ORIGINAL RESEARCH

# Investigating the Trajectory of the COVID-19 Outbreak in Milwaukee County and Projected Effects of Relaxed Distancing

Amin Bemanian, PhD; Kwang Woo Ahn, PhD; Mallory O'Brien, PhD, MS; Darren J. Rausch, MS; Benjamin Weston, MD, MPH; Kirsten M. M. Beyer, PhD, MPH, MS

## ABSTRACT

**Introduction:** The coronavirus pandemic has placed enormous stresses on health care systems across the United States and internationally. Predictive modeling has been an important tool for projecting utilization rates and surge planning. As the initial outbreak begins to slow, questions are being raised regarding long-term coronavirus mitigation plans. This paper examines the current status of the coronavirus outbreak in Milwaukee County, Wisconsin, and simulates several scenarios where physical distancing measures are removed.

**Methods:** The outbreak's doubling time, reproductive numbers at several points, and incidence curve were calculated to assess outbreak progression. Compartmental models were used to estimate the number of hospitalizations and critically ill patients in Milwaukee County if distancing policies were removed.

**Results:** The compartmental models predict a substantial spike in cases and overwhelming medical resource utilization with an abrupt end to social distancing. Partial reduction in social distancing policies would likely result in a smaller spike, with less severe strain on available medical resources.

**Conclusions:** Milwaukee County remains very susceptible to a resurgence of COVID-19 cases. Removing physical distancing policies poses significant risks with regard to resource management.

## INTRODUCTION

The coronavirus disease 2019 (COVID-19) pandemic has placed an unprecedented strain on health care systems across the nation and around the globe. In order to help assess the impact COVID-19 could have on hospital beds and critical care services, multiple teams have developed model-based projections or projection tools to inform policy and decision-making as the pandemic has progressed.[1–5] These projections have been accomplished using a variety of approaches, including compartmental models such as the suspected-infected-recovered and suspected-exposed-infected- recovered (SIR, SEIR) models,[3–5] stochastic agent models,[2] and curve-fitting methods.[1] In particular, projections shared by the Institute for Health Metrics and Evaluation (IHME) at the University of Washington suggest that many states will have passed their peak of new deaths during the early part of April.[1] For Wisconsin, the IHME model placed the peak of new deaths on April 5 and peak health care utilization on April 14, both dates that have passed at the time of this writing. Other projection approaches, when applied to the Wisconsin setting, have predicted a less optimistic outcome, with much higher potential case counts and loss of life, as well as a greater strain on local health systems.[3,5] Milwaukee County, in particular, has had a very high burden of cases relative to the rest of the state. As of May 17, 39% of the state's 12,543 cases of coronavirus were in Milwaukee County (4945), despite the county comprising only 16% of the state's population. Furthermore, the county has 56% of the 453 fatalities in the state.

In order to mitigate the outbreak, Wisconsin and many other states enacted policies to encourage physical distancing. In Wisconsin, efforts have included the closure of schools and banning of gatherings greater than 10 people beginning on March 18 and the Safer at Home order issued by Governor Tony Evers, which took effect March 25. Subsequently, Wisconsin has experienced economic decline and individuals across the state have struggled with the impact of these policies for their jobs, families, and

• • •

**Author Affiliations:** Institute for Health and Equity, Medical College of Wisconsin, Milwaukee, Wis (Bemanian, Ahn, O'Brien, Beyer); Greenfield Health Department, Greenfield, Wis (Rausch); Department of Emergency Medicine, Medical College of Wisconsin, Milwaukee, Wis (Weston).

**Corresponding Author:** Kirsten M. M. Beyer, PhD, MPH, MS, 8701 W Watertown Plank Rd, Milwaukee, WI 53226, phone 414.955.7530; email kbeyer@mcw.edu; ORCID ID 0000-0002-7513-8528.

lifestyles. Thus, while physical distancing policies are essential to stop the spread of the novel coronavirus, there are immense pressures to consider future scenarios for opening the economy and returning to some sense of normalcy, while limiting the burden of the virus on populations and systems. Ultimately, the Wisconsin Supreme Court overturned statewide distancing measures on May 13, 2020, and counties and municipalities across Wisconsin are developing new policies to balance economic reopening with public health concerns. The objective of this analysis is to examine information currently available about the COVID-19 outbreak in Milwaukee County and provide projections that consider how case counts and resource utilization may occur in several different practical scenarios of relaxing physical distancing policies.

