The Impact of Social Distancing on COVID19 Spread: State of Georgia Case Study

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Text: 2,848 words

KEY POINTS

Question: How social distancing strategies impact the spread of COVID19?

Findings: Extending shelter-in-place by one week delays the peak by about 8 days but it does not significantly reduce the peak. High compliance with voluntary quarantine following shelter-in-place reduces the peak by 40% in Georgia.

Meaning: There needs to be a very strong public messaging about social distancing when shelter-in-place is lifted, to achieve a better match between healthcare capacity and demand, considering different peak times across the communities.

ABSTRACT

Importance As the COVID19 spread in the US continues to grow, local and state officials face difficult decisions about when and how to transition to a "new normal."

Objective Project the number of COVID19 infections and resulting severe outcomes, and the need for hospital capacity under social distancing, particularly, shelter-in-place and voluntary quarantine.

Design We developed an agent-based simulation model to project the infection spread. We populated the model using COVID19-specific parameters for the natural history of the disease and data from Georgia on agents' interactions and demographics.

Setting The simulation study covered a six-month period, testing different social distancing scenarios, including baselines (no-intervention or school closure only) and combinations of shelter-in-place and voluntary quarantine with different timelines and compliance levels. The outcomes are compared at the state and community levels.

Main Outcomes The number and percentage of cumulative and daily new and symptomatic and asymptomatic infections, hospitalizations, and deaths; COVID19-related demand for hospital beds, ICU beds, and ventilators.

Results The combined intervention of shelter-in-place followed by voluntary quarantine reduced peak infections from 180,000 under no intervention and 120,000 under school closure, respectively, to below 80,000, and delayed the peak from April to June or later. Increasing shelter-in-place duration from four to five weeks yielded 3-14% and 4-6% decrease in cumulative infection and fatality rates, respectively. Regardless of the shelter-in-place duration, increasing voluntary quarantine compliance decreased daily new infections from almost 80,000 to 50,000, and decreased cumulative infection rate by 50%. The total number of fatalities ranged from 6,150 to 17,900 under different scenarios. Peak infection date varied across scenarios and counties; on average, increasing shelter-in-place duration delayed the peak day by 7 days across counties. The peak percentage is similar across rural and urban counties. Region D is estimated to have the highest COVID19-related healthcare needs with 7,357 hospital beds, 1,141 ICU beds, and 558 ventilators.

Conclusions and Relevance Shelter-in-place followed by voluntary quarantine substantially reduce COVID19 infections, healthcare resource needs, and severe outcomes; delay the peak; and enable better preparedness. Time of the peak is projected to vary across locations, enabling reallocation of health system capacity.

INTRODUCTION

The novel coronavirus SARS-CoV-2 causes a rapidly spreading respiratory illness, Coronavirus Disease 2019 (COVID19), which has become a pandemic [1]. During the early stages of a pandemic, medical interventions, such as vaccines or antiviral treatments, are either non-existent or extremely limited [2]. Hence, local, national, and global governments and public officials wrestle with the difficult decisions of how, when, and where to implement non-medical interventions [3]. The decision-makers also need to understand how the type and duration of interventions, as well as the public's compliance levels, impact their effectiveness [4].

In this study, we developed an agent-based simulation model to predict the spread of COVID19 geographically and over time. The model captures both the natural history of the disease and interactions in households, workplaces, schools, and communities [5-9]. The model was populated with COVID19 parameters from the literature and population-related data from the state of Georgia, including demographic information, household sizes, and travel patterns, and validated using data regarding COVID19 confirmed cases and deaths in Georgia. The model's outputs include new daily infections (symptomatic and asymptomatic by age group), hospitalizations, and deaths at the census tract level.

We utilized the model to evaluate the effectiveness and impact of non-medical social-distancing interventions, including school closure, shelter-in-place (SIP), and voluntary quarantine (VQ) [6,10-16]. We tested various scenarios with different durations and time-varying compliance levels for interventions to inform decision-makers about potential social distancing recommendations to be shared with the public. We also developed a hospital resource estimation decision-support tool, which takes as input the model's daily COVID19-related hospitalization estimates, and predicts the number of hospital beds, ICU beds, and ventilators needed geographically (at the county level) and over time. We then aggregated these estimates across the fourteen coordinating hospital regions in GA, to provide insights about potential capacity shortages in the healthcare system[17].

