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Regional Health System Shortfalls with a Novel COVID-19 Model

Sarah R. Allred, Sean T. McQuade, Nathaniel J. Merrill, Benedetto Piccoli, Darren Spielman, Carla Villacis, Ross Whiting, Aayush Yadav, Doug Zacher, Devon Ziminski

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1 Abstract

Our ability to respond to COVID-19 depends on our health systems' capacity to serve people that are sick. And it depends on everyone's efforts to keep the number of sick people as low as possible. The fewer sick people there are at any given time, the better our health system can care for us.

Southern New Jersey's health systems serve people of all ages from rural to urban areas. Effective response to the spread of COVID-19 is contingent on many factors within our counties (Atlantic, Burlington, Camden, Cape May, Cumberland, Gloucester, Ocean, Salem). The Senator Walter Rand Institute for Public Affairs and the Center for Computational and Integrative Biology at Rutgers University-Camden in collaboration with New Jersey Health Initiatives explored the potential spread of COVID-19 relative to hospital capacity in southern New Jersey.

2 Executive Summary

We compared estimates of available hospital beds, by county, with the likely demand for hospital beds under several virus spread scenarios. The models that generated these numbers are adaptations of the Wu et al model[1]. The

Wu et al model was designed for China data. Our model included additional features and fit the Italian data from "Protezione Civile" [3].

It is best to think of the numbers reported here as one set of possible outcomes given our current knowledge about the disease. As more time passes, more people will be tested, and we will have more data to make model predictions more certain. For example, the predicted shortfalls will be less if we learn that fewer people transmit the disease before they know they are infected. Similarly, we do not know yet if warmer weather will slow the spread of COVID-19. If it does, the curve will flatten further, buying more time for social distancing efforts to impact virus spread.

Note that the main concern here is the health care system. Of those infected with COVID-19, current estimates are that 81% will not experience noticeable symptoms or mild ones. The expected hospitalization rate of those with symptoms is about 40-55%. Under even the worst case scenario, the majority of South Jerseyans will not experience symptoms from COVID-19. This report does not lead us, and should not lead anyone, to panic. To the contrary, the report points to our ability to minimize COVID-19 risk by implementing social distancing policies and practices. We also hope that this report will help the state and health care systems as they plan to address the region?s health needs.

To many people, these numbers may seem unexpectedly high. After all, the entire county of Italy had only about 21,000 cases as of March 14th, 2020, and we predict a bed shortfall of at least that in South Jersey. To understand why, look at the curves on one of the county graphs. Several days ago, Italy crossed the black line where need for bed exceeds capacity. But on all the curves, the modeling suggests that there are still weeks to go before reaching the peak of the outbreak.

We also note that COVID-19 is different in several ways from the seasonal influenza. First, many people have some immunity to seasonal influenza because of vaccines or previous exposure, and current estimates suggest that no one is immune to COVID-19. Second, the coronavirus that causes COVID-19 is more contagious than the flu. Third, the current model estimates that many infected people do not show severe enough symptoms to get tested and thus may infect others. Fourth, COVID-19 seems to have higher rates of hospitalization and mortality than most seasonal influenza.

2.1 Key Messages

For each county, we show:

- The number of available hospital beds.
- When we will hit peak hospital bed demand under three scenarios: 1) MINIMAL social distancing policies and practices, 2) MODERATE social distancing policies and practices, and 3) STRONG social distancing policies and practices to curb the spread of COVID-19.
- How much demand for hospital beds will exceed capacity under each of the three scenarios.
- The effect of social distancing practices is modeled as a change in R0. Unfortunately the disease is too new to confidently give specifics about how a particular set of policies will change the curves.
- We can say with certainty that more social distancing curbs the spread of COVID-19.
- The majority of South Jerseyans will not experience symptoms from COVID-19. Essential assets such as grocery stores, pharmacies and medical centers will almost certainly remain open and functioning.

Social Distancing Policies and Practices: The term *social distancing* describes infection control actions taken by public health offices to slow the spread of a contagious disease. Social distancing practices can prevent overwhelming local, state, and federal health care systems by COVID-19's spread. Across the globe, various levels of social distancing policies and practices have been implemented to delay and reduce the outbreak of COVID-19.

