COVID-19 in North Carolina

Modeling COVID-19 in North Carolina: An Update

Overview

Building on prior work, this brief provides an update on coronavirus disease 2019 (COVID-19) in North Carolina and efforts to model its effects to inform capacity planning and readiness. Drawing on recent data, we provide an update on the current situation in this state, including summarizing what we see as "tailwinds" (favorable factors) and "headwinds" (unfavorable factors) that inform how we approach the month of May ahead.

We then provide additional details about ongoing efforts to model the effects of COVID-19 to facilitate resource planning. During the early stages of an epidemic when "ground truth" is still emerging, we underscore the need to understand the uncertainty inherent in modeling. In particular, we illustrate this by varying key parameters within an agent-based model framework developed by North Carolina collaborators to estimate the impact of COVID-19 on the healthcare system. We discuss how changing key inputs and assumptions may influence model forecasts and then consider how or whether updated forecasts, in turn, influence suggested policy approaches.

In short, many details about COVID-19 epidemiology remain currently unknown and are still emerging. Yet, consistent with a previous April 17 brief, North Carolina appears to have healthcare capacity available to warrant a gradual reopening, as long as vigilance is maintained, since exceeding hospital capacity remains a plausible possibility. We reach these conclusions based on an updated model to reflect selection of more conservative parameters than were used in a prior April 6 brief.

Current Situation

Overview of key trends:

- **How many COVID-19 cases have been reported in North Carolina?** As of April 27, 2020, 9,142 laboratory confirmed COVID-19 cases have been reported[1] in North Carolina. Reported case counts are affected by a variety of factors, including testing capacity and availability, testing strategy, and whether infected individuals are symptomatic or seek medical care. As COVID-19 testing capacity expands, the number of reported cases will increase as more are identified. The true number of infections in the population, however, remains unknown at this time.
- **How many people with COVID-19 are hospitalized?** As of April 27, there are approximately 473 people hospitalized with laboratory-confirmed COVID-19 in North Carolina.[2] The available stock of empty hospital beds fluctuates daily, and is currently approximately 8,311 statewide.[2] In the last two weeks, there have been moderate, intermittent increases in hospitalizations.[2]
- **Has the spread of the virus slowed? (i.e., have we 'flattened the curve?')** Recent trends indicate viral spread has slowed in North Carolina, as people have adhered to public health recommendations for physical (or social) distancing. One method for assessing viral spread is by examining doubling times of reported case counts in the population (a longer doubling time corresponds to slower epidemic growth). In mid-March, the total number of reported COVID-19 cases in North Carolina doubled every 2-4 days, but it slowed to a doubling time of 7-8 days in early April, and 13-14 days by April 22.[3]
- **What is the status of local outbreaks?** In recent weeks, some localities have experienced a sudden increase in reported COVID-19 cases. For example, in the 7 days prior to April 26, 2020, the statewide average of reported cases was 2.2 per 10,000 population, but Granville (21.3), Chatham (17.4), Lee (11.7), and Vance (10.8) counties all saw much higher reported cases per 10,000 population during that week.[3] Most localized outbreaks in North Carolina have

[1] Meeting the current case definition for COVID-19, for example, at least one respiratory specimen that tested positive for the virus that causes COVID-19 in a person.
[2] Data provided by NCDHHS and adjusted for hospital response percentage. For data updated daily, see: https://www.ncdhhs.gov/divisions/public-health/covid19/covid-19-nc-case-count
[3] NCDHHS provides the case data per county. Population figures are from the U.S. Census, see: https://www.census.gov/programs-surveys/popest.html

occurred in "congregate" work and residential settings (e.g., nursing homes, prisons, food processing facilities, etc.).

- **How many COVID-19-related deaths have been reported in North Carolina?** As of April 27, there have been 306 reported deaths related to COVID-19 across 64 of the State's 100 counties.[4] In recent weeks, there has been an increase in reported deaths per day. Between April 8 and April 15, there were on average 9 COVID-19 related deaths reported per day. That increased to an average of 18 COVID-19 related deaths per day between April 19 and April 26.