## METHODS

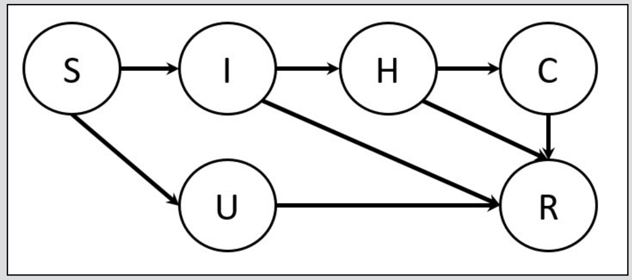
This study focuses on projecting COVID-19-related health care utilization in Milwaukee County. Public case data from the Wisconsin Department of Health Services were used to determine the daily number of cases. Case information from the Wisconsin Electronic Disease Surveillance System (WEDSS) was used to make estimates of typical hospitalization parameters. Since this research involved no contact with individuals and all data sources were either anonymous or deidentified, it was not considered human subjects research,

Basic characterization of the outbreak was done using the *incidence* package in R.[6] Reproductive numbers ($R_t$) were calculated using the *EpiEstim* package in R based on a method previously used for the calculation of the basic reproductive number of the Diamond Princess cruise liner COVID-19 outbreak.[7–9] Mean serial interval of 4.0 with a standard deviation of 0.5 was used for estimation of $R_t$.[10] Reproductive numbers were calculated at 3 points in the outbreak: (1) early in the outbreak from March 16 to March 22, when the first distancing orders would likely not have had enough time to affect incidence given the incubation period of coronavirus;[11] (2) March 23 to March 29, in the week following the first distancing orders and prior to the full effect of the Safer at Home order; and (3) May 9 to May 16 for the current effect of distancing policies.

### Projection Methods

The projection model is based on a classical SIR model. The SIR model dynamically simulates the 3 primary stages of an infection: susceptible, infected, and recovered. Using differential equations, it is possible to estimate what proportion of the population is in any stage of the disease at one time. The number of new daily infections is a function of how many people remain susceptible and how many people are currently infectious. Infected people remain infectious for a fixed amount of time and then transition into the recovered compartment, where they no longer can be infectious. This simulation continues until all of the population is infected or the susceptible population is too small to sustain the growth of the outbreak (ie, sufficient immunity is achieved). The threshold for when the outbreak ends is dependent on the effective reproductive number ($R_t$), which is the average number of individuals infected by a case at the current time of the outbreak. This is distinct from the basic reproductive number ($R_0$), which represents the initial reproductive rate of the virus.

**Figure 1.** Schematic of Model




S – susceptible, I – confirmed infected, H – acute bed hospitalized, C – critically ill (intensive care unit), U – unconfirmed infected, R – recovered.

Our model has been modified to have 2 additional compartments for acutely hospitalized patients (H) and critical care patients (C). A proportion of the infected population enters the hospitalized pool, while the rest recover. There is a similar progression of hospitalized patients to either critical care or recovery. Additionally, there is a compartment for persons infected or exposed to SARS-CoV-2 (COVID-19's virus) who do not get tested (U). This includes patients whose condition is so mild that they are not eligible to receive testing or those who do not seek testing on their own. This model diagram is shown in Figure 1. Progression through the model follows the differential equations below. $\beta$ is the infection rate, dependent on the reproductive number ($R_t$). $\gamma_i$ is the transition rate from the infected compartments (both confirmed and unconfirmed) to either hospitalized or recovered. It is calculated as the reciprocal of the infection duration. Similarly, $\gamma_h$ is the transition rate of hospitalized patients to either critically ill or recovered, and $\gamma_c$ is the transition rate of critically ill patients to recovered. These are calculated as the reciprocal of the length of stay for each kind of hospitalization. $\eta_h$ is the hospitalization rate among infected persons, and $\eta_c$ is the critical care rate among hospitalized patients. The recovered pool in this SIR model includes deaths. Deaths were not modeled separately due to the lack of enough fatalities to properly estimate a fatality rate from each compartment in the model. $c$ is the testing coverage level, which is defined here to be the proportion of cases of SARS-CoV-2 confirmed by testing.