3 Math Modeling

We built a model starting from that proposed in [1] for diffusion of COVID-19 in Wuhan and its international spread. Our model reads:

$$\begin{cases} \frac{dS}{dt} = -\frac{S}{N}\left(\frac{\tilde{R}_0}{D_I} I\right) \\ \frac{dE}{dt} = \frac{S}{N}\left(\frac{\tilde{R}_0}{D_I} I\right) - \frac{E}{D_E} \\ \frac{dI_A}{dt} = \alpha\frac{E}{D_E} - \frac{I_A}{D_I} \\ \frac{dI_S}{dt} = (1-\alpha)\frac{E}{D_E} - \frac{I_S}{D_I} \\ \frac{dH}{dt} = \sigma\frac{I_S}{D_I} - \frac{H}{D_H} \\ \frac{dR}{dt} = (1-\sigma)\frac{I_S}{D_I}, \end{cases}$$

The first two equations are as in the model proposed in [1] and represent a classical SEIR model: the population as: S are susceptible, E exposed, N total population. The main novelty is to split infected into symptomatic I_S and asymptomatic I_A, so total infected is given by $I = I_A + I_S$, with α the asymptomatic incidence estimated 0.81 as in [2]. Then the not symptomatic infected transition into the recovered population R, while the symptomatic infected transition either to R or to the hospitalized population H at a rate σ and discharged after D_H days. From [3] one would get σ of up to 0.55, but this may change depending on the number of people tested.

A key point is to relate our parameter $\tilde{R}_0$ to a the infection rate R_0 used in descrete models. We have:

$$\tilde{R}_0 = \frac{D_I}{D}\ln(R_0), \tag{1}$$

where D_I is the time (days) for which an person harbors latent infection and is spreading the virus; D is the time (days) for an infected person to infect a susceptible person.
Let us justify this relation. Assume same initial exposed and infected, the expected growth of the exposed is:

$$E(t) = e^{\frac{S}{N}\cdot\frac{\tilde{R}_0}{D_I}t}E(0),$$

thus after D days we have $\frac{E(D)}{E(0)} = e^{\frac{S}{N}\cdot\frac{D\,\tilde{R}_0}{D_I}}$. At initial stages $\frac{S}{N} \sim 1$ and so $R_0 = e^{\frac{D\,\tilde{R}_0}{D_I}}$ from which we deduce the relationship. The choice of [1] is

$R_0 \sim 2.6$ which, for $D_I = 5$, would correspond to $D \sim 2$, in other words the infection would occur within 2 days. If we fit the model to Italian data growth in hospitalization (from 200 on 2/24/20 to around 6K on 3/11/20 on a population of around 25M affected in North Italy [3]), this would result in $R_0 = 3.9$.

The complete set of parameter is given in next table. Simulations were done with different choices of infection rate: the Lancet article [1] gives $\tilde{R}_0 = 1.3$, newer estimates give $\tilde{R}_0 = 2.6$, and the worst case scenario is $\tilde{R}_0 = 3.9$

Name	Description	Estimate	Units
$\tilde{R}_0$	rate of infection	{1.3,2.6,3.9}	-
D_I	latent period	5	days
D_E	infectious period	4	days
D_H	hospitalization period	7-14	days
α	asymptomatic rate	0.81	-
σ	hospitalization rate	0.1-0.55	-

Many variants are possible, modifying the infectious mechanism (I_S become isolated and only I_A infect). Similarly one can distinguish among infectious rates for I_A and I_S. Data was sourced from a publication from the Chinese Center for Disease Control and Prevention regarding the largest case series to date of coronavirus disease [2], and from more recent data from the ongoing tragedy in Italy [3] in order to inform parameters of our model.

Main takeaways:

- The model is slight modification of the one proposed in [1] whose parameters were fit to large data set.
- The distinction between I_A and I_S should further explain the difficulty in containment.
- The model can be adapted to different situations. In particular the hospitalization rate σ may vary, as well as well as the asymptomatic incidence α.
- Data on mortality rates by age from [2] suggests incidence of 0.08 for range 70-79 and 0.148 for over 80 of detected cases.

