Lean Six Sigma as an organizational resilience mechanism in health care during the era of COVID-19

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Abstract

Purpose – The purpose of this study was to investigate how Lean Six Sigma (LSS) may help mitigate the impact of COVID-19 within health care environments. The goals of this study were to understand the current knowledge of LSS and COVID-19 through a systematic review of the current literature, identify the gap in the current knowledge of LSS in COVID-19 mitigation within health care environments and define the principles of LSS, within organizational resilience that support a health care organization's ability to mitigate the impact of COVID-19.

Design/methodology/approach – A narrative literature review was conducted to identify relevant research. A total of 21 subject matter experts (SMEs) meeting the inclusion criteria were approached through a guided interview process. Content analysis was conducted to describe how LSS principles contribute to supporting health care organizations operating in the era of COVID-19.

Findings – Study results report that personal safety is the primary subject, followed by supporting dimensions of process redesign, and telemedicine. LSS topics that directly relate to COVID-19 are in four thematic areas: tools, applications, benefits and challenges. Particular areas of application, techniques, challenges and benefits are identified and discussed that could be applied proactively and reactively, to organizational and supply chain resilience to recover from COVID-19.

Research limitations/implications – There were a number of limitations to the generalizability of this work. The sample size was small and purposeful, thus, external validity of the study results are not determined. The SMEs in this study have not implemented the practices noted in the results at the time of the study, and knowledge of results is limited to the study aims.

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Originality/value – This study of LSS principles and COVID-19 has implications for practitioners and offers specific guidance for areas of health care adoption of LSS techniques and tools that benefit patient safety, challenges for the user to be mindful of and potential benefits in resilience of operations in the era of COVID-19.

Keywords Lean six sigma, Health care, Organizational resilience, COVID-19, Supply chain resilience

Paper type Research paper

1. Introduction

Lean Six Sigma (LSS) has been applied to various health care processes with the goal of improving operations (Henrique and Godinho Filho, 2020). LSS health care studies have included laboratory testing, emergency logistics, emergency care and surgical areas (Antony *et al.*, 2018; Deblois and Lepanto, 2016)). Previous work found that more than 75% of LSS implementations in health care environments were performed in surgery, administrative, operations, imaging and radiology, pharmaceutical and emergency and traumatology operations (Honda *et al.*, 2018). Studies by Antony *et al.* (2018) and Costa and Filho (2016) noted an improvement in patient satisfaction. A number of other LSS studies focused on indirect patient care, where health care business processes, quality of services and efficiency in operations were the goal (Antony *et al.*, 2018; Costa and Filho, 2016; Deblois and Lepanto, 2016; Mousavi Isfahani *et al.*, 2019). For example, LSS implementation in hospitals has resulted in the lowering of inventory levels and improving process efficiency and overall performance (Honda *et al.*, 2018). LSS implementation in health care may be broadly classified into two categories of patient care: indirect and direct. LSS in direct patient care focuses on improving processes related to providing health care services to patients, while indirect care supports these direct care processes. Examples of direct patient care processes include emergency services, surgical services and inpatient or outpatient care, among other processes. Examples of indirect care support processes include managing surgical supplies inventory and linens that support surgery or inpatient care processes.

The COVID-19 global pandemic has resulted in widespread disruption and change. The damage of the pandemic is enormous. According to the Gates (2020), the pandemic has erased 25 years of progress in human development. The ability to manage the disease until viable vaccinations become available is partially based upon the health care systems' ability to treat patients with the disease. COVID-19 has severely disrupted operations in health care systems. The COVID-19 pandemic has impacted the demand, supply and capacities of health care systems worldwide (Leite *et al.*, 2020). When facing disruption, supply chain networks require reconfiguration to continually meet customer requirements for subsequent patient treatment during the pandemic (Ambulkar *et al.*, 2015; Ivanov, 2020; Leite *et al.*, 2020). To maintain hospital operations continuity and recover from disruptions, health care supply chains should encompass resilient capabilities (Leite *et al.*, 2020). The rationale behind "flattening the curve" has been to control the demand and reduce the load for health care through lockdowns; thereby, delaying an acute impact on constrained health care operations (Leite *et al.*, 2020). Public health care capacity is measured by the availability of hospital facilities, beds, finances and human resources. Halcomb *et al.* (2020) found that bed capacity plays a crucial role in managing the COVID-19 demand for hospital operations. In addition, the increased demand for limited health care resources (e.g. beds, materials, equipment and medications) led to the issue of arrival rate variability at the consumer (patient) end (Halcomb *et al.*, 2020). As a result, the need to mitigate the impact of COVID-19 upon hospital capacity is considerable. In the USA for instance, vulnerable populations represent almost 63% of the non-institutional adult population (Trump *et al.*, 2020).

A COVID-19 response, as a low probability event, requires a resilient response to capacities to address both known and unknown phenomenal factors, rather than risk mitigation frameworks based upon relative, ongoing outcomes (Linkov *et al.*, 2018a, 2018b). Events such as a pandemic or disaster, result in higher impacts, which negatively affect business performance and jeopardize an organization's competitive position and survivability (Ambulkar *et al.*, 2015; Leite *et al.*, 2020). health care resilience plays a crucial role in handling events such as the COVID-19 pandemic for bolstering capacities and building elasticity in the operational context (Kennan, 2020). Both proactive and reactive capabilities of an organization help in being able to respond more efficiently and effectively to the COVID-19 pandemic. While reacting to events is common, proactive organizational resilience should be developed before facing the disruption (Birkie, 2016). As an operational excellence approach, LSS principles may be applied to manage and prioritize resource capacities, support staff in redesigning processes and sustain meaningful change to break down hierarchical barriers for building proactive capabilities toward resilience (Leite *et al.*, 2020).

The aim of this study was to investigate how LSS may help mitigate the disruption of COVID-19 within health care environments. This research provides a narrative literature review of LSS, COVID-19 and health care organizational resilience. The research methodology applied to evaluate the LSS factors that may support the mitigation of the impact of the COVID-19 pandemic in the health care system within hospitals is discussed. Finally, the research findings, conclusions and future research are presented.

2. Literature review

In the narrative literature review, LSS applications in health care are discussed that relate to hospitals, organizational resilience, LSS and the impact on organizational resilience in health care.

2.1 Lean Six Sigma applications in health care

Poor management in hospital operations can lead to serious consequences on the quality of service (Regattieri *et al.*, 2018). Lean principles are applicable in health care operations to manage demand and capacity, improve quality, improve safety, improve supplier relations and reduce costs to improve supporting processes for patient care (Womack and Jones, 1997). In a study of Lean implementation, Antony *et al.* (2019) identified 11 factors among various studies that motivate health care services to use Lean. These 11 factors include providing better services, enhancing patient satisfaction, improving operational efficiency, improving service quality, transforming organizational culture, organizing the process, reducing delays, reducing administrative inefficiencies, gaining competitive advantage, eliminating waste and eliminating non-value tasks (Antony *et al.*, 2019).

