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How Lean Six Sigma Principles Improve Hospital Performance

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ABSTRACT

The healthcare industry continues to emphasize quality and productivity improvements. This study focuses on the implementation of Six Sigma and Lean Six Sigma (LSS) principles in hospitals. Through a qualitative analysis of 35 published case-based papers (33 of specific case studies plus two studies with more than one reported case), the authors found that implementing Six Sigma and LSS concepts can significantly contribute to improving process performance, including waiting time reduction and patient flow with the subsequent impact of increasing patient satisfaction. At the same time, these process improvement techniques also reduce operating costs and inventories, which translate into significant savings for hospitals, thereby creating a win-win situation. This study also shows that taking a multidisciplinary team approach, coupled with Six Sigma training, is critical to successfully implementing Six Sigma and LSS. The limitations to implementation appear to be primarily related to the organization (political hierarchy) and infrastructure of the hospitals. The authors' analysis of these cases clearly demonstrates that Six Sigma and LSS can provide effective solutions to improving the quality and processes in a healthcare service environment while simultaneously creating a cultural change within the organization by involving everyone associated with the process being evaluated.

KEYWORDS

continuous improvement; healthcare; hospitals; lean; quality; Six Sigma

Introduction

Some of the greatest challenges facing healthcare organizations today include: a) accreditation requirements; b) the needs and expectations of patients; and c) social and ethical values. At the same time, they are attempting to maintain or even reduce costs, which are continuously increasing due to the need for advanced technology, an aging population, and new medical treatments for diagnosis and intervention processes (de Koning et al. 2006; Verbano and Crema 2013; Ortiz Barrios and Felizzola Jiménez 2016). As a result, these institutions have focused their attention on improving quality in healthcare and the continuous improvement of their processes (Verbano and Crema 2013). Programs such as Six Sigma and Lean Six Sigma (LSS) provide healthcare organizations with a viable approach to not only reduce costs but also improve quality (Foster 2007).

History of Six Sigma

Six Sigma is a continuous improvement program developed at Motorola in 1987 in an effort to reduce manufacturing errors to less than 3.4 errors per million opportunities (Polk 2011). Although Six Sigma was first introduced at Motorola, the most successful company in implementing this methodology was General Electric (GE) (Coronado and Antony 2002). CEO Jack Welch made it a corporate goal, requiring it to be implemented across all company divisions during the 1990s. Within four years, GE identified more than $2 billion in savings that was attributed to Six Sigma (Coronado and Antony 2002). The fact that Six Sigma projects are tied directly to financial benefits is one of the major reasons Six Sigma continues to be recognized as an important quality improvement tool.

Six Sigma has become a successful approach for organizations that want to achieve operational excellence, achieving high standards of quality and reducing costs to be more efficient while becoming world-class companies (Ortiz Barrios and Felizzola Jiménez 2016). Organizations that implement Six Sigma focus on quality improvement, cost reduction, and increased efficiency (Heuvel, Does, and Verver 2005).

Six Sigma methodology and benefits

To quantify the performance of a given process, a Six Sigma project begins by defining and implementing relevant measures and metrics, the so-called critical-to-

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Table 1. Brief description of the five DMAIC stages (Liefvergreen et al. 2010; Bertolaccini et al. 2011).

Stage	Description
DEFINE (D)	Definition of project goals and boundaries; identification of issues that need improvement to achieve the higher sigma level
MEASURE (M)	Gathering information about the current situation to obtain baseline data on current process performance and to identify problem areas; determining characteristics of process/product that are critical to customer satisfaction
ANALYZE (A)	Evaluation of the current operation of the process to determine the root causes of quality problems and to confirm those causes using appropriate data analysis tools
IMPROVE (I)	Design and implementation of the solutions that address the problems (root causes) and analysis of cost/benefit
CONTROL (C)	Documentation of the solutions and monitoring the results of "improve" phase via statistical process control methods

quality characteristics. Six Sigma generally addresses performance problems in five phases (BertolaccinI et al. 2011): define (D), measure (M), analyze (A), improve (I), and control (C), as shown in Table 1.

Despite the well-defined steps and the structured methodology provided by the DMAIC framework, organizations often combine Six Sigma with other improvement initiatives, such as lean (Drohomeretski et al. 2014). Even though lean is recognized by many as a methodology that focuses primarily on eliminating waste, it should be viewed as a philosophy based on the customer's needs and continuous improvement (Dobrzykowski, McFadden, and Vonderembse 2016).