4 Relating the Model to Figure and Capacity

To estimate peak bed shortfall in each county, we need to know: (1) *Capacity:* the number of hospital beds in each county, (2) *Demand at Baseline:* the number of hospital beds occupied by non-COVID-19 patients, and (3) *Demand from COVID-19:* the number of COVID-19 patients needing hospital beds. Then:

$$\text{Shortfall} = \text{Demand}_{\text{COVID-19}} + \text{Demand}_{\text{Baseline}} - \text{Capacity}.$$

To estimate *Capacity*, we took information from the New Jersey Department of Health Website on March 13, 2020. The website permits search by different categories, and we included General Acute Care Hospitals and Special Hospitals. For Special Hospitals, we examined each facility to make sure it provided clinical health services useful for COVID-19 treatment. To compute total beds per county, we then added the number of beds at every facility in each county, for a total number of beds. We note that there are a variety of publicly available reports of hospitals and beds in hospitals. This is the number we calculated.

To estimate *Demand at Baseline*, we took data from American Hospital Directory. We estimated the number of admissions as being the same as the number of discharges (from the website), and *AvgDaysPerAdmission* as days charged to insurance from the website. From this website, we calculated demand in each county, but then averaged across counties in this reports for a more reliable estimate. This means we estimate baseline demand as the same rate in each county. As we establish confidence in county-level baseline rates, this may change.

$$\text{Demand}_{\text{Baseline}} = \frac{\text{NumAdmissionsPerYear} * \text{AvgDaysPerAdmission}}{365}.$$

To estimate *Demand from COVID-19* we took the model output (see Model Section). The model takes as input the estimated length of hospitalizations. We computed model values for average hospitalization of 7 and 14 days, then averaged outputs for each of these for the reported Demand number. In the curves shown below, we use the 7-day hospitalization scenario. This is why the peak of the curves in these figures is less than the bed shortfall reported.

The model estimates *Demand from COVID-19* at each day of the outbreak. We defined *Peak Shortfall* as the day of maximum COVID-19 hospitalizations, and this is the *Time to Peak of Outbreak*. In the figure, we approximate the calendar date from this number.