Applying Lean and Six Sigma techniques in health care could offer complementary practices that help units reduce process defects and support clearer and more understandable processes for employees (McFadden *et al.*, 2015). Laureani *et al.* (2013) reported on five different LSS projects completed in Irish hospitals. The LSS projects focused on managing inventory with the 5S methodology, improving availability of medical records through define-measure-analyze-improve-control (DMAIC), eliminating process waste in the laboratory, preventing patient falls and implementing Lean in clinical settings. These LSS projects found that leadership commitment and proper communication between stakeholders are critical success factors for LSS implementation (Laureani *et al.*, 2013). Further, Bhat *et al.* (2019) conducted multiple case studies and implemented LSS in Indian hospitals. The medical records department was chosen for their study with the goal of LSS implementation to reduce patient

service time, waiting time and inventory management of patient records (Bhat *et al.*, 2019). Implementing LSS resulted in faster service to patients, minimizing queue size and significant cost savings (Bhat *et al.*, 2019). Finally, Trakulsunti and Antony (2018) took four cases from the existing literature to investigate medication errors reduction through LSS implementation. The research findings indicated that top management commitment and communication play a major role in LSS implementation success. Through LSS process improvements, the reported cases reduced pharmacist's workload by applying the poka-yoke concept (i.e. automatic machine to detect dispensing errors) and determined critical factors that resulted in medication and pharmacist dispensing errors (Trakulsunti and Antony, 2018).

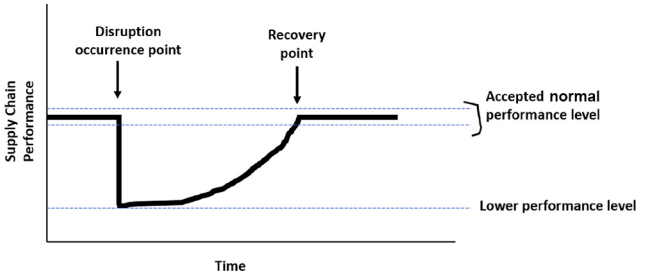
Another area of LSS health care applications that impacts direct patient care is surgical operations as it has direct impact upon patient health (Deblois and Lepanto, 2016; Mason *et al.*, 2015; Montella *et al.*, 2017). For example, Mason *et al.* (2015) conducted a literature review of LSS in the surgical context and found that LSS resulted in improving process efficiency while reducing surgical complications, infections and mortality (Mason *et al.*, 2015). These improvements resulted in improved patient care and satisfaction (Mason *et al.*, 2015). In a study of Lean implementation by Beck *et al.* (2016) in a pediatric setting, Lean was used to improve patient throughput of an emergency department in a children's hospital by reducing the patient discharge time. Gijo *et al.* (2013) found that Six Sigma implementation decreased patient waiting time by 50% and reduced the average waiting time of patients by 40%. In addition, Furterer (2018) found that the LSS focus within surgical operations, specifically in emergency room (ER) operations, often focused on patient throughput. Through a DMAIC project, Furterer's (2018) study resulted in a streamlining of the ER operations, which reduced patient hospital stays by 30% and increased ER capacity by 12 patients/day, as well as increased patient satisfaction by 24% to achieve the top 1% of hospitals in the USA (Furterer, 2018). Subsequent financial performance was also impacted. An estimated yield of more than US$3m was accrued over a subsequent two-year period (Furterer, 2018).

The seriously ill have been studied from an LSS context in other studies (Eldridge *et al.*, 2006). Eldridge *et al.* (2006) examined hand hygiene practices through a Six Sigma project to increase compliance with Centers for Disease Control recommendations in a hospital intensive care unit. In this case study, Six Sigma allowed the hospital to capture data from the hand sanitization process, implement necessary actions and improve user compliance from 47 to 80% (Eldridge *et al.*, 2006). Carboneau *et al.* (2010) focused on reducing infections using LSS. In this study, LSS implementation reduced patient infection occurrences by 51% in a single-year time period (Carboneau *et al.*, 2010). Similarly, another study found that LSS application helped reduce hospitalization rates by 20% by focusing on reducing patient infections (Montella *et al.*, 2017). LSS techniques have been adopted to study a COVID-19-related issue as well; Hina-Syeda *et al.* (2013) quantified the initial process capability to immunize against pneumococcal and influenza.

2.2 Organizational resilience

Resilience is the ability of an organization or system to return to the organization's original functioning state after a disruption by an external force over a short time period (Bhamra *et al.*, 2011). The impact of a disruption and subsequent recovery for an organization is shown in Figure 1 as a conventional resilience or recovery curve. After a disruptive event, an organization's ability to bounce back quickly and regain normal operations determines the resilience of an organization (Munoz and Dunbar, 2015).

Birkie (2016) categorizes the operational resilience into five key capabilities: sense, build, reconfigure, re-enhance and sustain. Sense is identifying risks to the business's operating



Source: Adapted from Munoz and Dunbar (2015)

Figure 1.
Impact of disruption of supply chain

environment and build is the capability for business continuity, which is based upon contingency plans (Birkie, 2016). Reconfiguration is the capability of the supply and demand network to recover and re-enhance is the capability of handling processes to recover customer service to levels prior to disruption (Birkie, 2016). Sustain is defined as the operation's ability to build a robust organization (Birkie, 2016). Non-resilient organizations take more time to recover, if at all, from disruptions, which leads to severe impact on the organization's market share and perhaps the firm's survival (Brandon-Jones *et al.*, 2014; Chowdhury and Quaddus, 2017; Ponomarov and Holcomb, 2009). Building organizational resilience has been discussed in disaster management literature, where a four-step process is noted that includes mitigation, preparedness, response and recovery (Madu and Kuei, 2014; Altay and Green, 2006). Mitigation focuses on either preventing the onset of a disaster or reduction of a disaster's impacts (Altay and Green, 2006). Organizational preparedness anticipates and prepares an organized response to support a return to normalcy (Altay and Green, 2006). Responding to disruption occurs through a response plan for recovery, or the long-term actions taken after an immediate disaster's impact, with the goal to stabilize the organization for restoration to some semblance of normalcy (Altay and Green, 2006). Organizational resilience goes beyond the individual organization and requires a network or supply chain approach, as each organization is not an island unto itself with regard to operating.

2.3 Lean, Six Sigma and organizational resilience

Implementation of Six Sigma results in a reduction of process variation and improved risk management in an organization. A primary goal of LSS is to identify and reduce process variation, and reduce risk through systematic process monitoring and control to reduce instability, uncertainty and lack of reliability that comes from excessive process variation. Organizations that adopt Six Sigma focus on developing personnel with improved risk management awareness, with a goal of risk reduction to an organization's operations (Andersson and Pardillo-Baez, 2020). In turn, organizations often deploy LSS through their respective supply chains, resulting in improved risk reduction among those supplier's risk reduction and improved supplier and customer collaboration in the supply chain (Andersson and Pardillo-Baez, 2020). LSS risk reduction includes identifying critical failure points and mitigating those points through the LSS approach. As a result, LSS projects often result in process improvements and innovation that improves organizational resilience (Madu and Kuei, 2014). The adoption of LSS results in robust processes and minimizes organizational risks through monitoring and mitigation of risk sources (Andersson and Pardillo-Baez, 2020). There are a variety of LSS techniques by which risk is managed. LSS uses critical to quality (CTQ) characteristics and voice of the customer (VOC) techniques to capture critical

requirements from customers or end users. Monitoring CTQs and collecting the VOC lead to the determination of risks to the organization. The application of failure modes and effects analysis (FMEA) and development of control plans are performed to identify and manage risks (Antony *et al.*, 2018). Six Sigma may also be applied proactively to build resilience through risk mitigation and preparedness. Risk mitigation starts with assessment as processes under improvement are conducted with LSS techniques such as FMEA, CTQs, root cause investigation and process control (Madu and Kuei, 2014).

