant figures.

***Peak and cumulative ICU hospitalizations is the estimated number of needed ICU beds. These may be in excess of capacity at peak times.

The projected impact of complementary interventions implemented in parallel with social distancing

Here we consider three additional intervention scenarios implemented concurrently with the relaxation of social distancing. For the purpose of these scenarios, we assume the current levels of social distancing are maintained through the currently scheduled end of the stay at home order (4/26). We assume each of the interventions described below are implemented in parallel with relaxation of social distancing corresponding with a 45%, 55% or 65% reduction in the typical contact rate.

Partially relax social distancing and advise older adults (age>60) to maintain high levels of social distancing (Scenario B). Older adults are most vulnerable to severe health impacts and death when infected with SARs-CoV-2. This scenario considers targeted messaging to encourage older adults (>60 years of age) to maintain current levels of social distancing (currently estimated at 76.5%). Whether older adults are willing and able to adhere to such high levels of social distancing for extended periods of time is unknown.

Partially relax social distancing and promote mask wearing by the public (Scenario C). There is evidence suggesting the use of cloth face masks by the public can reduce transmission by asymptomatic and pre-symptomatic individuals ([Tian et al](#) and [Howard et al](#)). The effectiveness of mask wearing depends on both the ability of the mask to trap viral particles and the proportion of the population wearing masks appropriately. We assume masks made from basic household materials are approximately 50% effective at trapping viral particles shed by infectious individuals and that masks are worn by 50% of the public based on the evidence from [Tian et al](#) and [Howard et al](#) cautioning that there remains considerable uncertainty about both of these assumptions. Given that approximately one third of an individual's contacts in normal circumstances are with household members, mask wearing outside the home is assumed to impact the approximately 67% of total contacts that are outside the home. Recognizing that some transmission may also be occurring via fomites (including via touching masks), we model the effectiveness of masks as a net 13% percent reduction in infectiousness by asymptomatic individuals. Additionally, we assume mask wearing reduces transmission by pre-symptomatic individuals (assuming an individual who ultimately becomes symptomatic is infectious for 8 days and asymptomatic for the first day – this is modeled as a 3.4% reduction in infectiousness for symptomatic individuals). This does not account for potential reduction in infectiousness by symptomatic individuals by wearing masks, as most are assumed to be isolated, but we note that this would result in an additional benefit of mask wearing ([Leung et al](#)).

Partially relax social distancing and pursue aggressive case detection and containment (Scenario D). Prompt detection of cases and containment of those individuals can reduce the spread of infections by symptomatic individuals. The effectiveness of this strategy depends both on the time between the onset of infectiousness and containment, as well as the percent of symptomatic cases detected and contained. We borrow the assumptions of others and assume cases are identified and contained within 48 hours of infectiousness. Based on Colorado's current estimated testing capacity, we assume 35% of symptomatic cases are detected as of 4/26, increasing by 5% per week to a maximum of 90% symptomatic case detection by July 12. Our current model fits indicate approximately 60% of symptomatic cases are isolating within 48 hours, indicating a number of people who likely have COVID-19 but have not been diagnosed are complying with isolation recommendations. We assume this level of isolation is maintained until testing capacity allows detection of greater than 60% of cases (estimated to occur approximately June 1), at which point the proportion of cases isolated increases with testing capacity. In reality, the proportion of symptomatic cases detected will likely also hinge on the total number of symptomatic cases –meeting (or even exceeding) testing capacity targets is more likely if the actual number of cases is low. This scenario does not address reductions in transmission that could be attained through contact tracing and isolation of case contacts.

