Proceedings of the 2020 Winter Simulation Conference
K.-H. Bae, B. Feng, S. Kim, S. Lazarova-Molnar, Z. Zheng, T. Roeder, and R. Thiesing, eds.

UTILIZING BAYESIAN METHODS FOR COVID-19 FORECAST AND STATISTICAL INFERENCE

Gary Lin
Alisa Hamilton
Yupeng Yang
Oliver Gatalo
Eili Klein

Center for Disease Dynamics, Economics & Policy
962 Wayne Ave, Suite 530
Silver Spring, MD 20910, USA

Anindya Bhaduri

Department of Civil and Systems Engineering
Johns Hopkins University
Baltimore, MD 21218 USA

ABSTRACT

Given the continued threat of COVID-19, policymakers rely on computational models to provide statistical forecasts of deaths, hospitalizations, and case counts in order to make large-scale decisions. Another utility of models is to determine the impact of policy decisions on mitigating spread and hospitalizations. Bayesian methods achieve these objectives by providing likely forecast trends while also allowing for inference on parameters that are fitted to actual data. We utilized a data-driven, compartmental model to forecast COVID-19 trends and conduct inference on parameter values that directly translate to policy decisions. Additionally, we can use Bayesian inference to quantify the uncertainty in the parameter estimation as well as forecasted trends that can inform testing strategies and future data collection efforts.

1 INTRODUCTION

Coronavirus Disease 2019 (COVID-19) has now spread to all 50 states and DC, with the country as a whole witnessing over 7 million confirmed cases and nearly 205,000 related deaths as of September 28th, 2020 (Dong et al. 2020). Forecasting the epidemiological trajectories of COVID-19 is crucial for aiding policy-makers in devising appropriate policies. While National and State government policies drive the overall response, knowing where to allocate resources and how to support local decision-makers who are often tasked with implementing decisions, is crucial, particularly for estimating the demand for critical services (Barrett et al. 2008).

Many models with varying conceptual structures have emerged to predict the number of hospitalizations and deaths, thus creating a challenge for concise forecasting. Attempts at consolidating existing models to provide a consensus-based forecast have emerged, most notably the US Forecast Hub (Ray et al. 2020). As cases in the US continue to rise, the need for robust predictions of cases, and more importantly, hospitalizations will be of value. With any prognostication of outcomes, however, errors will inevitably arise from the model predictions and the need for uncertainty and error quantification will benefit the decision-making process. Understanding the potential impact of the disease allows decision-makers to weigh the impacts of their intervention or policy choices.

2 METHODOLOGY

We used the classical compartmental model by Kermack and McKendrik to construct a differential equation-based model to capture the epidemiological dynamics of COVID-19. We then conducted Bayesian analysis using Markov Chain Monte Carlo (MCMC) methods, specifically a Hamiltonian Monte Carlo (HMC) to sample the posterior distribution of the parameter values. To aid decision-makers, we developed a model to forecast cumulative and daily peak hospitalizations, confirmed cases, and deaths in all 50 states as well as more localized county-level forecasts for 3,141 counties in the US. We fitted our model to cumulative confirmed case and death data from the Johns Hopkins Center for Systems Science and Engineering COVID-19 dashboard (Dong et al. 2020) and hospitalization data from the COVID-19 Tracking Project (2020) for each state from January 22nd to August 9th. State populations were based on estimates from the US Census Bureau (2018). In order to scale up computational capacity, we utilized Amazon Web Services (AWS) to conduct MCMC simulations for all US counties.

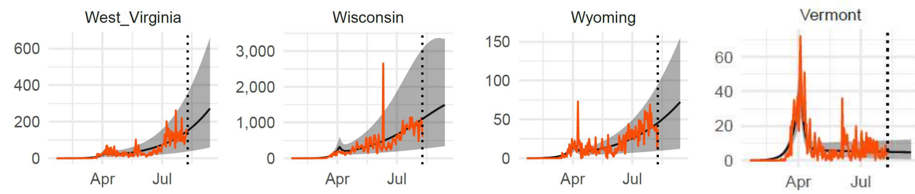

Figure 1: Example of model output. Daily cases for four select states through September 9th, 2020.

3 SIMULATED OUTCOMES

Based on the HMC sampling, the model was able to forecast the volume of cases, deaths, and hospitalizations, as well as the associated peak times. Furthermore, the error bounds of forecasted trends can be derived from the sampled posterior distribution. The output also included proportion of cases that are asymptomatic and mildly symptomatic that were not identified with testing which is a subset of total infections. Finally, we quantified the uncertainty around the parameter fits based on the posterior sampling.

4 CONCLUSION

Several healthcare resource decisions hinge on expected COVID-19 hospitalizations, including the number and distribution of ICU/hospital beds and mechanical ventilators, the number of scheduled visits and admissions, staffing decisions, and the purchasing of personal protective equipment (PPE). This model is particularly useful to decision-makers allocating human and material resources to prepare for future surges as it considers undetected/asymptomatic cases, uses observed hospitalization data, and quantifies uncertainty. Bayesian updating with real-time data can allow for timely and appropriate preparation for future peaks in cases, deaths, and especially hospitalizations, thus greatly reducing mortality and morbidity due to COVID-19. Given the generality of our model, we were able to extend this model for other geographical locations including Italy, Spain, and South Korea (Lin et al. 2020).

ACKNOWLEDGMENTS

This work was supported by the Centers for Disease Control and Prevention (CDC) Modeling Infectious Diseases in Healthcare Network (MInD - Healthcare) Program.

REFERENCES

Barrett, J. S., J. T. Mondick, M. Narayan, K. Vijayakumar, and S. Vijayakumar, 2008. "Integration of Modeling and Simulation into Hospital-based Decision Support Systems Guiding Pediatric Pharmacotherapy". *BMC medical informatics and decision making* 8(1):1-12.

Dong, E., H. Du, and L. Gardner, 2020. "An Interactive Web-based Dashboard to Track COVID-19 in Real Time". *The Lancet infectious diseases* 20(5):533-534.

Lin, G., A. T. Strauss, M. Pinz, D. A. Martinez, K. K. Tseng, E. Schueller, O. Gatalo, Y. Yang, S. A. Levin, and E.Y. Klein, 2020. "Explaining the Bomb-Like Dynamics of COVID-19 with Modeling and the Implications for Policy". *medRxiv* 2020.04.05.20054338.

Ray, E. L., N. Wattanachit, J. Niemi, A. H. Kanji, K. House, E. Y. Cramer, J. Bracher, A. Zheng, T. K. Yamana, X. Xiong, and S. Woody, 2020. "Ensemble Forecasts of Coronavirus Disease 2019 (COVID-19) in the US". *medRxiv* 2020.08.19.20177493.

The COVID-19 Tracking Project. 2020. https://bit.ly/3gb9pQf, accessed 9th August, 2020.

US Census Bureau. 2018. ACS 1-year Estimates. https://data.census.gov/cedsci/, accessed 9th August, 2020.