An Analysis of the Literature on Hospital Operational Systems to Address Issues Associated with the COVID-19 Pandemic

University of Massachusetts, Amherst

Commonwealth Honors College

Student: Jayke Sudana

Sponsor: Dr. Jarice Hanson

Abstract

The COVID-19 virus has spread around the globe to infect hundreds of millions of people over the course of two years. One of the industries most impacted by the waves of infections were hospitals. The high volume of patients pressured hospitals and their ability to administer treatment effectively. Hospitals managed both COVID-19 and non-COVID-19 inpatients during the pandemic but were faced with capacity shortages in personal protective equipment (PPE), ventilators, and beds. Thus, the operational systems of hospitals had to be adapted to manage the end-to-end pathway of a patient throughout their treatment.

So, there were two parts to the thesis which required further research: (1) the operations problem definition during the pandemic needed to be outlined via literature and (2) to adjust to those problems, hospitals needed to build new solutions at the operational level. To address each part, a systematic literature review was undertaken and 40 operations and information management studies, spanning January 2020 – April 2022, were reviewed.

The studies uncovered solutions that included qualitative practices of effective LEAN leadership (a systems and process improvement method for business collaboration, idea implementation, and growth), quantitative approaches that used data-driven predictive analytics for patient treatment and diagnosis, allocation of equipment and patients, efficient scheduled management of staffing, and holistic solutions which identified the successes and limitations of COVID-19-curated hospitals ("secondary," "makeshift," "shelter," or "field" hospitals) (Jiang et al. 2021; Baughman et al. 2020; D'souza et al. 2020). The findings implied a need for further accuracy in predictive analytics, a wider range of studies to represent a broader demographic, and longer durations of studies to capture data and results of multiple waves of the pandemic.

Introduction

As the pandemic began to tear throughout populations in countries worldwide, people who required healthcare support flocked to hospitals. For instance, over the course of 3 waves – Winter 2020-2021, Delta variant, and Omicron variant periods – hospitalizations in the United States alone have consistently surpassed 10,000 hospitalizations for a 7-day moving average (highlighted by the grey areas of the graph in Figure 1) as of January 2022. Although a wide scale vaccination effort in the United States, which started at the beginning of 2021, has quelled the most dramatic and lethal symptoms, the virus has mutated into a more transmissible form and as of 2022, the weekly average positive case rate has been at its highest during the pandemic, excluding other countries but the United States ("COVID-19 Map" n.d.; Figure 1).

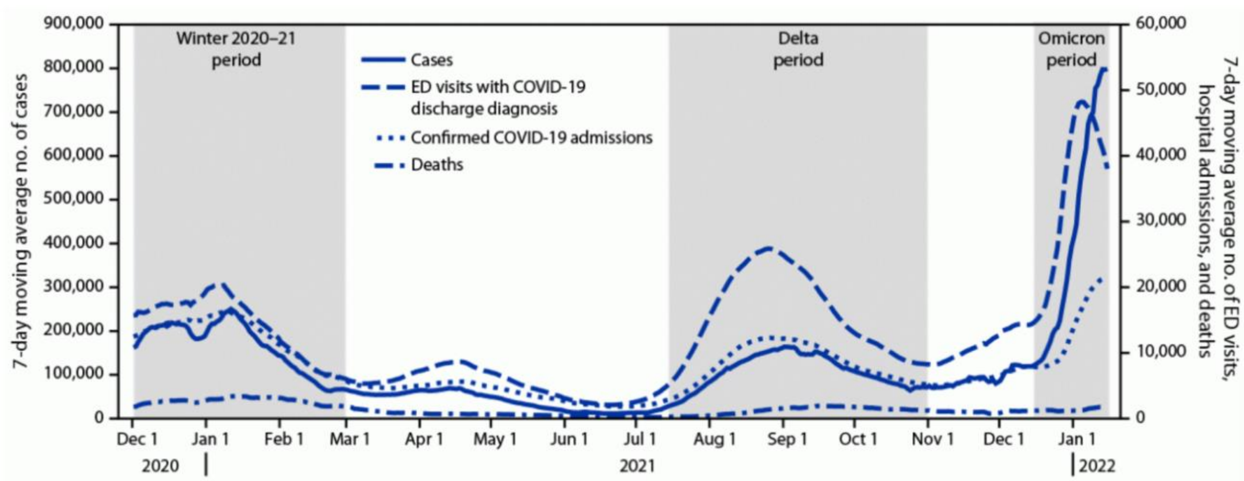

Figure 1. "Seven-day moving average number of COVID-19 cases, emergency department visits, hospital admissions, and deaths – United States, * December 1,2020 – January 15, 2022" (CDC 2022b). This data was derived from 199 U.S. hospitals (CDC 2022).

One prevalent topic from the expanse of research on SARS-CoV-2 considered how the population of infected were managed and treated. This was where the role of the hospital came in. Hospitals handled the symptoms of infected patients – fever, cough, shortness of breath, fatigue, muscle or body aches, headache, new loss of taste or smell, sore throat, congestion or runny nose, nausea or vomiting, or diarrhea – dependent upon patient and hospital-level information, and coupled with the overall context of the pandemic such as the timeline and access to vaccinations (CDC 2022a).

The typical system of healthcare treatment, or the patient pathway through a hospital, was disrupted because of the pandemic. For example, the World Health Organization (WHO), an agency of the United Nations which leads global efforts in healthcare issues (especially emergencies), broke COVID-19 patient care into a simple and sequential checklist, which followed the acronym C.A.R.E.: Confirm, Assess, Respond, and Evaluate ("COVID-19 Clinical Care Pathway" 2022). "Confirm" meant to test the patient for SARS-CoV-2 infection; "Assess" categorized the person's "symptoms, risk factors and severity" into three statuses (Non-severe, Severe, and Critical); "Respond" implied the application of appropriate care and treatment for the patient based on their status; "Evaluate" monitored the patients throughout illness and recovery ("COVID-19 Clinical Care Pathway" 2022). The C.A.R.E. framework exemplified a response system – a set of interrelated parts which constitute the whole –formed in relation to COVID-19 in hospitals.

With respect to the pathway of care for patients, multiple steps of the overall healthcare system were tested. Alongside the continued prevalence of the virus, hospitals have had to cope with overrun intensive care units (Ma, Zhao, and Guo 2022; Sarkar et al. 2021; Shi et al. n.d.), capacity shortages induced by unprecedented demand levels (White and Lo 2020; Melman, Parlikad, and Cameron 2021; Bertsimas et al. 2021), overworked and stressed healthcare employees (Cross et al. 2021), and strained end-to-end operations (Kadri et al. 2021).

Hospitals faced difficult questions, like how they could properly handle the infected alongside the average intake of patients, and if their current system of operations had the capacity to effectively treat the expected inflows of infected. Additional factors, such as distrust held by minorities, and the general population for that matter, in healthcare systems in the United States (Armstrong et al. 2006), the cancelling of elective surgeries by people who feared infection (Collaborative 2020), and demographic-associated comorbidities also surrounded healthcare systems functions (Azar et al. 2020). Plus, the location of the hospital in the world, which would reveal the status on funding and level of care of a hospital, could determine health outcomes for infected patients.

A systematic literature review (SLR) was performed via a sample of peer-reviewed publications sourced from *Business Source Complete*, published between January 2020 and April 2022. This range of dates was chosen because it was important to capture multiple COVID-19 waves and vaccination efforts.

The SLR aimed to answer the five following research questions (RQs). These were:

1. **Research Question1:** Considering the smaller parts of the whole in hospital systems, what steps in the patient treatment pathway were challenged due to the pandemic?
2. **Research Question 2:** What kinds of solutions propped up healthcare systems in their delivery of treatment?
3. **Research Question 3:** Since this research topic is fast-growing and constantly evolving, what were some bigger picture demographics of the hospitals or healthcare systems within the reviewed literature?
4. **Research Question 4:** What were the gaps and limitations of the prior literature?
5. **Research Question 5:** What are future endeavors or possibilities for the field?

To answer these questions, the thesis involved summarization and analysis of 40 studies identified through a filtering protocol adapted from a model SLR (Kaur et al. 2021).. The problems associated with the pandemic were broken down into three main issues: (1) hospital, (2) patient, and (3) healthcare staff problems. Additionally, the solutions were broken into three general topics: (1) qualitative, (2) quantitative, and (3) holistic solutions. Next, an analysis of article demographics was performed to highlight limitations and areas which recommended areas of future research.

A discussion of the literature's gaps and limitations based on the SLR highlighted key recommendations for future areas of study in the ever-growing pedagogy. Finally, a conclusion and limitations section acknowledged the inherent limitations of this thesis and how the possibility for excluded information confounded the study.

Literature Review

Contents of SLR

The system of patient treatment was a sequential pathway; thus, the literature review was organized sequentially by starting with the problems, moving to solutions, then demographics of the hospitals and studies were applied to understand when and where the studies took place in the context of the pandemic.

Problems

A content analysis in this SLR reviewed the methods, findings, conclusions, and future implications of the sampled articles to identify key problems faced by the studied hospitals and healthcare systems during the COVID-19 pandemic. The WHO C.A.R.E. model, which was not necessarily used by every study, was included to track which steps of the patient pathway was most affected by a particular problem. As a reminder, the C.A.R.E. model was an acronym (Care – Assess – Respond – Evaluate) that represented a standard for the clinical care pathway advised by the World Health Organizations for hospitals.

For this particular section, the research question to consider was: considering the smaller parts of the whole in hospital systems, what steps in the patient treatment pathway were challenged due to the pandemic? This section was broken into three parts: (1) general hospital issues, (2) patient mortality and treatment, and (3) healthcare staff issues.

