

Supporting the Quadruple Aim Using Simulation and Human Factors During COVID-19 Care

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Abstract

The health care sector has made radical changes to hospital operations and care delivery in response to the coronavirus disease (COVID-19) pandemic. This article examines pragmatic applications of simulation and human factors to support the Quadruple Aim of health system performance during the COVID-19 era. First, patient safety is enhanced through development and testing of new technologies, equipment, and protocols using laboratory-based and in situ simulation. Second, population health is strengthened through virtual platforms that deliver telehealth and remote simulation that ensure readiness for personnel to deploy to new clinical units. Third, prevention of lost revenue occurs through usability testing of equipment and computer-based simulations to predict system performance and resilience. Finally, simulation supports health worker wellness and satisfaction by identifying optimal work conditions that maximize productivity while protecting staff through preparedness training. Leveraging simulation and human factors will support a resilient and sustainable response to the pandemic in a transformed health care landscape.

Keywords

health care simulation, patient safety, Quadruple Aim, COVID-19, system preparedness

Introduction

Coronavirus disease 2019 (COVID-19) has uniquely stressed health care systems, policy makers, and

health care workers throughout the world as they face the worst health and economic crises of our lifetimes. Administrators are rapidly navigating their institutions through uncertain times, providing leadership and strategic plans to manage numerous evolving systems threats. Many of these plans run counter to the accepted mantra in modern times, including intentional cancellations of profitable elective procedures and layoffs or furloughs of dedicated medical staff during the pandemic.¹

The Triple Aim of health system reform addresses ongoing and future challenges faced by the health care sector,² with recent calls for expansion to a Quadruple Aim³ to include considerations and protection for staff. These 4 interdependent goals consist of (1) enhancing patient experience and safety, (2) improving population health, (3) reducing costs and preventing loss of revenue, and (4) improving wellness and satisfaction of health care workers. The fourth Aim incorporates the increasing understanding that excellent health care is not possible without a physically and psychologically safe and healthy workforce. COVID-19 has created unique threats and unanswered challenges to each element of the Quadruple Aim (Table 1).

Human factors⁴ is a scientific discipline that addresses the complex interwoven variables that affect health care workers' ability to deliver safe,

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Table 1. Quadruple Aim and COVID-19 Challenges.

Aim	Frame/context	COVID-19 challenge
Patient experience and safety	Optimizing and testing workflows before and during implementation ensures safety and quality care during pandemics.	Are new processes and equipment safe for patients? How can we support patient-centered care during social distancing and grieving? How can we ensure teamwork with challenges to communication during COVID-19?
Population health	Quick changes during COVID-19 to education and staffing may be necessary for immediate response but can negatively impact long-term health care safety and maintenance of workforce. Contingency plans for delivery and training are needed.	How do we ensure adequate health delivery when care models have been disrupted or altered? How can we continue supporting education for the next generation of medical students, nurses, and resident caregivers when access to bedside experiences is limited and potentially dangerous?
Reducing cost and preventing loss of revenue	Cost reduction must be balanced with safety and care quality in the system to be effective. Involving stakeholders and align “work as done” versus “work as imagined.”	How do we reach patients who do not have COVID-19 to continue providing services and minimize loss of revenue? How do we best prevent infection of health workers and minimize viral transmission in health care settings? How can we safely reuse PPE or retrofit existing equipment before purchasing mass quantities?
Health worker wellness and satisfaction	Combating the pandemic has been compared with war and disaster response. The workforce must be protected for all other health care missions to be effective.	How do we ensure safe practices and avoid overstraining staff with extended hours/physical demands? How can we build resilience and preparedness for health workers as protocols and guidelines change?

Abbreviation: COVID-19, coronavirus disease 2019; PPE, personal protective equipment.

high-value patient care, and is particularly applicable in the rapidly changing environment of COVID-19. It applies a sociotechnical systems approach to study how humans interact with the world and improve system performance and reliability. Human factors methods can assist health care administrators to meet the needs of their patients, workers, and organizations, especially those resulting from the added stressors of the pandemic response.