METHODS

Study population

Population in Georgia stratified by age groups 0-4, 5-9, 10-19, 20-65, 65+.

Case Projection Model

We adapted an agent-based simulation model with heterogeneous population mixing to predict the spread of the disease geographically over a period of six months [5-8]. The model captures the natural history of the disease at the individual level, by age group, as well as the infection spread via a contact network consisting of interactions in households, peer groups (workplaces, schools), and communities, with different rates of transmission [13,18-23].

The model was populated with COVID19-specific parameters [18-20,24-38] and data from Georgia, including household type[1], household size[1], children status[1,2], workflow[3] and population demographics[1] at the census tract level. To seed the model, we utilized the confirmed case data for Georgia, at the county level[4].

Outcome measures reported are averages of 30 replications ran for each scenario. *Online-Supplement A* provides additional details on the model implementation. *Online-Supplement Table A1* provides the input model parameters.

Intervention Analysis

Social-distancing is a non-medical intervention which reduces the interactions in a population. The following are analyzed in our study:

1. *No intervention (NI)* – the population interacts with each other normally; nothing prevents peer-to-peer interaction;

2. *School Closure (SC)* – no peer-group interactions among children (i.e., no K-12 school interactions);

3. *Voluntary Quarantine (VQ)* – All household members stay home if a member experiences symptoms, until the entire household is symptom-free.

4. *Shelter-in-Place (SIP)* – Household members stay home.

[1] Source: U.S. Census Bureau; American Community Survey, 2017 American Community Survey 5-year Estimates (data.census.gov)
[2] Source: U.S. Census Bureau; 2010 Census Summary File 1 (data.census.gov)
[3] Source: U.S. Census Bureau; Census Transportation Planning Products, 5-year data (2012-2016) (http://data5.ctpp.transportation.org)
[4] Source: The New York Times (https://github.com/nytimes/covid-19-data)

Household members following SIP or VQ do not engage in peer group or community interactions. Compliance levels (<100%) under SIP and VQ probabilistically determine individual compliance and corresponding social interactions.

NI and SC were considered as *baselines* for comparison. In scenarios 1-9, SIP durations (4, 5, and 6 weeks) and gradually decreasing post-SIP VQ compliance levels (low, medium, high) were tested (*Figure 1); s*helter-in-place was in effect for 4 weeks (April 3-April 30) in Georgia [39]. Because all K-12 schools in Georgia were closed starting March 16th until the end of July, Scenarios 1-9 assumed school closure.

Healthcare Resource Needs Projection Model

The hospitalization output from the simulation model was further used to estimate the daily demand for hospital beds, intensive care unit (ICU) beds, and ventilators for COVID19 patients. Daily hospital bed demand was calculated by aggregating the number of hospital beds needed in the previous day with the number of new hospitalizations, minus the proportion of the population that was discharged from the hospital based on the average hospitalization duration. ICU bed and ventilator demand were estimated using the percentage of hospitalizations that require ICU (by age), average ICU duration, percentage of ICU patients that require ventilation, and the average ventilation duration.

We derived county-level risk factors (see *Online-Supplement Figure A2*) by applying the principal component analysis on several factors known to impact a higher risk of complications and severe outcomes for COVID19 infections, including prevalence of asthma, diabetes, obesity, smoking, cardiovascular disease and chronic conditions in general [40]. We then adjusted the estimated demand using these risk factors.

Online Supplement A provides additional details on the estimation approach and the input model parameters along with their references.

Outcome Measures

The outcome measures considered in this study include:

- *New Infection Count (NIC):* number of new daily symptomatic and asymptomatic infections.
- *Infection attack rate (IAR):* cumulative percentage of the population infected.
- *Peak infection (PI):* maximum percentage of the population infected on a given day, within a time period.
- *Peak day*: The day when NIC is highest.
- *Clinical attack rate (CAR):* percentage of symptomatic cases among the total population.
- *Infection severe outcome rate (ISOR):* cumulative percentage of hospitalizations among the infected.
- *Infection fatality rate (IFR):* cumulative percentage of mortality among the infected.
- *Hospital Bed Demand (HB):* number of hospital beds needed due to severe outcomes among the infected.
- *Intensive Care Unit Bed Demand (ICUB):* number of ICU beds needed due to severe outcomes among the infected.