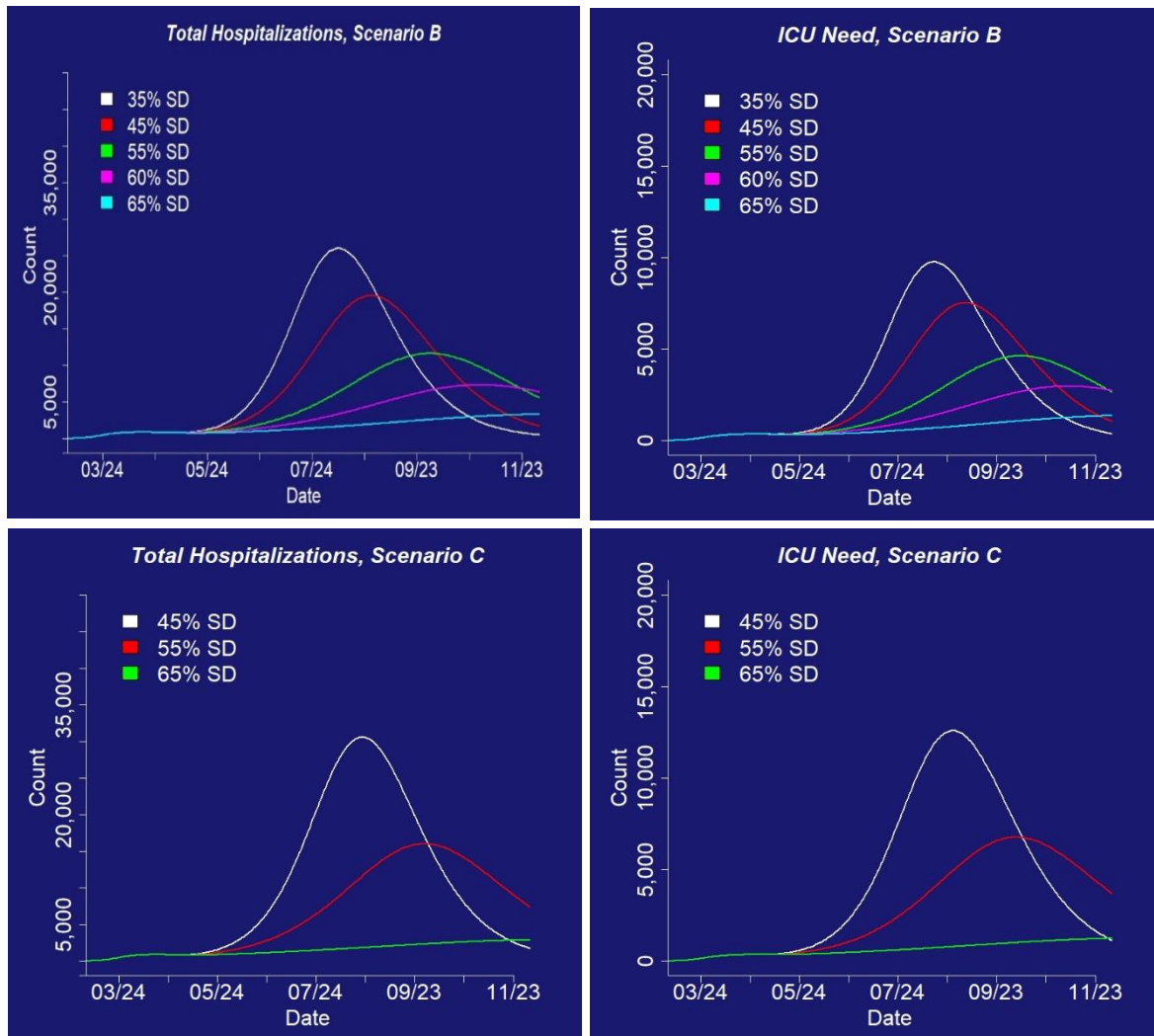
We also consider combinations of scenarios, as follows.

Partially relax social distancing, promote mask wearing and pursue aggressive case detection/containment (Scenario E). This scenario considers the combined impact of general social distancing plus mask wearing plus case detection and containment.

Partially relax social distancing, promote mask wearing, pursue aggressive case detection/containment and recommend older adults maintain high levels of social distancing (Scenario F). This scenario considers the added impact of older adults maintaining high levels of social

distancing, in addition to lower levels of social distancing by the general public, mask wearing and case detection and containment.