The military and aviation sectors have successfully implemented human factors methods extensively using simulation, a burgeoning technical field that applies experiential techniques for the purposes of practice, learning, evaluation, testing, or gaining insight into systems or human actions.⁵ Simulation incorporates human factors approaches to address complex operational challenges, including improvement of individual and team performance, as well as adaptive systems development to decrease the rate of fatal errors and system failures.⁶ In the health care sector, simulation techniques can be leveraged to preserve the financial solvency of institutions by enhancing clinical operations, identifying latent safety threats, testing new protocols and patient pathways, improving the execution of complex medical procedures, and streamlining the hospital supply chain. Simulation experts use a wide variety of technologies to tackle these challenges, ranging from high-fidelity mannequins to computer-based models that can analyze big data and apply model predictions to analyze and forecast anticipated changes needed because of performance and operational demands.

As governmental mandates on travel restrictions and social distancing are relaxed, experts warn of an

impending “future waves” of infections in the upcoming months.⁷ Health care systems also need to resume elective procedures and non-COVID-19 operations as the initial crisis passes and financial recuperation efforts begin. These considerations highlight the possibility for an extended response curve and fluctuating operational demands for COVID-19 in conjunction with routine care in the near future. Given this anticipated lengthy response to the pandemic, action is necessary now to prevent long-term repercussions to the health care system. This article leverages the framework of the Quadruple Aim to provide practical simulation and human factors-based solutions for systems improvement. The overlapping goals of patient safety, population health, cost reduction, and preservation of workforce can be implemented to combat the deleterious effects of COVID-19 (Figure 1). Each of these 4 aims is discussed further in the following sections.

Aim 1: Enhancing Patient Experience and Safety

Three main challenges relating to patient experience and patient safety have emerged during the current COVID-19 pandemic: (1) equipment and critical care bed shortages, (2) patient isolation during care delivery, and (3) health care worker communication and teamwork challenges. Simulation-based innovation can test changes in health care services and address equipment modifications quickly before implementation of changes to actual patient care.⁸ As knowledge builds and recommendations evolve during the outbreak, simulation can