2.4 Lean Six Sigma, COVID-19 and health care resilience

There are emerging papers on LSS applied research related to the COVID-19 pandemic. For instance, Locke (2020) and Marsi (2020) describe applying LSS principles of continuous flow, 5S organization and standardized processes for field hospital operations in the UK and Italy to support non-specialists delivering COVID-19-specific care. The LSS concepts of resource optimization and increased efficiency for improving indirect patient care for health care operations were part of these studies (Locke, 2020; Marsi, 2020). LSS research related to COVID-19 focuses on particular techniques as well such as visual management, standard operating procedures, 5S, multi-disciplinary team communications, supplier quality and relationships as these are all considered potential benefits to health care systems to support organizational resilience and robust supply chains (Leite *et al.*, 2020). The COVID-19 crisis has shown how important it is to sustain the operations of an organization for continuity and recover from major disruptions. The aim of this study was to investigate how LSS may contribute to mitigating the impact of COVID-19 within hospital environments. In the following section, the research methods, including interviews with subject matter experts (SMEs) and subsequent content analysis are presented.

3. Methodology

The research approach used in this study is based upon content analysis. Content analysis is a research methodology for making valid inferences from data to their context. Content analysis is widely adopted among scientific fields with the purpose of gaining knowledge and insight and guiding practice (Elo and Kyngäs, 2008; Krippendorff, 2004). The aim of content analysis is to attain a description of the phenomenon and concepts under study, with the purpose of building a model, conceptual map or categories (Rodgers *et al.*, 2019; Krippendorff, 2004). In this paper, the concepts include LSS, COVID-19 and organizational resilience. The content analyzed was collected through semi-structured interviews with LSS health care SMEs. The participants were well established, experienced and represented a wide range of health care roles, organization types and geographic areas, as summarized in Table 1 below. As a measure of experience with LSS, our inclusion criteria of SMEs were preferably credentialed as black belts or master black belts with at least three years of experience as reported by the participants (Rodgers *et al.*, 2019). The purposive sampling or convenience sampling (n = 21) is used to collect the qualitative semi-structured interview data from the experts in the field of LSS and health care. The rationale for using purposive sampling for expert opinion is substantiated by the literature and studies (Kreuger, 1988, p. 4) in the field of qualitative methods. The authors enlisted SMEs known to the authors, who were contacted via email with a description of the aim and goals of the study for subsequent consent. Interviews were scheduled and conducted over a four-week period, in approximately 40-min virtual Zoom meetings between the SME and two of the authors. Videos were recorded for data collection purposes, where audio was transcribed and analyzed using NVivo software to identify the main and sub-themes.

Given the exploratory nature of the research and qualitative approach, semi-structured interviews were conducted (Rodgers *et al.*, 2019). The semi-structured interview is a versatile

Participant	Role	Organization type	Geographic areas where LSS is applied
Participant A	Consultant	Consulting firm	The Netherlands
Participant B	Professor, consultant and trainer in Six Sigma	University	India
Participant C	Lead Service Line QI Coordinator	Nationwide children's hospital	USA
Participant D	Consultant and trainer in Six Sigma	Consulting firm	Brazil
Participant E	Head of Quality and OR	Indian Statistical Institute	India
Participant F	Health care Consultant	AtosInova Saúde	Brazil
Participant G	Assistant Vice President of Finance and Resource Management	Mount Sinai Medical	USA
Participant H	Consultant	Consulting firm	India
Participant I	Chief Executive Officer	Children's hospital (complex care)	Scotland
Participant J	Consultant	Consulting firm	Brazil
Participant K	Consultant	Consulting firm	The Netherlands
Participant L	Vice President of Quality	Delphi Technologies	USA
Participant M	Consultant	Consulting firm	UK
Participant N	Director Performance Improvement	Brigham and Women's Hospital	USA
Participant O	Senior Partner	EMS Consulting Group	USA
Participant P	Global Operational Excellence Director	Curium Pharmaceuticals	USA
Participant Q	Manager	IU Arnett Health	USA
Participant R	Senior Director – Strategic Innovation	Banner Healthcare	USA
Participant S	Industrial Engineer	Veterans Army Health care	USA
Participant T	Healthcare Consultant	Health care firm	Brazil
Participant U	VP/Chief Analytics	Navicient Health Care	USA

Table 1. Detailed interview participants' information

and powerful qualitative research method (Galletta, 2013). This interview technique is characterized by its flexibility and is sufficiently structured to address research aims, while leaving space for study participants to add meaning to the study topic (Galletta, 2013). The questions were drawn from prior exploratory research of LSS and operations excellence literature, and combined experiences of the authors (Rodgers *et al.*, 2019). Face validity of the questions was ensured by conducting an independent review of the questions prior to the interviews and refined through the content analysis approach proposed by Mayring (2008). A pilot pre-test of the semi-structured interview script was conducted with academia participant researchers with expertise in LSS and health care operations by primary graduate student researchers for refining the semi-structured questionnaire categories and the subsequent face validity by expertise (Downe-Wamboldt, 1992). After the face validity, the semi-structured interviews ($n = 21$) were conducted by the graduate student researchers with the participants expertise following purposive sampling approach (Kreuger, 1988, p. 94). The 40-min virtual interviews were scheduled with participants with expertise in different geographical locations using online meeting platform and all the interviews were conducted in the timeframe of six weeks. The pre-test questions in the semi-structured interviews were developed following the structured literature review thematic or content analysis (Mayring, 2008) framework. The benefits of Mayring's (2008) approach is that key concepts of the results

could be systematically and objectively defined through the coding process (Potter and Levine-Donnerstein, 1999). The basic four-step process model by Mayring (2008) has been adopted in a variety of studies (Kallio *et al.*, 2016; Castilla-Polo and Ruiz-Rodriguez, 2017; Hundal and Laux, 2020). The steps of content analysis consist of:

- delimiting the material to be analyzed through predefined screening criteria defining the unit of analysis (data collection);
- assessing the material with predefined criteria and refining the categories or themes (category selection);
- providing the background for subsequent analysis (descriptive analysis); and
- material is then analyzed per analytic dimensions related to categories or themes defined in the category selection step using analytic coding techniques (material evaluation).

The final interview questions are provided in Table 2.