LSS focuses on measuring and eliminating errors (through variance reduction) and improving workflow so it is both efficient and value-added (through the elimination of waste) in a culture of continuous improvement (Lin et al. 2013). Generally there are specific tools and templates that are used for LSS, some of which are listed in Table 2 (George 2003).

Linderman et al. (2003) noted that while Six Sigma continues to gain popularity among practitioners, it still lacks the necessary theoretical framework that can provide the basis for academic research. Linderman et al. (2003) studied Six Sigma from a goal-theoretic perspective, with this objective in mind, defining the relationship between goals and Six Sigma success through several propositions. Foster (2007) similarly examined the long-term financial and operational impacts of implementing Six Sigma. His research revealed that Six Sigma can be applied when firms want to improve cash, earnings, or productivity. Foster also noted that larger firms tend to have the necessary resources and assets to invest in Six Sigma programs, and they correspondingly show great capacity to improvement.

Another approach for developing a theoretical framework for research is through the development of cases that are focused on the topic (but not necessarily best practices). Professor W. Earl Sasser, who is recognized as one of the early pioneers in the field of service

Table 2. Possible DMAIC tools and templates (George 2003).

D	M	A	I	C
Project Selection Tools	Operational Definitions	Pareto Charts	Brainstorming	Control Charts
Performance |Improvement Plan (PIP) Management Process	Data Collection Plan	Cause and Effect Matrix	Benchmarking	Standard Operating Procedures (SOP's)
Value Stream Map (VSM)	Pareto Chart	Fishbone (Ishikawa) Diagram	Total Productive Maintenance (TPM)	Training Plan
Financial Analysis	Histogram	Brainstorming	5S	Communication Plan
Project Charter	Box Plot	Detailed As-Is	Line Balancing	Implementation Plan
Multi-Generational Plan	Statistical Sampling	Process Maps	Process Flow Improvement	Visual Process Control
Stakeholder Analysis	Measurement System Analysis	Basic Statistical Tools	Replenishment Pull	Mistake-Proofing
Communication Plan	Control Charts	Constraint Identification	Sales & Operations Planning	Process Control Plan
SIPOC (Suppliers, Inputs, Process, Outputs, Customers) Map	Process Cycle Efficiency	Time Trap Analysis	Setup Reduction	Project Commissioning
High-level Process Map	Process Sizing	Non-Value-Added Analysis	Generic Pull	Project Replication
Non-Value-Added Analysis	Process Capability	Hypothesis Testing	Kaizen	Plan-Do-Check-Act Cycle (PDCA)
Voice of the Customer (VOC) and Kano Analysis		Confidence Intervals	Poka-Yoke	
Quality Function Deployment (QFD)		Failure Mode and Effect Analysis (FMEA)	FMEA	
Responsibility Assignment Matrix (RAM) and Quad Charts		Simple & Multiple Regression	Hypothesis Testing	
		Analysis of Variance (ANOVA)	Solution Selection Matrix	
		Queuing Theory	To Be' Process Maps	
		Analytical Batch Sizing	Piloting and Simulation	

operations, took this approach in the late 1960s and early 1970s when he decided to introduce for the first time courses on service operations management at Harvard Business School (Heineke and Davis 2007). The authors have adopted this case-based approach to better understand the implementation issues related to LSS in healthcare.

Six Sigma and healthcare

There are several examples in the literature of very successful cases of Six Sigma implementation in healthcare. For example, Bush et al. (2007) conducted a study at Charleston Area Medical Center where they implemented Six Sigma in the obstetrics department. The wait times for new obstetrical visits decreased from 38 to 8 days, the patient time spent in the clinic dropped from 3.2 to 1.5 hours, and the mean patient satisfaction scores increased from 5.75 to 8.54 (on a 10-point scale). They concluded that the application of the Six Sigma principles resulted from a team approach to addressing the clinic's productivity issues.

According to Sabry (2014), healthcare organizations cannot tolerate any errors, because even the smallest error can cost a human life and therefore must be eliminated. With zero defects in processes as a goal, Six Sigma appears to be the best choice in the healthcare environment. The fact that Six Sigma often successfully combines quality improvement with cost reduction further justifies it as a solution to financial health problems (Heuvel, Does, and Verver 2005).