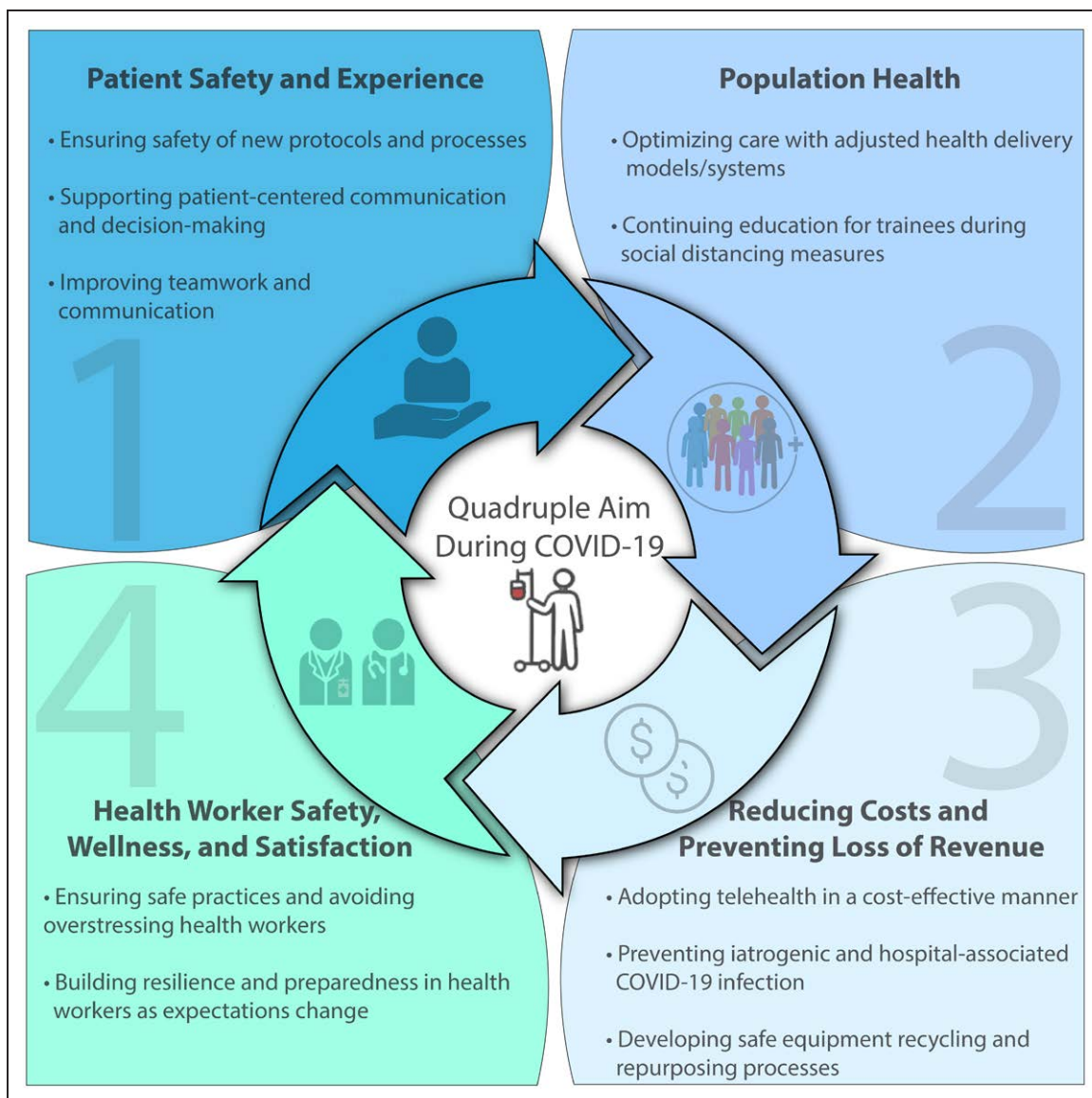


Figure 1. The Quadruple Aim and health system improvement challenges during COVID-19. Abbreviation: COVID-19, coronavirus disease 2019. This figure is available in color online (www.AJMOnline.com).

assist in the development of new techniques that iteratively refine the deployment of new clinical strategies, equipment, bed utilization, and workflows.

Resource limitations have forced health care systems to deploy nontraditional treatments and technologies during COVID-19, such as the use of noninvasive ventilation via oxygen helmets.⁹ Similarly, many hospitals piloted the use of a single ventilator machine to simultaneously ventilate 2 or more patients.¹⁰ Simulation uses human factors techniques to help effectively implement medical innovations such as these in the clinical environment by engaging health workers as end users in the development, testing, and improved deployment of new

equipment. Simulation also can assist staff in using unfamiliar equipment and practicing new techniques, or refreshing their skills that have decayed, in a safe and controlled environment, particularly in higher-risk settings such as intubating behind plexiglass in operating rooms and intensive care units. Telementoring or tele-simulation, as an adjunct to “brick-and-mortar” simulation laboratory-based training, has shown promise as an effective method to teach mechanical ventilation techniques during clinical care by allowing instructors to remotely train, assist, and debrief health care workers.¹¹

Isolating large numbers of COVID-19 patients has presented operational and social challenges for

patients and their families. Videoconferencing technology can support families in providing critical information about their family members to medical staff, communicate with their loved ones, and facilitate end-of-life conversations in a patient's last moments. Scaling up of innovative video-based interactions for emotionally charged patient interactions may face unexpected technical, interpersonal, and cultural barriers when rapidly introduced during a viral pandemic. The implementation process is likely to be difficult and resource-intensive, and would benefit from iterative testing and refining of the technology and implementation in a simulated environment.

Changes in team roles and communication modalities, disrupted and distracted patient handoffs, and the use of bulky personal protective equipment (PPE) present challenges to effective teamwork and communication. Simulation can assist with efforts to address safety through coordination and optimization of health care team performance during COVID-19. In situ simulation of high-risk and invasive procedures on COVID-19 patients in an intensive care unit revealed latent safety threats related to difficulties in communication effectiveness among team members wearing PPE.¹² Team members learned how to engage with muffled voices, identify colleagues with concealed faces, and manage the loss of nonverbal cues through real-time simulation training. Corrective measures included learning to project their voice, use of walkie-talkie communication, and focused closed-loop feedback communication skills to minimize medication errors and improve the efficiency of equipment preparation.¹³

Simulations of system testing and innovation can help improve individual and organizational safety outcomes by identifying potential exposure threats, mitigating risks and threats to patients, incorporating new technologies into existing workflows, and to help better appreciate the impact of new protocols on team coordination. This would mirror well-established military utilization of simulation to ensure safety and readiness by preparing, training, and deploying new standards for conflict scenarios, managing emotional conflicts, and honing new combat leadership skills and techniques.¹⁴