Hospital Issues

A consensus among the reviewed articles was that the COVID-19 pandemic resulted in a strain on hospital equipment capacities. Within the system of hospitals, this issue most affected the “Respond” component of the WHO C.A.R.E. model, since limited equipment quantities led to inadequate response (Kadri et al. 2021). Such capacity limits may have been conducive to 1 in 4 deaths across 558 U.S. hospitals from March to August 2020 (Kadri et al. 2021). This was determined by *the surge index range* for a hospital, which differentiated systems between those that were strained from those which handled COVID-19 cases well (or well enough). Hospitals with low capacities coupled with high patients were labelled as having a “high surge index,” defined by Kadri et al. (2021), through a model which weighed a hospital’s patient-case severity equipment requirements. A higher surge index was associated with more frequent patient mortality (Kadri et al. 2021). For example, invasive mechanical ventilation was given a higher weight than an ICU visit without invasive ventilation (Kadri et al. 2021). Additionally, patient-level covariates, which were additional demographic- and comorbidity-related factors, were weighed according to likelihood for need of critical care (Kadri et al. 2021). Hospital-level covariates included location in the U.S. and ventilator status (level of and access to particular ventilator treatments), and was also weighed and factored into a hospital’s surge index. Each of these weights marked an area in treatment that made it difficult (or simple) to treat a patient with COVID-19. For future studies, an application of a surge-related index could provide useful for (1) understanding the current state of risk in a hospital faced with COVID-19 and (2) categorizing that hospital into a stratified priority list. If a hospital’s challenges could be identified via a standardized index, then outside public health resources may have helped to bring in more equipment and clinical advice, or helped transfer patients to low surge index hospitals nearby (Kadri et al. 2021).

One important note from this study was that the improved inpatient survival from March to May was not tied to the surge index; the opposite effect was seen, as later on in the pandemic, mortality risk increased with higher surge capacities (Kadri et al. 2021). However, standard of treatment for patients adapted and improved; for example, more intubation was associated with higher deaths, so the U.S. hospitals in this study were more selective in which patients required intubation (Kadri et al. 2021). Such adaptation measures would have improved treatment and lowered mortality rates. However, this study could not be generalized for every U.S. hospital despite its wide coverage of data. So, problem definition in the treatment pathway was just as pertinent to the individual hospital.

One of the specific equipment shortages witnessed by hospitals that had a detriment to the "Response" step was the potential lack of critical care beds. There were studies in this review which looked at how bed management and inventories failed to meet demand (demand being the number of inpatients) for a given hospital. For instance, critical care beds were reallocated to COVID-19 patients as total bed supply dwindled: "critical care (CC) beds… used by both COVID-19 and non-COVID-19 patients [were] extremely scarce and resource-intensive" (Melman, Parlikad, and Cameron 2021). This brought up problems with proper bed allocation to meet the demands of COVID-19 and non-COVID-19 patients: ”The anticipated high spikes in demand for hospitalization, and particularly for prolonged treatment in intensive care units (ICUs) with scarce equipment, meant that a strategy relying only on the acute health system was likely to have a high failure rate, as seen in several parts of Italy, Spain, and New York City" (Cepiku et al. 2021). A hospital in Mumbai, India "faced an utter collapse of proper treatment" and "had run out of beds due to the overwhelming tally of COVID-infected patients" (Leite, Lindsay, and Kumar 2021). What does this mean for how hospitals treated their patients?

Due to bed shortages, certain hospitals could not administer treatment to every patient - waitlists were a concern as the number of patients increased and the number of available beds consequently decreased (Ma, Zhao, and Guo 2022). When beds in both critical care and non-critical care wards were filled towards the beginning of the pandemic, the result was longer waiting times for patients with COVID-19 (Leite, Lindsay, and Kumar 2021) as well as patients requiring emergency non-COVID-19 care (Melman, Parlikad, and Cameron 2021). For example, in a Mumbai hospital faced with shortages, ”patients were seen standing in the long queues (lines) before hospitals for admission for hours with an acute shortage of doctors and medical staffs" (Leite, Lindsay, and Kumar 2021).Were there other factors which may have hindered the treatment of patients?

The studies pointed to the diminished supply of personal protective equipment (PPE). PPEs included surgical facemasks, face visors, respirator masks, long sleeved gowns, gloves, and aprons to "create a barrier between healthcare workers and an infectious agent from the patient" and were used and disposed frequently ("Personal Protective Equipment | PHA Infection Control" n.d.). A side-effect of social distancing and wide mask usage was the surge in demand for PPE. One study based in a Toronto hospital proclaimed the public's consumption of PPE "had a detrimental effect on the ability of hospitals to source PPE… and outfit their staff," which increased risk of infection and death amongst patients (Furman et al. 2021). A university hospital in Antwerp predicted a clinical facemask shortage (Vanhooydonck et al. 2021) and in the Lombardy region in Italy, clinicians ran out of PPE which "led to some deaths and also made the doctors vehicles of disease diffusion" (Cepiku et al. 2021). Delivery delays were another cause for PPE shortage, such as in Wuhan, where an adequate supply of PPE was met but was not distributed to hospitals in a timely manner (Liu, Bai, and Wu 2021).

The studies showed how equipment shortages led to capacity-dependent deaths and ultimately reduced care. However, they were limited by timeline and location of study. The review did not go over the potential increase or decrease in capacities during the 2nd and 3rd wave of cases. Shortages reviewed were located in U.S., Indian, and Italian hospitals, but because this was a global event, more hospitals required across a wider range of countries should have been investigated. Although it was useful to gain a sense of why shortages were conducive to reduced treatment, a limited scope of review meant that over-generalization of figures could have been at play. Plus, shortages may have been worse in certain countries or at different stages of the pandemic; this began to highlight the limits of the methodology in answering all parts of the 1st research question.

Patient Mortality and Treatment

The literature review linked certain patient demographics, comorbidities, and location of care with risk of mortality. Patients needed to be assigned to the proper level of care; thus, this section fell into the "Assess" step of the WHO C.A.R.E. model, as patient-level was dependent on severity of disease. Yet, there were many factors which played into the disease severity notwithstanding symptoms. The studies categorized patient risk and the dangerous symptoms caused due to infection. Traits of at risk-patients included >60 years old (African COVID-19 Critical Care Outcomes Study (ACCCOS) Investigators 2021; Drake et al. 2021), >1 comorbidity (Yu et al. 2021), and male (Bertsimas et al. 2021; African COVID-19 Critical Care Outcomes Study (ACCCOS) Investigators 2021). Comorbidities such as hypertension, atrial fibrillation, and heart failure were predominant in deceased cases (Giuliani et al. 2022). However, the studies and the current failures in proper treatment bolstered that more features of patient data were needed to discern allocation of critical care from regular care. For instance, nearly every study had a majority White (non-Hispanic) sample (Barbaro et al. 2020; Drake et al. 2021; Yu et al. 2021) based on hospitals in the United Kingdom (Yu et al. 2021; Drake et al. 2021) and United States (Barbaro et al. 2020). Plus, although the symptoms of severe patients were predominately fever and cough, "symptoms are quite different in Asia vs. Europe or North America," as shortness of breath was the main issue in North American countries and "more than 75% of Asian patients [experienced] fever as compared to less than half in Europe and North America" (Bertsimas et al. 2021). The mixed symptoms of patients paired with a bias of racial demographics was a confounding aspect of the studies.

Hospital level of assessment could have depended on the the country and even the region within the country that the hospital was located; on the other hand, assessment could be strictly patient demographic-related. Most likely, the integration of both aspects played a role in how patients were assessed. For instance, it was shown that in a demographic study of 4.3 million patients that (1) access to medical care for those infected with COVID-19 was lower in Hispanic individuals, (2) COVID-19 positivity rates were highest in Black and Hispanic individuals (adjusted for age and sex), and (3) higher income medians were associated with lower mortality rates in Hispanic and Black individuals (Azar et al. 2020). This study derived its data from 68 studies taken place in the United States spanning just over a year (Jan 1, 2020 – Jan 6, 2021).

Yet, regional location may have played a factor in mortality rates, as well – two Italian regions (Lombardy and Veneto) witnessed vastly different outcomes. While Lombardy's hospitals were described as poorly managed, with doctors that did not wear PPE, the Veneto region utilized a hub-and-spoke network of dedicated hospitals "which streamlined the process for intake and treatment, and reduced the risk of COVID-19 infections among medical staff and patients (Cepiku et al. 2021). Veneto was characterized as having a strong collaborative effort between health professionals, academia, and community, while Lombardy's hospitals scrambled to provide care and "neglected" the aid of public health and community assistance in the emergency (Cepiku et al. 2021). The result? The regions began at equal death counts in February 2020; one and a half months later, Veneto registered 1,087 deaths while Lombardy had 10,511 deaths. These findings showed how the "Assess" step could be confounded by a multitude of aspects, whether it be the patient demographic or the public health policies which surrounded the hospitals. Thus, analyzing patient demographics in a vacuum may not be conducive to proper assessment and diagnosis of infection severity. As much as this was a case-by-case issue, the comparative strategies and outcomes of Lombardy and Veneto showed how this was a region-by-region problem as well.

An understanding of patient demographics needed to be further placed into context at a country-by-country level. For example, in a study of 64 hospitals in 10 countries in Africa (i.e., Egypt, Ethiopia, Ghana, Kenya, Libya, Malawi, Mozambique, Niger, Nigeria, and South Africa), critically ill patients with COVID-19 observed an excess mortality of 11-23 deaths per 100 patients compared with the global average of 31.5% mortality (African COVID-19 Critical Care Outcomes Study (ACCCOS) Investigators 2021). "[The] critical care in-hospital mortality was higher for African countries than for other, non-African countries" possibly due to "the scarcity of critical care resources in African countries," "inadequate critical care beds, with only one in two patients referred to critical care being admitted," and "very under-resourced critical care facilities" (African COVID-19 Critical Care Outcomes Study (ACCCOS) Investigators 2021). The data from the study showed that just 10.6% of patients who died had delayed admissions; was delayed admission a significant enough factor to cause death? (African COVID-19 Critical Care Outcomes Study (ACCCOS) Investigators 2021). The review showed how the stratification of COVID-19 patient risk prediction could be convoluted with consideration to not only the patient's symptoms, but also the comorbidities, location of care, the financial well-being of the patient, and the availability of the hospital.