Clearly, there are major opportunities for achieving process improvement and associated cost savings in healthcare organizations. As an example, Awards Help Set Standards for Healthcare Excellence (2017) identified some common gaps in healthcare organizations and potential solutions for closing them, many of them recognizing Six Sigma as one approach for accomplishing this and which are presented in Table 3. Using the systematic approach provided by the DMAIC methodology framework, Six Sigma has significant potential to improve existing processes through the reduction of process variation, setting specific target goals. In addition, the integrated use of lean and Six Sigma methodologies provides strong step-by-step succession planning, helping organizations to overcome the lack of leadership and process ownership (see Table 3).

Table 3. Common gaps in healthcare and potential solutions ("Awards Help Set Standards for Healthcare Excellence" 2017).

Common Gaps	Potential Solutions
Process variation and errors (either excessive, or lack of knowledge and information to adequately measure)	Six Sigma – DMAIC to improve existing processes and DFSS to create new processes where necessary
Capacity constraints driven by systemic bottlenecks and inefficiencies	Lean techniques such as value stream mapping and Six Sigma projects as indicated by the significance of the data and complexity of the problem
Misaligned incentives and inadequate or unclear performance evaluation processes	Management and leadership systems designed to link organizational objectives with strategic planning and performance
Quality programs that are either ineffective or not connected to the mission and vision	Six Sigma as part of an overall performance improvement initiative
Lack of a strong leadership "bench"	Succession planning and leadership development programs
Cultural silos and lack of teamwork to solve problems	Change management program to break down barriers, facilitate rapid decision making, and mobilize commitment

Research question and objective

This article therefore focuses on analyzing Six Sigma and LSS case studies within healthcare, through a qualitative analysis of 35 published case-based papers, with the goal of providing a better understanding of this topic that can contribute to the academic research in this area. In addition, the authors attempt to identify the key elements of successful implementation, including suggested hospital areas where it can best be applied, measurement of results, team composition, and specific tools to adopt.

The most important element in any academic research project is properly framing the research question, because this then guides the search for primary studies, the data extraction, and the data analysis. Originally, the motivation for this research was to investigate the implementation of Six Sigma in hospitals. However, due to the number of cases that were identified that had adopted a joint implementation of lean and Six Sigma, the authors decided to carry out a more comprehensive analysis considering both improvement methodologies. The research question therefore proposed for this article is the following: What are the common trends, benefits, and limitations related to implementing the Six Sigma and LSS methodologies within a hospital environment? Toward this objective, this article includes a critical analysis of LSS implementation in hospitals, which to be achieved was divided into specific goals that guided the authors' study:

- Literature review (exploratory + systematic)
- Determination of papers with relevant Six Sigma and LSS published case studies
- Content analysis of published case studies
- Identification of the main dimensions that contribute/hinder the implementation of Six Sigma and LSS in a healthcare organization

Research method

This article attempts to address the research question through a two-stage approach. The first stage consists of a quantitative analysis using a systematic literature review (SLR); this step is critical because it identifies the articles to be studied in detail in the second stage, which adopts a qualitative approach. In this phase, published case studies were analyzed.

Research method – Stage I: Systematic literature review

In recent years, the number of databases and sources of information have increased dramatically (Petticrew and Roberts 2006). This explosion in readily available information has significantly affected academic research both positively and negatively. From a positive perspective, information can be easily and broadly accessed. At the same time, the negative perspective can be related to the difficulty in filtering a huge amount of data and identifying only what is relevant to a particular research question.

The SLR provides a structured approach to addressing this problem, since it can "map and assess the existing intellectual territory, and to specify a research question to develop the existing body of knowledge further" (Tranfield, Denyer, and Smart 2003). With an SLR, it is therefore possible to identify, assess, and analyze all relevant studies for a particular topic, mapping the body of knowledge available in the literature in a systematic, scientific, and replicable way (Kitchenham and Charters 2007; Tranfield, Denyer, and Smart 2003). A major disadvantage of SLR is the additional effort required for the data analysis to detect and distinguish biases from true events (Kitchenham and Charters 2007). However, when the purpose of the study is to assess the transferability of particular interventions among organizations, reviewing the results of multiple case studies provides a test of both generalizability and transferability (Petticrew and Roberts 2006). Therefore, the SLR conducted for this article focused on identifying the best evidences available in the literature on what have been the trends, benefits, and limitations associated with the application of the Six Sigma and LSS methodology in healthcare organizations.