Aim 2: Improving Population Health

Population health focuses on improving community-wide health outcomes by addressing patterns of health determinants as well as the policies and interventions that link to those outcomes. Two primary threats to population health relate to system

operations and have dramatically risen since the emergence of the COVID-19 pandemic include (1) interruptions and shifts in care delivery models, and (2) disruption in education and training activities resulting in long-term consequences for the system's ability and readiness to deliver care.¹⁵

Mitigation strategies to minimize viral transmission and preparation for resilience of health systems in the COVID-19 era become crucial when preparing for an influx of patients falling ill because of the pandemic.¹⁶ In response, administrative bodies have quickly implemented radical changes such as cancellation or postponement of educational activities and redeployment of personnel from their normal practice environments. Simulation provides a platform to safely advance new delivery models into practice and prepare clinicians for current and future challenges in care delivery.

Near-term consequences have included disruptions or alterations in the delivery of care, especially for populations with serious illnesses who may fall ill without continued support and care coordination. Robust digital telehealth services are undergoing rapid adoption in many health care systems to minimize exposure to the virus for uninfected patients who seek evaluation or require maintenance care. This is especially crucial for vulnerable populations such as elderly patients, those with long-term conditions, and individuals receiving chemotherapy or immunosuppression. Yet, health care workers train and practice in a primarily face-to-face model of care, and care delivery systems are ill-equipped to expand their capacity for telehealth under time and resource pressure during the current public health emergency. Cognitive task analyses and usability testing with both patients and clinicians can inform implementation of telehealth visits that support effective rapport while maintaining continuity of care for the broader population.¹⁷ Simulation-based training with virtual or standardized patients can prepare clinicians and health care workers to rapidly implement new protocols, adopt efficient changes in bedside performance, and use new digital interfaces including remote home monitoring services¹⁸ needed to deliver safe and effective telehealth care.¹⁹

While health care systems are delivering nonemergent care through telehealth appointments, many are also redeploying clinicians to practice in care areas outside of the normal scope of their specialties to meet surges in clinical needs and workforce reduction related to staff infections.²⁰ Simulation can provide ad hoc training, testing, and assurance to prepare practitioners as they take on duties outside their scope and training during COVID-19 before and during their deployment. Refresher just-in-time training on correct

use of unfamiliar medications, procedural tasks, cognitive skills, and COVID-19-specific challenges can incorporate digital technology and simulation techniques. Finally, discrete event simulations can use epidemiologic data to model and predict patterns of clinical demands. For example, computational algorithms such as Monte Carlo simulations allow for accurate and evidence-based predictions for hospital needs and adjustments in staffing while minimizing the negative impacts on system capacity and finances.²¹ These planning and prediction techniques have been used in Italy to mitigate system collapse, and are critical for the near future as various local and state and federal agencies start reversing public lockdown measures. Without prepared communities, we anticipate surges in reinfections and death rates.²²

COVID-19 has brought radical changes to medical education, creating potential long-term impacts on the capacity of health care to serve the population in the future. This has included removal of medical students from clinical rotations, cancelation of in-person lectures and hands-on activities, and even allowance for early graduation from medical school to buffer the workforce capacity.²³ For graduate medical training, some residency programs have implemented emergency restructuring to limit direct patient contact and reserve procedures with high-risk exposure to the most skilled personnel.²⁴ Digital technologies can provide innovative opportunities for students and residents to continue their participation, even while quarantined or socially distanced, with clinical teams caring for COVID-19 patients. Learners can participate virtually in bedside care and observations through screen-based applications and devices while being mentored by faculty and senior residents. In addition, didactics and experiential learning can continue virtually through tele-simulations and screen-based platforms, supporting the powerful strengths of simulation-based learning through self-reflection and robust feedback while adhering to social distancing rules.²³

Public health experts have long championed the use of simulation and modeling to test, predict, and prepare for threats to population health.²⁵ In the face of massive changes to care delivery models and disruptions in medical education related to the pandemic, the ability of simulation to facilitate rapid adoption of innovations is even more critical to maintain the health of our most vulnerable populations.