- *Ventilator Demand (V):* number of ventilators needed due to severe outcomes among the infected.

RESULTS

State-Level Outcome Measure Analysis

Figure 2 shows the NIC outcome for Scenarios 1-9. *Table 1* includes summaries across all scenarios and outcomes. *Online-Supplemental Figures B1-B3* provide state-level outcomes for scenarios 1-9.

The estimates provided were based on the Georgia population of approximately 10,519,000[5].

The maximum NIC was 180,000 (April 18th) and 120,000 (April 24th) under NI and SC, respectively. Under Scenarios 1-9, the maximum NIC was below 80,000, with the earliest peak in June. Compared to NI and SC, in scenarios 1-9 NIC was at least 28% and 17% lower, and 1,890,260 and 966,700 fewer people infected, respectively. Extending SIP by 1-2 weeks or following SIP by high VQ further reduced NIC and delayed the peak day.

Similar trends were observed for CAR, with the number of symptomatic cases reducing significantly, at least 28% and 17%, compared to NI and SC, respectively.

Increasing the SIP duration from four to five weeks (i.e., extending by one week) yielded 3-14% decrease in IAR and CAR, approximately 2% in ISOR and 4-6% in IFR.

[5] Source: U.S. Census Bureau; American Community Survey, 2018 American Community Survey 1-year Estimates (data.census.gov)

Increasing the SIP duration from five to six weeks (i.e., extending by two weeks) yielded 7-18% decrease in IAR, 1-2% in ISOR, and 1-8% in IFR.

Higher VQ compliance after SIP, regardless of the SIP duration, decreased the peak NIC from almost 80,000 to 50,000 and decreased IAR by up to 50%.

SC had a lower IAR outcome than NI, but with small differences in severe outcomes (IFR and ISOR). Healthcare resource demand estimates (HB, ICUB, and V) decreased by about 25% from NI to SC. Approximately 28,490 and 24,550 people in GA would die, and approximately 223,090 and 198,900 people would be hospitalized under NI and SC, respectively.

The total number of deaths for Scenarios 1-9 ranged from 6,150 (Scenario 9) to 17,900 (Scenario 1); the number hospitalized was between 63,900 (Scenario 9) and 162,200 (Scenario 1); peak hospital bed needs ranged from 11,064 (Scenario 9) to 24,880 (Scenario 1). Peak ICU bed and ventilator needs ranged from 1,874 (Scenario 9) to 3,918 (Scenario 1) and from 944 (Scenario 9) to 1,923 (Scenario 1), respectively. Scenario 9, where SIP extends up to at least mid-May followed by high VQ, provided the lowest IFR and ISOR. IFR and ISOR follow similar patterns among all scenarios except for the baselines.

Infection Spread Outcome Measure Analysis by County

Tables B1-B2 include the estimated peak day and percentage by county across all scenarios. *Figure B4* includes the maps of the NIC by county for different dates.

Peak infection date varied across scenarios and counties; however, on average, increasing SIP duration by one week moved the peak day by 7 days across counties. Due to their population size, most populated counties (e.g., Fulton, Gwinnet, Cobb, DeKalb, Chatham) delayed their peak day by an average of 8-9 days with each week of SIP extension. Smaller counties (e.g., Glascock, Clay, Webster, Quitman, Taliaferro) delayed their peak day by an average of 3-4 days. Increasing VQ compliance from low to medium and from medium to high delayed the peak day by an average of 9 and 16 days, respectively. In most scenarios, rural counties peaked on average 5 days later compared to urban counties. Differences in the peak day observed in rural and urban counties was consistent across all scenarios.

PI fluctuated depending on SIP duration. Rural counties and urban counties did not differ much in terms of PI. See *Online-Supplement A* for examples of an analysis of urban and rural counties in GA.

The concentration of NIC was in the densely populated Fulton county and other surrounding counties in the Atlanta metropolitan area across all scenarios. The counties with the latest peak day were in the southwest and eastern counties. The following counties also saw large increases in NIC as compared to surrounding counties: Chatham, Columbia, Richmond, Houston, Bibb, Dougherty, Lowndes, and Muscogee.