Healthcare Staff Issues

Hospitals could only be adequately prepared to deal with the pandemic with the proper quantity and quality of staff. Healthcare staff played the most critical roles in every step of the C.A.R.E. framework and thus, were an integral component to the proper application of the hospital's system. So, what kinds of problems did healthcare staffing face in light of the pandemic which could have been a detriment to the overall system? The review highlighted several difficulties hospitals incurred related to healthcare workers, which included the scheduling, safety, and mental health of healthcare staff. The surge of cases within hospitals, on top of an already-high-risk-high-stress job, resulted in "physical fatigue… fear of being infected" and imposed further stress on employees which went as far as "depression, anxiety, disengagement from work, and intention[s] to quit" for nurses (Tulucu, Anasori, and Kinali Madanoglu 2022; Güler and Geçici 2020). Stress-inducing factors included "additional overtime, high patient mortality, resource-intensive and stressful care requirements… and mental exhaustion" (von Eiff, von Eiff, and Ghanem 2021).

So, where did this stress come from? "Ethical dilemmas and moral injuries for the torment of life-or-death decisions required to be made fast and without the support of optimal care protocols, the pain of losing patients and colleagues, and the risk of infection for themselves and their families" (Leo et al. 2021). Uncertainty played a factor too, as future waves of cases felt unpredictable but inevitable for employees. There were possible demographic factors involved with staff burnout as well: "high exposure to risk for female workers may be linked to their predominance in patient-facing roles" and "high exposure to risk for black and Latino HCW (personal healthcare workers) was linked to a greater fear of exposure to COVID-19 due to racial concordance between workers and patients (black and Latino were overrepresented among patients hospitalized with COVID-19" (Leo et al. 2021). Effected workers had a tendency to be younger (<30 years old), as work-induced stress was shown to decrease with age (Leo et al. 2021). The issue was not solely demographic-oriented, however. Organizational cultures which could not "balance the personal identity of the worker with that of the work organization nand social context" incurred higher rates of stress among their employees (Leo et al. 2021). Employees were required to change role duties frequently and an emergency hospital status consequently led to "poor communication, medical errors, and [lower quality of] patient outcomes and safety" (Leo et al. 2021). This study derived its ideas from a narrative review of COVID-19 and a filter of healthcare-staffing-stress publications. It should be noted that the location, hospital sizes, and number of inpatients were unspecified.

There is a need for further research on COVID-19-induced stress for hospital staff, as their role represented a vital cog in the machine, the core of a hospital's efficacy, yet there was no "standardized and validated measurement tools" or "follow-up for long-term mental health implications and comparisons with other time periods" (Leo et al. 2021). Thus, the pandemic revealed a major problem not only in its resultant stress, but also in how healthcare staffing was managed. As additional evidence of burnout reached the surface, it became clear that a large part of why hospitals incurred higher mortality rates was due to staff who were drained and stress (Leo et al. 2021). This called for future studies to create more linkages between healthcare staff and mortality rates – for example, nurse to patient ratios were an underutilized metric throughout the reviewed studies – while also providing staff-centered solutions which could alleviate the difficulties faced by employees.

Solutions

The "Problems" section highlighted how multiple steps in the patient care pathway system were disrupted due to the pandemic. Briefly in review, hospitals overall had reduced levels of care leading to more deaths which may have been due to equipment shortages affecting the "Respond" phase, patient demographics that convoluted the "Assess" phase, and healthcare staff burnout and stress affecting every phase in the WHO C.A.R.E. model. This section delved into how the systems of hospitals attempted to “fix” themselves. In different steps of the patient pathway, certain adaptations and solutions had to have been made, as is human nature.

This section attempted to answer the second research question: what kinds of solutions propped up healthcare systems in their delivery of treatment? Qualitative, quantitative, and holistic strategies were covered in three separate sections: (1) hospital leadership and management, (2) data-driven predictions, and (3) COVID-19 hospitals.

Hospital Leadership and Management

Multiple studies asserted the value of proper hospital leadership, a value which was especially reinforced during the pandemic crisis. A useful testament to a hospital’s leadership was through case studies, in which a study observed tangible results from certain initiatives. One such case study practiced the adoption of a LEAN methodology, a business-oriented framework inspired by Toyota’s Car Manufacturing operational focus on continuous improvement (kaizen), waste (muda) elimination, involvement of managers at the frontlines (the gemba i.e., where work is done), and a systematic way of thinking (Baruch et al. 2021; Liker 2021). Although LEAN was a framework created and popularized by a car manufacturing company in Toyota, the application of the model itself had a broad spectrum and was adopted by many industries including healthcare and clinical research. This was because LEAN was not manufacturing-specific; it was simply a principle to guide alignment, strengthen collaboration and culture, and implement ideas through a continuously improving standard of work (Liker 2021). Through application of LEAN methods such as PDCA (Plan-Do-Check-Act) and going to the gemba, management in a New York City Hospital collaborated closely with their healthcare staff (the frontline workers) to uncover specific problems and come up with solutions (Baruch et al. 2021). In the hospital setting, the gemba referred to the front lines, where management would literally watch clinicians administer treatment to patients. Observation is useful for spotting problems unseen by the clinician and made decision-making well-informed rather than guess work. For example, management and staff witnessed staff shortages in ICUs and low PPE supply; thus, management acted immediately and developed alternate staffing models to supplement ICU nurses.

Furthermore, staff members were coached continuously and sometimes cross trained to provide additional support within ICUs: "ICU staff members taught [SD staff members] to draw blood samples from arterial lines, adjust drips, manage endotracheal tubes, and perform oral care on intubated patients" (Baruch et al. 2021). Ventilator shortages were problem-solved as "anesthesia machines were used as ventilators, and ventilators were split and shared between patients" (Baruch et al. 2021). This study displayed problem-solving, collaboratively made efforts between management and staff, however, results were not demonstrated and a question as to how effective these efforts were for bettering treatment remained. Whether or not these alternate staffing models and makeshift ventilators were useful in easing the patient treatment pathway should be a focus of future studies on LEAN approaches in COVID-19 affected hospitals.

Crisis management required hands-on and proactive leadership. Just like the frontline healthcare workers who were putting their patients first, leadership provided a foundation of support to address healthcare staffing needs and to define and solve problems missed by the occupied healthcare employees. Although LEAN has been proved to improve processes, there have also been cases where this kind of implementation was too disruptive to an organization's system and was quickly abandoned (Liker 2021). So, further application of LEAN practices at hospitals could have mixed results, but this could only be determined through a wider basis of research. The next steps for recognition of LEAN practices during emergency healthcare crises suggested a success factor or guideline. While Baruch et al. (2021) highlighted how several processes were improved via LEAN, they did not got into the specifics of whether in-hospital mortality rate decreased or how PPE was allocated, preserved, or obtained.

Data-Driven Predictions and Models Employed by Hospitals

Data-driven approaches were pertinent in the “Assess” and “Respond” steps of the WHO C.A.R.E. model, mostly due to the usage of relevant data which made predictions for (1) patient-symptom severity and risk of critical care requirement and (2) the proper allocation (movement from one hospital function to another) of patients, staff, and equipment. Data-driven models were required to be accurate and useable, thus, this subsection highlighted the usage of prediction models to improve those steps in the hospital system.

Marin-Garcia et al. (2021) suggested that their data set be used to assess and assign patients to different levels of care; their claim was that the level of detail in their data could aid clinicians in the decision-making process by locating the patients who required critical care through machine learning. However, this data set was not actually applied in a clinical setting during the study, which marked a severe limitation of the claim and implicated a need for a predictive model to be backed by actual results

The Marin-Garcia study reviewed data solely in Italy, but Bersimas et al. (2020) included data from 160 clinical studies which spanned Europe, Asia, and North America, with the listed features:

> [C]ohort-level statistics on demographics (e.g., average age, gender breakdown), comorbidities (e.g., prevalence of diabetes, hypertension), symptoms (e.g., prevalence of fever, cough), treatments (e.g., prevalence of antibiotics, intubation), lab values (e.g., average lymphocyte count), and clinical outcomes (e.g., average hospital length of stay, mortality rate). We also track whether the cohort comprises “mild” or “severe” patients (mild and severe cohorts are only a subset of the data) (Bertsimas et al. 2021)

For example, 2,831 patient demographics, symptoms, and comorbidities were modeled for mortality risk against “40 random data partitions,” and applied in training and test sets. This divided the data into subsets which generalized data predictions and attempted to avoid overfitting, a statistical term for a model whose accuracy aligned only with the original dataset and would not perform well with new data. The evaluative performance of this model was strong (93.8% area under the curve, closer to 100% means a higher model accuracy), and usable for physicians who wanted to assess mortality risk in patients before admittance. Bertsimas et al. (2021) found C-Reactive Protein markers, white blood cell count, calcium levels, AST biomarkers, and temperature were most indicative of a patient’s risk factor for infection severity. This model was “used by several hospitals within the ASST Cremona system to support triage and treatment decisions, ultimately alleviating the toll of the pandemic” (Bertsimas et al. 2021). However, the study did not delve into how their model helped to alleviate the toll at the ASST Cremona system and required further inspection. Additionally, the mortality risk model did “not take into account medication and treatments during hospitalization… due to the fact that, during the first months of the COVID-19 pandemic, no systematic treatment protocol had yet been established” (Bertsimas et al. 2021). Patient-level models provided a detailed level of data about the patients which could have aided physicians in the “Assess” step of the C.A.R.E. model, but unfortunately, the studies only made it so far as to never describing the actual implementation and efficacy of such models. Did these predictive models actually help physicians assign risk-levels to patients more accurately? It would be difficult to conclude whether or not they did, since the models were solely implemented yet never reviewed. Although usage of such a model was founded on robust data with viable predictive models, they remained just that: models. Hence, research on predictive analytics during emergencies sometimes only speculative. Plus, other forecasting models were retrospectively inaccurate, overpredicting surges and requirements for hospitals (Ioannidis, Cripps, and Tanner 2022).