Figure 3. Projected hospitalizations (left, ICU and non-ICU combined) and ICU need (right) for complementary interventions including higher levels of social distancing for older adults (scenario B), mask wearing (scenario C), aggressive case detection and isolation (scenario D), and combinations of mask wearing plus aggressive case detection and isolation (scenario E), and all three interventions (scenario F) implemented along with under relaxed social distancing scenarios implemented on 4/27. Different colors indicate the different levels of social distancing for the general population.



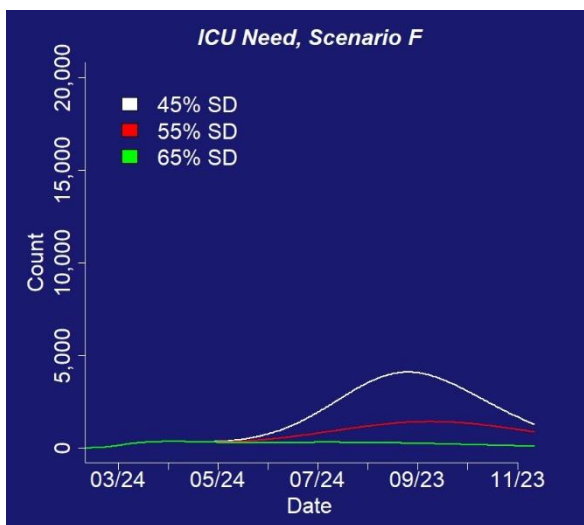
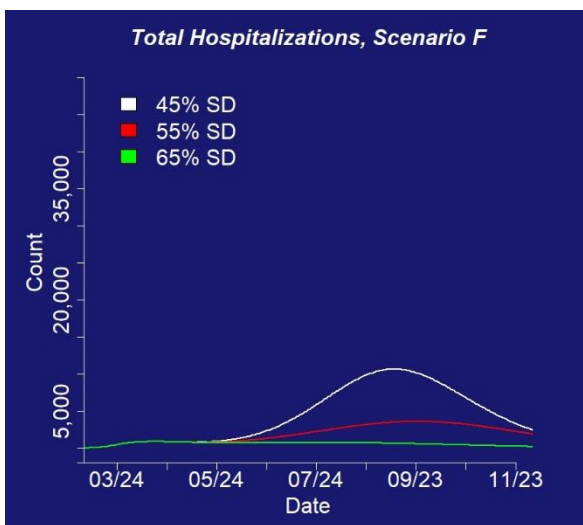
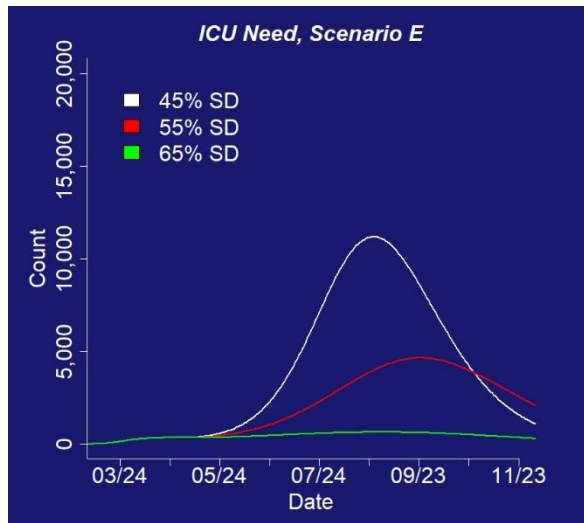
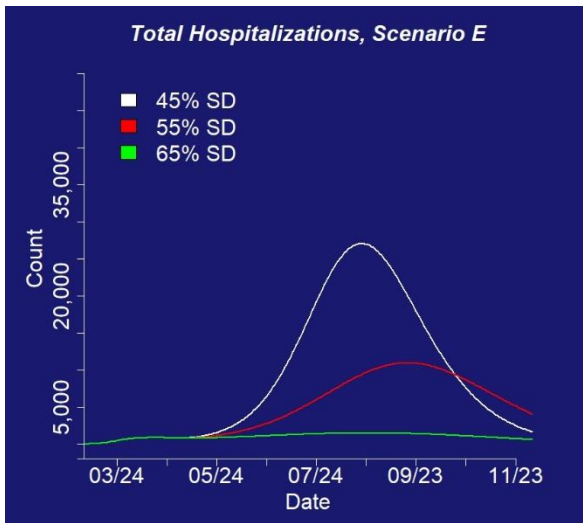
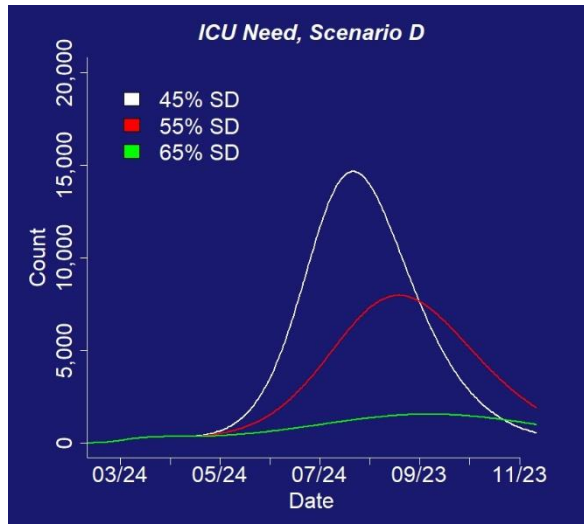
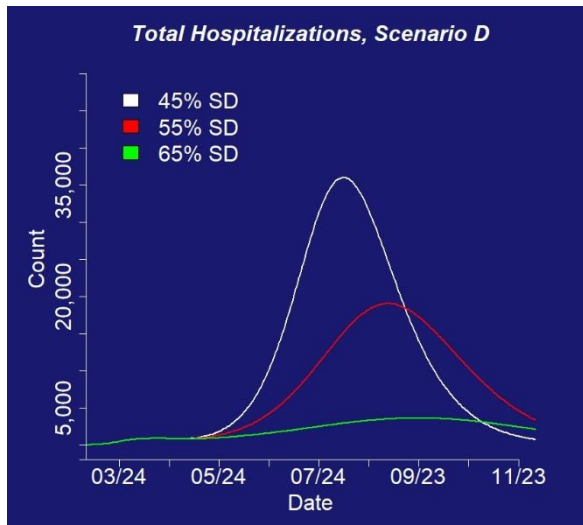