Data were imported into NVivo 12, a qualitative analysis software program for the directed content analysis approach. A directed approach may be considered to lead to what is described by Hsieh and Shannon (2005) as an informed but nonetheless strong bias as the research approach may be viewed as seeking to confirm previous findings, rather than to confirm or negate them. The approach is to validate or extend prior research (Hsieh and Shannon, 2005), which, in turn, assisted in the coding of the data in NVivo. This approach has been described as a deductive category application (Mayring, 2000). The internal validity of the findings from the coded interview data is conducted following the triangulation approach (Yazan, 2015), with the structured literature review thematic analysis data and the participant researcher's expertise knowledge. The inter-reliability check of the coded data analysis is conducted among the graduate student researchers as raters ($n = 3$) following the approached highlighted in the previous studies (Hruschka *et al.*, 2004, Yazan, 2015) and observing the kappa value to be greater than 0.70 among the raters.

4. Results

The data from the 21 semi-structured interviews were analyzed through content analysis following purposive sampling of experts in health care operations and operational excellence. The interview data were coded by three raters in the NVivo 12 software. The inter-reliability value between the raters was $k = 0.77$, which is considered a substantial reliability rating (Hruschka *et al.*, 2004). The visualization of the data was conducted based on the categories of the questions asked to the participants in the semi-structured interviews. The interview questions are presented in Table 3. The question categories used for coding themes from the interview data included:

Table 2.
Semi-structured interview questions

1	How might LSS be applied to the current COVID-19 issue?
2	What are the benefits of LSS that may be applied to COVID-19?
3	What are the challenges of applying LSS to COVID-19?
4	What tools and techniques of LSS that could be applied?
5	What are the potential areas of LSS toward COVID-19?
6	How has your organization responded to COVID-19?
7	How has the pandemic changed the way that you prioritized and selected LSS projects?
8	How could LSS methods be applied to make hospitals more resilient to COVID-19?

- COVID-19 response in health care operations;
- potential application areas of LSS for COVID-19 response in health care operations;
- benefits of LSS for COVID-19 response in health care operations;
- LSS tools for COVID-19 response in health care operations;
- challenges of applying LSS for COVID-19 response in health care operations;
- organizational resilience for COVID-19 response in health care operations; and
- supply chain resilience for COVID-19 response in health care operations.

Topic area	Research interview questions
Reactive resilience	How has your organization responded to COVID-19? What are the potential areas, within your organization, for LSS application toward mitigating the impact of COVID-19? How could the pandemic change the way that LSS projects are prioritized and selected?
LSS response	What tools and techniques within LSS could be applied toward the current COVID-19 situation? What are the benefits of LSS that may be applied to COVID-19? What are the challenges of applying LSS to COVID-19? What are the potential, negative consequences of applying LSS toward COVID-19? Have you worked on other projects related to LSS and COVID-19 in other countries? If yes, what were the challenges you faced while working on these projects?
LSS response proactive resilience	How could LSS methods be applied to make health care systems more resilient to COVID-19? How could LSS methods be applied to prioritize tasks and balance resources accordingly? How could applying LSS methods improve resilience in your organization? How could applying LSS methods improve supply chain resilience in your organization?
Other	Is there anything else you would like to state before we end the interview?

Table 3.
LSS and COVID-19 research interview questions

Area	Proactive approach (mitigation phase and readiness phases)	Reactive approach (response phase and recovery phase)
Six Sigma tools	SIPOC, FMEA, VSM, process mapping, simulation and root cause investigation	VSM, process mapping, predictive modeling and systematic problem solving
Projects	Continuous improvement projects to decrease process variation, DFSS projects – adopting technology to manage hospital operations (including cloud computing), building process reliability and process risk assessment by using FMEA and SIPOC tools	Safety projects – workspace preparation to minimize virus transmission, re-design processes impacted by COVID-19, offering telehealth services, reducing process wastes and improving the utilization of existing resources
Resilience elements	Flexibility building – cross training workers, IT infrastructure for data collection, adopting data analytics on various organization levels to gather real-time data and key performance indicator monitoring	Predicting capacity for operations and hospital units and balancing resources accordingly

Note: DFSS = Design for Six Sigma

Table 4.
Contribution of LSS principles to organizational resilience and response to COVID-19

The bubble diagram shown in Figure 2 highlights the themes that have emerged from the COVID-19 response to health care operations (Table 4). Safety is the major theme that emerged from the interviews. The safety theme includes the projects that health care systems have initiated because of the COVID-19 pandemic. Preparing a safe workplace for health care staff, patients and ER preparedness is critical to health care organizations. Developing safe workplace routines to prevent the spread of COVID-19 transmission is the first priority for health care systems. For example, one of the participants (Participant O) noted that creating a safe environment should be the top priority, responding:

> I think the prioritization should be focused on safety. How do we maximize the safety of our patients when they come in here? How do we maximize our employee safety? Because that also affects the availability of our employees, right? If we allow the spread to happen, then our team is down, and then we're going to have trouble managing our patients. So that also goes to, you know, human lives and costs. I mean, over time, and then having people work extra time to fill in is really difficult anyway because it puts a strain on people, so that's not a good thing. So, I think that has to be the top priority.

Bifurcating the facility for COVID-19 patients and non-COVID-19 patients will improve hospital process efficiency and simplify the disinfection process. Because of the pandemic, health care systems were forced to change their existing processes. Use of LSS tools such as process flow mapping and value stream mapping (VSM) help health care systems evaluate the impact of process changes as well as implement process changes efficiently. Participant R provided an example of process redesign using Six Sigma, stating:

> I would assume that a lot of what they're doing as far as Six Sigma goes has to really deal with how do we change our processes by which there is less person interaction with patients and with each other to try to lower the incidences and really create a load of the instances of potential infections? As well as how do we create that social distancing, by automating processes more?

The participants in this research study have reported that COVID-19 has exposed process gaps or inefficiencies in their current processes. Participant U pointed out:

> I think the pandemic, as I'm thinking about this has actually helped us highlight where there are significant process improvements or opportunities within our hospital system, right, because sometimes it takes a pandemic for you to even recognize these things.

Hospitals have worked on improving processes through implementation of LSS tools or new technology to improve process performance.

Another major theme that came out of the interviews is virtual care. Patients expect hospitals to offer telehealth services virtually that do not require a visit to the hospital. Offering telehealth care service is beneficial for patients and hospitals as they can avoid traffic in hospitals and preserve resources for COVID-19 patients and other critical patients who need in person care.

The radial graph is a visualization of the content analysis results and identifies the relationships of concepts noted in the interviews. The radial graph in Figure 3 highlights the potential application areas, benefits and challenges of LSS for COVID-19 response in health care operations as reported by the participants interviewed.