$$\frac{dS}{dt} = -\frac{\beta S(I+U)}{\mathrm{N}}$$

$$\frac{dI}{dt} = \frac{c\beta S(I+U)}{N} - \gamma_i I$$

$$\frac{dU}{dt} = \frac{(1-c)\beta S(I+U)}{N} - \gamma_i U$$

$$\frac{dH}{dt} = \eta_h \gamma_i I - \gamma_h H$$

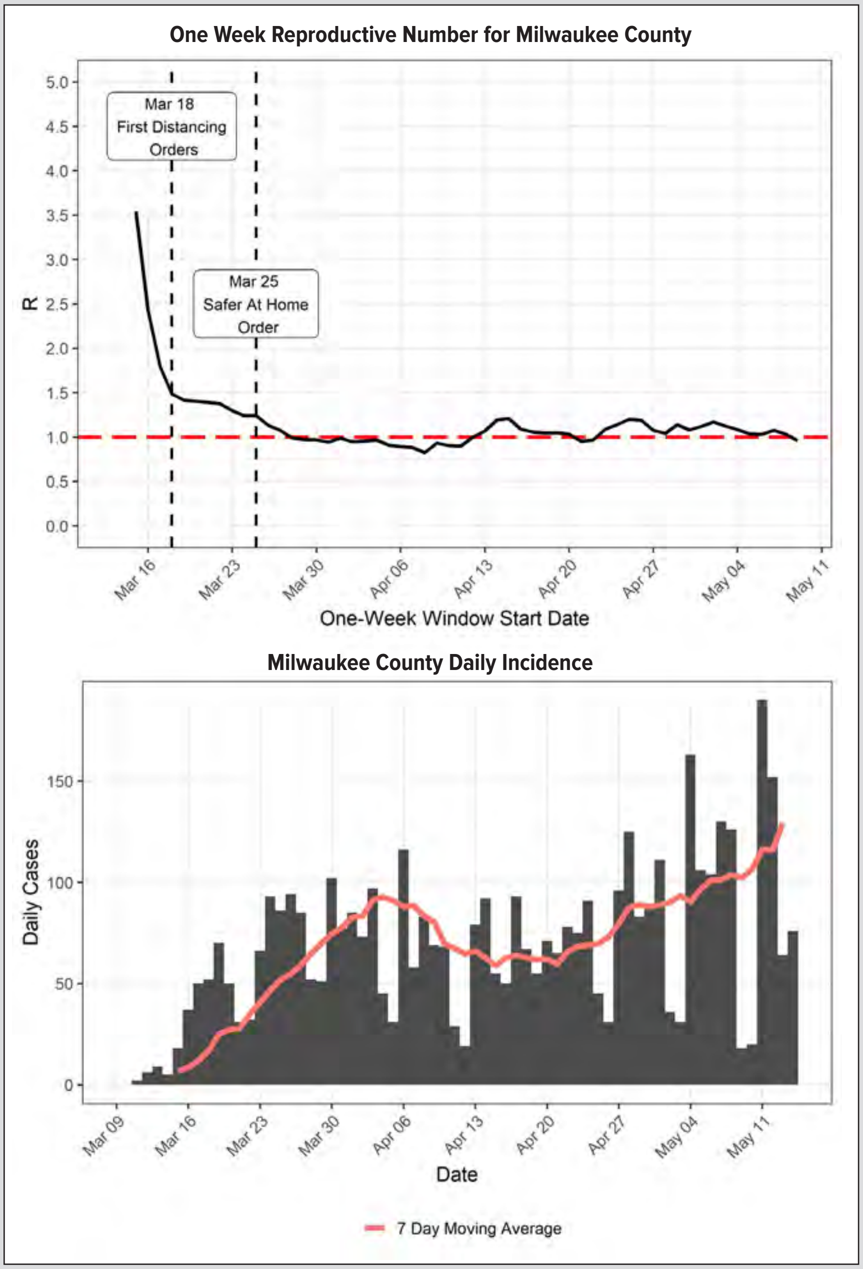
$$\frac{dC}{dt} = \eta_c \gamma_h H - \gamma_c C$$

$$\frac{dR}{dt} = (1-\eta_h)\gamma_i I + \gamma_i U + (1-\eta_c)\gamma_h H + \gamma_c C$$

$$N = S + I + U + H + C + R$$

$$\beta = R_0 \gamma_i$$

**Figure 2.** COVID-19 Reproductive Number and Daily Incidence for Milwaukee County




Line indicates the 7-day moving average of the incidence curve.

We have fit certain parameters to the Milwaukee County outbreak data. The current $R_t$ (based on May 9-15) was used for the transmission rate at the beginning of the projection. We first tested the unlikely scenario where the current level of physical distancing persists indefinitely. We then tested several scenarios where physical distancing relaxes. We tested the total relaxation of distancing measures by using the reproductive number for the week of March 16-22, starting just before the first set of distancing orders was placed. We tested the partial relaxation of distancing using the week of March 23-29, which is after the initial distancing orders and as the Safer at Home order was becoming active. The loosening of physical distancing was tested at May 21, based on plans by several Milwaukee County municipalities to end their distancing orders on that date.