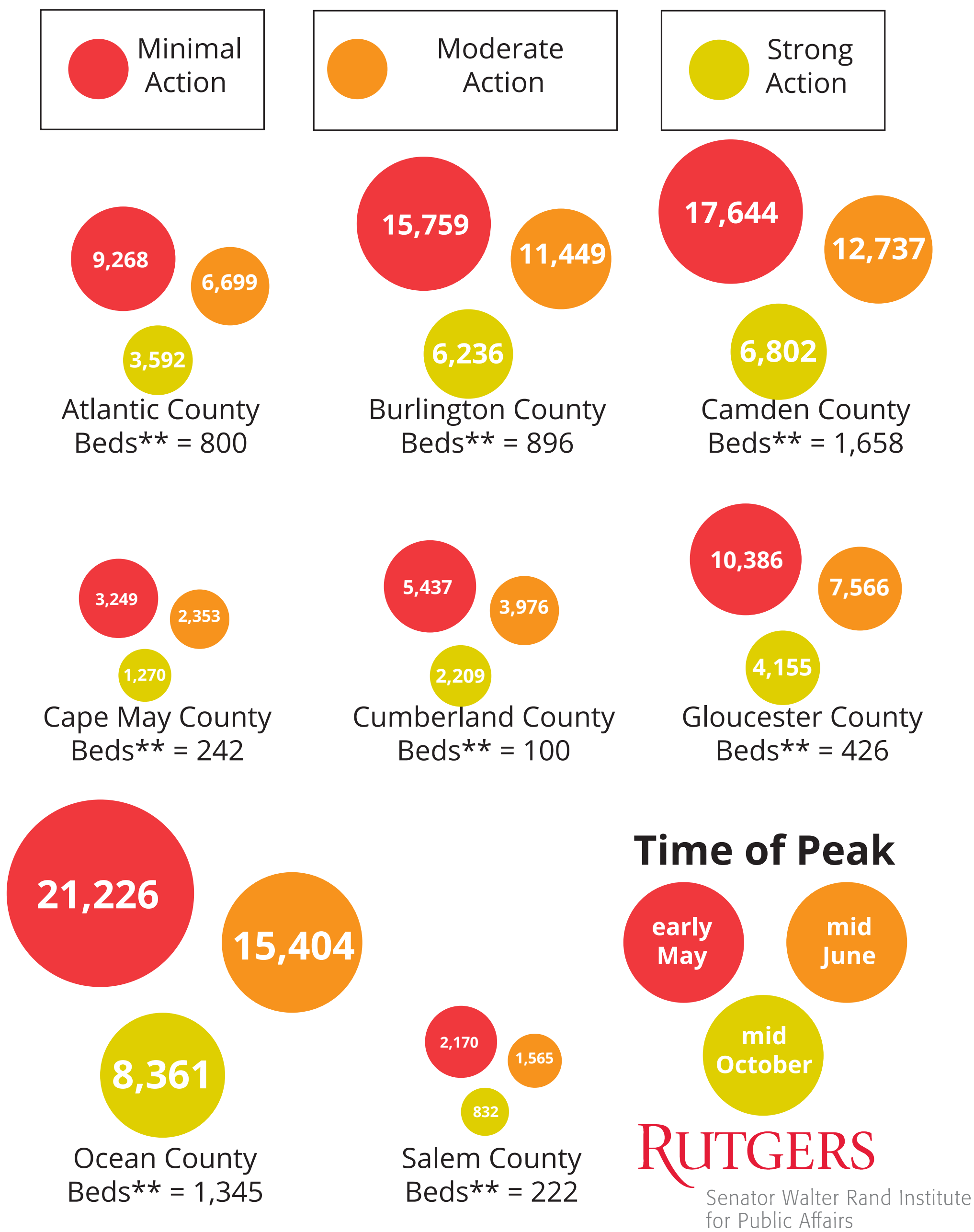
In the figure, we report shortfalls as a function of three scenarios. We manipulated R_0 as our operationalization of increasing social distancing. To date, there are no known models of how different levels of social distancing determine R_0, although we expect these to be forthcoming as the pandemic evolves. We assumed that *minimal action* was the observed R_0 of 2.66, and that *moderate social distancing* was R_0 of 1.5, and that *strong social distancing* was R_0 of 1.0. Thus these categories do not map neatly onto any particular behaviors.

5 Conclusion and Addendum

This is an early draft of an ongoing developing model and will be edited. For questions, contact:

- Math Modeling questions: Benedetto Piccolo (piccoli at camden.rutgers.edu)
- Figure or Capacity questions: Sarah Allred (srallred at camden.rutgers.edu)

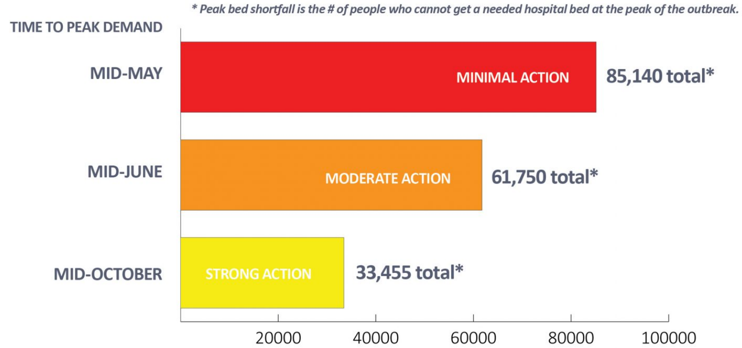
Peak Bed Shortfall* by County



*Peak bed shortfall is the # of people who cannot get a needed hospital bed at the peak of the outbreak.
** Beds in each county are taken from the New Jersey Department of Health website on March 13, 2020.
The number includes beds reported in profiles of General Acute Care and care-providing Special Hospital facilities.