Table 4. Projected timing and magnitude of the peak number of ICU hospitalizations for complementary interventions including high levels of social distancing by high-risk groups (scenario B), mask wearing in public (scenario C), aggressive case detection and containment (scenario D), and implemented in combination with social distancing. All scenarios are implemented on 4/27 and maintained indefinitely. Scenarios B through F assume social distancing is also implemented such that contact rates are reduced by 45%, 55% or 65% of normal levels and thus can be viewed as addition to scenario A.

	Relax social distancing to 45%		Relax social distancing to 55%		Relax social distancing to 65%	
	Est. peak ICU need*	Est. date of ICU peak	Est. peak ICU need*	Est. date of ICU peak	Est. peak ICU need*	Est date of ICU peak
Scenario A: Partial relaxation of social distancing (reference)	15,600	08/07/2020	9,670	09/06/2020	3,070	11/13/2020
Complementary interventions						
Scenario B: Older adults maintain social distancing at current high levels	7,530	8/28/2020	4,630	10/01/2020	1,380	12/11/2020
Scenario C: Mask wearing by the public	12,600	08/20/2020	6,770	09/28/2020	1,270	12/21/2020
Scenario D: Improved case detection and isolation	14,700	08/07/2020	7,980	09/03/2020	1,560	09/22/2020
Combinations of complementary interventions						
Scenario E: Mask wearing, and improved case detection and containment	11,200	08/20/2020	4,650	09/17/2020	653	08/24/2020
Scenario F: Mask wearing, improved case detection and containment, and older adults maintain current high levels of social distancing	4,100	09/10/2020	1,420	09/24/2020	355	04/21/2020

*Rounded to 3 significant figures.