Tailwinds and headwinds

In light of the current situation described above, there are several tailwinds (favorable factors) and headwinds (unfavorable factors) we should keep in mind as we approach the month of May.

Tailwinds (favorable factors)

- Viral spread has slowed in North Carolina, and this is good news. A reduction was anticipated with increased implementation of effective physical distancing. Yet, the magnitude of the reduction appears even more pronounced than anticipated in early April. Consistent with findings in an April 17 brief, the healthcare system and workforce currently appear to have sufficient capacity available for COVID-19 hospital care. As the state gradually lifts stay-at-home policies, and mobility patterns and physical distancing practices change as a result, we may see increased pressure on the healthcare system; however, expected hospital demand levels appear manageable at least over the next several weeks.

Headwinds (unfavorable factors)

- COVID-19 reported cases continue to rise. Although some of this increase can be attributed to the increase in testing volume and throughput, some is likely due to continued viral transmission. As noted above, the last few weeks have been marked by infection clusters in high-risk communities such as congregate settings.
- The increase in COVID-19-related deaths is, of course, bad news. One indicator of epidemic containment will be the COVID-19-related deaths reported per day decreasing in a sustained way over several weeks. We do not appear to be there yet.
- As we have not yet achieved sustained decreases in reported cases or deaths, we must remain vigilant and continue containment efforts.

Modeling COVID-19

Background

Across North Carolina and around the world, a variety of modeling approaches and techniques are being used to assess the potential effects of COVID-19. Here, we highlight and utilize an adaptation of an agent-based model[5] that was previously developed through a partnership among RTI International, UNC Health, and the North Carolina Department of Health and Human Services (NCDHHS) and supported by a 2017 US Centers for Disease Control and Prevention grant.[6] Prior works from this model have been published[7,8] (with more forthcoming), source code documentation of the original model is posted publicly,[9] and additional documentation is added as the model is further refined.

[4] Data provided by NCDHHS . For data updated daily, see: https://www.ncdhhs.gov/divisions/public-health/covid19/covid-19-nc-case-count
[5] Agent-based models simulate the individual actions of each separate population member which can be represented using a synthetic population. See, for example, the description of RTI's synthetic United States population.
[6] This work was supported, in part, by Cooperative Agreement U01CK000527 funded by the US Centers for Disease Control and Prevention (CDC). The contents of this brief are solely the responsibility of the authors and do not necessarily represent the official views of the US CDC or the Department of Health and Human Services, or any other agency or organization.
[7] Jones K, Munoz B, Rineer J., et al. On Calibrating a Microsimulation of Patient Movement Through A Healthcare Network. Proceedings of the 2019 Winter Simulation Conference. https://www.informs-sim.org/wsc19papers/437.pdf
[8] For example, see: Rhea S, Hilsher R, Rineer J., et al. Creation of a Geospatially Explicit, Agent-based Model of a Regional Healthcare Network with Application to Clostridioides difficile Infection. August 19, 2019. Health Security. Aug 2019. 276-290. http://doi.org/10.1089/hs.2019.0021
[9] Documentation of the original model is available at: https://github.com/RTIInternational/NCMInD

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This model, originally built to evaluate interventions for healthcare-associated infection prevention in North Carolina, simulates "agent" (i.e., simulated person-level) movement among over 500 modeled healthcare facilities (i.e., hospitals and long-term care facilities) and the community in North Carolina. The model utilizes a geospatially explicit "[synthetic population](#)" of North Carolina reflecting the sociodemographic characteristics of the state's actual population. The underlying simulation of agent movement in the model is calibrated using multiple state-specific data sources and healthcare facility-specific details (e.g., geographic location, number of beds, admission rate).[10]

As the COVID-19 outbreak emerged in North Carolina in March 2020, the first steps were taken to adapt the model to the COVID-19 context, and this work continues.

Discussion of key assumptions

In this section, we highlight several of the most important parameters used for the present illustration of model forecasting using the highlighted model. We also describe how and why we have made changes to these key parameters from the previous forecast.