Healthcare Resource Needs Analysis by Coordinating Hospital Region

Figure 3 presents the healthcare resource peak demand under Scenario 2, by hospital region. (A map of the Georgia hospital regions is provided in *Figure B5.*) *Figure 4* shows hospital and ICU bed needs over time for region N under Scenario 2. Similar patterns are seen for other scenarios.

The highest need for COVID19-related healthcare resources was in region D, with 7,357 hospital beds, 1,141 ICU beds, and 558 ventilators. Region D includes three of the top four populous counties in Georgia. The four regions with the highest need across all outcomes were regions D, F, J, and N, which are regions that include populous counties.

There is a gap between HB and ICUB demand and availability in many regions. For example, consider region N under Scenario 2. The peak hospital bed need for COVID19 patients occurred on July 15th with a demand of 2,704 beds, yet hospital bed availability for all (including non-COVID19) patients is 1,692. Peak ICU bed demand for COVID19 patients was 425 also occurring on July 15th whereas availability for all patients is 157.

DISCUSSION

During the early phases of a pandemic, in the absence of a vaccine or effective treatments, non-medical interventions are of utmost importance. During COVID19, the majority of schools in the US closed around mid-March for the remainder of the school year [41], and governors issued shelter-in-place orders [42] during March or April. Many states are now considering ending shelter-in-place orders towards the end of April or early May, given the financial, social, and psychological impacts of shelter-in-place. For example, in Georgia, schools closed on March 16th [43], shelter-in-place orders were issued on April 3rd, transitioning out of shelter-in-place started on April 24th [44], and shelter-in-place is planned to end on April 30th. In this paper, we analyzed the impact of shelter-in-place duration and social distancing compliance levels, particularly voluntary quarantine, using data from Georgia.

For baseline comparisons, we ran two scenarios: no intervention and school closure only. We tested nine intervention scenarios, assuming school closures starting on March 16th, followed by shelter-in-place on April 3rd. In these nine scenarios, we modeled a slowly decreasing social distancing compliance prior to school closures, shelter-in-place durations of 4-6 weeks, and voluntary quarantine compliance levels of low, mid, and high after the end of shelter-in-place. The timeline ended mid-August, given the high uncertainty about various factors beyond August.

Compared to scenarios 1-9, infections are higher in the baseline scenarios, with peak infections occurring around mid-to-late April. Scenarios 1-9 show that shelter-in-place could significantly slow down the disease spread, protecting public health, and offering the opportunity for better preparedness of healthcare resource capacity. Each week extension of shelter-in-place (beyond 4 weeks) could delay the peak day by about 8 days.

Social distancing (modeled by voluntary quarantine compliance) showed a significant impact on all outcome metrics, particularly, peak day and peak infections. Depending on social distancing compliance levels, the peak infections under low compliance levels could exceed 70,000. State level peak percentage could also decrease significantly as the voluntary quarantine compliance increases, observing the same effect of post shelter-in-place compliance at the county level as well.

After shelter-in-place ends, voluntary quarantine compliance also demonstrated to have a significant impact on COVID19-related deaths, which could approach 18,000 by the end of July in the case of low compliance. The death numbers could be even higher because the demand would significantly exceed healthcare capacity, especially around the peak.

Infection spread across counties varied over time, with earlier peak days in some counties compared to others, which impacts resource allocation decisions across the state. For example, in Scenario 2 (shelter-in-place 4 weeks, medium voluntary quarantine compliance after shelter-in-place), several of the larger counties could reach their peak around early July, with the peak days of other counties extending to late July or early August. Similarly, there was a variation among counties in terms of the peak infection percentage under different voluntary quarantine compliance levels.

Estimates for COVID19-related needs for hospital beds, ICU beds, and ventilators suggested shortages in all scenarios across the 14 coordinating hospital regions in Georgia. Even if all available hospital resources were used for COVID19 patients, at the peak, these resources would still not be sufficient for most of the regions. In some regions, the shortage would continue for several weeks. These results further emphasize the importance of shelter-in-place and high compliance levels for social distancing after the end of shelter-in-place.