The hospitalization rate (median estimate: 19.0% of all cases) and intensive care unit (ICU) rate (median 26.5% of all hospitalizations) are estimated as binomial variables based on the proportion of cases in Milwaukee County that have been hospitalized so far. The average duration for mild cases (both for the I and U compartments) is assumed to be 13 days, based on a consensus estimate of 3 days of infectivity during the incubation period and 7 to 14 days of infectivity after symptom onset.[2-4] Using the Wisconsin Electronic Disease Surveillance System (WEDSS) and internal hospitalization data, average length of stay for hospitalization was set at 5 days and length of stay for critical patients at 4 additional days. We assume the unconfirmed cases remain mild, and they do not become hospitalized or die. Based on the relatively high rates of hospitalization in Wisconsin earlier in the outbreak (~30%) relative to other areas with closer to only 10% of hospitalizations, we estimate that *c* (the testing coverage level) is a binomial variable with a median of 20% and a standard deviation of 4%. Our capacity estimates are based on aggregated data compiled by hospitals in the county and assume there is a maximum of 2475 acute care beds and 475 ICU beds, prior to any surge planning.

We assume that spread of the infection occurs evenly across the entire region (Milwaukee County), as this is a core assumption of SIR models. We also assume that spread from neighboring counties is not a significant cause of new infections. Hospitalized patients are not considered to be a significant cause of infections either and, therefore, are modeled as noninfectious after they enter the H and C compartments. The starting population for the recovered pool is estimated as all infected cases whose onset is 3 weeks earlier than the projection start date. All patients who have been infected and transition into the recovered pool are thought to be permanently immune. Projections are made using a Runge-Kutta numerical solver in the R programming language with the *deSolve* package.[12] For each scenario, 1000 simulations were conducted. In each simulation, the estimated parameters were resampled to create a distribution of projections. All projections use data up to May 15, 2020, to set initial conditions.

