Northeastern University Hospital Surge Capacity Planning Model: Bed, Ventilator, and PPE 1-30 Day Demand

Download tool and updates: https://www.hsye.org/covid-19-capacity-mgmt

1. Model Overview

The COVID pandemic is placing enormous surge demand and strain on health system capacity, staff, personal protective equipment (PPE), and other supplies, individually and regionally. Many hospitals and policy makers need real-time information about these evolving demands to make critical operational decisions. We developed the Hospital Surge Capacity Planning Model to help health systems estimate and visualize 1-to-30 day ahead hospital-specific demand for medical and ICU beds, ventilators, PPE, medications, and available staff on a rolling basis.

The tool is freely available to any health system worldwide and can be downloaded from our COVID models website at http://www.hsye.org/covid-19. We rapidly developed this model by adapting and integrating 10 years of prior research supported by the Agency for Healthcare Research (AHRQ), National Science Foundation (NSF), and National Institutes of Health (NIH) on three separate sets of new generalizable methods for modeling epidemics (originally focused on the U.S. opioid epidemic, and later vaping), detecting changes in hospital outbreaks, and predicting hospital daily occupancy on unit-by-unit under normal, changing, and surge conditions.

The resulting model provides 1-to-30 day ahead projections on a rolling basis of any individual hospital’s (1) bed demand and occupancy (census) for medical beds, ICU beds, and ventilators, and other critical equipment; (2) 1-to-30 day ahead PPE consumption “burn” rates and stock-out dates as a dynamic function of predicted occupancy; and (3), shortly, staff needs and availability, which also can change dynamically as a function of bed occupancy, patient type mix, and caregiver exposure. The overall objective is to provide early signaling of capacity, supplies, and staffing concerns at hospital and system levels.

This model can complement more macro-level epidemic models informing public health policies, most using conventional susceptible-recovered concepts. While such large-scale models unquestionably are useful, more granular methods and data are needed for individual systems to make key operational day-today decisions about PPE and supply needs, opening ICU and medical space, modifying admission thresholds, allocation of dwindling supplies and medications, invoking makeshift PPE and equipment policies, and so on. Our approach blends theoretic and data-driven modeling methods to produce detailed actionable decision support, integrating current patient census by type, local new COVID case predictions, projected regular admissions, and probabilistic admission units (medical bed, ICU, ventilated), lengths of stay, and staff and PPE needs based on projected occupancy by type over time.
2. Examples of Use

The model can be used in a number of ways to help hospitals prepare for and manage capacity concerns from COVID like epidemics, including providing general information, operational decision making, expediting significant concerns, and in extreme situations to start making decisions on space to convert, admission criteria, use of makeshift PPE, patients who might need to be moved to different locations to free up space for patients in critical conditions. Examples of questions the model can help answer include:

a. General information
   - How many patients will a hospital have in the ICU each day, and how many are going to be ventilated?
   - How much spare medical/surgical unit capacity will be available each day should a hospital need it?
   - When in the future is demand likely to exceed capacity? What is the expected timing of these events locally within this hospital?
   - How fast will the hospital consume PPE and other supplies?
   - Will there be enough capacity and supplies at an epidemic’s peak, and if not, how large will the shortage to help plan accordingly?
   - How many staff, by type, are likely to be unavailable due to exposures, and how will this affect all the above?

b. Operational decisions
   - When should a hospital convert routine space to ICU or isolated beds?
   - When will a hospital need to decant, defer, or transfer non-COVID patients to other facilities and/or how much adaptive capacity will be needed?
   - What percent of patients to decant, divert elsewhere, etc?
   - What would be the impact of changes in admission criteria or location while waiting for test results?
   - When to transition space back to its original use?

c. Best/worst case scenarios (sensitivity analysis)
   - Given inherent variability (e.g., random lengths-of-stay) what is the probabilistic range of results a hospital might expect over the next week and month?
   - Given lack of historical data and various input uncertainties (COVID intubation durations, ICU lengths-of-stay, in-hospital mortality, new case arrival rates), what do any of the above look like under different assumptions?
   - What assumptions are a hospital’s results most critically sensitive to (e.g., to inform data analysis and external benchmarking)?
d. Crisis management

- When to invoke makeshift PPE and equipment policies?
- When to enlist retired caregivers, primary care providers, and others in staffing routine healthcare acute care setting delivery needs?
- Early warning about needs to expedite supply and medication replenishments, and/or share resources between facilities?
- How to optimally use combined capacities and resources across a multi-facility health system?

e. Future planning

- How to prepare for future possible epidemic waves, such as a potential recurrence when the spread of COVID slows and we re-start normal activities?
- How to revise surge capacity policies, as a learning health system, to enable more proactive surge management in the future?