According to Zucchi, Del Nero, and Malik (2000), as a population ages, the need for health services increases dramatically and continuously. In addition, healthcare costs within an economy continue to increase as life expectancy rises (New England Healthcare Institute 2008). Given this current environment, it is critical that healthcare organizations improve their operational procedures in terms of both effectiveness and efficiency, whether or not they involve the patient directly (Niemeijer et al. 2011).

The most important step in an SLR is the definition of the review protocol, which specifically identifies the systematic approach, thereby facilitating the study's reproducibility. In medical research, the review protocol consists of a plan developed before the review, which states the criteria for including and excluding studies, the search strategy, including the databases used, and the description of the methods to be used (Tranfield, Denyer, and Smart 2003). For the purpose of this article, the selection of articles included case studies prior to June 2016 when this research effort began. In addition, only articles and conference papers published in English were considered. The exclusion criteria consisted of removing duplicate case studies, studies that did not show a real application, and papers to which the researchers did not have access. Two databases were chosen to conduct the study, Scopus and Web of Knowledge. Based on the original motivation of this research, the strings used to search for articles in these databases are shown below:

- Scopus: TITLE-ABS-KEY((healthcare OR hospital OR "medical Center" OR clinic) AND ("Six Sigma" OR "6 Sigma") AND (improvement OR benefit OR limitation))
- Web of Knowledge: TS=((healthcare OR hospital* OR "medical Center*" OR clinic) AND ("Six Sigma" OR "6 Sigma") AND (improvement* OR benefit* OR limitation*))

Although the terms "lean," "lean manufacturing," or any derivation was not chosen in the string, several results presented the implementation of hybrid methodologies (LSS), most likely because the current organizational practices of implementing both lean and Six Sigma methods in improvement initiatives.

The initial number of articles identified was 413: There were 264 from Scopus and 149 from Web of Knowledge. After removing duplicates and applying the exclusion criteria, the authors obtained a total of 131 articles. Next, these articles were prioritized by the number of citations in other publications. A final selection of 35 articles (33 of specific case studies plus two studies with more than one reported case) was obtained.

Research method – Stage II: Qualitative review

The final selection of 35 articles is the basis for the authors' quality assessment of Six Sigma and LSS-related issues with respect to their implementation within a healthcare environment. For the authors' study, the quality assessment of the implementation was the most important topic in these reviews, with the main goal to identify the following information:

- General information, for example, country and area of the hospital where the improvement occurred. The department division within the hospital was: administrative and operations; anesthesiology; oncology; dermatology; digestive disease; emergency and traumatology; endocrinology and metabolism; head, neck, and otolaryngology; heart and vascular; intensive care unit (ICU); imaging and radiology; neonatal and pediatrics; neurological and psychiatry; obstetrics and gynecology; ophthalmology; orthopedics and rheumatology; pathology and laboratory; pharmacy; respiratory; surgery; and urology and nephrology. The category "general" was used when the improvement did not occur in a specific area.
- The improvements, benefits, and limitations for each application, including a detailed numerical description of the benefits, where applicable.
- The team composition, to determine if it was a multidisciplinary team and which professionals were parts of it. In order to standardize and compare different case studies, the following codes were created to describe the team's composition:
  - IPL: Internal Project Leader
  - IPC: Internal Project Champion
  - IGB: Internal Green Belt
  - IBB: Internal Black Belt
  - IMBB: Internal Master Black Belt
  - EPL: External Project Leader
  - EPC: External Project Champion
  - EGB: External Green Belt
  - EBB: External Black Belt
  - EMBB: External Master Black Belt
- Did any staff training occur in the improvement initiative? Who participated? What topics were covered and how long did it take to train?
- The implementation structure to understand if it followed lean principles, DMAIC, PDCA, PDSA, and others.
- How often were meetings held by the improvement team?
- How long did it take to implement?
- Which tools and techniques were used with Six Sigma or LSS to obtain and sustain the benefits?
- Main limitations categorized as behavioral, political, or technical. Behavioral limitations include staff resistance, cultural impact, difficulty to engage all stakeholders, and any other barrier related to the staff and stakeholder's behavior. Technical limitation includes technological challenges and statistical and methodological barriers, such as data collection and seasonal variation impacting the analysis. Political limitations are related to hospital and stakeholder's policies that may impact and impose challenges to the success of an improvement initiative.
- The main critical factors for success (enablers).