Each of the complementary interventions, implemented in combination with relaxation of social distancing is projected to slow the growth of infections compared to partial relaxation of social distancing alone (Figure 3 and Table 4). The greatest impact is seen when these three complementary interventions are implemented jointly. Even when all three of these interventions are implemented in our models, the level of social distancing by the general public remains an important driver of the future epidemic. At 45% social distancing by the general public, hospital capacity is projected to be exceeded even when all three complementary interventions are implemented. In contrast, higher levels of social distancing by the general public (55% or 65%), coupled with these complementary interventions have the potential to avoid a severe second wave of infections that exceeds hospital capacity.

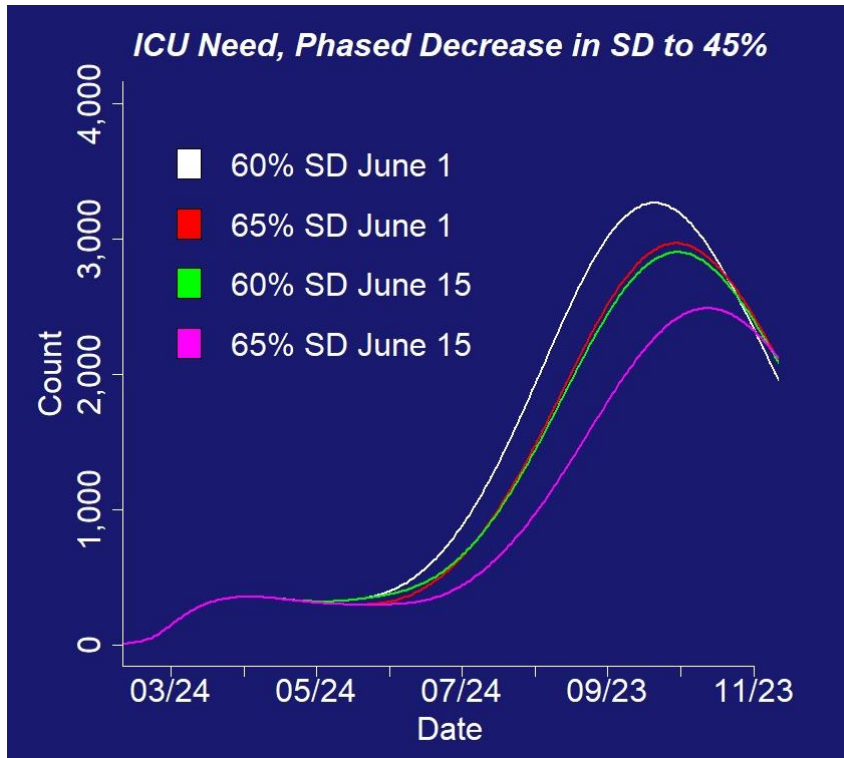
The projected impact of a phased reduction in social distancing.

Lastly, we consider the potential impact of a phased reduction in social distancing, implemented such that social distancing is lowered slightly to 60% or 65% (meaning the contact rate is reduced by 60% or 65% compared to normal levels) at the end of the stay at home order (4/27), and then further relaxed to 45% on June 1 or June 15. For this scenario, we assume all other complementary interventions are

implemented (higher social distancing by older populations, mask wearing, improved case detection and containment).