## RESULTS

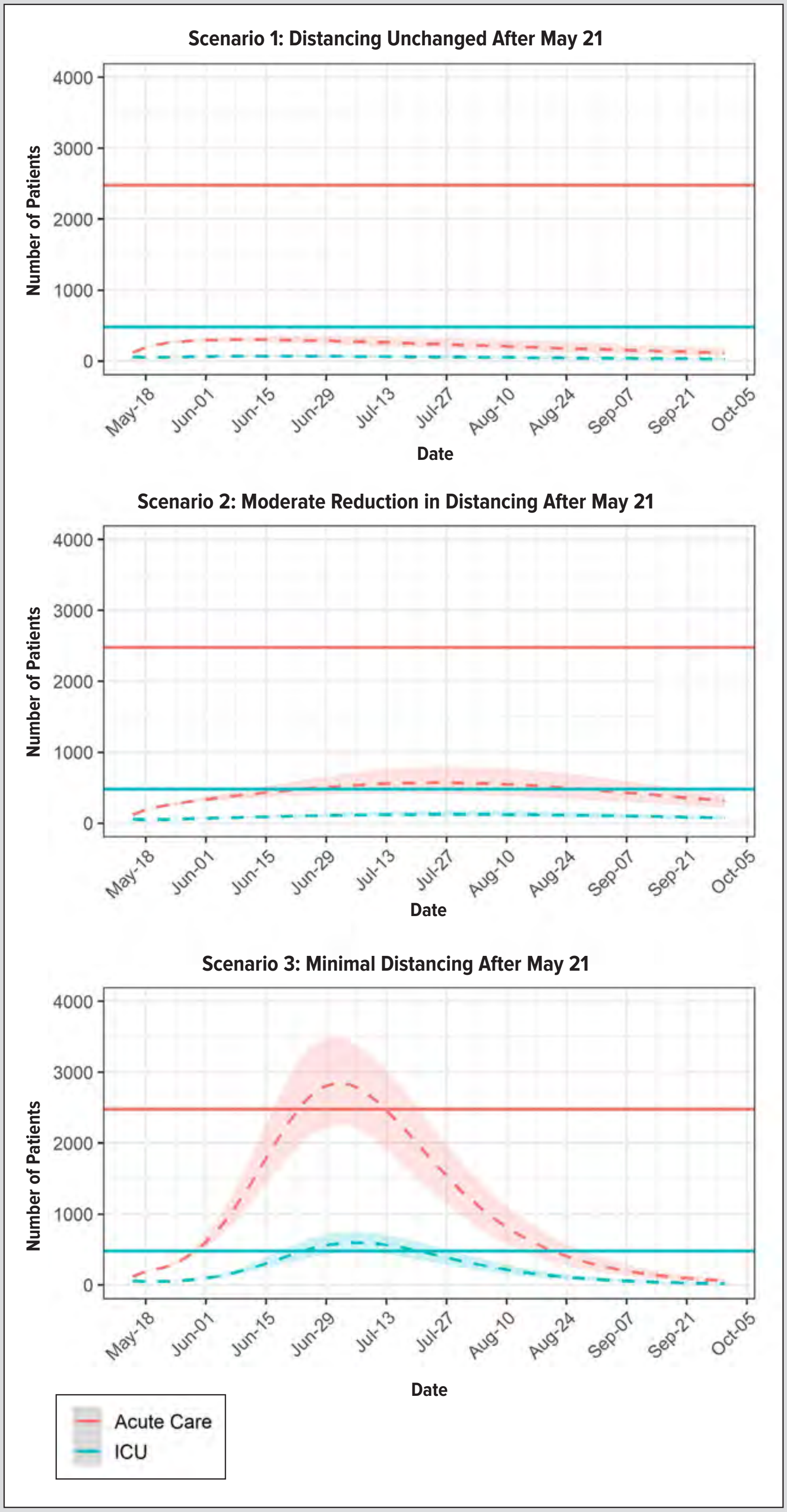
### Current Outbreak Status

The first confirmed case of coronavirus in Milwaukee County was identified on March 11, 2020. Due to the lack of testing kits and the range of clinical presentation (from mild self-resolving illness to critical respiratory failure), it is unclear whether cases of coronavirus were present in the county prior to the first confirmed case. Initial reproductive numbers were over 3, as shown by Figure 2, but quickly decreased as testing expanded. After initial distancing measures were placed, the reproductive number dropped under 1.5 and stabilized around 1 following the Safer at Home order. The incidence curve (Figure 2) shows that new daily cases rapidly increased during the first 2 weeks of the outbreak. Incidence initially peaked during the week of April 5 and began to decrease over the next 2 weeks. However, since late April, the incidence has begun to rise again.

### Projection Results

Our 3 projection scenarios are shown in Figure 3, with hospitalization peak summaries shown in the Table. For all of the following scenarios, we assume the peak has not yet occurred in the outbreak. In Scenario 1, all physical distancing policies remain unchanged through October 1. If this policy approach is taken, we project only a minor peak of hospitalizations in June. Some hospitalizations would continue through summer. By the end of the simulation duration, we project, on average, that 80.6% of Milwaukee County residents would still be susceptible to SARS-CoV-2 in this scenario (95% CI, 74.6%-85.3%). In Scenario 2, we assume a moderate amount of physical distancing to be relaxed on May 21. This scenario also assumes distancing returns to the March 23-29 levels (ie, limitations on restaurants and businesses, small gatherings

**Figure 3.** Projected Scenario Time Courses




Hospitalization census refers to acute care patients and is separate from ICU patients. Dashed lines indicate the median simulation with bands indicating 95% of simulation range. Solid lines are the capacity of acute care beds and intensive care unit (ICU) beds, without any additional surge capacity.