Hospitals also deployed models to address shortages in equipment in the face of low capacities coupled with patient surges. This harkened back to the equipment shortages mentioned earlier in this thesis and highlighted some of the solutions which were taken. Adequate equipment levels helped the "Response" step in the patient care pathway; thus, it was critical for such models to be developed and used in light of PPE, bed, and ventilator shortages.

A paradigm in the effort to address shortages surrounded the appropriate allocation of-, rationing of-, planning for-, and prediction of- COVID-19-pertinent equipment. For example, shortest transportation routes for delivery of medical supplies were calculated via a dynamic programming algorithm and a delivery schedule for distribution to Wuhan hospitals and was successfully adopted (Liu, Bai, and Wu 2021) in China. This model helped to effectively deliver – from the Wuhan airport and Wuhan railway station to 5 designated hospitals – medical supplies via optimal transportation routes while matching the appropriate demand with supply for those destination hospitals. This study called for hospital management to organize a "routine preparation of medical supplies scheduling" in a response to public health emergencies (Liu, Bai, and Wu 2021). While delivery routes were optimized and supplies were successfully distributed to the 5 designated hospitals, the study remarked on the small number of hospitals which their allocation models were based on. The scenario would have been different given a higher number of hospitals (and therefore a higher number of medical supplies needed to be delivered). This demonstrated how allocation models could be used and applied in real-time, but also demanded a look into whether these models could remain viable in the delivery of many more supplies to a higher hospital count.

One study addressed ventilator shortages that were state-dependent in the United States – in this case, New York hospitals were faced with shortages, so, a deterministic time-dependent ventilator sharing model allocated ventilators according to capacity, which was recommended for usage in New York and New Jersey (shortage states) and Ohio, Pennsylvania, and North Carolina (non-shortage states) (Bertsimas et al. 2021). By modeling "ventilator pooling" and the demand of ventilators for a certain hospital by state and day, the evolution of ventilator shortages was tracked, and optimal inter-state transfers were determined based on supply and demand of ventilators (Bertsimas et al. 2021). The prediction model was adopted by the Hartford HealthCare system in Connecticut "using county-level forecasts of ventilator demand obtained from DELPHI-pred" (Bertsimas et al. 2021). However, and as seen earlier in this subsection, how well this model worked in that setting was not explained, which marked another limitation to predictive-analytics during COVID-19 – the research did not dive into the application and results of predictive analytics in a real setting. The viability of the solution was put into question – it made sense for the model to bolster hospital systems by sharing equipment, however, whether or not this actually occurred was not mentioned by the study. It would be useful to see if hospitals took the advice of academia and attempted to eliminate shortages via inter-state coordination.

An analytical approach was also used for optimal healthcare staff models, such as staff scheduling and allocation. One hospital established three new COVID-19-specific departments and created an optimal shift schedule for physicians with respect to the relevant variables: departments (of which there were 17), number of physicians, number of regular shifts, COVID-ICU, COVID-Service, and COVID-Emergency (the three novel COVID- departments) (Güler and Geçici 2020). A mathematical model was used to categorize the optimal placement of physicians from their specializations into appropriate departments. Much like the equipment and patient models, this article engaged with the problem set and curated a solution given the input of data. Optimal staff scheduling provided a benefit by reducing the amount of stress placed on the clinician; for example, the model incorporated work breaks into the schedule (Güler and Geçici 2020). Despite the variety of predictive models used across the literature, they were similar with respect to focus outcome: improved patient and healthcare worker conditions or adequate supply used to improve patient and healthcare worker conditions. As previously mentioned, an in-depth solution on staff scheduling and how it eased the stress-levels of workers was still obscured from the review but would have been useful to develop.

These models complemented each other and served as useful tools for actual hospitals or healthcare systems for use. However, these models were not employed by the clinicians, therefore the application of such models required engineers, analysts, and management initiation. Operational efficiency models for hospitals faced with COVID-19 should therefore continue to be published and suggested to hospitals for further problem-solving considerations, plus have relevant and applicable use for physicians that played an integral role within the patient treatment pathway.

Emergency COVID-19 Hospitals

So far, the review has covered solutions specified for either patients, healthcare workers, or equipment. However, there were articles included in the review which incorporated all these elements and were deemed as "holistic approaches" to combat COVID-19. Every one of the articles detailed a case study or description of a "COVID-19 hospital"; in other words, a makeshift facility or building retrofit to administer COVID-19-pertinent treatment to patients, model the space for optimal provision of care, and have implicitly built-in protections for healthcare staff. These makeshift hospitals had to be built from an existing building or from the ground up, thus, each operational step considered patients infected with COVID-19. The studies in this review witnessed a total of 0 deaths – such a low rate of mortality was impressive and required further analysis and review.

Known as "secondary," "shelter," "makeshift," or "designated" hospitals, the variety of models made use of integrated technology systems (Zhou et al. 2022), team-based collaboration and structure (Baughman et al. 2020; D'souza et al. 2020), careful site selection and on-boarding processes ("Designated COVID-19 Hospitals: Case Studies and Lessons Learned" n.d.), and specific allocation of medical supplies and personal protective equipment (Moulick et al. 2020). D'Souza et al. (2020) formed "[a] multidisciplinary team [comprised] of hospital administrators and caregivers from both public and private healthcare systems were involved in operationalizing [a] makeshift COVID-19 hospital" (D'souza et al. 2020). This hospital was set up in Karnataka India starting April 6th in response to anticipated case surges. This hospital distinguished itself as it highlighted the motivations of the task force and the intentions for a makeshift hospital. In the case of Karnataka's secondary hospital, management sought:

> To ensure protection of the vulnerable patients availing care, safety of hospital staff, and to reduce stress levels among them, lessening the impact on the hospital revenues, to avoid substantial disruption for doctors in training while saving on the cost of PPE and cost care
> (D'souza et al. 2020)

The agenda can be interpreted as a holistic approach for a hospital dealing with a pandemic, since the team considered multiple aspects of the hospital: the logistics of staff, patients, and equipment. The agenda served as the backbone to the Covid-19 taskforce's model. Patient pathways were designed into three levels – screening areas, a facility for stable hospitalized patients, and a facility critically ill hospitalized patients – and staffing was organized into 6 categories and further divided into 4 teams: Team A, B, C, and D. Using a team-based model for staffing, the hospital designated team leader while the Task Force scheduled shifts (D'souza et al.

2020). The number of healthcare workers required was determined in proportion to critically ill patients. For additional standardization, the taskforce drew a patient pathway, or the route a patient would go through after arriving at the hospital, based on the levels of need from the patient.

In the span of the study, there were 202 admitted, 149 recovered, 4 patients requiring ICU care, and 0 mortalities. The study noted the importance of leadership and collaboration with healthcare staff as a strong component in the operationalization of a makeshift hospital. In the case of Karnataka's makeshift Covid hospital, an emphasis was placed on nurse training, temporal separation for health care workers, the proper use and supply of personal protective equipment, staff housing for quarantining from families, and mental health awareness for healthcare workers (D'souza et al. 2020). Hence, this case study emphasized certain successful areas on the patient-side and staff-side, which became a pattern of COVID-19 hospitals.

In the immediate wake of COVID-19's spread throughout Wuhan, 16 Fangcang shelter hospitals were established and opened which provided "13,000 beds to admit mild/moderate cases symptoms" (Jiang et al. 2021). One shelter hospital, the Optics Valley Fangcang Shelter Hospital, was further investigated in the review because of its relative success in patient treatment and integrative approach. The Optics Valley Fangcang Shelter Hospital was characterized by its intelligent system which integrated a slew of COVID-19-related measures: patient flow pathway, robot usage, shelter design space, cloud data usage and sharing, and emphasis on healthcare employee protection (Zhou et al. 2022). Key technologies propagated the strength of the intelligent system. Through building information modeling (BIM), the internet of things (IoT), cloud computing, and intelligent robots, the shelter adapted its technology into the efficient treatment of its patients. For example, the indoor environment was specifically mapped by building information modeling (BIM) technology; therefore, modelers easily visualized patient flow and could design the shelter hospital in a manner that limited contact among patients and between patients and workers (Zhou et al. 2022). Adding on, the indoor ventilation system was acknowledged and implemented based on negative pressure to limit airborne pathogens from entering corridors (Zhou et al. 2022). This building was modeled with respect to COVID-19 and, unlike the public and private hospital institutions which had to adapt their environment, airborne transmissibility was a heavy factor. Furthermore, medical control of inpatients paired with technology usage promoted "decision-making and… efficiency of medical services" (Zhou et al. 2022). For example, patient diagnosis was uploaded into the cloud platform in real time and shared between three large hospitals for shared recommendations and treatment amongst physicians (Zhou et al. 2022). This technology enabled constant monitoring of via a patient electronic bracelet; real-time updates of symptoms like sleeping, breathing, and coughing were paired with algorithmic analyses that sent doctors constant reminders of patient statuses (Zhou et al. 2022). Real-time detection of exacerbated symptoms allowed clinicians to immediately aid patients instead of relying on regular rounds of check-ups, which could have occurred much later than the systems point of exacerbation.