Results and discussion

As previously mentioned, the results of the SLR identified multiple case studies that highlighted the use of lean together with Six Sigma (LSS), even though the term lean had not been included in the string. In some cases it has been merged with Six Sigma into a single implementation framework, so it was not possible to either analyze them separately or disregard these examples, because they represent improvements in which Six Sigma was used successfully. Consequently, additional discussion will be given to this topic, since these two methodologies enhance each other and cannot be analyzed separately in the context of this research.

Where Six Sigma or LSS was applied and main outcomes

According to the division proposed for this article, the five hospital departments where Six Sigma or LSS was most often applied were: a) surgery; b) administrative and operations; c) imaging and radiology; d) pharmacy; and e) emergency and traumatology, which represented almost 75 percent of all the case studies selected for analysis. Even though cases could be allocated inside the same hospital departments, differences existed in the results and improvements because each one had a specific goal. However, similarities could be found with concrete and specific improvements for each hospital department shown in Figure 1.

With surgery, a major improvement was the reduction in the length of stay, which is an important quality indicator for services, especially for hospitals. Bertolaccini et al. (2011), in a case study aiming to improve air leaks in patients who underwent pulmonary intervention, revealed that the length of stay

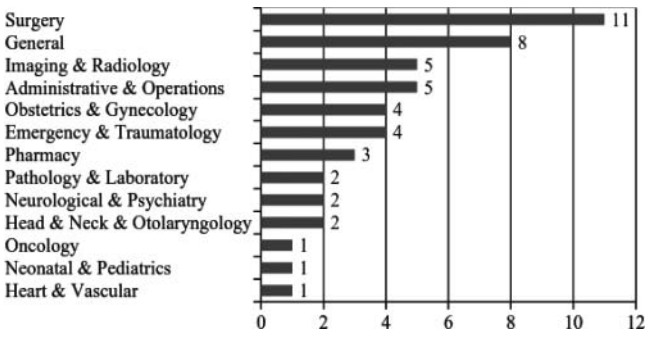

Figure 1. Selected case studies by hospital departments.

decreased from 7.1 to 6.5 (8.5 percent) days after implementing Six Sigma. Another application focused on reducing costs on joint replacement surgical procedures resulted in a 36 percent decrease in the length of stay (Gayed et al. 2013). Niemeijer et al. (2013) describe a process improvement for hip fractures surgery where the length of stay was reduced from 13.5 to 9.3 days (31 percent). Patient waiting time was also an important improvement in surgical applications, as described by Cima et al. (2011). In addition, improvement in the surgical department led to a 14 percent decrease in personnel costs despite having 26 percent more employees (Bender et al. 2015); a 39 percent reduction on pre-operative clinic visits and a 32 percent reduction in instrument use, which translated to a savings of $72.50 per patient (Warner et al. 2015).

Regarding the administrative and operations departments, patient waiting time improvements represented the great majority of the improvements. Fischman (2010), by applying the LSS methodology in an internal medicine residency clinic, showed that patient waiting times were reduced from 14 minutes to five minutes (64 percent). A similar improvement is described by Shreeranga, Gijo, and Jnanesh (2014), with a 94 percent reduction in average patient waiting times, and by Gijo and Antony (2014), reducing patient waiting time from 56.95 minutes to 24.5 minutes, which represents a 57 percent reduction. Some specific applications were found within this department, such as the one described by Taner and Sezen (2009), where the Six Sigma methodology could reduce the turnover of doctors by 11 percent, in addition to improving the process and increasing patient satisfaction. The case described by Breslin, Hamilton, and Paynter (2014) aimed to improve readmissions in the Medicare population and, after 30 days of a pilot program, the readmission rate dropped from 16.2 percent to 6.5 percent.

