

# Responding to a Pandemic: COVID-19 Projects in the Malone Center

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Kimia Ghobadi, PhD<sup>1</sup>, Greg Hager, PhD<sup>1</sup> , Axel Krieger, PhD<sup>1</sup>, Scott Levin, PhD<sup>1</sup>, and Mathias Unberath, PhD<sup>1</sup>

## Abstract

As the scope and scale of the COVID-19 pandemic became clear in early March of 2020, the faculty of the Malone Center engaged in several projects aimed at addressing both immediate and long-term implications of COVID-19. In this article, we briefly outline the processes that we engaged in to identify areas of need, the projects that emerged, and the results of those projects. As we write, some of these projects have reached a natural termination point, whereas others continue. We identify some of the factors that led to projects that moved to implementation, as well as factors that led projects to fail to progress or to be abandoned.

## Keywords

biomedical engineering, acute care surgery, radiologist

## Introduction

By early March 2020, it became increasingly apparent that the outbreak of SARS-CoV-2 would not be contained to Wuhan, China, where it had originally emerged. Rather, COVID-19 would scale to a global pandemic causing a ubiquitous threat to life, health, wealth, and existence. Many concerned citizens, scientists, and engineers—whether previously exposed to research on infectious diseases and epidemiology or not—mobilized to volunteer their time and complementary expertise to fight the pandemic.

At Johns Hopkins, we had already established the Malone Center for Engineering in Healthcare with the mission of accelerating the translation of engineering methods and solutions into tools that improve the effectiveness and efficiency of health care. This mission became particularly relevant when, on March 10, 2020, Johns Hopkins University announced that it was canceling in-person classes and that the university was moving online. Although there had not been confirmed cases of COVID-19 in student, faculty, or staff populations at that time, Johns Hopkins Medicine was already pivoting to prepare for the anticipated wave of highly infectious patients requiring urgent, acute care.

In response to these changes, the Malone Center organized a series of conversations between clinicians and engineers to identify some of the anticipated challenges that COVID-19 would impose on the health system. Each topic area launched groups to further delineate both the problem space and potential solutions. Broadly speaking, the challenges spanned the gamut from immediate clinical

needs, for example, methods to allow for safe, scalable testing and for PPE reuse, to tactical innovations to enhance patient care, for example, finding solutions for remote management of ventilators, to longer-term solutions such as creating well-structured datasets that would allow for the development of effective clinical decision-support tools. Even further downstream were projects addressing some of the anticipated mental health problems that we now see arising in the population. A complete set of COVID-19-related projects appears in [Figure 1](#).

In the remainder of this article, we describe some of the projects that arose in more detail, focusing largely on those that, with the efforts of dedicated faculty, staff, and students, were ultimately deployed in real-world settings. Many others made significant progress but were not put to use because either the anticipated demand did not arise or because some regulatory, logistical, or technological barrier limited their progress. We extract some lessons learned from those projects that may inform future efforts in the conclusions of this article.

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<sup>1</sup>Malone Center for Engineering in Healthcare, Johns Hopkins University, Baltimore, MD, USA

### Corresponding Author:

Gregory Hager, Malone Center For Engineering in Healthcare, Johns Hopkins University, 3400 N. Charles St, Baltimore, MD 21218-2625, USA.

Email: [hager@cs.jhu.edu](mailto:hager@cs.jhu.edu)