Number of infections

As noted above, the true number of infections in the North Carolina population remains unknown, thus making it quite challenging to estimate the number of people who may require COVID-19-related hospitalization in the future. Considering this unknown, one common modeling approach is to estimate the underlying ("true") number of infections by applying a multiplier to account for unreported cases. For example, infectious disease epidemiologists and modelers have suggested that for every one reported COVID-19 case, there could be 5 to 20 infected individuals in the population.[11,12,13] However, there is substantial uncertainty around these estimates, and they are likely variable by subpopulation and geography.

- For this brief, we tested a more modest (or optimistic) case multiplier of 10 to seed the model at the beginning of the simulation, using North Carolina county-level reported cases as of April 22, 2020.[14] In counties with zero reported cases, we assumed there was still probably at least one there, and seeded with one COVID-19 case (and nine additional infections) at the beginning of the simulation.
- Of note, this model's previous forecasts in early April assumed a higher case multiplier of 25 at the beginning of the simulation, which was based on a review of literature and consultation with other epidemiologists. The rationale for testing a lower parameter value here is described further below.

Hospitalization among infected people

- As noted above, the true number of infections in North Carolina is unknown, making it difficult to estimate the proportion of infected individuals who may require hospitalization. Older adults and people with underlying health conditions are among those at highest risk for COVID-19 complications and hospitalization. However, detailed data on hospitalization by underlying health status are not readily available.
- Researchers from other jurisdictions have assumed that 4.4% of infected people require hospitalization, on average.[15] For this reason, the model used this 4.4% figure in the [April 6 brief](#). There are a variety of reasons why the actual overall proportion of hospitalization among infected people could be lower than 4.4%.

[10] For example, we use data published on the NCDHHS website to estimate available hospital capacity.
[11] Li R, Pei S, Chen B., et. al. Substantial Undocumented Infection Facilitates the Rapid Dissemination of Novel Coronavirus (SARS-CoV2). March 16, 2020. https://science.sciencemag.org/content/early/2020/04/24/science.abb3221
[12] Coronavirus Could Overwhelm U.S. Without Urgent Action, Estimates Say. New York Times. March 20, 2020. https://www.nytimes.com/interactive/2020/03/20/us/coronavirus-model-us-outbreak.html
[13] To know the real number of coronavirus cases in the US, China, or Italy, researchers say multiply by 10. Business Insider. April 19, 2020. https://www.businessinsider.com/real-number-of-coronavirus-cases-underreported-us-china-italy-2020-4
[14] A multiplier of 10 means for every laboratory-confirmed COVID-19 case reported to public health authorities, we modeled nine additional undiagnosed and unreported infections at the beginning of the simulation.
[15] Ferguson NM, Laydon D, Gemma NG., et al. Impact of NPIs to reduce COVID-19 mortality and healthcare demand. March 16, 2020. https://www.imperial.ac.uk/media/imperial-college/medicine/sph/ide/gida-fellowships/Imperial-College-COVID19-NPI-modelling-16-03-2020.pdf

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- For purposes of illustration in this brief, therefore, we tested an assumption that 2.2% of infected people may eventually require hospitalization (i.e., half of the commonly-referenced 4.4% value noted above). We continue to assume 14-day length of stay for hospitalized agents with COVID-19.[14,16] Among these hospitalized agents, we also continue to assume 30% require ICU-level care.[14]

Viral spread

To simulate the "spread" of the virus for modeling purposes, various methods can be used, including a doubling time parameter for new infections. The doubling time can be mathematically converted to an approximate effective reproductive number (R_e).[17] R_e is an epidemiologic metric used to describe the contagiousness of an infectious pathogen. Similar to R_0, R_e is a measure of transmissibility; the higher number, the higher the transmissibility and the faster an epidemic will progress. In particular, R_e considers 1) how long a person is contagious, 2) how likely it is that transmission occurs between two people if one of them is infected, 3) the rate at which people contact each other, and 4) the proportion of the population that is susceptible. The incorporation of this 4th factor differentiates R_e from R_0.