Intelligent logistics were helpful as well, which made use of delivery robots that were connected to the cloud platform. Since the cloud platform already contained BIM data as well as patient data, these robots could be informed of patient statuses immediately and could navigate the hospital through a GPS in the delivery of medical supplies, meals, and other daily necessities (Zhou et al. 2022). The robots performed many of the functions that would otherwise occupy the time of nurses and doctors, which freed healthcare staff to focus on critical patient emergencies and get rest (Zhou et al. 2022). This goes back to the bigger picture of limiting contact, as well, since robot delivery ensured a contactless experience for patients and healthcare workers for otherwise risk-laden tasks. The significance of the Optics Valley Fangcang Shelter Hospital study paralleled with the Karnataka secondary hospital; both implementation systems were planned and integrated a systematic approach model for end-to-end processes. Like the Karnataka hospital, the 875 patients treated displayed 0 deaths, but also had 0 personnel infections. An end-to-end COVID-19 adaptive hospital with adequate planning demonstrated in these studies marked an important possibility for future usage in an on-going pandemic.

In Boston, Massachusetts, the demonstrated benefits of a makeshift hospital were seen through a 1000-bed field hospital led by a large nonprofit multicenter health care system constituted of 2 academic medical centers, a PAC network, and several community hospitals (Baughman et al. 2020). The site was assembled in 9 days and organized according to the needs of patients and clinical care teams; “staffing were provided by local health care organizations and an Army Reserves Military Task Force” (Baughman et al. 2020). Different from the technologically integrated Optics Valley Fangcang Shelter Hospital, this field hospital carefully constructed strong clinical teams to manage a variety of functional department areas, i.e., the creation of teams for respiratory therapy, leadership, staffing and workflow, acute care and code team, admissions staff and workflow, mental health, PT/OT/SLP, and MD/APP staffing and workflow (Baughman et al. 2020). These teams collaborated often in daily interdisciplinary huddles. Pharmacy and laboratory services were provided for patients and radiology, wellness, and virtual consultations were created for both patient and staff (Baughman et al. 2020). Like other hospitals in these studies, this field hospital witnessed 0 deaths over the course of 7 weeks with 394 admitted patients.

Overall, the scope of research highlighted how hospitals which developed each aspect of their operations – from their technology to their leadership – into a guided framework based on COVID-19 oriented problems. While already-established hospital studies addressed a single dimension of issue related to COVID-19, the publications on secondary articles developed a holistic plan to combat each problem associated with the pandemic. Thus, proper clinician teams were present within collaborative systems; and, in the case of the Fangcang case study, those systems were intelligent, i.e., technologically integrated, and adequate treatment was administered along with minimal contact. These studies showcased an ideal environment to combat the pandemic and informed future studies and strategies for model adoption. The size and timeline of these studies, however, were not expansive and demanded more examples of caseload management during surges.

Hospital Demographics

It would be beneficial to know where and for how long the demographic of these reviewed studies observed. What does this have to do with the patient pathway and proposed problems and solutions? Certain questions from some of the limitations posed in the previous sections obligated a better understanding of the overall scope of the entire review. This pointed to the limitations of the review, which could be seen clearly via a demographic analysis. Location of the studies confounded the patient-level data and their resulting treatment since it was learned that demographics provided only a glimpse into the risk-factors of patients.

As the pandemic has endured for close to 2.5 years (as of May 2022), the review showcased how studies encompassed just small portions of the pandemic. A consideration of these two issues – location and duration of study – would promote areas of interest for future study, highlight the limitations in the current methodology, and give context to the problems and solutions posed along the patient treatment pathway.

This section was based on the 3rd research question: since this research topic is fast-growing and constantly evolving, what were some bigger picture demographics of the hospitals or healthcare systems within the reviewed literature? To capture some of these demographics, an analytically driven review of the studies was performed and organized into two sections: (1) study location and (2) duration of the studies.

Study Location

There were 32 publications produced based on empirical investigations across 13 countries in the sample review (Figure 2). The 8 other articles in the review were primary literature articles which used simulated models (Ma, Zhao, and Guo 2022; Wood et al. 2020; Tavakoli et al. 2022; Moulick et al. 2020) and data at the global level (Reyes-Santias, Barrachina-Martinez, and Vivas-Consuelo 2021; Bertsimas et al. 2021; Ioannidis, Cripps, and Tanner 2022) The results suggested that, although this topic is a worldwide issue, all but 11 studies were performed in what the World Bank Classification System categorized, “high income” status countries (“WDI - The World by Income and Region” 2020); 21 of 32 studies occurred in the United States, United Kingdom, Netherlands, Spain, Italy, Belgium, Cyprus, and Saudi Arabia (“high income”); 6 of 32 studies occurred in China (“upper middle income”); 2 in India (“lower middle income”); 1 in Turkey (“upper middle income”); 1 in Iran (“lower middle income”); 1 in Egypt (“lower middle income”) (“WDI - The World by Income and Region” 2020; Figure 2). From Figure 2, the lack of color on the map indicated the confinement of research to countries in high- and upper-middle income statuses. Hence, the sample literature demonstrated that hospital model research for COVID-19 has been limited in its global scope; the bulk of research on health information management has been dominated by the United States, China, India, and countries in Europe in 1996 (“SJR - International Science Ranking” n.d.). The SLR did not examine any studies from countries in South America and contained just 1 study taking place in multiple African countries (African COVID-19 Critical Care Outcomes Study (ACCCOS) Investigators 2021).

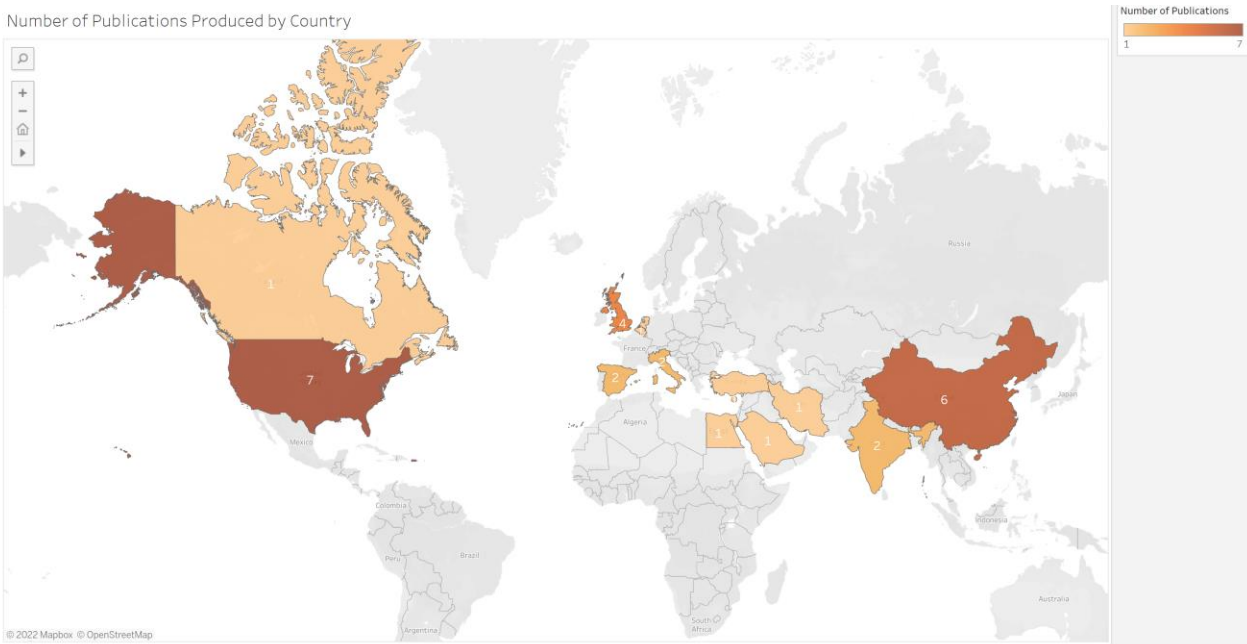

Figure 2. Number of publications by country, indicated by the number on the map. Data was organized in Excel, cleaned in R, and visualized via Tableau.

Without a more diverse spectrum of studied countries, the WHO C.A.R.E. patient pathway could not be applied across different settings. This was especially concerning for countries that witnessed high quantities of cases and hospitalizations such as Brazil and Indonesia, whose hospital models were not investigated in the research and limited how much was understood about those systems put in place. Instead, the thesis was familiarized in high income and upper-middle income solutions; this dearth in worldwide studies should be filled by future publications coming from hospitals across the expanse of countries. How were the hospital systems in those other countries disrupted by COVID-19?

Duration of the Studies

For added context, the estimated pandemic timeline has spanned a total of ~875 days (estimated from the first reported case in Wuhan, December 2019, up until May 2022). During this time, 3 waves have occurred with 2 being caused by either the Delta or Omicron (B.1 and B.2) variants. This subsection asked the question: how much of the pandemic was actually captured by the studies? An investigation of the length of study based on number of days revealed an average study length of 151.9 days with a median of 31.0 days. However, when extreme values were removed, the average study length was 112.0 days with a median of 62.0 days (Figure 3). Therefore, the average study length captured just about an eighth of the total pandemic. To compare, the average span of the waves seen in the pandemic lasted roughly over 90 days (and one could argue that the Omicron variant wave was still on-going). It would be useful to showcase prolonged studies which could capture multiple waves of patient data and observed solutions. For instance, the Optics Valley Fangcang Shelter Hospital witnessed 0 deaths across a 3-month period; if the hospital had witnessed multiple surges over a longer period of time, would certain successes have been changed like the mortality rate?

Furthermore, the median, denoted by the black-bolded horizontal line in Figure 3, showcased a graph that is positively skewed, implicating a higher concentration of studies less than or around the median of 62 days, or a bit under a fourteenth of the total length of the pandemic. Systems were measured in the short-term, however, the evolving nature of COVID-19 and the uncertainty of future variants ran against short-term successes. For instance, the short-lived mask mandate in the United States in 2021, followed by a mass reopening in all states and an ensuing 3rd wave due to Omicron, highlighted how a short-lived success did not outrun the marathon-like nature of the persisting pandemic. Could these adapted systems hold it together as well? More long-term studies which accounted for the evolution of the virus in relation to the system's adaptations would provide more confidence in the system itself.