Modest relaxation of social distancing at the end of the stay at home order (e.g. a reduction of the contact rate to 60% or 65% of normal levels), along with the implementation of complementary interventions will avoid a rapid, catastrophic second wave of infections in May and June (Figure 4). However, further relaxation of social distancing to 45% (e.g. a reduction of the contact rate to 45% of normal levels) in early June has the potential to allow a catastrophic second peak of infections in the fall, even complementary interventions including mask wearing, case detection and isolation and higher levels of social distancing by older adults is maintained.

Figure 4. Projected ICU need for phased reduction in social distancing by the general public in combination with adoption of all three complementary interventions: high levels of social distancing by high-risk groups, mask wearing in public and improved case detection and isolation. Projections assume social distancing is relaxed to 60% or 65% at the end of the stay at home order and then stepped down to 45% on June 1 or June 15.



Interpretation and general comments

The model projections presented above are based on a model of Sars-CoV-2 that reflects our current understanding of this recently emerged pathogen. The modeled scenarios are just that – scenarios that we created to attempt to evaluate the potential impacts of an array of interventions that have been proposed in order to minimize the risk of a devastating second wave of COVID-19 while allowing a relaxation of the current high levels of social distancing. Below we discuss what we view to be the key considerations in interpreting these projections.

Translating social distancing to policy. For the purpose of this report, we model social distancing as a percent reduction in the contact rate (technically, the rate at which an infected individual contacts others in the population in ways relevant to transmission – e.g. close physical contact). There are large questions of how our measures of social distancing map to specific policies. Moreover, the contact rate is likely driven by a combination of policies, risk perception and social norms. In our models, we make the strong assumption that social distancing is maintained at current levels until the stay at home order is lifted. If people start to perceive a decrease in risk of COVID-19, it is possible that the current levels of social distancing will not be maintained in the coming week, which would slow the rate of decline of the epidemic. If cases start to plateau in the coming days, our projections could be overly optimistic in terms of the timing of the next peak.

Age and use of critical care. In estimating the need for critical care beds and ventilator utilization, we have incorporated figures from a paper by Verity et al., which draws on the experience in Hubei (Verity et al. 2020). The estimates for need for critical care beds rise sharply with age reaching 70 percent for those in the age category 80+. In Colorado, being placed into the critical care unit has largely coincided with a need for mechanical ventilation.

In developing the models and projecting need for ventilators, we have relied on the estimates from [Verity et al.](#), absent any data on Colorado. To date, we lack information on the demographic characteristics of those individuals needing either critical care or ventilator support. However, anecdotal information from colleagues at the University of Colorado Hospital suggest that in this institution, the majority of those receiving ventilator support are less than 60 years of age. If this is the case throughout the state, then the current model may be overestimating ventilator need to a substantial degree. Additionally, it is possible that comorbid conditions in younger populations may be driving ventilator need (e.g., [Petrilli et al.](#)). We will seek further data to better align the model to what is happening in Colorado.

Masks. In the projections provided in part 2 of this report, use of masks has been added to the model, as an increasingly applied strategy for control of contagion. Masks worn by the public can be protective of others by reducing exposure to the droplets propelled into the air by coughing and sneezing. Masks worn by health care professionals and others at high risk are also intended to protect against inhalation of the virus; N95 masks are needed for this purpose as they block inhalation of small infectious particles. There is still uncertainty as to whether the virus is present in both the larger particles (referred to as droplets) and the smaller particles (referred to as aerosols). Masks that would be generally worn by the public are effective to varying degrees (depending on materials and patterns of use) in reducing exposure to droplets.

Beyond the physical barrier that masks provide, they may also alter behavior by keeping wearers from touching their faces and they shift cultural norms around avoiding contact with others. Some have proposed that using masks may lead to a misconception that wearers are protected against infection. Overall, we view use of masks as a “no regrets” addition to the strategies that can be used to reduce the spread of infection.

Consequently, in this iteration of the model, we have incorporated use of masks into the model, following the approach of Tian et al. Conceptually, the effectiveness of masks depends on how many people use them and how well they work in actuality.

Methods Appendix

Methods for part 1.