During shelter-in-place, the percentage of the population staying at home was directly correlated with the compliance level, e.g., when 80% of the population complies with shelter-in-place, 80% stays home at a given time. The withdrawal of a large percentage of the population from interactions raises social and economic concerns. By contrast, stay-at-home rates were significantly lower under voluntary quarantine, even under high compliance levels. For example, during the week following a four-week shelter-in-place, only 3% of the population stayed home when voluntary quarantine compliance is 80% (Scenario 3). If voluntary quarantine compliance is increased to 100% during the peak week in the same scenario, only 8.4% of population stayed home. Hence, voluntary quarantine is an effective intervention when compliance levels are high, but significantly less disruptive than shelter-in-place.

Another important advantage of voluntary quarantine is the ease of communication and implementation. When COVID19 diagnostic testing capacity is limited, voluntary quarantine can be implemented based on symptoms. Household members are advised to stay home if there is a person with cold- or flu-like symptoms in the household (even in the absence of testing or confirmation of COVID19), until the entire household is symptom-free. High compliance with voluntary quarantine would reduce not only the spread of COVID19 but would have the side benefit of also reducing the spread of the cold or flu.

Limitations

Most of the limitations of this study lie in the limited data available on the behavior of COVID19 infection and transmission, and the related parameters, which impact the natural history and severe outcomes for the projected period. Testing of various scenarios allowed us to better understand the impact of social distancing compliance on the projections of COVID19 outcomes.

Conclusions

As states plan to transition out of shelter-in-place, our results suggest that there needs to be a very strong messaging to the public about social distancing. It is important to re-emphasize that some people might be infected with little or no symptoms and infect others [45]. Voluntary quarantine is one form of social distancing that is easy to communicate. While voluntary quarantine reduces infection spread (both from symptomatic and asymptomatic individuals), it does not prevent it. There may be households with COVID19 infection, and yet no household member might be experiencing symptoms – these households would not be impacted by voluntary quarantine. Therefore, while it is essential to promote voluntary quarantine, strongly encouraging households to continue voluntary shelter-in-place, to the extent possible, or other forms of social distancing would help slow the spread of COVID19. It is also important to enact policies and guidelines for promoting voluntary quarantine at the local and national levels. Without such policies, compliance will be low and hence, such interventions will become quickly ineffective.

Acknowledgement

Author Contributions: Professors Pinar Keskinocak and Nicoleta Serban had access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

Study concept and design: Keskinocak had provided the guidance and supervision for the study concepts and design.

Acquisition of data: All authors have participated in the data acquisition.

Analysis and interpretation of data: All authors have participated in the analysis and interpretation of the data.

Drafting of the manuscript: All authors have contributed to the drafting of the manuscript.

Critical revision of the manuscript for important intellectual content: Keskinocak and Serban provided the critical revisions of the manuscript for important intellectual content.

Statistical analysis: All authors have contributed to the statistical analysis.

Obtaining funding: Keskinocak and Serban obtained the funding for the research.

Supervision: Keskinocak and Serban supervised the research project.

Conflicts of Interest Disclosures: The authors do not have conflict of interest to disclose.

Sources of Funding and Support: The research was supported by the William W. George and by the Virginia C. and Joseph C. Mello endowments at Georgia Tech. This research was supported in part by NSF grant MRI 1828187 and research cyberinfrastructure resources and services provided by the Partnership for an Advanced Computing Environment (PACE) at the Georgia Institute of Technology.

Additional Contributors: The authors of this paper are thankful to state representatives for sharing multiple data sources from the cases confirmed in Georgia to date. The authors are also thankful to Melody Shellman, Hannah Lin, Ethan Channel, Pravara Harati, Zhuoting April Yu, and Christopher Stone for supporting various parts of the projects.