3. Tool Description

The model is implemented in an Excel front-end for ease of use and sharing (Figure 1), with all mathematics computed in the background, which take into account day-to-day census and bed occupancy flows, resources on hand, lengths-of-stay, patient escalations and step downs between medical and ICU beds, transfers and mortality. The file consists of five worksheet tabs – one for bed demand, PPE consumption, staff availability, input instructions, and calculation FAQs. Results are displayed graphically as run charts over time and tabularly, formatted for 8.5x11 printing to facilitate bed huddles, surge management meetings, and the like.

For basic functionality, the user enters various hospital and population specific information including historical lengths of stay for medical, ICU, and ventilated patients, admission rates and percentages by patient type, percentages that escalate and step down, and so on. Similar information is entered or estimated for COVID patients. Several op-
tions exist for new COVID and non-COVID patient projections under drop down menus, i.e. doubling rates, local estimates, external epidemic model projections, curve fitting (see FAQ for detailed explanation and use). The model then computes 1-30 day ahead COVID and non-COVID (1) new admissions by day and location (med/sur, ICU, intubated) and (2) total bed occupancy by day and location, and if desired corresponding PPE consumption rates and days remaining inventory corresponding to occupancy and status projections.

Optional functionality includes additional PPE and staff worksheet tabs. A hospital can enter key PPE, consumable supplies, or medications to track, along with historical, estimated, or benchmark consumption rates by patient type (COVID, non-COVID) and bed type (medical, ICU, ventilated). A similar prototype worksheet exists (completed shortly) for staff availability by type based on exposure rates and isolation durations and as a function of bed occupancy. A random simulation (Monte Carlo) option also exists to account for random admission volumes, admission units, lengths of stay, in-hospital transfers, and mortality. Since these all vary in actual practice, this can help a hospital visualize the range of possible futures that actually might occur to develop a sense for the likely range of scenarios they will experience.

We also recommend conducting sensitivity analysis on any inputs a hospital is unsure about in order to develop a similar sense of the range of possible futures. The model has been thoroughly debugged and is as accurate as the input assumptions. By example, health systems are reporting 85-95% accuracy in bed demand one-to-five days into the future using estimated historical lengths-of-stay, admission units, and other inputs.

4. Further Information and Resources

Further details on model logic, inputs, and calculations can be found in:

- The “Input Instructions” and “Calculations FAQ” tabs of the Hospital Surge Capacity Model spreadsheet.
- A seven-minute video on the tool website demonstrating its use and explaining the various inputs and outputs (surge capacity tool video)
- The below working paper (References section)
- There also is an evaluation form to provide feedback on use, suggestions, and accuracy. We will report back on the tool website case studies and accuracy data (only with a hospitals permission). Confidential feedback also is invaluable as we continue to expand the tool.

5. Development of Tool

The Hospital Surge Capacity Planning Model was developed by Principal Investigator James Benneyan and his team at the Healthcare Systems Engineering Institute at Northeastern University, in collaboration with Dr. Michael S. Rosenblatt at the Beth Israel Lahey Health-Lahey Hospital and Medical Center. Additional input was provided by several healthcare organizations
affiliated with our collaborative research Center For Healthcare Engineering Research (CHER). This project was indirectly supported by the Agency for Healthcare Research and Quality (P30HS02445301), National Institute of Drug Abuse (R21DA046776-01), and National Science Foundation (CMMI-1742521).

6. Feedback

We are continually updating the tool, with revisions and supporting materials posted to the same link (https://www.hsye.org/covid-19-capacity-mgmt). To provide feedback, improvement suggestions, or experiences and successes using the model, please contact us at hsys@coe.neu.edu.

7. References

Benneyan JC, Rosenblatt M, Bargal B, Yap S, Kaya Y (2020), A hospital surge capacity bed, equipment, and staff demand planning model, working paper.

8. Tool Citation


9. About the Developer

James Benneyan, PhD, is executive director of the Healthcare Systems Engineering Institute and a professor of industrial engineering at Northeastern University. Benneyan is a nationally recognized expert in healthcare systems engineering, Co-PI or Co-I on four AHRQ Patient Safety Learning Labs, and past president of the industrial engineering Society for Health Systems. His research focuses on development and application of systems engineering methods to improve healthcare broadly, including patient safety, care access, capacity modeling, rural disparities, epidemic modeling, and burnout. He and his team are funded by AHRQ, NIH, NSF, and members of the university/industry collaborative research Center for Healthcare Engineering Research (CHER).

[Links to Healthcare Systems Engineering Institute and CHER]
Figure 1. Hospital Surge Capacity Tool. (a) Projected daily new cases and total demand for COVID and non-COVID medical/surgical beds and ventilators, (b) Projected daily PPE consumption rates and days of remaining inventory.