We used an age-structured SEIR model described previously ([April 6, 2020 COVID-19 Modeling Report](#)) to estimate the impact of social distancing measures, implemented in March, on COVID-19 in Colorado.

Social distancing was modeled as a percent reduction in contact rates, a key driver of the spread of infections between susceptible and infected individuals. Social distancing was implemented in two phases in Colorado. In mid-March a number of social distancing measures were implemented in Colorado including local school closures (various dates), cancelation of large gatherings (3/13), and an executive order closing restaurants, bars, theaters and casinos in the state (3/17). On 3/26 a state-wide stay at home order was issued. We expected the first wave of social distancing, implemented in mid-March, to have a more modest impact on contact rates than the statewide stay at home order. For this reason, we modeled social distancing in two phases, defining one parameter to describe the effectiveness of social distancing from 3/17 to 3/25, and a second parameter describing the effectiveness of social distancing from 3/26 forward.

In order to estimate the impact of the social distancing measures, we fit the SEIR model to Colorado COVID-19 case reports through April 16 provided by CDPHE. Due to lags in reporting, making the most recent days unstable, we fit the model to case reports with an onset date of April 8th or earlier. For cases with missing onset date, we imputed onset date by taking the date of report and subtracting 7 days. Model fitting was used to re-estimate the effectiveness of the first and second wave of social distancing.

Additionally, we used model fitting to estimate parameter values which could be specific to Colorado (e.g., the probability that a symptomatic case is detected) and/or for which there is considerable uncertainty in the current literature (Table 1). To improve parameter stability, we fixed the start date of the outbreak (modeled as the importation of the first infection) on January 24.

Best-fitting parameter values were identified via a least squares cost function minimizing the comparison between the estimated proportion of expected cases that would be detected in the model and the number of confirmed COVID-19 cases in Colorado. The cost function was minimized using a two-stage fitting algorithm in R, first applying a pseudo-random optimization algorithm (Price, 1977) to find a region of minimum difference between the model and the data. The second phase used least squares optimization applying the Levenberg-Marquardt algorithm (More, 1978).

Appendix Table 1. Model parameters estimated by fitting our model to Colorado COVID-19 surveillance data through April 16.

	Range of possible values and sources	Fitted value
Estimated effectiveness of social distancing		
Effectiveness of social distancing interventions implemented in mid-March (modeled with a start date of March 17), assessed 3/17 - 3/25	0.1 - 0.7 (see text)	65%
Effectiveness of social distancing interventions implemented as of March 26	0.5 – 0.95	Best fit within the range of 75 – 78%
Other parameter values fit to the current model		
The rate of infection (beta)	0.2 - 0.6 (MIDAS*)	0.5
Proportion of symptomatic individuals that self-isolate after March 5 (sil)	0.3 - 0.8 (Ferguson et al)	0.47
Ratio of infectiousness for symptomatic vs. asymptomatic individuals (lambda)	1.0 - 4.0 (Li et al , Zou et al)	1.5
Probability symptomatic cases are identified by state surveillance (pID)	0.05 - 0.6 (MIDAS*)	0.33

*The range of potential parameter estimate values were obtained from the MIDAS Online COVID-19 compilation of parameter estimates available [here](#).

Methods for part 2.

We used the same age-structured SEIR model described above, with the fit parameters from Appendix Table 1, to generate projected number of hospitalizations and ICU need for each scenario. Based on the aforementioned model fits, we assumed social distancing from 3/17 to 3/25 resulted in a 65% decrease in the contact rate, and social distancing from 3/26 onward resulted in a 76.5% reduction in the contact rate. In reality we think the true impact of social distancing increased over time up to the stay at home order implemented until 3/26. We modeled a start date for the scenarios of 4/27, two weeks later (5/11) and four weeks later (5/25) in order to evaluate the impact of the timing of the repeal of the stay at home order and the transition to these scenarios. We assume social distancing is maintained at current levels until the start date of these scenarios.

Code for these scenarios and the model are posted on GitHub: <https://github.com/agb85/covid-19>