COVID-19 Projects	
Project Name	Status
<b>Data</b>	
A County-Level Dataset for Informing the U.S. Response to COVID-19	Dataset maintained through August 2020
Deep Learning to Identify Signs of COVID-19 in Chest X-Rays	<a href="#">Paper published in Journal of Thoracic Imaging</a>
Enabling Optimal COVID-19 Disposition Decision-Making by Data-Driven Clinical Decision Support	In operation
Predicting Covid-19 severity with clustering techniques	Data collection completed in December 2020
Social Media Data Analytics for COVID-19	<a href="#">Published papers</a>
<b>Devices</b>	
Ultrasound Imaging System to Detect COVID-19 Biomarkers Using Deep Learning	In progress
Filter testing and Quality Assurance of Reprocessed / UVC-decontaminated Masks	In operation
Teleoperated In-ICU Robotics to Reduce Exposure of Critical Care Personnel	Moving toward first clinical testing
UVC Decontamination of CT Scanners	In operation
Value of Monocyte Distribution Width (MDW) in Diagnosing COVID-19 and Predicting Severity of Disease in Adults and Multi-Inflammatory Syndrome in Children (MIS-C)	In-progress with goal of FDA emergency use authorization (EUA) and publication
UVC Decontamination of N95 Masks	In operation
Mobile COVID-19 Testing Booths to Keep Healthcare Providers Safe	In operation
<b>Systems</b>	
COVID-19 Spread Simulation Tool/Model	Finalizing first-generation simulator
A Mathematical Framework for Estimating Risk of Airborne Transmission of COVID-19 (CAT Inequality)	<a href="#">Paper published in Physics of Fluids</a>
PPE Usage and Optimization Models	In progress
SARS-CoV-2 Positivity Rate for Latinos in the Baltimore–Washington, DC Area	Informed interventions in the Latinx community in Baltimore. Published
Surveilling the Impact of COVID-19 on Mental Health in the General Population	Initial stages of development
Targeted Rapid Testing for SARS-CoV-2 in the Emergency Department is Associated with Large Reductions in Uninfected Patient Exposure Time	Supported strategic deployment of limited rapid tests in the ED. Published.
Hospital Bed Occupancy Management during COVID-19 Surges	In operation

Figure 1. COVID-19-related projects at the Malone Center.

## Projects

The Malone Center engineering capabilities are organized around the themes of Data, Systems, and Devices, with a fourth overarching theme of Human-Centered Design. In what follows, we describe some of the projects that we pursued organized into these engineering themes.

### Data

Many of the most rapidly developed efforts at the Malone Center revolved around data science and evidence-based decision-making, possibly due to the fact that (1) a significant fraction of the Malone Center's faculty have core expertise in data science and artificial intelligence, (2) compared to device development, data-based projects require little resources, and (3) these efforts scale well, enabling other groups to help advance the project or catalyzing novel approaches.

At the very center of data science, however, is the data itself. Creating large datasets of high quality is generally considered one of the biggest challenges in developing meaningful tools for evidence-based reasoning.<sup>1</sup> In addition to contributions to the now ubiquitous JHU CSSE Coronavirus Dashboard,<sup>2</sup> Malone Center faculty initiated several efforts aimed at curating and contributing large, high-quality datasets to facilitate data science research around COVID-19. Here, we highlight 2 of these efforts led by John C Malone, Associate Professor of Computer

Science Mark Dredze, and Assistant Professor of Computer Science Mathias Unberath, a former Malone Fellow.

*A twitter COVID-19 dataset with automated annotations.* Together with colleagues at the University of Maryland, the University of Colorado Boulder, and the George Washington University, Mark Dredze started to collect Tweets containing keywords related to the pandemic, including “coronavirus,” “covid,” or “wufu.” To date, the dataset contains tens of millions of Tweets that are all annotated automatically with the corresponding keyword as well as the geolocation of the Tweet (country, state, and city).<sup>3</sup> They demonstrated that Tweet location can be used to derive a mobility index that can be used to quantify the efficacy and compliance with stay-at-home orders.<sup>4</sup>

*A county-level dataset for informing the US response to COVID-19.* Rather than implementing a federal response, the United States delegated the implementation of non-pharmaceutical interventions to curb the spread of COVID-19 to local governments on the county level. Because the pandemic did not affect all of the United States simultaneously, local governments can draw on the experience of regions that are more advanced in an outbreak to support their reasoning around the implementation and rollback of non-pharmaceutical interventions. To facilitate research on and development of such evidence-based predictive modeling tools that would

amplify the value of precedents, a group of motivated students led by Mathias Unberath contributed a machine-readable dataset and code snippets for its use. The dataset—honored with a *Kaggle COVID-19 Dataset Award* for its usefulness and ease of use—aggregates relevant metrics from multiple governmental and academic sources on the county level. In addition to county-level time-series data from the JHU CSSE Coronavirus Dashboard,<sup>2</sup> the dataset contains more than 300 variables that summarize population estimates, demographics, ethnicity, housing, education, employment and income, climate, transit scores, healthcare system-related metrics, and most importantly, the dates of implementation and eventual rollback of non-pharmaceutical interventions. The dataset is available on GitHub,<sup>1</sup> and a detailed description of all variables and the respective sources is provided in the accompanying preprint.<sup>5</sup>