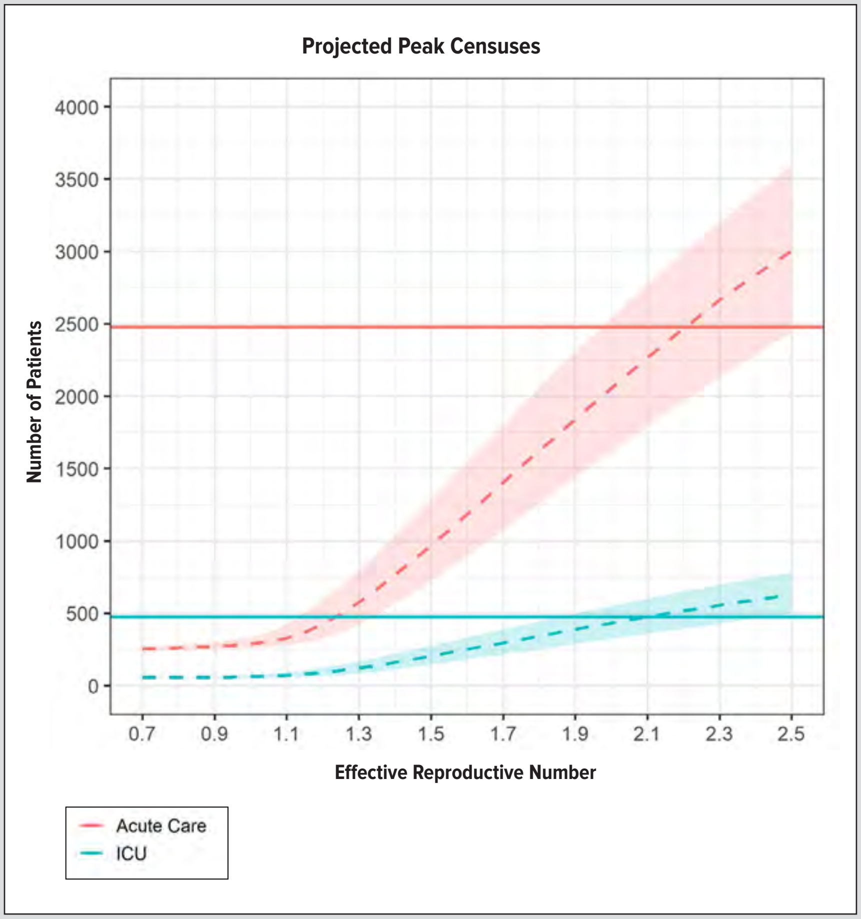
<10 individuals permitted, schools remain closed). We expect a spike in cases in late May, but this spike would still be within normal capacity of the county's health care systems. Finally, in scenario 3, we model a total relaxation of distancing on May 21. Here there is a spike in late June/early July that would significantly exceed both acute care and ICU bed capacities. We also calculate the peak censuses for a range of $R_t$ values, as shown in Figure 4. Based on these simulations, we expect that COVID-19 cases alone reach 50% of acute care capacity for $R_t$ values between 1.6 and 1.7, and they exceed acute care capacity for $R_t$ values above 2.2.

## DISCUSSION

The Milwaukee County COVID-19 outbreak presented with an initial rapid rise of new daily cases. The incidence curve plateaued in April and then continued to rise into early May. There are early signs that physical distancing behaviors were successful at preventing a more severe outbreak. The effective reproductive number rapidly decreased in the first weeks of the outbreak and has remained around 1 since enactment of the Safer at Home order. We are limited in our ability to identify each policy's effects since they were enacted in rapid succession. We also cannot isolate the impact of the April 7 election, which was held during the Safer at Home order. The City of Milwaukee's Election Commission reported that there were 18,803 in-person voters at 5 election sites.[13] This was a substantial exposure risk. There is a rise in the daily incidence beginning 2 weeks after the election, but this also coincides with the expansion of testing.[14]

Projecting the future course of the COVID-19 epidemic, as well as the impact of potential policy changes, is challenging due to multiple sources of uncertainty, including each policy's effect on the virus's reproductive rate and the number of actual COVID-19 cases covered by testing. It is difficult to predict how the population will respond to future policy changes, such as the removal of the Safer at Home order, as few places have attempted these changes. Given that Wisconsin and many other places have not levied travel restrictions, there remain opportunities for cases to continue to enter the population through travel. However, there is evidence that there has been decreased mobility during this outbreak; Milwaukee County and its neighbors all have 60% or greater decreased mobility based on cellphone GPS data.[15]

**Figure 4.** Projected Peaks as a Function of the Effective Reproductive Number ($R_t$)




Simulations were run for a range of $R_t$ from 0.7 to 2.5. Each reproductive number was simulated 200 times. Dashed line indicates peak census with bands indicating 95% of simulation range. Solid lines are the capacity of acute care beds and intensive care unit (ICU) beds, without any additional surge capacity.

**Table.** Projections for Peak Hospitalizations in Milwaukee County Based on 3 Different Scenarios

| | Median | 2.5 percentile | 97.5 percentile |
|---|---|---|---|
| S1: Distancing unchanged after May 21 ($R_t$: ~1.0) | | | |
| Peak acute bed census | 298 | 266 | 352 |
| Peak ICU census | 64 | 57 | 77 |
| Peak date (2020) | June 10 | June 3 | June 27 |
| S2: Moderate distancing after May 21 ($R_t$: ~1.3) | | | |
| Peak Hospitalization Census | 569 | 414 | 800 |
| Peak ICU census | 121 | 86 | 171 |
| Peak date (2020) | July 25 | July 14 | August 2 |
| S3: Minimal distancing after May 21 ($R_t$: ~2.4) | | | |
| Peak acute bed census | 2858 | 2255 | 3515 |
| Peak ICU census | 596 | 466 | 747 |
| Peak date (2020) | July 2 | June 28 | July 6 |

Median indicates the median simulation for each scenario.
Abbreviation: ICU, intensive care unit.