The critical application areas of LSS application in health care operations as shown in the Pareto chart in Figure 4 are business operations, patient safety and ER improvements. This resonates with the COVID-19 response areas as reported by the participants (Figure 2). The LSS methods and tools provide a structured problem-solving approach as one of the participants reported, stating: "Patients waiting time is a potential metric that has LSS

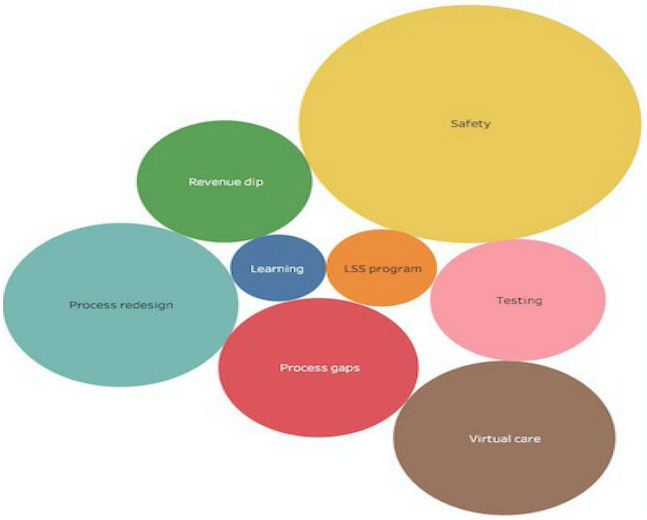


Figure 2.
COVID-19 response in health care operations

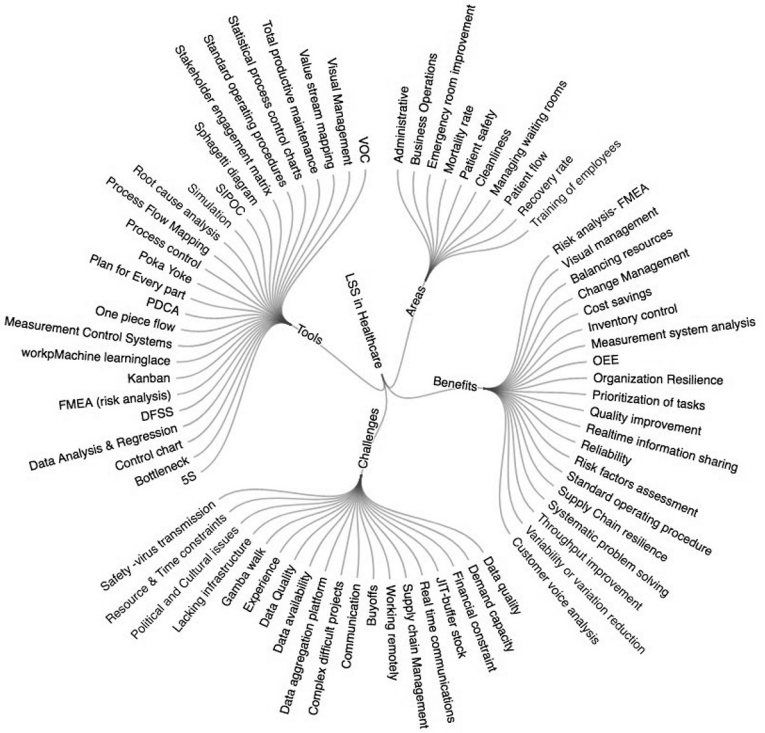


Figure 3.
LSS tools, application area, benefits and challenges for COVID-19 response in health care operations

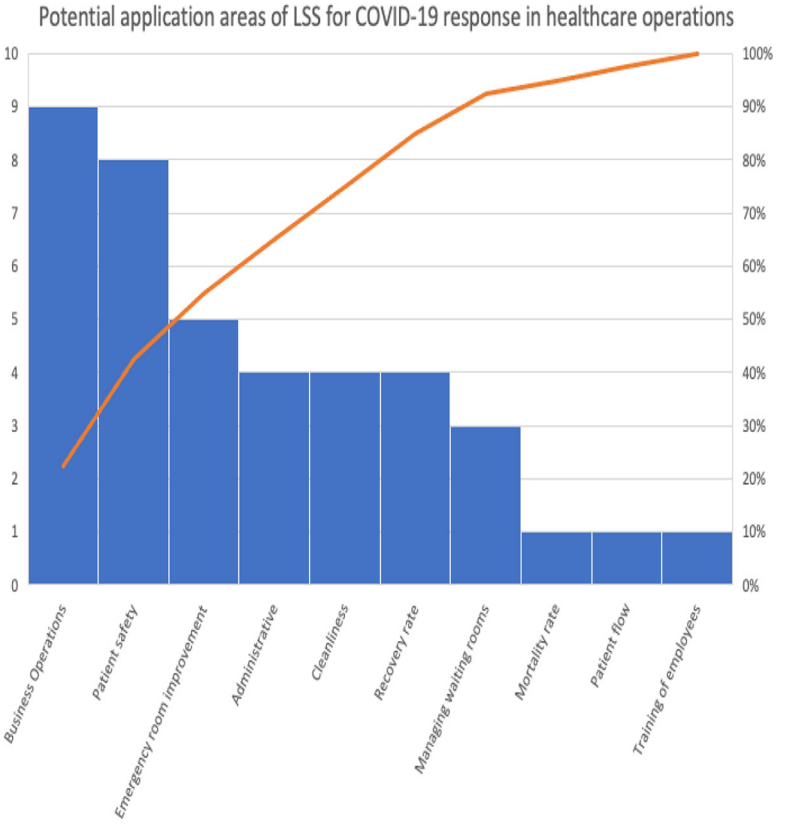


Figure 4.
Potential applications of LSS for COVID-19 response in health care operations

application. Setting a priority and developing visual systems for standard operating procedures could help to streamline the incoming patient flow". The patient waiting time before getting treated is critical for ensuring patient safety as one of the participants said, "Patients waiting in the hospital facilities any longer than they absolutely have to be, just to reduce risk to exposure".

The Pareto chart provided in Figure 5 shows the frequency and percentage importance of each LSS tool for COVID-19 response in health care. The top five LSS tools mentioned by the SMEs are VSM, FMEA, data analysis including regression analysis, poka-yoke and process flow mapping. VSM is the most commonly mentioned tool across the interviews. VSM is useful for mapping the current state of the operations, identifying inefficiencies in the process and helping health care organizations map both the current and future improved state. Participant R suggested that VSM is the top tool to use for responding to COVID-19, stating:

> I think value stream mapping to streamline processes for optimal utilization of resources and removing non-value added resources. In LSS we can use VSM to see what steps are really adding value, what is not adding value so that we can then determine whether it should be either streamlined or even eliminated along the way. So to me, that would probably be the biggest thing.