- For purposes of illustration in this brief, we assume that under a phased-reopening plan, people would come into more frequent contact with each other and the R_e may increase. However, it is very challenging in the near term to project the precise magnitude by which R_e will change in a phased reopening that could result in, for example, some people shopping in stores or going to parks more frequently. Additionally, R_e varies across populations and geographies. Therefore, our approach is to select several ranges of R_e to illustrate the effects on forecasted outcomes.
- We converted the model's doubling time parameter for new infections to an approximate R_e (based on an infectious period of 14 days) which was scaled over time to represent a reduction in susceptible agents (i.e., people).
- R_e values were sampled from a uniform distribution more than 100 times each across three ranges:

1) lower transmission, represented by the range of R_e: 0.9-1.3,

2) moderate transmission, represented by the range of R_e: 1.3-2.0, and

3) higher transmission, represented by the range of R_e: 2.0-2.5.

- Note that the lowest R_e range above is lower than the assumptions used in the "Maintain" scenario in the prior April 6 brief, reflecting our sense that, presently, viral spread may be lower than previously anticipated.

The reductions in the case multiplier and hospitalization parameters, as compared to those used in the April 6 brief, were not due to newly-available insights about the true value of these parameters relative to what is already in the published literature.

Rather, we wanted to test the likelihood that modeling under more optimistic parameter assumptions than currently used by other modelers would still lead to similar conclusions about the potential COVID-19 impact to the healthcare system under circumstances of reduced physical distancing. That is, would the updated results, modified by more optimistic parameter assumptions, still imply that caution during reopening is warranted? Or, rather, would the updated results show ample hospital capacity, such that it wouldn't be exceeded even if demand on the healthcare system increased under a hypothetical version of rapid, full reopening that significantly increased viral transmission?

By illustrating how these modified parameters influence forecasted outcomes, we thus update the April 6 results and also offer a simple sensitivity and uncertainty analysis, particularly about scenarios in which levels of demand for hospital beds (ICU beds in particular) could reach or exceed the limit of available capacity under various conditions.

[16] Zhao W, Yu S, Zha X., et al. Clinical Characteristics and Durations of Hospitalized Patients with COVID-19 in Beijing: a Retrospective Cohort Study. March 17, 2020. https://doi.org/10.1101/2020.03.13.20035436

[17] $T_d = ((\ln 2)/(R_e - 1)) \times D$, where T_d is the doubling time and D is the duration of the infectious period.

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Simulation output

In Exhibit 1, at right, we show estimated cumulative infections using three different ranges of R_e, depicted with three different colors. These are estimates of the true number of infections under the given assumptions: both reported cases and unreported illnesses, including mild illnesses as well as asymptomatic infections.

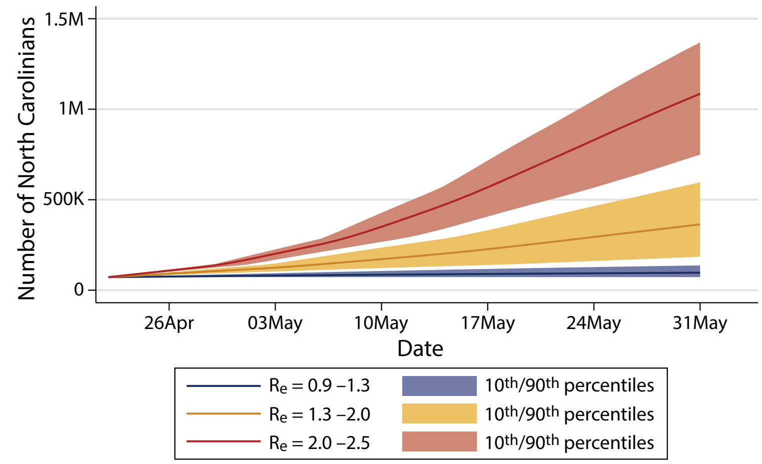
When R_e is sampled from a range of 0.9-1.3, in the blue region, the model estimates the number of infections to be between 75,000 and 150,000 by the end of May.