Another limitation of our approach is that the SIR model assumes homogeneity of infections across the study population. In reality, we have seen the clustering of new cases in different neighborhoods throughout Milwaukee. Furthermore, with the early removal of the Safer at Home order, different municipalities within the county are approaching distancing differently. This will likely cause spatial variation in the amount of spread. However, since the neighborhoods and cities within a county are so tightly interconnected, we believe the county is an ideal unit for SIR model, especially compared to statewide and nationwide projections.

We do not incorporate the effect of seasonality, which may result in a second peak in the fall or winter,[16] as it is currently unknown whether this specific virus is subject to seasonal changes. We chose not to model deaths because the primary purpose of these models was to gauge health care utilization. Additionally, the limited number of fatalities in Milwaukee County makes it difficult to properly estimate the case fatality rate for each of the compartments. The fatality rate may change significantly over the course of the outbreak, depending on the amount of strain on the health care infrastructure. Similarly, we do not model how health care systems manage non-COVID-19 patients. Currently, many nonemergent procedures and visits have been postponed to ensure enough capacity for potential COVID-19 surges. However, much of this care is essential and will need to be conducted before the pandemic ends. Finally, we cannot and have not incorporated the potential effects of future developments such as mass antibody testing; increases in remote work to sustain physical distancing; or general changes to workplace, social, or behavioral practices as of yet unknown. Despite these limitations, we believe that these projections are a useful tool to frame discussions of policy moving forward. Importantly, the goal of our projections is not to give specific point estimates on how many hospitalizations there will be on any given date, but rather to highlight the risks associated with policy changes based on the best available information.

Our projections show that if physical distancing policies were maintained in full through the end of September, the continued burden of cases would remain well within the capacity of health care systems in Milwaukee County. However, realistically continuing the current levels of physical distancing through the summer would have potentially catastrophic economic costs. Unfortunately, since the vast majority of the county's population remains susceptible to this infection, the pandemic course is very sensitive to the degree of relaxation. Full relaxation of these policies (ie, removal of Safer at Home with no other distancing policies) and a return to preoutbreak activity levels will almost assuredly cause a new wave that would likely overwhelm our health systems. Furthermore, seemingly small increases in $R_t$ can have exponential effects on future hospitalizations. If reopening can be done in a cautious and phased manner while keeping the $R_t$ under 1.5, then future peaks will likely be well within the county's health care capacity.

Policymakers must consider what public health infrastructure is necessary to prevent a resurgence of cases as plans are made to reopen the economy. Public health functions essential to outbreak control include robust testing and contact tracing capabilities and adequate personal protective equipment for health care workers and all essential employees at significant risk of exposure. Additionally, novel economic and business policies that encourage physical distancing during the limited reopening of restaurants and shops or staggering which days of the week individuals can go to nonessential businesses should be considered. Finally, any reopening requires awareness that a second outbreak may happen and contingency plans to reimplement more stringent physical distancing policies if the daily incidence were to increase too quickly. We recommend monitoring the current effective reproductive number to determine whether the outbreak remains controlled.

## CONCLUSION

Continuing the current levels of physical distancing through the summer is unrealistic due to the long-term economic costs and the judicial revocation of the Safer at Home order. Relaxation of these distancing policies risks a significant resurgence in COVID-19 cases. Removal of the Safer at Home order will likely require some additional new policies that continue at least a moderate level of physical distancing. Prior to Safer at Home, this level was achieved through closures of schools, restaurants, and bars and a ban of mass gatherings. Other combinations of policies could achieve similar effects on disease suppression. However, without such efforts, Milwaukee County will likely see a significant surge that will strain our health care resources beyond capacity. These are exceptionally difficult decisions affecting the health, livelihoods, and quality of life of all Wisconsinites. We hope this analysis can provide evidence to assist decision-makers as these policies are determined.

**Acknowledgements:** We would like to thank John R. Raymond, Sr., MD, Laura Cassidy, MS, PhD, John Meurer, MD, MBA, Amanda Simanek, PhD, MPH, and Geoffrey Swain, MD, MPH, for their support in the development of this paper.

**Funding/Support:** This research was funded in part by the Advancing a Healthier Wisconsin Endowment at the Medical College of Wisconsin.