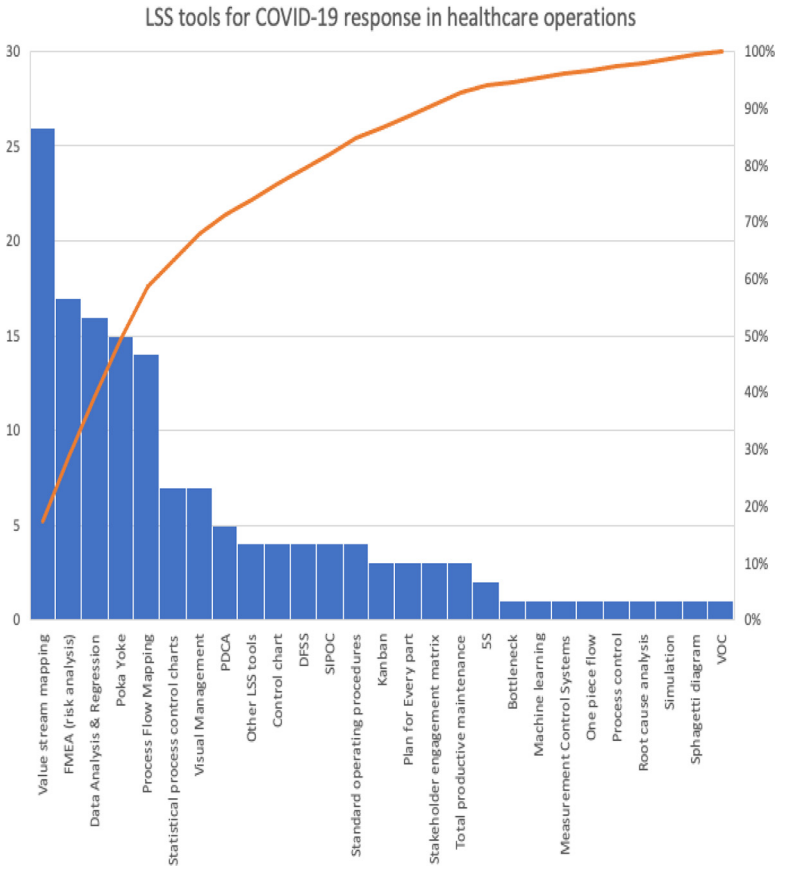


Figure 5.
LSS tools for COVID-19 response in health care operations

Combined with process mapping (one of the top five tools from the interview results), VSM helps health care organizations streamline their operations to better serve patients during the COVID-19 pandemic. The second most commonly mentioned tool is FMEA. FMEA helps hospitals identify the risk areas in their operations and implement controls to mitigate operational risks.

The important benefits of applying LSS as highlighted by the interview results are balancing resources, prioritizing tasks and implementing a systematic problem-solving approach to improve health care processes (Figure 6). Participant A states that:

> Lean Six Sigma tools and especially Six Sigma give me insights in the data about what to expect. And I think a lot of companies are reacting to what they see [. . .]. If you want to anticipate two things you have to use six sigma and I think that six sigma helps organizations to make a better estimation about what to expect.

One of the participants highlighted the importance of "Failure Modes and Effects Analysis" for prioritizing critical inventory needed. Other participants highlighted the benefits of visual management tools such as interactive dashboards inside emergency management

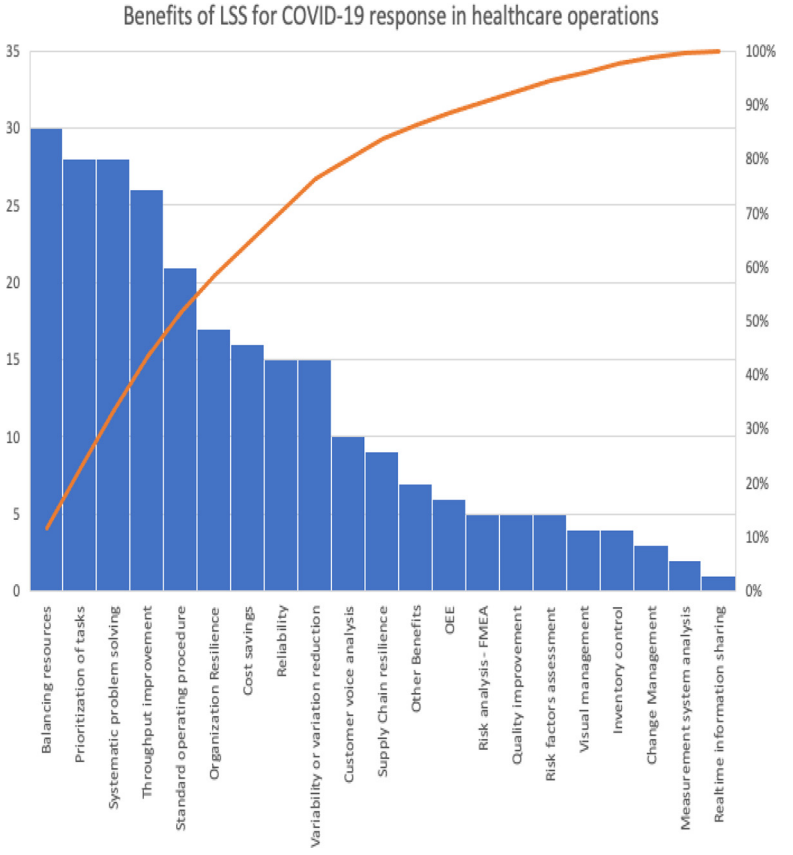


Figure 6.
Benefits of LSS for COVID-19 response in health care operations

rooms for maintaining standard operating procedures. LSS is a systematic approach to meet customer requirements, while doing so efficiently. Supporting this theme is task prioritization, identifying critical and key resources that relates to the third most frequently mentioned benefit of systematic problem solving.

The path diagram in Figure 7 highlights the potential tools for improving operational resilience for COVID-19 response in the context of supply and organizational resilience for health care operations. Some of the tools mentioned synergize with LSS tools such as supplier analysis, demand forecasting, root cause analysis and Gemba Walk.

The Pareto chart provided in Figure 8 shows the organizational resilience tools that health care organizations may implement to make their supply chains more resilient. The most frequently mentioned resilient element was flexibility, such as flexibility obtained through cross training of employees across multiple job functions. A quote from Participant O's interview highlights the need for the workforce flexibility, stating:

> We definitely need to have that flexibility so things like cross training, you know, using skills matrix, along with cross training so we can see, you know, who's available, who do we need to train so that we can be flexible?

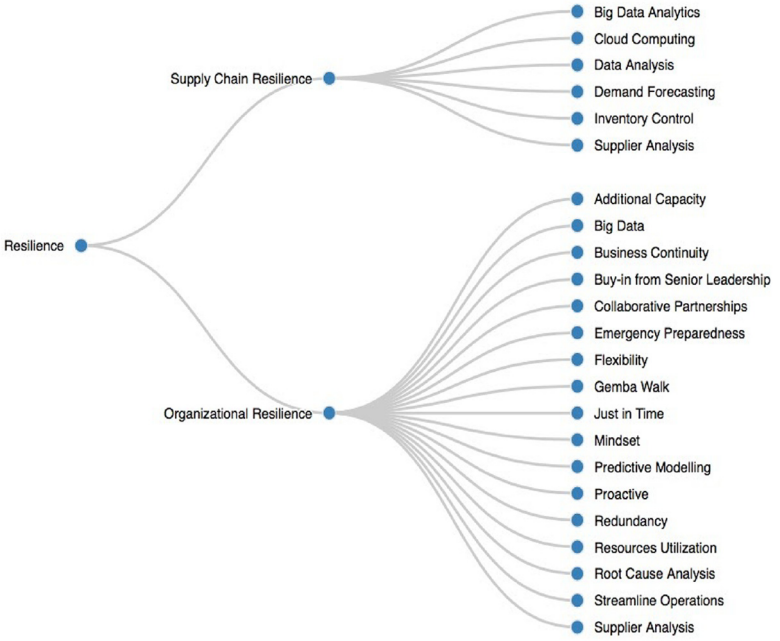


Figure 7.
Resilience for COVID-19 response in health care operations

Flexibility in health care operations may range from the flexibility to modify processes, operational flexibility, assets flexibility, mode of service delivery, workforce flexibility and supply flexibility. Predictive modeling and real-time data support organizational resilience were noted next by our SMEs in rebounding from the event of COVID-19 and managing through the crisis.