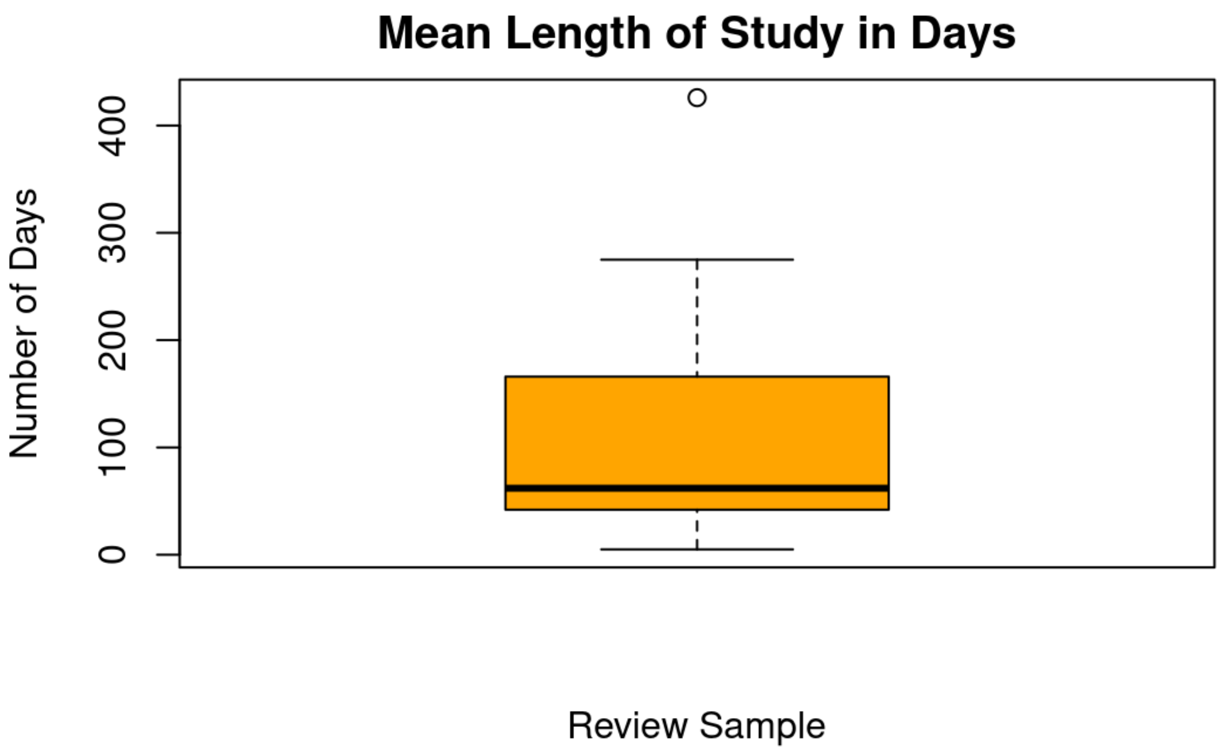

Figure 3. Boxplot of the duration of study. Mean = 112.0; Median = 62.0; Max = 426.0; 3rd Quartile = 166.0; 1st Quartile = 42.0; IQR = 124.0.

Methodology

A collection of articles concerning hospital operation systems problems and adaptations were produced. Since there was an expansive number of articles related to COVID-19, a considerable amount of filtering for articles used specific search keywords, inclusion and exclusion criteria, and citation chaining. The methodology used to determine the criteria of selection for research articles followed the first phase selection method of Kaur et al. (2020). This first phase "focused on determining research objectives, identifying appropriate databases, and determining keywords and article selection (inclusion & exclusion) criteria for curating the study sample" and will be applied to the this thesis based on the research questions and objectives (Kaur et al. 2021).

The University of Massachusetts's Libraries A-Z Databases contain a wide selection of field-specific and general databases to address research needs. *Business Source Complete (BSC)* is an online database of business-related scholarly articles from many different fields. *BSC* was chosen over specialized hospital-related databases compared with more- and less- specialized scholarly databases (*Business Source Complete, PubMed, American Hospital Association, Cochrane Library, and Scopus*); these libraries were suggested to be used for hospital systems studies by the University of Michigan Library, cross-referenced with Stony Brook University Libraries, Duke University's Medical Center Library and Archives, and available in the University of Massachusetts' Amherst Libraries A-Z Databases (Koos n.d.; "Welcome | Duke University Medical Center Library Online" n.d.; Library n.d.).

For each database, identical search syntax filters were applied, and the search results were compared. Upon review of the search results, the *Cochrane Library* and *Scopus* were excluded since the former had a narrow result (7 results) while the latter was too general and did not allow for keyword-specific searches. The goal of the thesis was to apply a worldwide lens to hospital systems, so although *The American Hospital Association* databases contained useful research on hospital systems, they were constrained to studies which surveyed United States hospitals only ("Fast Facts on U.S. Hospitals, 2022 | AHA" n.d.). Moreover, the search result contained over 10,000 articles, which would require further filtering; in this case, the possibility for more research on U.S. hospital systems and COVID-19 can be forwarded.

Furthermore, the search results for *BSC* and *PubMed* contained 234 and 34 results, respectively. The publication titles, abstracts, and keywords were examined from each database and *BSC* was selected for 2 reasons: (1) There was a wider variety of operational systems models applied to hospitals and (2) although *PubMed* had multiple useful articles which could be applied to this thesis, there were too many non-systems oriented or non-hospital related publications that would be excluded from review (just 12 of the 34 articles were usable).

It should be noted that after *BSC* was selected for review, another database was found called *UpToDate*, which housed hospital-related peer-reviewed publications. In retrospect and with respect to the search criteria, this database would have been selected over *BSC*, as the search results were slightly more specialized to hospitals while articles from the *BSC* search were operations-oriented within hospitals. This highlighted one of the confounding aspects of this thesis, as a more viable and specialized database could have produced articles that were useful to answering this thesis' topic questions. On the other hand, the articles from *BSC* were both hospital- and operations-oriented and resulted in a variety of hospital models that proved useful for analysis. Although *BSC* was limited in specialization, the results produced were still highly relevant in the field of operations and could be seen as a useful database for an operations-based research endeavor across multiple industries.

The search functionality in *BSC* enabled lookup of multiple keywords in tandem and used the operators -and, for a filter which required a keyword to be included in the resulting publications, and -or, which for a filter which the results may have included as a keyword. Thus, an initial search specified the keywords "COVID-19," "SARS-CoV-2," "2019 pandemic," **or** "2019 novel coronavirus" **and** "hospital" **and** "model," limited to peer reviewed publications with a t resulting search of 234 relevant studies. Next, specific article criteria were specified to further filter the set of results through an inclusive set – the target studies – and the exclusive set – studies with keywords, topics, or additional criteria which would not be relevant to cover (Kaur et al. 2021).

A read through from the abstracts of the 234 resultant articles helped to develop inclusion and exclusion criteria; these criteria ensured relevance to the research questions I hope this thesis would provide a before-and-after outlook on these systems, in other words, to investigate how the hospitals struggled considering COVID-19 and what was done to solve those issues. Inclusion criteria referred to the main ideas found from the abstracts which tied back with the research questions: problems and solutions to the overall hospital system. The inclusion criteria were formatted as follows:

1. The terms “COVID19” (or its other names), “hospital,” and “model,” was mentioned in the abstract, keywords, or title.
2. Hospital operational models were empirically investigated through a primary literature study.
3. The full text of the study was available in English.
4. The study was published in a peer-reviewed journal from the dates 2019-2022.

In tandem with the inclusion criteria, an application of exclusion criteria was needed to filter out publications which strayed too far from the topic of operations systems in hospitals during the pandemic. This was a difficult choice to make, since of the 234 resulting articles, a large number were relevant to some aspect of the patient treatment pathway. The main ideas of the publications had to stay within the boundaries of a hospital. While vaccination played a role in helping patient infection severity, the topic represent a big picture idea in the pandemic, so it would stray too far from the patient treatment pathway witnessed within hospitals. To try to remain as specific to the research questions as possible, the exclusion criteria was determined as follows:

1. The study did not investigate COVID-19 within a hospital setting,

2. The study focused on social distancing, quarantining, lockdown procedures, contact tracing, or other non-hospital measures against COVID-19.
3. The study was related to an industry outside of healthcare (for example, finance).
4. The study focused on COVID-19 vaccine efficacy.
5. The study was a duplicate of an earlier search result.

The exclusion criteria represented one of the main limitations to this SLR, since the exclusion barred potentially relevant and useful articles from being reviewed. Thus, if this SLR was performed a second time, more publications would have been included to capture additional models and solutions covered by the current SLR's excluded literature.

Additionally, backward and forward citation chaining reviewed any additional studies to be considered in the review (Kaur et al. 2021). As a result, 4 publications were included into the review. Considerable review of the content and keywords for every publication was performed to ensure the content was appropriate for review. For example, articles were excluded during this review phase because they were not primary literature publications.

After careful consideration of the 234 search results from the previous search, the following narrowing-steps took place to specify the sample: (1) 154 articles removed due to exclusion criteria a, b, c, and d, (2) the full text was not fully available for 10 publications, and (3) 34 publications removed which were not primary literature articles. The final sample contained 40 articles for review to answer the proposed research questions.