PEAK BED SHORTFALL*

** Peak bed shortfall is the # of people who cannot get a needed hospital bed at the peak of the outbreak.*



	MINIMAL	MODERATE	STRONG
Atlantic	9268	6699	3592
Burlington	15759	11449	6236
Camden	17644	12737	6802
Cape May	3249	2353	1270
Cumberland	5437	3976	2209
Gloucester	10386	7566	4155
Ocean	21226	15404	8361
Salem	2170	1565	832

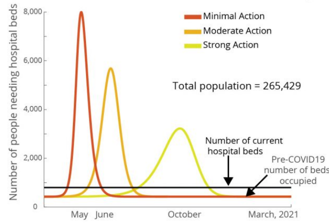
HOSPITAL BEDS BY COUNTY

Atlantic	800	Gloucester	426
Burlington	896	Ocean	1345
Camden	1658	Salem	222
Cape May	242	TOTAL	5689
Cumberland	100		

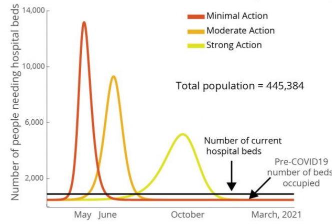
** Beds in each county are taken from the New Jersey Department of Health website on March 13, 2020. The number includes beds reported in profiles of General Acute Care and care-providing Special Hospital facilities.

REGIONAL HEALTH SYSTEM SHORTFALLS WITH A NOVEL COVID-19 MODEL

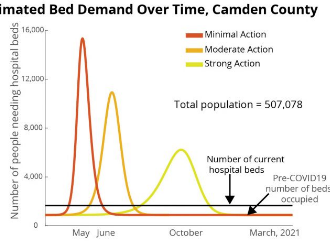
Estimated Bed Demand Over Time, Atlantic County



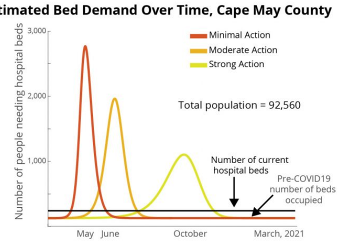
Estimated Bed Demand Over Time, Burlington County



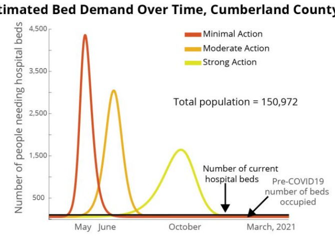
Estimated Bed Demand Over Time, Camden County



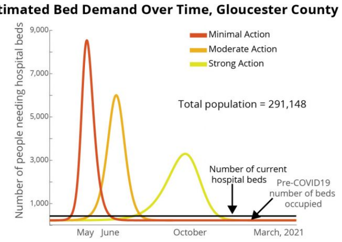
Estimated Bed Demand Over Time, Cape May County



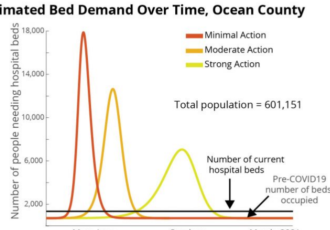
Estimated Bed Demand Over Time, Cumberland County



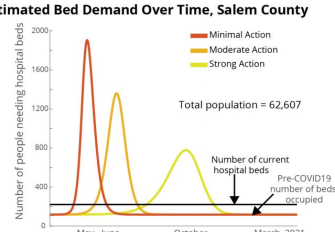
Estimated Bed Demand Over Time, Gloucester County



Estimated Bed Demand Over Time, Ocean County



Estimated Bed Demand Over Time, Salem County



Due to the use of multiple models, there are small differences between the figures in the county graphs and the summary figure above.

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References

[1] Wu, Joseph T and Leung, Kathy and Leung, Gabriel M. Nowcasting and forecasting the potential domestic and international spread of the 2019-nCoV outbreak originating in Wuhan, China: a modelling study. *The Lancet*,395(10225):689–697, 2020.

[2] Wu, Zunyou and McGoogan, Jennifer M. Characteristics of and important lessons from the coronavirus disease 2019 (COVID-19) outbreak in China: summary of a report of 72 314 cases from the Chinese Center for Disease Control and Prevention. *Jama*,2020.

[3] https://github.com/pcm-dpc/COVID-19/blob/master/schede-riepilogative/regioni/dpc-covid19-ita-scheda-regioni-20200302.pdf.