Figure 9 identifies the supply chain resilience tools that came through SME interviews. Demand forecasting and big data analytics are the two important tools for accurate forecasting using big data models. The importance of real-time data analysis and cloud computing platforms for accurate forecasting and predictive modeling fosters supply chain resilience mitigating risks during disruptions (Mensah *et al.*, 2015). The issue of big data analytics is also in line with Laux *et al.* (2017) that big data is a crucial area for LSS research and propose a revised LSS/big data approach.

The challenges of applying LSS for COVID-19 response are summarized in Figure 10. The three highest frequency challenges identified were buy-in, data quality and resource and time constraints. The major challenge of applying LSS for COVID-19 response is getting buy-in from senior management, process owners and cross-functional teams for executing a Six Sigma project. High expectations of Six Sigma project outcomes and longer time to complete projects were mentioned as reasons that hinder buy-in from management and cross-functional teams. As shown in Figure 10, participants highlighted that allocating necessary resources and time for completing Six Sigma projects was a challenging task during the pandemic. Another major challenge is availability of quality data for Six Sigma projects. These results are in line with studies by Antony *et al.* (2018) and Henrique and Godinho Filho (2020), which have listed that lack of participation from management, availability of quality data and lack of resources are top challenges for applying LSS in health care. Therefore, developing a less resistant environment for applying LSS to mitigate

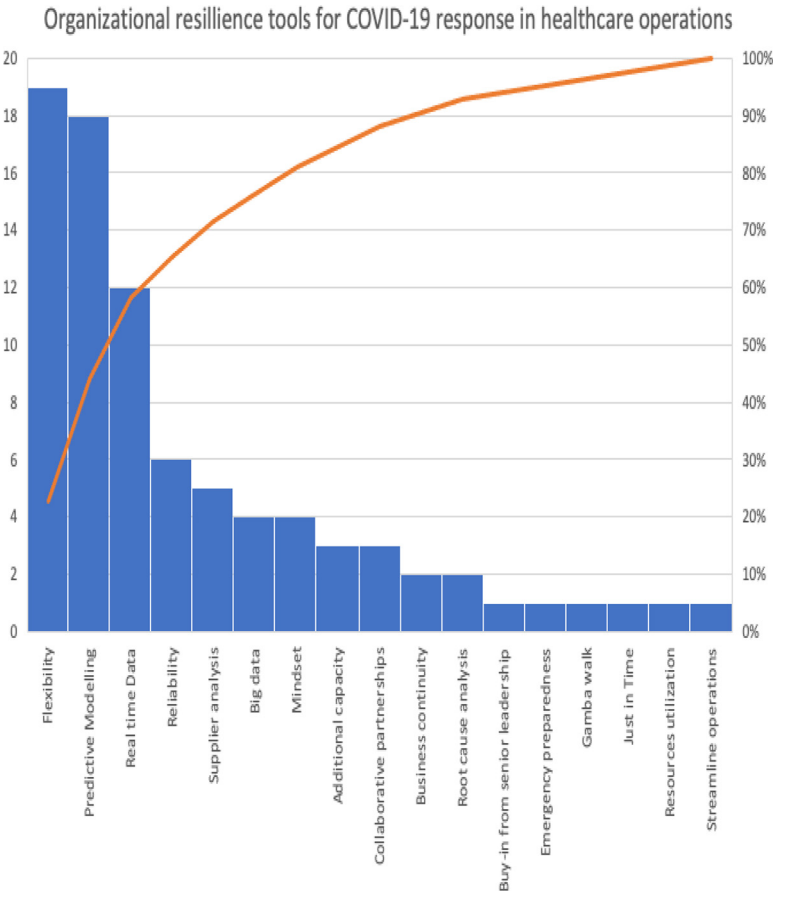


Figure 8.
Organizational resilience for COVID-19 response in health care operations

COVID-19 impact and educating employees about Six Sigma tools is a necessary step from the top management.

The summary of findings from the interviews related to which tools, types of LSS projects and resilience elements are important to LSS and COVID-19 response is shown in Table 2. The table classifies the contribution of LSS to the COVID-19 response, based on the response strategy of having a proactive approach or a reactive one. Six Sigma may contribute to organizational resilience in both a proactive and a reactive manner (Christopher and Rutherford, 2004; Birkie, 2016). A proactive response enables the organization to incorporate forward thinking tools, projects and resilience elements to get ahead of a pandemic type of event before it happens. The reactive approach reacts to the event after it has already started to occur. Interestingly, some of the LSS tools appear in both the proactive and reactive approach, including VSM and process mapping, which demonstrates the robustness of those techniques. Applying a simulation tool may take more time to collect data and create the simulation, indicating that time becomes an issue once the organization is in the mid of a pandemic. The focus of the Six Sigma projects becomes focused more directly on safety related to COVID-19

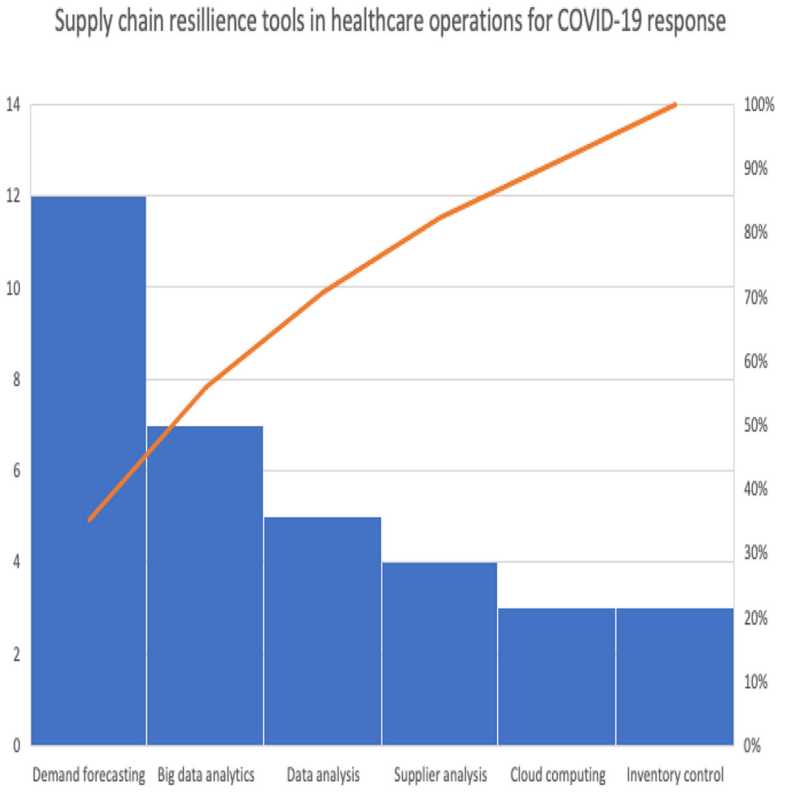


Figure 9.
Supply chain resilience tools for COVID-19 response in health care operations

and improving utilization of overworked resources, when reacting to the pandemic. Focus on decreasing process variation, adopting technology to manage hospital operations, building reliability and reducing risk becomes more important in a proactive environment. Resilience elements in a proactive mode include flexibility building for information technology (IT) infrastructure for data collection, adopting data analytics and real-time data monitoring. Resilience elements in a reactive mode focus more on predicting capacity for operations and balancing resources.