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Figure 1: *Description of the intervention scenarios considered in this study along with their scenario number referred in the Results Section.*

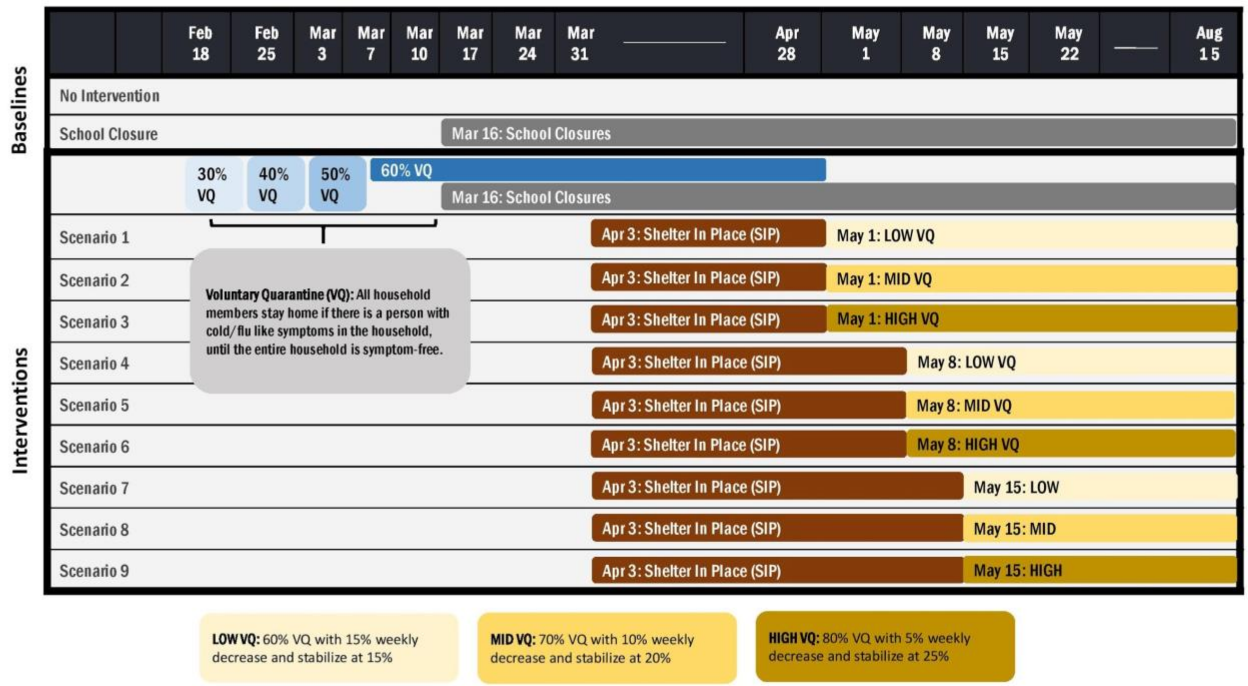

Table 1: *State-wide outcome measures: Statistical Summaries that compares Baseline and Intervention scenarios with respect to Peak Infection (%), Peak Day, Number of Peaks, IAR (%), CAR (%), ISOR (%), IFR (%), Peak HB, Peak ICUB, and Peak V.*

	Peak Infection (%)	Peak Day	Number of Peaks	IAR (%)	CAR (%)	ISOR (%)	IFR (%)	Peak HB	Peak ICUB	Peak V
No Intervention	1.82	18-Apr	1	63.58	41.33	3.44	0.426	51,492	8,157	4,097
School Closure	1.22	24-Apr	1	54.80	35.61	3.55	0.427	38,097	6,068	3,012
Scenario 1	0.76	30-Jun	2	45.61	29.45	3.48	0.385	24,880	3,918	1,923
Scenario 2	0.65	10-Jul	2	41.42	26.63	3.43	0.363	21,374	3,356	1,638
Scenario 3	0.45	6-Aug	2	28.09	17.73	3.26	0.324	15,124	2,383	1,164
Scenario 4	0.76	11-Jul	2	44.19	28.42	3.43	0.362	24,690	3,897	1,915
Scenario 5	0.64	20-Jul	2	38.68	24.70	3.36	0.340	21,269	3,336	1,629

Scenario 6	0.47	15-Aug	2	24.25	15.19	3.19	0.309	14,142	2,256	1,120
Scenario 7	0.74	19-Jul	2	40.99	26.17	3.37	0.336	24,131	3,822	1,882
Scenario 8	0.65	30-Jul	2	38.24	24.51	3.29	0.313	21,397	3,373	1,648
Scenario 9	0.44	15-Aug	2	19.81	12.33	3.16	0.305	11,604	1,874	944