Aim 3: Reducing Costs and Preventing Loss of Revenue

The COVID-19 pandemic is estimated to have cost >\$1 trillion worldwide in 2020.²⁶ Hospitals and

health systems face unprecedented financial pressures because of the pandemic. Simulation can assist in alleviating these financial pressures through 3 main areas: (1) more effective adoption of telehealth, (2) enhanced infection prevention, and (3) development of safe equipment recycling and repurposing processes.

Although simulation-based initiatives may require an initial investment in equipment, personnel, and resources, there is significant literature supporting its overall cost-effectiveness and cost savings returns.²⁷ For example, several studies have shown good returns on investment with the use of simulation to prevent adverse outcomes and mitigate medicolegal payments from medication errors, improper use of new equipment, and suboptimal performance during invasive procedures.²⁸ Simulation can be used for financial recuperation through preparation for expanding digital health services in light of public lockdown measures. The Centers for Medicare & Medicaid Services now allows the use of telehealth services for all beneficiaries of fee-for-service Medicare, and the Department of Health and Human Services has announced that it will not impose penalties for using Health Insurance Portability and Accountability Act-noncompliant private communications technologies (eg, cellular phones) and software (eg, Skype, Facetime) to provide telehealth services during COVID-19.²⁹ System dynamics modeling techniques have been used extensively for health care and public health applications to study the dynamic interactions and behavior of health care issues and provide a framework to develop insights into policies and potential interventions. Modeling data can be combined with computer-based simulations to test how potential digital strategies may impact costs, determine best streams of service to target, and design the technology and workforce infrastructures necessary to make telehealth feasible and profitable.³⁰ Investment in these testing procedures will facilitate sustainable adoption of telehealth and ensure continued generation of revenue beyond the immediate response to this current crisis.

Infection control and prevention are areas of great financial interest during this pandemic. In one recent report, it was estimated that 43% of patients acquired COVID-19 in the hospital setting.³¹ Simulation-based training in procedures such as practice of enhanced PPE donning and doffing and procedures to test patients without risk of contamination can improve quality, safety, and decrease the costs associated with health care worker infection rates.³² In situ simulation also can assist with identifying and mitigating systems-based latent safety threats associated with high-risk procedures, patient transfers, and other

critical tasks that increase viral transmission during the care of COVID-19 patients.

Finally, simulation can assist with optimizing costs and minimizing loss of revenue related to novel uses of limited equipment during this pandemic. For instance, the impending shortage of PPE has required reclaiming and reusing masks, shields, and gowns that were designed for single use. Other innovations have included repurposing of prefabricated masks or designing new modifications to existing equipment to serve as PPE that can be recycled or cleaned for reuse.³³ Although the Centers for Disease Control and Prevention accepts these practices, they are far from standard, and growing evidence suggests that both of these options may contribute to the ongoing high infection rates in health care workers.³⁴ Medical equipment design and refinement has increasingly adopted the use of human factors techniques to perform simulation-based usability testing, detect harm in real time, and ensure that quality standards are properly met. Usability testing increases safety, improves task performance, optimizes device use, and lessens product liability risks. In addition, simulation allows clinicians to examine, compare, and rate medical equipment to ensure durability and acceptability and prevent waste of scarce resources before purchase and deployment.³⁵

Aim 4: Improving Work and Wellness of Health Care Workers

Many have compared the COVID-19 response to a war with frontline Health Care workers combating the pandemic as soldiers and heroes. Without proper preparation and protection, health care workers face threats to their mission readiness, self-efficacy, trust in leadership, and individual safety. Simulation and human factors analyses can combat these threats and support health care worker readiness through (1) establishment of worker safety guidelines, and (2) support to develop and maintain worker skills in a rapidly changing clinical care environment. A functioning, assured, and engaged workforce is needed to improve the quadruple aim of patient safety, population health, and cost reduction.^{3,36}

Little has been published about the degradation of human performance when working in taxing clinical conditions to ensure self-protection during a pandemic or during protection from biologic exposure. Outcomes from simulations in preparation for the Ebola outbreak in 2014 reported PPE-induced stress responses that included overheating, sensations of claustrophobia, and movement restriction after only 2 hours of continuous PPE exposure.³⁷ With variable

PPE availability during the current pandemic, simulation-based techniques can build a deeper understanding of the impact of PPE on worker well-being, including the additional physical strain on breathing, and guide protocols for worker safety including the need for water breaks and adjustments in shift length and scheduling. For example, simulation testing with Glo Germ powder (Marlatek, Inc., Brockville, Ontario, Canada), a product designed to identify the simulated spread of microorganisms, identified the need to add neck protection and high-cuff gloves into a hospital's safety protocols for airway management of COVID-19 patients.³⁸ Previous simulation work on air dispersion under different ventilation methods³⁹ and current work developing potential precautions such as intubation barrier enclosures⁴⁰ offer key insights about the current pandemic and demonstrate the power of simulation to rapidly test and adjust care guidelines in response to clinical threats.