In the proactive approach, organizational resilience can be developed before facing the disruptions in operations (Altay and Green, 2006). Applying LSS tools such FMEA and suppliers, inputs, process, outputs and customers (SIPOC) will help identify the risks and risk areas that exist in health care operations. LSS risk assessment can be integrated with business continuity planning efforts and improve the organizational resilience in a systematic way (Participant B). From the interviews, it is evident that LSS plays a role in improving resilience. Six Sigma improves the process efficiency and innovations in an organization. Developing novel solutions to mitigate the existing risk in health care operations results in robust operational processes in hospitals (Hoerl and Gardner, 2010). Even though the COVID-19 has hit the health care operations without much advance warning, hospitals can still practice a proactive approach as multiple waves of COVID-19 spread.

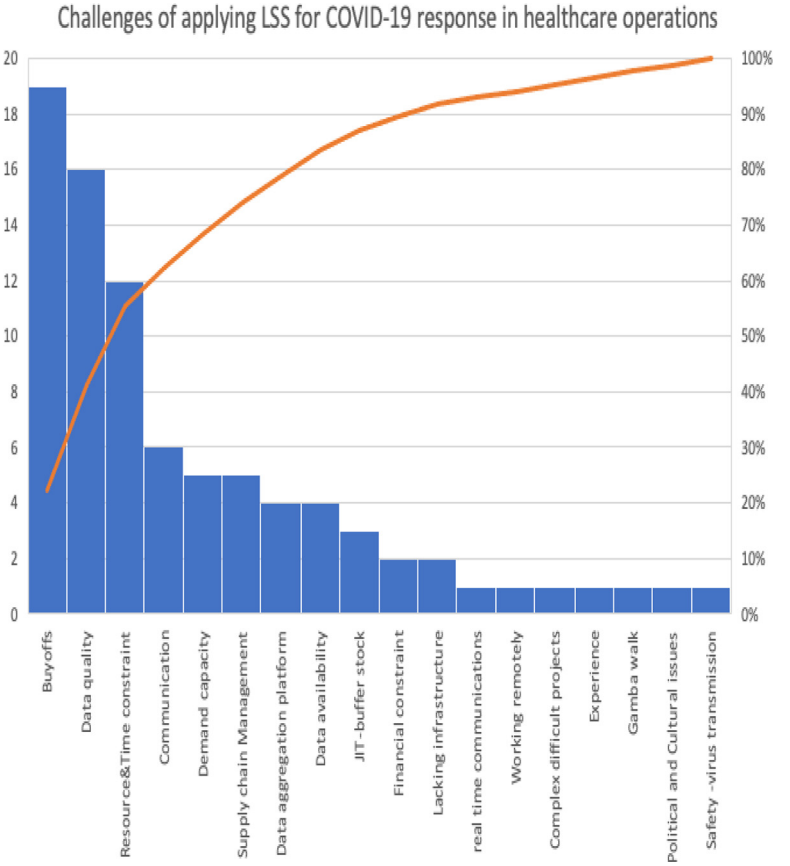


Figure 10.
Challenges of applying LSS for COVID-19 response in health care operations

Applying LSS tools to streamline the process and remove bottlenecks and wastes in the process (Antony *et al.*, 2019) is still critical in a reactive mode. Six Sigma aids in systematic problem solving. Applying Six Sigma tools and principles to make the current process more efficient and reliable is also important (McFadden *et al.*, 2015). The COVID-19 pandemic has led to a shortage of resources. Therefore, it is important to use the available resources such as employees, hospital supplies and hospital assets in an effective and efficient manner. With the application of LSS, health care can improve their processes to serve the patients better (Bhat *et al.*, 2019; Antony *et al.*, 2019). Efficient processes can make hospitals more resilient and reliable during a pandemic (Birkie, 2016).

The results from this study contribute to operations management and organizational resilience literature. Efficient process management and practicing operational excellence improves the reliability and capacity of processes (Bal *et al.*, 2017; Beck *et al.*, 2016). Developing LSS implementation routines, incorporating systematic problem solving, exploring novel solutions to continuously improve existing processes and innovating processes (via new technologies) results in reliable and resilient health care processes (Andersson and Pardillo-Baez, 2020; Hoerl and Gardner, 2010). LSS improves organizational

resilience through the creation of efficient, reliable and resilient processes and continuous learning and improvement (Andersson and Pardillo-Baez, 2020; Pal *et al.*, 2014).

5. Conclusions and directions for further research

The goals of this study were to understand the current knowledge of LSS and COVID-19, identify and define LSS principles to mitigate COVID-19 and, subsequently, support health care resilience. Personnel safety was an overriding theme: safety of the patients and of the health care professionals. Supporting this goal are the areas of process redesign and offering virtual health services and medicine. The LSS topics, as related to the COVID-19 pandemic and identified by our SMEs, were in four thematic areas: tools, application areas, benefits and challenges. These LSS dimensions were analyzed from the semi-structured interviews data coded following content analysis. A further contribution of this study is the identification of LSS techniques that could contribute to organizational and supply chain resilience. The findings of the VSM, data analytics and FMEA are the critical LSS tools for building organizational resilience in the potential areas of business operations, patient safety and ER improvement. Balancing resources, prioritization of tasks and structured problem-solving approach are the potential LSS benefits identified in health care operations for COVID-19 response. Accurate demand forecasting using big data analytics and predictive modeling techniques in LSS potential projects can foster resilience in health care organizations and supply chain operations. Use of surveys to validate the results from this research across multiple industry sectors is one of potential areas for future research. How LSS may be applied for supply chain and organizational resilience, in health care and other industries, such as manufacturing and service industries could be interesting areas to explore. We understand that this study of the COVID-19 crisis is one of many, but we found few studies of LSS and resilience, and we hope that this LSS study contributes to the body of COVID-19 research.

6. Limitations and future work

There were a number of limitations to the generalizability of this work. The sample size was small and purposeful; thus, external validity of the study results is not determined. The SMEs in this study have not implemented the practices noted in the results at the time of the study, and knowledge of results is limited to the study aims. The findings of this research study are characterized by the nature of the rigor of qualitative study. However, the statistical analysis of the coded data in NVivo 12 software highlighted in the study proposes the basis for hypothesis development providing an opportunity for an empirical study in the future.

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