The most common improvements in the imaging and radiology division were the increase in patient volume and decrease of repeated examinations by 9.5 percent and 84.12 percent, respectively, as described by Taner, Sezen, and Atwat (2012). In an attempt to improve patient flow in clinic radiology, Aakre, Valley, and O'Connor (2010) identifies an increase in daily patient capacity from 65 to 71 patients (9 percent), without requiring any additional personnel and equipment. Bahensky, Roe, and Bolton (2005), through a kaizen initiative, describe a 31 percent increase in patient throughput. Also, improvements were identified relating to a decrease in patient waiting time (Taner, Sezen, and Atwat 2012; Bahensky, Roe, and Bolton (2005)) and a reduction in walking distances for hospital staff (Aakre, Valley, and O'Connor 2010; Bahensky, Roe, and Bolton 2005).

In the pharmacy division, improvements were related to a reduction in prescription errors, a reduction in inventories, and a reduction in patient waiting time (Chan 2004; Chiarini 2012; Arafeh et al. 2014).

Framework implementations

Regarding the implementation approach, most of the cases chose DMAIC; there were no examples of pure application of PDCA, and one of PDSA. In other cases the authors created their own approach, as shown in Table 4. These findings would be expected, since the DMAIC is the Six Sigma language for applying PDCA in all improvement initiatives relating to Six Sigma projects.

Aakre, Valley, and O'Connor (2010) reported that they were successful in implementation primarily due to the structured methodology provided by DMAIC, which defines a logical sequence that links statistical and other tools that have been found to be effective in improving processes (Shreeranga, Gijo, and Jnanesh 2014).

Gayed et al. (2013) followed their own frameworks. They used the vision- analysis-team-aim-map-measure-change-sustain (VA-TAMMCS) model. The VA-TAMMCS method of process improvement is systems focused as opposed to focusing on individual inefficiencies, improving buy-in, and sustainability. They stated that VA-TAMMCS is an effective tool for lean and Six Sigma process improvement initiatives in a surgical practice, as their results showed previously.

Cima et al. (2013) described three stages: First, meetings were held that focused on reviewing available literature about the topic and process mapping. The second stage focused on improving current process steps to reduce variations between surgeons. The final stage was

Table 4. Framework implementations.

Framework	Author
DMAIC	Aakre, Valley, and O'Connor (2010); Arafeh et al. (2014); Bertolaccini et al. (2011); Bush et al. (2007); Chan (2004); Chiarini (2012); Cima et al. (2011); Drenckpohl, Bowers and Cooper (2007); Gijo and Antony (2014); Gijo et al. (2013); Huddle et al. (2016); Liefvergreen et al. (2010); Martinez et al. (2011); Niemeijer et al. (2012); Niemeijer et al. (2013); Parks et al (2008); Rai et al. (2016); Sheeranga, Gijo, and Jnanesh (2014); Stanton et al. (2014); Sutphin et al. (2015); Taner and Sezen (2009); Taner, Sezen and Atwat (2012); van den Heuvel, Does, and Verver (2005); Warner et al. (2015)
PDCA	
PDSA	Fischman (2010); Liefvergreen et al. (2010)
Others	Cima et al. (2013); Gayed et al. (2013)

the establishment of infrastructure to support process changes and staff education.

The adoption of quality tools in Six Sigma and LSS projects

Process mapping was the most often used tool, followed by statistical analysis tools and Ishikawa (fishbone) diagrams. The number of appearances for each tool used is shown in Table 5.

The SIPOC diagram also played an important role in the studies where it was applied. It was usually applied during the DMAIC "define" phase. According to Shreeranga, Gijo, and Jnanesh (2014), before starting any process management or improvement activity, it is important to understand/define the process being evaluated. A SIPOC diagram summarizes the inputs and outputs of processes in table form (Minami et al. 2016). The SIPOC process definition was developed to help the process owner and those working on the process to agree on the scope of the project before rushing off and drawing process maps (Shreeranga, Gijo, and Jnanesh 2014).

According to Chiarini (2012), failure mode and effects analysis (FMEA) was fundamental in calculating and analyzing the safety and health risks to nurses and physicians in their cancer drugs management project. Taner, Sezen, and Atwat (2012) used FMEA to analyze potential failure modes, effects, likelihood, and causes in order to allow team members to look at key drivers in the process. According to Breslin, Hamilton, and Paynter (2014), the team used FMEA to "score the severity, probability, and detectability of the discharge process against the reengineered discharge." However, there is still the need for further studies to verify if it is the best tool to use with LSS to manage those kinds of risks.