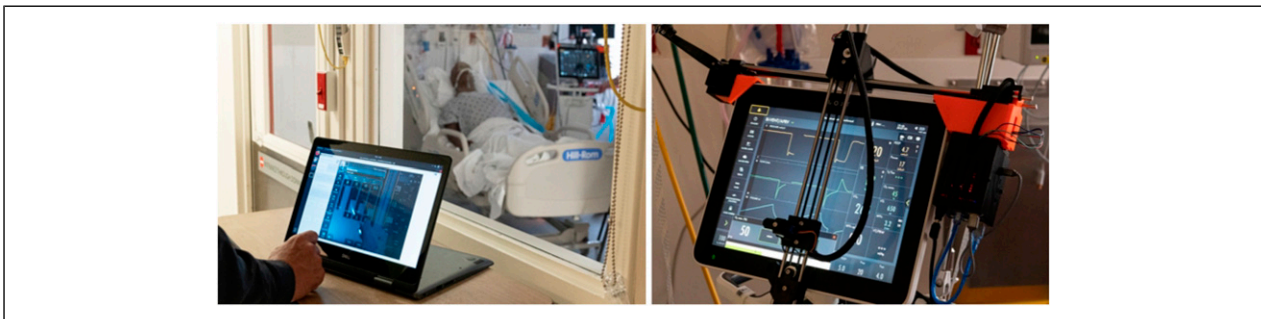
## Devices

The COVID-19 pandemic has shown that the scarcest resources necessary to fight COVID-19 are trained healthcare workers, personal protective equipment (PPE) to prevent infections for clinical staff, and ventilators to combat poor oxygenation. Three example medical device projects to mitigate the COVID-19 pandemic included (1) a telerobotic system for ventilators, (2) a low-cost testing booth, and (3) a negative pressure intubation hood.

**Telerobotic ventilator manipulation.** The goal for our first device project is to develop telerobotic systems that can press buttons and observe displays to allow healthcare workers to remotely operate equipment from outside the ICU room, starting with ventilators. Healthcare workers must don and doff PPE every time to enter the ICU, even if only to perform a simple task such as changing a setting on a ventilator. There is an estimated installed base of 160 000 ventilators in US hospitals that could be upgraded readily to remote operation with the proposed telerobotic

system, providing large PPE savings and reducing infection risks for healthcare workers. The proposed ventilator robot consists of a low-cost and lightweight Cartesian robot that attaches to the touchscreen of a ventilator. A healthcare provider controls the robot remotely via a secure tablet connection with the robot mimicking each push on the tablet interface on the ventilator. The robot incorporates an LED pattern on the finger pusher that is visible to a camera positioned to the side of the robot. Intelligent image processing and guidance undistorts the image, calibrates the robot and screen, and precisely guides the remote actuation of the ventilator touchscreen. As a result, for routine setting changes, healthcare providers can remain outside of the ICU, reducing exposure and consumption of PPE. We have successfully installed the prototype teleoperated Cartesian ventilator robot on a real-life Maquet Servo-U ventilator and tested the robotic system in the biocontainment unit (BCU) at Johns Hopkins Hospital (Figure 2).<sup>6</sup>

**Positive pressure testing booth.** Our second device project also aims to reduce PPE consumption and reduce the infection risk for healthcare workers, in particular during COVID-19 testing. Large-scale testing is an important measure to contain the spread of COVID-19, but presents considerable risk for the healthcare providers administering the roughly 1 million daily tests in the United States. We developed a positive pressure walk-up testing booth for collecting COVID-19 specimens, with our main contributions attributed to the booth's simple "DIY" (do-it-yourself) design, and the successful clinical deployment of 5 booths (Figure 3) in testing facilities in Baltimore, MD, USA.<sup>7</sup> The booth is affordable for local governments and is designed in a way that facilitates transportation across multiple communities. We showed that fine particulate matter was successfully blocked from entering the booth using high efficiency particulate air (HEPA) filters, eliminating the need to use and replace PPE during sample collection from patients. The booth was deemed to be safe



**Figure 2.** The Cartesian ventilator robot prototype during testing in the Johns Hopkins University biocontainment unit. The robot was controlled from the outside of the biocontainment unit bay using a touchscreen tablet (left). A close-up picture of the robot prototype clamped on the ventilator is shown on the right.