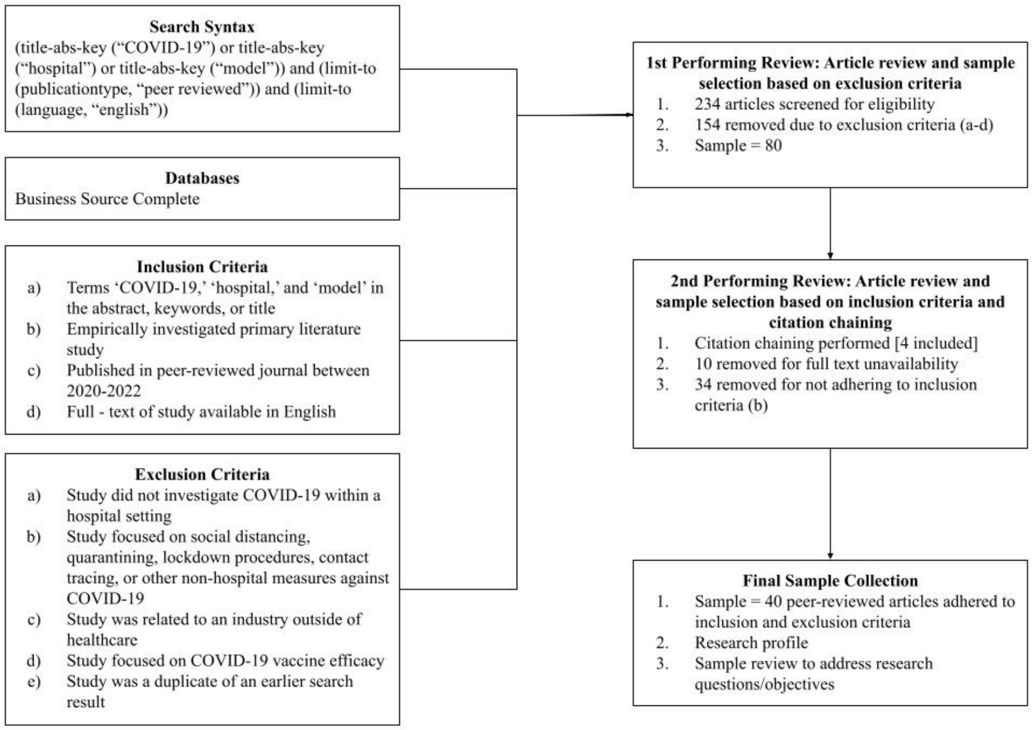

Figure 1. SLR sample selection protocols. This model followed the SLR selection framework of Kaur et al. (2020).

Discussion

Findings from the literature reviewed were further discussed for implications, current gaps, and recommendations for future research. In brief, the problems and solutions were analyzed in relation to the generalized WHO C.A.R.E. model. There were many problems which focused on the "Assess" and "Respond" steps of this model. Likewise, the solutions were concerned with the 'A' and 'R' portion as well. The goal for this systematic literature review was to curate a sample of literature that attempted to answer each research question:

1. **Research Question 1**: Considering the smaller parts of the whole in hospital systems, what steps in the patient treatment pathway were challenged due to the pandemic?

The caseload surge resulted in relatively low supplies which, in U.S. hospitals, was associated with higher (and unnecessary) mortality rates (Kadri et al. 2021). Higher mortality rates may have stemmed from a lack of adequate equipment for treatment but also factored in other variables, such as the longer waiting times, the stress of staff, or a reduction in treatment knowledge and experience. With the help of vaccinations, the mortality rates in U.S. hospitals declined; a contributing aspect may have been evolving treatment for patients (i.e., proper intubation allocation) (Kadri et al. 2021). Hospital supply management and the supply chain were disrupted due to this emergency; one takeaway which I found surprising was that the well-funded healthcare systems witnessed equipment shortages. Wouldn't healthcare systems have had emergency precautions and/or emergency protocols for a pandemic event? Instead, U.S. hospitals have adopted a just-in-time (JIT) inventory system, which aimed to minimize inventory to match with current demand for reducing waste (Chapman 1986). JIT management meant keeping a very low inventory (more inventory = higher costs) which would only be updated when needed. This may have backfired because as the pandemic hit U.S. hospitals, every system scrambled to source equipment and the resulting shortages ensued. JIT management may have proved useful for production; however, hospitals could not ignore the possibility of an emergency that resulted in patient surges and such adoption could have linked U.S. hospitals to the resulting shortages. Hence, further investigation into emergency equipment protocols would establish the readiness of a hospital for future influxes.

Hospital staffing were involved in every step of the patient treatment pathway. As a result, the high number of cases and relatively high mortalities of patients in critical care units burdened employees. The emotional and physical toll of being in a healthcare treatment position was also shown to affect Black and Latina women under the age of 30 the most (Leo et al. 2021). While patient demographics were so often reinforced into datasets through constant examination, this study highlighted how healthcare staffing demographics played a factor into the patient treatment pathway. Despite healthcare staff being a focal point to the operational system of a hospital, the research conveyed only some demographic and organizational-cultural issues which resulted in worker stress. Additionally, the review did not cover healthcare workers outside of the U.S. and U.K., so a generalization of the healthcare worker experience during the pandemic was still being made without consideration to the millions of other healthcare workers excluded from interviews, research, and observation.

Another challenge was accurate patient assessment based on the limited amount of information given upon entry into the hospital. Physicians tried to categorize patients based on certain comorbidities, demographics, and risk factors for admittance into certain levels of treatment (i.e., non-lethal vs critical care). This was not an entirely clear-cut process – not only were demographics varied and uncertain, but also the region/country and the strength of resources for a hospital may have impacted the patient risk factor. As the pandemic wears on, data collection of patient data, location, and hospital resource data may have helped physicians to make better decisions for treatment.

2. **Research Question 2**: What kinds of solutions propped up healthcare systems in their delivery of treatment?

First, there were studies that employed some method of predictive analytics for predicting patient quantities (Ozik et al. 2021; Zebrowski et al. 2021) as well as triaging and allocating patients within hospitals (Balinskaite, Bottle, and Aylin 2021; Ma, Zhao, and Guo 2022; Leite, Lindsay, and Kumar 2021; Wood et al. 2020) which produced various findings for research to build upon. These studies attempted to aid physician diagnosis of patients for having certain risk factors, expanded the capacity of equipment to meet imminent demand surges, and developed a quicker system of assessment for hospitals.

One hospital adopted a leadership, culture, and management practice called LEAN, and successfully created a better workplace environment for workers while developing makeshift ventilators and staffing models which could adjust for the surge in demand. On the worker and management-side, these results were positive, but the study made no conclusions on how such measures impacted the patient-side within their hospital. The practice of LEAN by Baruch et al. (2021) highlighted just that – the practice – and did not delve into the results of the initiative. LEAN implementation and its mantra of continuous improvement ("kaizen") has been proven to bolster organizations in all industries, so the possible adoption of LEAN practices in a crisis would be sensible. However, LEAN results of organizations in financial or manufacturing industries were always measurable via sales, employee growth, cost cutting, waste management, inventory supply, and the bottom line (Liker 2021). Future research about LEAN in hospitals could demonstrate both the changes and the impact of those changes through patient mortality rates, successful surgeries, transmission of disease within the hospital, the happiness of staff, and other outcome metrics.

Furthermore, it was found that studies on designated, shelter or secondary hospitals (referred to as COVID-19 hospitals in this thesis) were the only studies in the review which comprehensively addressed each aspect of a hospital's operations; the patient, healthcare worker, management system, and strategies for treatment were modeled into the overall hospital framework. The specialization of COVID-19 hospitals included limited contact among patients and between patients and workers (Zhou et al. 2022; D'souza et al. 2020), a collaborative healthcare workforce focused on improvement (Baruch et al. 2021; Baughman et al. 2020), a shared data network among other COVID-19 hospitals (Zhou et al. 2022; Jiang et al. 2021), wellness and mental health therapies for workers and patients (Zhou et al. 2022; Baughman et al. 2020), and even the use of robots to deliver medical supplies to patients (Zhou et al. 2022). These strategies are obviously not unique to COVID-19 hospitals, but each facet was carried out with respect to the virus itself, which in turn, created a more holistic system of processes.

3. **Research Question 3**: Since the research topic is fast-growing and constantly evolving, what were some bigger picture demographics of the hospitals or healthcare systems within the reviewed literature?

The spread of COVID-19 has affected hospital systems at a global level, despite this, the review and analysis of the demographics of articles showed how a majority of research came from high income and upper-middle income countries (29 of 32 publications). Brazil, Indonesia, Russia, Mexico, and Peru have witnessed world-high death tolls (>150,000 deaths), yet this thesis did not included publications from hospital systems in any of those countries ("COVID Live - Coronavirus Statistics - Worldometer" n.d.). This result highlighted how systematic reviews on an evolving and global topic could be inherently confounded, suggesting that more worldly reviews on hospital systems should actively search for research in different countries. In other words, this would avoid filtering out lower income or less represented countries implicitly. Likewise, a more global set of research articles may have been produced by a research database different from *Business Source Complete.*

Secondly, it is possible that this review showcased the dearth of research on hospitals from lower income countries. After all, high income countries like the United States and United

Kingdom have dominated the scientific and medical research space, so it would stand to reason that the ratios of publications were skewed (Scimago Institutions Rankings n.d.).

Considering the virus' persistence and global spread, the publications were found to cover only a fraction of the overall timeline. Most studies lasted under 62 days (<1/14 of the pandemic) and although successes were proven, it was unknown whether those solutions could withstand the wave of variants and associated COVID-19 seasons.

4. **Research Question 4**: What were the gaps and limitations of the prior literature?

While the C.A.R.E. model provided simplicity and straightforwardness, it was may have not been applicable in every instance and was therefore used solely as a guidance tool for this thesis.

Predictive analytics demonstrated mixed results, as some studies overshot the predicted number of cases in hospitals (Zebrowski et al. 2021) while other hospital studies witnessed accurate predictions and could employ these analytical models (Baas et al. 2021). Thus, the varying degrees of input required refinement and further analysis. Ioannidis et al. (2022) reinforced the current uncertainty of model usage by highlighting 3 prediction studies, all of which overestimated the number of cases and required beds for hospitals. However, the research had shown that almost 1 in 4 COVID-19 deaths in U.S. hospitals can be attributed to surges, thus overestimating capacity could lead to better outcomes than severely underestimating case surges (Kadri et al. 2021).