When R_e is sampled from a range of 1.3-2.0, in the yellow region, the model estimates 330,000 infections in North Carolina by the end of May, with a 10th to 90th percentile range of 185,000 to 596,000. Again, these are estimates of the *true number of infections* (inclusive of both confirmed and reported cases as well as unreported illnesses).

When R_e is sampled from a range of 2.0-2.5, in the red region, the model estimates approximately 720,000 more infections over the yellow region estimates. This illustrates the pronounced impact that higher effective reproductive numbers (representing increased viral spread) could have in a large population over a relatively short amount of time. As noted in a previous brief, even if a very small percentage of these infected individuals require hospitalization, it could create substantial pressure on the healthcare system and workforce in a compressed time period.

To be clear (discussed below), we do *not* believe we are presently on the 2.0-2.5 (red) trajectory; we include this scenario merely to depict the potential impact of a higher range of R_e compared to a lower range of R_e, even with the relatively optimistic case multiplier and hospitalization proportion assumptions incorporated here.

Exhibit 1 Estimated Cumulative SARS-CoV-2 Infections (Reported and Unreported) for Three Modeled Scenarios

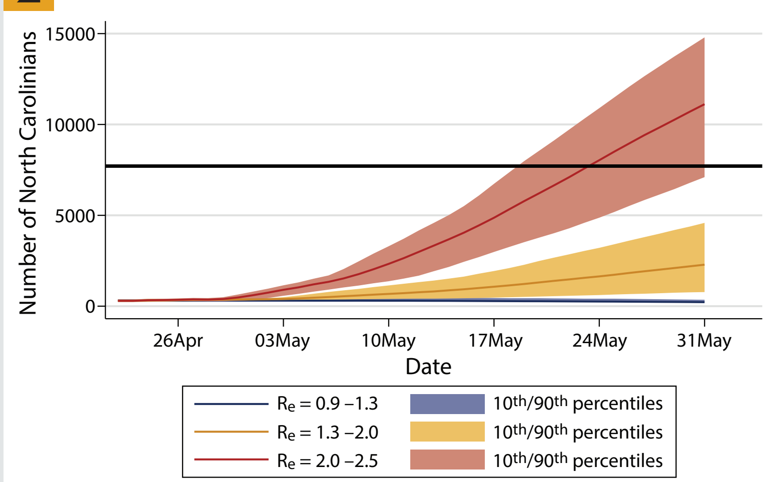


Models assuming 10x (#cases / #diagnosed) multiplier.

Exhibits 2 and 3, below and next page, depict the consequences of the Exhibit 1 infection forecasts on numbers of hospitalizations under different R_e ranges, given the illustrative assumption that approximately 2.2% of infected agents eventually require hospitalization. The solid black lines indicate the threshold of North Carolina hospital capacity at the time of the model run as given by a nightly survey conducted by NCDHHS of North Carolina hospitals, adjusted for the hospital response rate.

In Exhibit 2, only the projection using the highest R_e range indicates stress on acute bed capacity. The projections using the lower two R_e ranges (blue and yellow) forecast minimal stress on the aggregated acute bed capacity in North Carolina during the month of May.