**Figure 3.** The positive testing booths before clinical deployment.

for healthcare providers by medical experts and can be manufactured using exclusively off-the-shelf components from vendors such as McMaster Carr, Home Depot, and 80/20. The booth design was licensed to a local Baltimore company and is now commercially available.

**Patient aerosol containment chamber.** Our third example device project is also focused on reducing the infection risk of medical personnel. The Respiratory Aerosol Containment Chamber for Airway Management (Airway RACC), designed in collaboration with the University of Maryland, is a personal respiratory protective device designed to be used by healthcare providers during airway management procedures (including for endotracheal intubation and extubation) in patients suspected to be infected with COVID-19.<sup>8</sup> The product is intended to reduce exposure of healthcare providers to airborne respiratory aerosols and droplets that are ejected during airway management procedures. The design consists of an acrylic structure with rubber seals around the patient head and tubes (Figure 4). The in-room suction provides negative pressure to the booth, which reduces the risk of exposure to healthcare providers over more open hood designs. We received notice from the Food and Drug Administration (FDA) that the device falls under Emergency Use Authorization for Face Shields and submitted an EUA



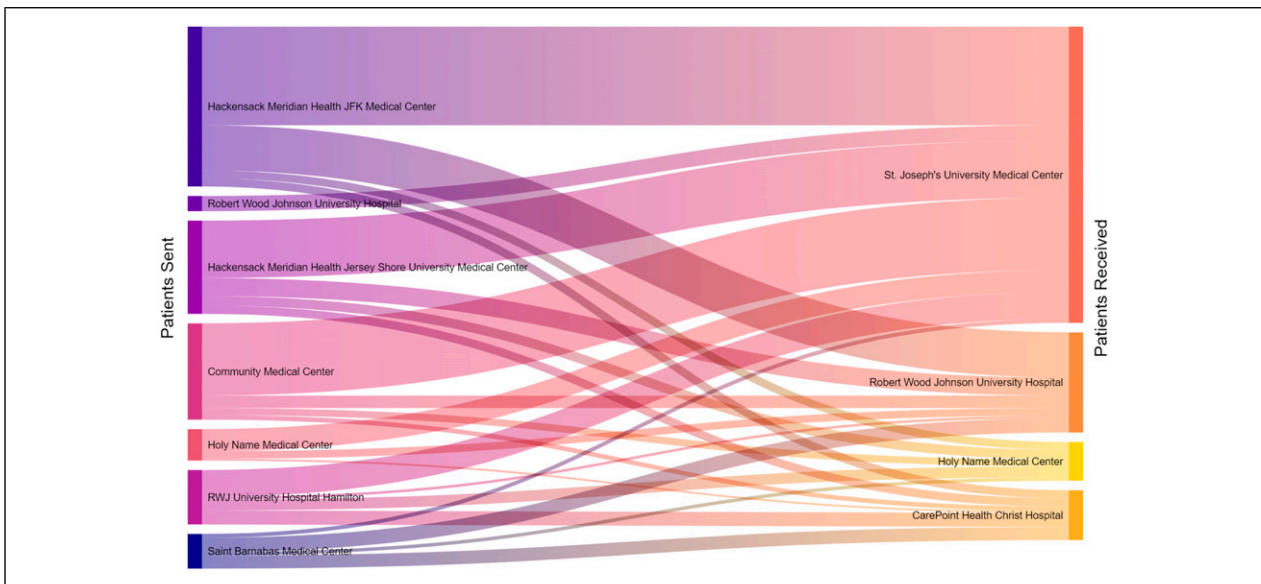
**Figure 4.** Picture of the Airway respiratory aerosol containment chamber prototype during testing.

application with the FDA, which has been under review since May 2020.

## Systems

The ongoing COVID-19 pandemic has placed a significant strain on healthcare systems due to the overwhelming surges in the number of hospitalizations and the unique clinical care requirement of these patients. Numerous innovative approaches to expand healthcare system capacity have been undertaken at both state and local levels, including building new capacity or repurposing existing ones for COVID-19 care. Optimal use of these resources requires matching patients to care locations based on current and anticipated clinical care needs and available beds. Two of the systems projects conducted by the Malone Center faculty focus on this problem by developing decision-support tools for healthcare providers to first predict patient outcomes and appropriate dispositions and then identify the best healthcare location that can accommodate the patient and without going overcapacity.