Furthermore, predictive analytics were useful in hospital-specific settings where, for instance, the accurate allocation of equipment in a timely manner could be modeled and performed (Liu, Bai, and Wu 2021). As the scope of the study and number of hospitals expanded, the data grew more robust yet was never actually implemented for patient treatment (Marin-Garcia et al.

2021) or was adopted by healthcare systems but the results were never mentioned (Bertsimas et al. 2021). Although the "Assess" step involved a multitude of features for bolstering data sets – demographics, comorbidities, symptoms, and biomarkers – the thesis never showcased if predictions based on those data sets contributed to bettering assessment and patient risk categorization (Bertsimas et al. 2021).

Although COVID-19 hospitals demonstrated high successes, there were gaps in the studies which limited the extent of the findings. For instance, the Boston-area field hospital study spanned just three months and the Optics Valley FangCang Shelter Hospital spanned 3 months; although success was witnessed, the prolonged efficacy of COVID-19 hospitals was still unanswered. Also, these studies may have captured the initial wave of COVID-19 cases and deaths, however, the 2nd wave in 2021 and 3rd wave in 2022 were uncaptured and required further attention. Additionally, the COVID-19 hospital studies were performed in 2020, which begged the question as to where these COVID-19 hospitals were in 2021 and 2022. The future of COVID-19 hospitals was hopeful, however, the lack of recent research may have caused forgetfulness of these historically positive initiatives.

5. **Research Question 5**: What are future endeavors or possibilities for the field?

It would be interesting to see more studies which focused not only on the stress-related factors of COVID-19 on healthcare staff, but *who* was in contact with patients the most (many of the studies pointed to nurses) and the stressors this caused for those groups of healthcare workers. Again, the importance of healthcare staff could not be understated, especially in a pandemic. Perhaps a management-employee collaborative model could bridge the communication gap and make work easier for healthcare staff (Baruch et al. 2021). Or, staff scheduling that was curated to ease workload and incorporated many departments could improve worker conditions and possibly boost morale in this turbulent time (Güler and Geçici 2020).

Therefore, a need for research from unrepresented countries was required for contribution to the overall scope of hospitals during the pandemic. This contribution also would strengthen the pool of data through added patient demographics. The average duration of study was 112 days; however, this distribution was positively skewed because most studies' average duration was below the median count of 62 days, which represented a small fraction of the overall pandemic timeline (62 of ~880 days, or ~7% of the pandemic's duration). For case studies in particular, this shortened timeline could have omitted one or several waves of cases and deaths of the pandemic. Case waves described the waves of exponentially increased positive cases and deaths due to COVID-19 in 2020, 2021, and 2022.

Limitations

There were certain constraints to the methodology which limited the capture of problems and solutions along the patient care pathway during the COVID-19 pandemic. One such limitation was the inclusion and exclusion criteria framework for study selection. While the criteria were useful for a narrowed sample of studies, it may have excluded certain studies which would have otherwise been useful to explore in the SLR. Some of these excluded studies may have addressed the gaps of the review or brought about other solutions and strategies incorporated by hospitals to combat the pandemic. Plus, studies that could have added to the scope of problems may have been excluded due to the rigidity of the search criteria. Despite its usefulness for forcing specificity, the inclusion and exclusion criteria prompted a narrow frame of reference on hospital systems. Plus, these criteria were built upon my own biases and interests in answering the research questions.

Ultimately, the use of search criteria may have proved useful in the Kaur et al. (2020) methodology since their topic was still at the beginning stages of its growth. Meanwhile, for a topic like COVID-19 in hospitals, the research flourished and was so bountiful that the search criteria could only capture a microscopic portion of the landscape.

Another limitation was the use of a single data base for article searching. Although Business Source Complete was comprehensive in its article topics, the research on COVID-19 was so expansive that other databases may have contained equally useful primary literature articles. Additionally, the use of a business-oriented data base provided sources based in business, but it may have proved insightful to garner information from other fields as well, especially from a clinical lens. As stated in the methodology, the same search criteria may have been more useful to apply within the *UpToDate* database which specialized in hospital- and clinical-level studies. Many of the studies in this search contained system pathway revelations for hospitals and COVID-19's impact to those systems. Moreover, a broadened scope of databases with additional keywords could have resulted in a hospital systems-specialized body of publications. Future scholars may consider using a wider scope of databases along with search criteria that was more inclusive of worldwide health organizations.

Search criteria, coupled with the usage of a single data base source, ultimately highlighted the overall limit to capturing the broader cultural, supply chain, economic, regional, and community aspects which were involved at hospitals during the pandemic. The demographic of research showed the narrow, from a country and access standpoint, review, as 29 of the 32 articles were covered in high income or upper middle income, research-prevalent countries. Overall, not every challenge faced by hospitals could have been included because the scope of the virus is so vast. Likewise, the solutions covered by this thesis were made within countries that had the resources to, for instance, build an entire field hospital in 9 days (Baughman et al. 2020). All in all, the multi-dimensional challenges and efforts about the hospital system should be approached at a simple, systematic level to capture a broad audience (i.e., the C.A.R.E. model), or via a highly specialized study which narrowed its focus onto one step of the patient treatment pathway.

Conclusions

The impact of COVID-19 on hospitals could not be understated and this thesis highlighted just a glimpse of how systematically disruptive the disease has been. Uncertainty still leads the way in this pandemic, however, as variants, which have a knack for emerging and maintaining vaccine resilience, have instigated case surges of COVID-19; daily case quantities have been at their highest during the Omicron period with two variants having emerged (B.1 and B.2). This may point to the now-widespread availability of testing (Zhang et al. 2022). Nonetheless, the landscape of the hospital systems has seemingly adapted to caseload surges and capacity shortages. Going back to the graph introduced in the first section, hospital-related deaths were lower during the Omicron period than in the two previous waves despite high COVID-19 admissions, cases, and ED visits (Figure 1, restricted to United States hospitals). One possible explanation points to vaccination efforts in the United States, a contributing factor that has quelled symptoms for millions of infected.

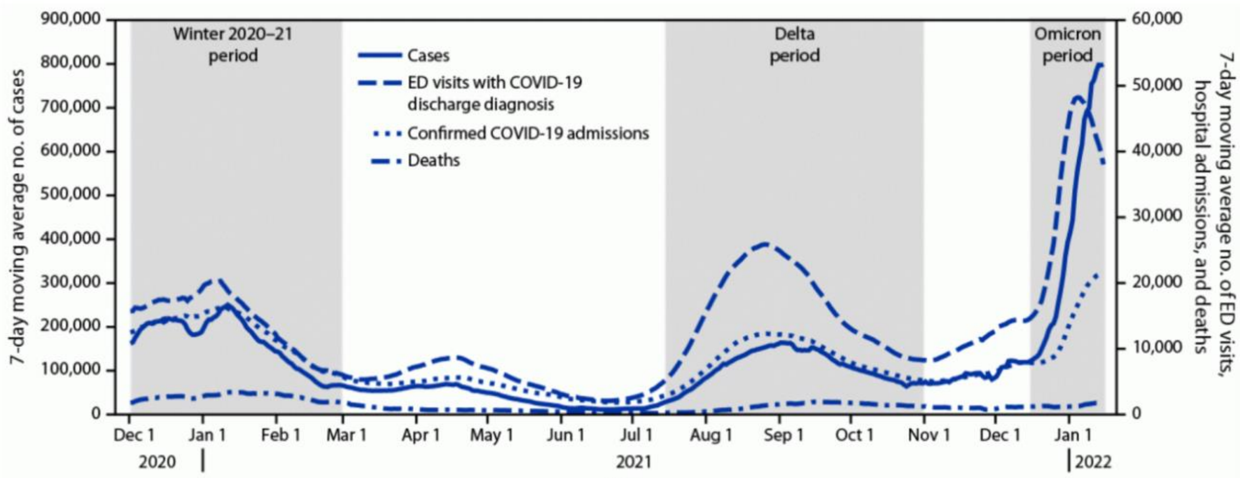

Figure 1. "Seven-day moving average number of COVID-19 cases, emergency department visits, hospital admissions, and deaths – United States, * December 1,2020 – January 15, 2022" (CDC 2022b). This data was derived from 199 U.S. hospitals (CDC 2022).

Ultimately, the systematic review was intended to find points of weakness along the patient treatment pathway caused by COVID-19: (1) capacity shortages in ventilators, PPE, and beds, (2) patient-level demographic data which muddled accurate risk assessment due to varied demographics and locations, and (3) the foundation of treatment, healthcare staff, were burnt out. What was done to absolve these negative symptoms? (1) LEAN practices established a leadership plus worker collaborative system of improvement, (2) data analytics helped physicians assess risk factors, were used to schedule staff at optimal times, (3) optimized delivery of medicines to hospitals, and (4) suggested equipment sharing between hospitals to avoid shortages. The limitations to these studies were (1) the location of the studies could capture only certain patient demographics and highlighted the lack of research in low-resource hospitals or countries, (2) predictive analytics were either inaccurate or were not applied in a real setting or did not demonstrate results in a real setting, (3) healthcare staff demographics as well as mental health was overlooked, (4) most of the studies captured a slim portion of the entire pandemic, which draws skepticism for the long-term success of a system, and (5) the systematic review itself was limited in the specialization of its articles due to its database source, inclusion, and exclusion criteria. This thesis could be used as a basis for future systematic reviews with adjustments which included the research limitations. In conclusion, the pandemic is still an evolving and changing landscape for research, thus, the review of this landscape requires constant reworking and rebuilding to solidify a global basis of knowledge for all of the important players and steps to the hospital system.

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