Simulation-based training can assess worker readiness through skill acquisition, planning, and preparedness as well. Drills incorporate simulation techniques to help establish health care worker resilience through increased competence and preparedness.⁴¹ The rules of engagement for health care workers on the front lines of COVID-19 are changing, especially during risky aerosol-generating procedures. A human factors analysis of PPE doffing in an outbreak preparedness simulation demonstrated multiple risks and errors in the use of enhanced PPE, even by experienced and monitored health care workers.⁴² Preparedness for these dynamic conditions calls for ongoing in situ simulation training of critical procedures and equipment, rapid response teams, and other ongoing training for these innovative high-stress clinical settings.⁴³ Yet, training in the time of shortages of critical supplies also must strike a balance in resource utilization.⁴³ Solutions may lie in the use of computer-based simulations with active feedback and coaching, which were found to decrease PPE doffing errors.⁴⁴ Additionally, the use of just-in-time simulation training immediately before entering a patient's room, which could support real-time preparedness in the clinical setting, may lead to avoidance of resource "waste" during periods of critical shortages.⁴⁵

It is already evident that the burden of working in COVID-19 care environments, with increased personal threat of infection, can increase worker stress and anxiety.⁴⁶ In addition to risks of occupational exposure, health care workers are subject to increased emotional and physical stressors from rising patient volume and acuity, expanded and changing workload expectations, and physical demands from

Table 2. Simulation-Based Solutions for COVID-19 Needs.

Aim	COVID-19 need	Human factors solution	Simulation technology and techniques	Key implementation examples and outcomes
Patient safety and experience	Ensuring safety of new protocols and processes	Testing new technologies (eg, ventilators, helmets) and workflow (eg, less bedside contact)	Laboratory beta testing; usability testing; tele-rounding and tele-simulation; in situ simulation	Design: Evaluation of 2 aerosol boxes on endotracheal intubations in COVID-19 patients with an in situ simulation crossover study ⁵⁰
	Supporting patient-centered communication and decision-making	Optimizing tele-technology to communicate with family members at end of life	Laboratory testing and refinement; virtual and standardized patients	Outcomes: Twelve anesthetists performed 36 intubations; intubation time with no aerosol box was significantly shorter, and breach of PPE occurred because of tears and damage to hoods
	Improving teamwork and communication	Testing and training for new team protocols among COVID-19 health workers	In situ simulation using PPE and real equipment	
Population health	Optimizing care with adjusted health delivery models/systems	Ensuring safe and reliable care with telehealth	Usability testing; cognitive task analysis; virtual/standardized patients	Design: Creation of digital peer support certification training with simulation training, audit and feedback; increases peer support specialists' ability to use digital technology for tele-mental health during COVID-19 pandemic ⁵¹
		Preparing health workers for new/urgent/out-of-practice skill sets (critical care, procedures)	Procedural simulation with task trainers; high-fidelity mannequin-based simulations; in situ simulation on new resuscitation protocols and equipment	Outcomes: An upward trend in peer support specialists' capacity to offer digital peer support occurred during the 3-month certification period
	Continuing education for trainees during social distancing measures	Matching needs and anticipated loss of workforce with adequate staffing Deploying digital technology to include learners remotely in bedside care Implementing virtual didactics and experiential learning	Discrete event simulations; computer-based modeling Screen-based applications/devices Screen-based learning platforms, tele-simulations	
Reducing cost and preventing loss of revenue	Adopting telehealth in a cost-effective manner	Determining which strategies and potential revenue streams are most feasible and profitable	Systems dynamics modeling; discrete event simulations	Design: Development of a Monte Carlo simulation model to represent the US population; estimated resource use and direct medical costs per symptomatic infection and at the national level to understand the potential economic benefits of reducing the burden of the disease ⁵²
	Preventing iatrogenic and hospital-associated COVID-19 infection Developing safe equipment recycling and repurposing processes	Practicing PPE donning/doffing and preparing for high-risk situations Testing of retrofitting of equipment (masks, 3D printing), reuse of PPE to ensure effective prevention of transmission	Procedural simulation; in situ simulation using PPE and real equipment Laboratory beta testing; usability testing	Outcomes: A single symptomatic COVID-19 case incurs a median cost of \$3045; 20% infection rate would lead to 11.2 million hospitalizations, 2.7 million ICU admissions, and \$163.4 billion in direct costs
Health worker wellness and satisfaction	Ensuring safe practices and avoiding overstressing health workers	Identifying staff limitations of working in PPE, exhaustion (for duty hours/breaks) and physiologic stress	Laboratory beta testing with PPE and equipment; in situ simulation on new resuscitation protocols and equipment	Design: A centralized provincial simulation response team, preparedness using learning and systems integration methods to respond to COVID-19 in Alberta, Canada ⁵³
	Building resilience and preparedness in health workers as expectations change	Drills and systems analyses to improve preparedness and skill acquisition	Just-in-time training; cognitive task analyses	Outcomes: 30 000 learners participated in >400 simulation sessions across the province over 5 weeks; major outcome themes generated were: safe PPE doffing; conducting environmental scans of care areas; testing transport routes; preventing contamination; practicing teamwork and communication; preparing for high-risk procedures