Table 5. Number of times each tool appeared in the case studies.

Process Mapping	14
Ishikawa	10
Statistical Analysis	10
SIPOC	8
VSM	6
Control Charts	5
Pareto Diagram	5
Histogram	3
FMEA	3
A3 Model	2
Checklist	2
Spaghetti Diagram	2
Run Charts	1
5 Whys	1
Gemba	1
Poka-Yoke	1
5S	1
DoE	1
Gantt Charts	1

The limited data available in these cases has highlighted the importance of using the basic quality tools. In most cases, the advanced statistical tools that are sometimes associated with Six Sigma were not required to achieve successful results (Lifvergreen et al. 2010). Bertolaccini et al. (2011) and Niemeijer et al. (2013) also reported a lack of statistical significance in the results of their project due to the small sample size. Gijo and Antony (2014) reported the collection of data, analysis, and interpretation of the results were complicated because the team members were not familiar with these activities. Shreeranga, Gijo, and Jnanesh (2014) highlighted that statistical tools and techniques could be successfully applied in the service sector for root cause analysis, for a well-prepared data collection plan and for people with the right training to make proper use of them. Gijo and Antony (2014) identified the use of extensive data collection and software packages as an enabler for process improvement. Lifvergreen et al. (2010) stated that these difficulties made basic improvement tools such as Ishikawa diagrams, affinity diagrams, histograms, times series plots, scatter plots, Pareto charts, and control charts even more important.

Almost all the improvement in the cases studied used process mapping to better understand the process flow and obtain a big picture of what was going to be improved. In addition, especially for the case studies that were based on the lean methodology, value stream mapping (VSM) was used. As pointed out by Warner et al. (2015), VSM helped to delineate the processes of care and to identify specific targets for quality improvement. VSM was applied in the audiology scheduling process to identify and eliminate wasteful steps (Huddle et al. 2016). Niemeijer et al. (2013) points out that VSM provided valuable information about the workflow (process times) and wastes, including waiting times and other inefficiencies, and was created from the patient's point of view.

Discussion of successes and failures with respect to Six Sigma implementations

The team composition for implementing Six Sigma projects identified an interesting pattern in the case studies the authors analyzed. In 31 out of 35 case studies, the implementation was conducted by a multidisciplinary team. These teams consisted of doctors, pharmacists, physicians, managers, nurses, external advisors, and so on. In addition, 11 cases had an internal project leader (IPL), which is a critical role in Six Sigma-based quality improvement initiatives, while several other studies had an internal project champion (IPC). In the case studies described by Bush et al. (2007) and Gijo and Antony

(2014), the presence of both an IPL and IPC was crucial to its success. The former was trained as a Black Belt and was responsible for managing the team and making sure the project was running according to schedule. The latter was responsible for providing support to the team in terms of making resources available, and for reviewing the project periodically. For some studies, in order to provide expertise and support to the project, External Black Belts (EBB) (Chiarini 2012; Niemeijer et al. 2012; Shreeranga, Gijo, and Jnanesh 2014; Arafeh et al. 2014) and External Master Black Belts (EMBB) (Gijo et al. 2013; Gijo and Antony 2014) participated as members of the improvement team. Linderman et al. (2003) stated that having a mandate from senior leadership also increases goal commitment since Champions, Black Belts, and Green Belts serve as role models and influence peers, which contributes to increasing the commitment level for achieving Six Sigma goals.

Another important factor in most of the multidisciplinary improvement teams was the training received by the staff prior to the beginning of the project. According to Parks et al. (2008); Taner and Sezen (2009); Martinez et al. (2011), and Taner, Sezen, and Atwat (2012), the performance improvement team received training in Six Sigma methodology. In addition, several cases had internal Green Belts (IGBs) and internal Black Belts (IBBs) as members of the improvement team, who also received training. Lifvergreen et al. (2010) reported that a Black Belt course was designed to support all project managers (future IBBs) during their Six Sigma projects. Six Sigma theories were interwoven into real-life improvement projects, thereby developing the skills and abilities required to be a Black Belt. On the improvement team described by Niemeijer et al. (2012), a 14-day training was held for IBB and an eight-day training for IGB. Gijo et al. (2013), Gijo and Antony (2014), and Shreeranga, Gijo, and Jnanesh (2014) point out that Green Belt training was offered for specific team members who were responsible for executing Six Sigma projects, collecting data on respective processes, and acting as change agents. Heuvel, Does, and Verver (2005) reported that in their case study, a Master Black Belt (MBB) was appointed to set up a management control system to evaluate progress and to support Green Belts in completing their projects. The MBB organized the necessary training programs and ascertained that Green Belts completed a project. Linderman et al. (2003) stated that the training must be proportional to the degree of involvement, they emphasized that training may not create substantial benefits for simple improvement tasks, which means the training should be differentiated for Green Belts and Black Belts and also Champions.