Figure 2: *State level Outcomes:* ***(a)*** *Daily new COVID19 infections under all scenarios including baseline (top left plot),* ***(b)*** *Daily new COVID19 infections when 4-week SIP followed by Low (Scenario 1), Medium (Scenario 2), High (Scenario 3) VQ compliance (top right plot),* ***(c)*** *5-week SIP followed by Low (Scenario 4), Medium (Scenario 5), High (Scenario 6) VQ compliance (bottom left plot),* ***(d)*** *6-week SIP followed by Low (Scenario 7), Mid (Scenario 8), High (Scenario 9) VQ compliance (bottom right plot).*

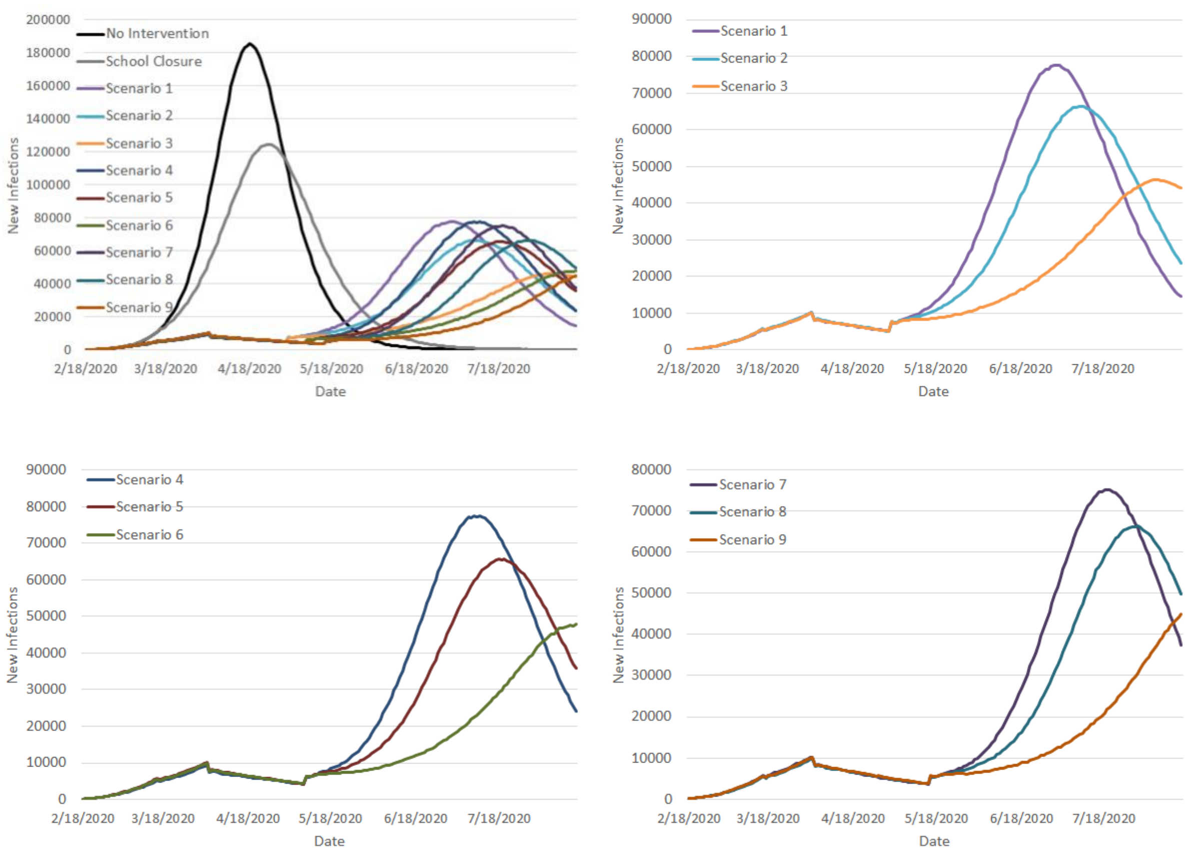

Figure 3: *COVID19-related hospital bed (top left plot), ICU bed (top right plot), and ventilator (bottom center plot) peak needs for 4-week SIP, Medium VQ compliance post-SIP (Scenario 2)*

Figure 4: *COVID19-related hospital bed (left plot) and ICU bed (right plot) needs over time for region N under 4-week SIP, Medium VQ compliance post-SIP (Scenario 2)*