Exhibit 2 Acute Bed Demand Estimates for Three Modeled Scenarios



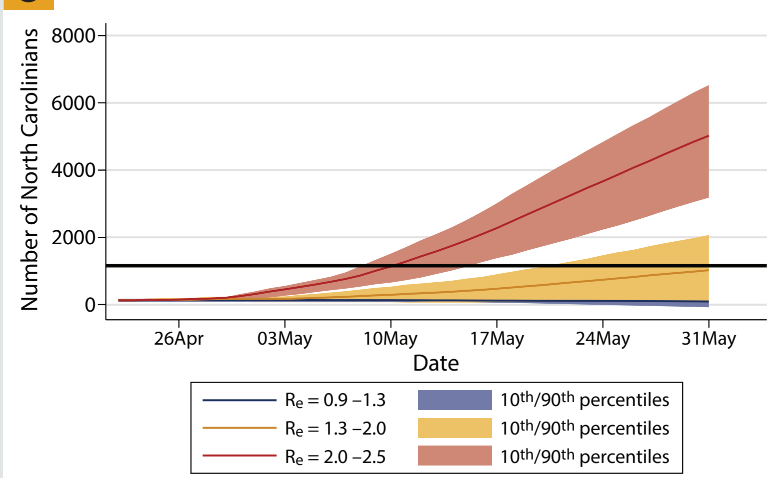
Models assuming 10x (#cases / #diagnosed) multiplier.
Thick black line = current estimated capacity.

However, in Exhibit 3, the projection using the middle R_e range (yellow), sampling between 1.3-2.0, joins the projection using the higher R_e range (red) in forecasting ICU demand that could reach or exceed supply by the end of May. For the middle R_e range, this is shown by the overlap of the solid black line of ICU capacity with the yellow-shaded 10th to 90th percentile region.

The projection using the middle R_e range (representing moderate viral spread) anticipates hitting ICU capacity even after we made optimistic assumptions, relative to prior estimates, for the case multiplier and hospitalization proportion among infected people.

Therefore, though ICU capacity appears sufficient in the near term, this modeling illustration shows a plausible scenario of pressure on healthcare capacity if a higher R_e range turns out to reflect the ground truth of viral transmission, assuming the other parameters are reasonable.

Exhibit 3 ICU Bed Demand Estimates for Three Modeled Scenarios



Models assuming 10x (#cases / #diagnosed) multiplier.
Thick black line = current estimated capacity.

Where are we now?

Which of these scenarios is more likely in May? We cannot answer with certainty. However, we offer a few observations:

In the near term (the next few weeks), the red color-coded projections associated with higher R_e ranges are *not* likely in line with current ground truth, as they don't align with results from other near-term forecasting methods.[18] Despite uncertainties regarding key modeling parameters like the true number of infections and the proportion of hospitalization among infected people, there are several reasons why we reach this conclusion:

- First, as noted, we will likely begin the month of May with lower-than-expected viral spread, possibly even lower than modeled in the "Maintain" scenario in the first brief on April 6. This good news has kept hospitalizations somewhat lower than previously predicted.
- Second, the announced gradual reopening plan is a phased approach, which could lead to a less dramatic increase in viral transmission than than a full and immediate reopening.
- Third, as outlined in the second brief on April 17, North Carolina has immediate and near-term hospital capacity available. It is quite unlikely we will see the kind of short-term hospitalization growth rates necessary to put our healthcare system in serious crisis within 4 weeks of today, especially given a phased reopening strategy.

Despite these notes of near-term optimism, it is very important to avoid a sense of complacency about the potential impact of COVID-19. As we also stated earlier, we remain in a critical stage of a dangerous, highly infectious epidemic, with some localized outbreaks occurring among particularly at-risk populations and settings. We further note that even when we significantly modify key parameter assumptions from those used in the April 6 brief, resulting in more optimistic projections, we still reach a similar conclusion about caution being warranted during reopening to help avoid potential pressure on healthcare capacity. This is most clearly evident in the yellow color-coded projection of ICU bed demand in Exhibit 3.

[18] For example, the synthetic control group near-term forecasting method referenced in the April 6 brief.

As the state continues to expand the scale of its public health response (e.g., testing, contact tracing, etc.), we must continue to monitor short-term COVID-19 trends and act quickly to mitigate rapid upswings if confirmed case count and hospital demand start to rise even more substantially in the coming days and weeks.

Going forward, the model highlighted in this brief will be used to furnish detailed results to NCDHHS. Given the many uncertainties described above, the approach to reporting model forecasts will include a range of estimates at state and regional levels with several varying parameter values (similar to our approach in this brief) to produce standard output (e.g., cumulative infections, hospitalizations, etc.) updated on a regular basis. This process will begin in the near term and will inform statewide and regional capacity planning.

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