Abbreviations: COVID-19, coronavirus disease 2019; PPE, personal protective equipment.

donning/doffing of PPE.⁴⁷ This is especially problematic for frontline COVID-19 health care workers who are already known to be at the highest risk for burnout.⁴⁸ Simulation has shown significant benefits in decreasing occupational strain by offering psychologic first aid and enhancing adaptive coping mechanisms during high-risk situations of patient care

(psychological PPE). Simulation helps to address the known gaps in management's understanding of "work-as-imagined" and test it against what clinicians struggle with: "work-as-done." A culture shift from understanding "what went wrong," also known as Safety-I, when there are undesired outcomes, to understanding and optimizing "what went right,"

also known as Safety-II, can allow the health care system to celebrate the sensemaking of frontline workers who proactively mitigate the effects of the degradations in system's safety levels.⁴⁹ This approach can offset the emotional toll exacted on health care workers and help channel some of their frustrations with the pandemic into constructive efforts to combat the outbreak.

Conclusions and Policy Implications

Simulation and human factors science have successfully tackled some of health care's most challenging problems. During the dynamic conditions of COVID-19, they offer structured methods to improve each of the quadruple aims, helping organizations to see organizational and financial returns. Working toward quadruple aim goals can help hospitals see financial and organization improvement from enhanced staff engagement, cost efficiencies, and higher levels of patient satisfaction. Table 2 summarizes major applications of simulation and human factors that address each aim and provides key examples from the

literature that have demonstrated improved safety outcomes during the pandemic. Significant challenges remain to improve the quality, safety, and efficiency of care delivery as health care systems strive to manage this pandemic effectively. Added financial, organizational, and political constraints have arisen and difficult decisions regarding allocation of resources that have become scarce during this crisis will need to be made. However, investments in simulation and human factors expertise will create powerful and robust tools in supporting a resilient and adaptive health care system for ongoing and future demands of the COVID-19 pandemic.

Implementation of simulation and human factors science will need to be tailored to the needs and constraints of each local institution or system. The authors propose an innovative set of core elements necessary to apply simulation and human factors methods in the form of a modified fishbone or Ishikawa diagram.⁵⁴ Adopted by the health care quality sector, these diagrams visually depict potential solution pathways for system improvement by mapping the complex causal factors contributing to better safety and quality