**Financial Disclosures:** None declared.

## REFERENCES

**1.** IHME COVID-19 Health Service Utilization Forecasting Team. Forecasting COVID-19 impact on hospital bed-days, ICU-days, ventilator-days and deaths by US state in the next 4 months. Preprint. medRxiv. Posted online March 2020. doi:10.1101/2020.03.27.20043752

**2.** Ferguson NM, Laydon D, Gemma N-G, et al, on behalf of the Imperial College COVID-19 Response Team. Report 9: Impact of non-pharmaceutical interventions (NPIs) to reduce COVID-19 mortality and healthcare demand. Imperial College London; March 16, 2020. https://spiral.imperial.ac.uk:8443/bitstream/10044/1/77482/14/2020-03-16-COVID19-Report-9.pdf

**3.** Predictive Healthcare. COVID-19 Hospital Impact Model for Epidemics (CHIME). Penn Medicine, The University of Pennsylvania. Published March 13, 2020. Accessed April 12, 2020. https://penn-chime.phl.io

**4.** Hill A. Modeling COVID-19 spread vs healthcare capacity. Updated March 21, 2020. Accessed April 12, 2020. https://alhill.shinyapps.io/COVID19seir/

**5.** Henderson M, Carlson E. Covid Act Now Model. CovidActNow.com. March 20, 2020. Updated April 12, 2020. Accessed April 12, 2020. https://data.covidactnow.org/Covid_Act_Now_Model_References_and_Assumptions.pdf

**6.** Kamvar Z, Cai J, Pulliam J, Schumacher J, Jombart T. Epidemic curves made easy using the R package incidence. F1000Res. 2019;8(139). doi.10.12688/f1000research.18002.1

**7.** Zhang S, Diao MY, Yu W, Pei L, Lin Z, Chen D. Estimation of the reproductive number of novel coronavirus (COVID-19) and the probable outbreak size on the Diamond Princess cruise ship: A data-driven analysis. *Int J Infect Dis.* 2020;93:201-204. doi:10.1016/j.ijid.2020.02.033

**8.** Jombart T, Cori A, Nouvellat P. EarlyR: Estimation of Transmissibility in the Early Stages of a Disease Outbreak; 2017, version 0.0.1. Accessed May 16, 2020. https://rdrr.io/cran/earlyR/

**9.** Cori A, Ferguson NM, Fraser C, Cauchemez S. A new framework and software to estimate time-varying reproduction numbers during epidemics. *Am J Epidemiol.* 2013;178(9):1505-1512. doi:10.1093/aje/kwt133

**10.** Nishiura H, Linton NM, Akhmetzhanov AR. Serial interval of novel coronavirus (COVID-19) infections. *Int J Infect Dis.* 2020;93:284-286. doi:10.1016/j.ijid.2020.02.060

**11.** Guan W, Ni Z, Hu Y, et al. Clinical Characteristics of Coronavirus Disease 2019 in China. *N Engl J Med.* 2020;382:1708-1720. doi:10.1056/nejmoa2002032

**12.** Soetaert K, Petzoldt T, Setzer RW. Solving differential equations in R: package deSolve. *J Stat Softw.* 2010;33(9):1-25. doi:10.18637/jss.v033.i09

**13.** Klein T. Nearly 19,000 in Milwaukee brave polls for Election Day. WTMJ-TV. April 8, 2020. Accessed April 12, 2020. https://www.tmj4.com/news/coronavirus/nearly-19-000-in-milwaukee-brave-polls-for-election-day

**14.** Marshall J. Gov. Evers says Wisconsin is taking big steps to increase COVID-19 testing. *WTMJ-TV.* April 20, 2020. Accessed May 16, 2020. https://www.tmj4.com/news/coronavirus/gov-evers-says-wisconsin-is-taking-big-steps-to-increase-covid-19-testing

**15.** GeoDS Lab. Mapping mobility changes in response to COVID-19. University of Wisconsin-Madison. Accessed May 16, 2020. https://geods.geography.wisc.edu/covid19/physical-distancing/

**16.** Neher RA, Dyrdak R, Druelle V, Hodcroft EB, Albert J. Potential impact of seasonal forcing on a SARS-CoV-2 pandemic. *Swiss Med Wkly.* 2020;150:w20224. doi:10.4414/smw.2020.20224

advancing the art & science of medicine in the midwest

# WMJ

*WMJ* (ISSN 1098-1861) is published through a collaboration between The Medical College of Wisconsin and The University of Wisconsin School of Medicine and Public Health. The mission of *WMJ* is to provide an opportunity to publish original research, case reports, review articles, and essays about current medical and public health issues.