**Clinical decision support for COVID-19 patients.** Prediction of clinical trajectory for patients with COVID-19 can be challenging. Widespread use of the electronic health record (EHR) has generated continuously growing pools of data with potential to increase our understanding of disease trajectories in individuals. In this project, we



**Figure 5.** An optimal COVID-19 ICU patient transfer strategy for hospitals in New Jersey during April and May 2020. The transfers can reduce the need for additional beds by over 50%.

designed an end-to-end artificial intelligence–driven clinical decision-support system capable of generating reliable outcome predictions for individual patients in real time. This tool is integrated into current EHR and risk-stratifies based on cardiopulmonary deterioration within the next 3 days. The predictions are translated to actionable decision support for ED clinicians at the point of disposition decision-making. Our models have been cross-validated using a cohort of patient visits to 5 EDs within the Johns Hopkins Health Systems, generating real-time risk estimates that rely exclusively on routinely collected EHR data (demographics, symptoms, vital sign trends, comorbidities, and laboratory as it accumulates during the ED stay.

**Healthcare systems occupancy management.** With the ongoing surges in COVID-19 cases, hospitals across the United States are rapidly reaching their capacity, and critical resources such as ICU beds are becoming scarce.<sup>2</sup> Keeping up with the increasing demand has proven a significant challenge for individual hospitals. However, the load can be shared among hospitals in the same region by optimally transferring patients between them and better utilizing the available critical resources. For instance, patients can be transferred from facilities that currently (or forecasted to) have high occupancy to nearby facilities that can accommodate the patients at the appropriate level of care (e.g., Figure 5 shows how hospitals in New Jersey could have transferred their ICU patients in April and May 2020). These transfers occur at the point of disposition decision-making in the EDs. Our optimization models consider future demands, occupancy levels, and expected length of hospitalizations. The decision-support tool can

identify the optimal transfer patterns and also provide insights for strategic capacity management decisions. Our approach is validated on state, county, and hospital levels based on publicly available data during the first and second waves of the pandemic.<sup>3</sup>

## Conclusion

While we hope that the challenges of the past year are not repeated anytime soon, there are useful lessons that can be drawn. First and foremost, we would like to highlight that the speed of our response was a testament to a cadre of engineers and healthcare workers who *already had prior experience in working at the intersection of engineering in health care*. It cannot be understated how much this shortened the learning curve and made early conversations between engineering and clinical team members focused and efficient. Further, institutional responses that accelerated review and approval of research and development cleared the way to move these advances into practice far more quickly than we would have expected under normal circumstance. Finally, the ability to quickly convene groups at the “grass roots” level meant that we could pivot to solving problems within days rather than weeks or months.

At the same time, the pathway to deployment of solutions also hit unanticipated roadblocks. For example, the Airway RACC was available for use relatively quickly. However, FDA Emergency Use Authorization (EUA) was never obtained within a timeline that allowed for deployment. If, for a temporary time, local authority for such approvals had been granted, we suspect that progress

toward deployment would have been accelerated. Also, while we had unfettered access to clinical staff, we did not have unfettered access to facilities that were already in high demand. Some innovations languished for lack of a real-world deployment “sandbox” which would have allowed teams to gain experience and trust.

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### Author Contributions

All authors contributed equally to this article.

Study concept and design: Kimia Ghobadi, Greg Hager, Axel Krieger, Scott Levin, and Mathias Unberath.

Acquisition of data: Kimia Ghobadi, Greg Hager, Axel Krieger, Scott Levin, and Mathias Unberath.

Analysis and interpretation: Kimia Ghobadi, Greg Hager, Axel Krieger, Scott Levin, and Mathias Unberath.

Study supervision: Kimia Ghobadi, Greg Hager, Axel Krieger, Scott Levin, and Mathias Unberath.

### Declaration of Conflicting Interests

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### ORCID iD

Greg Hager  <https://orcid.org/0000-0002-6662-9763>

### Footnotes

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