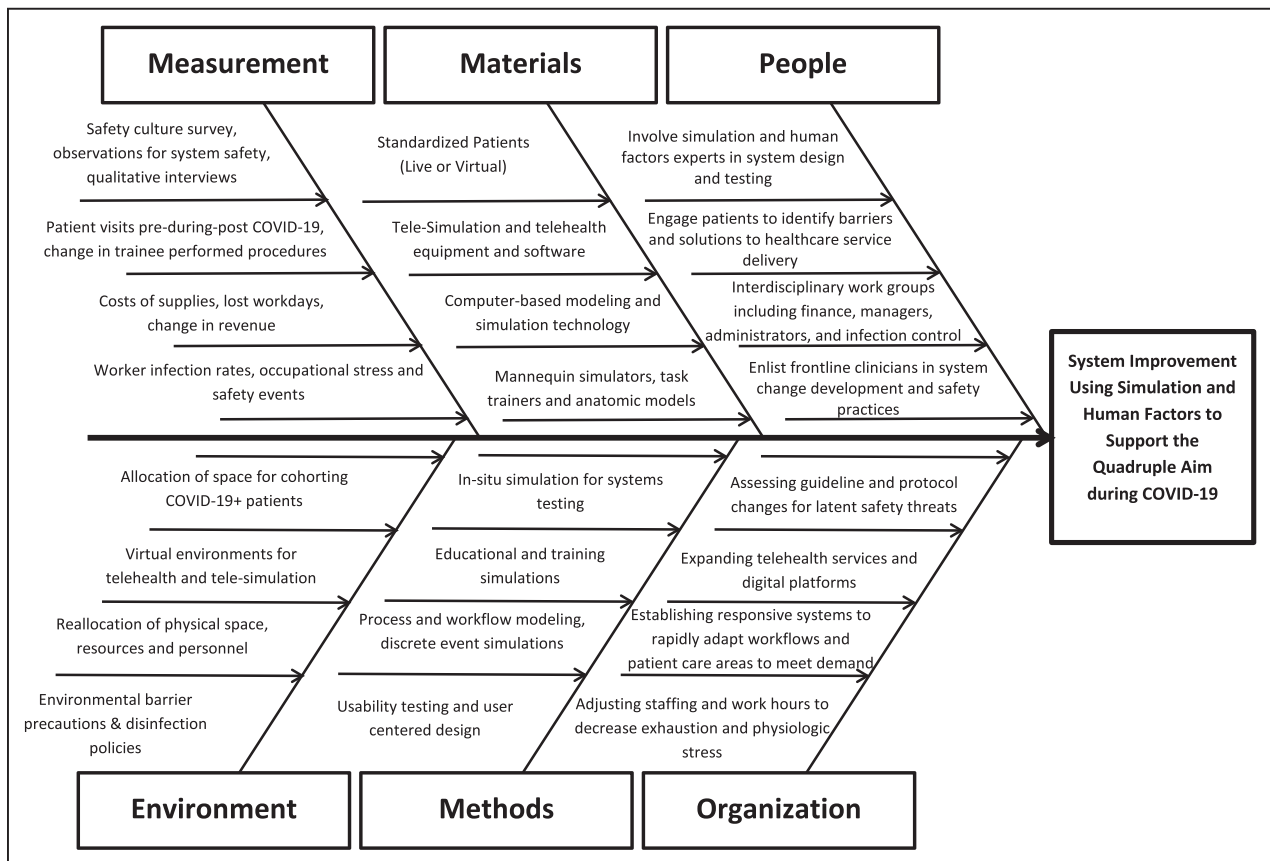


Figure 2. Fishbone/Ishikawa diagram of components for system improvement using simulation and human factors during COVID-19. Abbreviation: COVID-19, coronavirus disease 2019.

outcomes.⁵⁵ Figure 2 represents the general system components and resources needed to apply simulation and human factors methods for system improvement during COVID-19. The components coalesce into 6 main domains: measurement (quality markers and outcomes), materials (resources and equipment), people (human capital and personnel), environment (physical settings), methods (simulation and human factors techniques), and organization (climate, culture, and philosophies). This diagram unites the 4 Aims presented in this paper to consider the needs and impact of improvement initiatives for each Aim. While it provides a general solution map and outlines the pragmatic steps for overall implementation, adaptations will be needed to identify local system characteristics, conditions, and primary outcomes most critical to each individual institution and system. Future work will include testing and piloting these solutions, and customizing and applying them to a variety of clinical and organizational settings.

Author Contributions

Drs Wong, Ahmed, and Barach conceived the design of this work. All named authors wrote significant portions of the initial draft and contributed to critical revisions of the article for important intellectual content. Dr Barach provided administrative and technical support for derivation of figures. Dr Wong takes responsibility for the article as a whole.

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Conflicts of Interest

The authors have no conflicts of interest to disclose.

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