Limitations were reported in some case studies. Parks et al. (2008) applied LSS in a traumatology department and stated that they had not yet received the outcome data to show the impact of their project, so they were not able to confirm if the interventions proposed would actually produce the desired result at the time they wrote their article. According to Cima et al. (2011), the greatest challenge for a high-efficiency operating room in a surgery department is accounting for the variability in patient problems, operation types, and unexpected events that occur in any surgical practice.

Niemeijer et al. (2012) identified difficulties related to a hospital's decentralized structure, which was divided into 10 sectors and managed by different sector managing directors. The problem here was that most managers did not allow interference in their respective departments from plans designed by others. Moreover, interventions were beyond the scope of the Champion, and implementation depended heavily on information and communication technology. There were also internal budgets and oblique financial structures that made interventions financially unattractive. The internal financial structure was not transparent, making it difficult to calculate the costs of activities. Stanton et al. (2014) pointed out the organizational political barriers in healthcare. Most healthcare managers tend to operate in hierarchical organizations where a wide range of powerful stakeholders influence the nature of work, the way work is undertaken, and the resources that are available.

Lin et al. (2013) pointed out as a limitation the potential implications of the "observer effect" (i.e., the Hawthorne Effect), meaning that physicians and staff may have performed more efficiently when being observed. Stanton et al. (2014) highlighted a difficulty regarding multidisciplinary teams. They report that clinical staffs are already highly skilled with a high degree of autonomy, doctors and nurses have allegiance to professional colleges, and multiskilling is restricted by professional demarcation traditions. Other studies also showed the importance of the construction of an engaged multidisciplinary team. According to Bush et al. (2007), the designation of a project Champion was a critical factor for success, helping to give guidance and keep the project on track. Martinez et al. (2011) points out that it was essential for the project's success that most members of the team received training on the LSS methodology because it assured that the team members were sharing the same basic framework for discussing the problems. Lifvergreen et al. (2010) emphasize that Black Belt and Green Belt educations contribute to the spread of more profound knowledge about how to work on improvements,

especially as the education is tied to a real-life improvement project. Lin et al. (2013) highlight as an enabler the fact that representatives from all internal customer groups were involved in the process, which helped to assess the impact of potential changes on the VSM.

The presence of a culture characterized by highly collaborative team-based care (Cima et al. 2013) is also important. It is recommended to maintain a high level of empowerment with the team members, which in turn leads to high levels of motivation (Minami et al. 2016). Lifvergreen et al. (2010) pointed out that the commitment from clinical management and steering committees, involving co-workers and physicians in the projects, and continuous communication were important success factors. According to Linderman et al. (2003), it is possible to achieve more team member effort, commitment, and persistence through specific and complex goals. They concluded that more challenging goals motivate people to work longer at tasks than other goals. Also, it is important to focus team members on goal-relevant activities to create a focal point where they are achieving the target improvement levels.

Heuvel, Does, and Verver (2005) presented some recommendations for categorizing projects. According to these authors, a number of areas can be identified that are particularly profitable to initiate projects. They identify five categories: a) shortening the length of patient stays; b) minimizing the use of materials and devices; c) optimizing the use of available capacities; d) reducing the amount of staff; and e) improving cash flow. In their hospital study, Lifvergreen et al. (2010) identified two major types of projects: those primarily addressing care quality and patient safety, and those focused on resource utilization-based projects.

According to Lifvergreen et al. (2010), managers who lack knowledge in process improvement can result in program failure. This is because they lack not only the importance of project communication, but also the importance of being actually involved. Continuous quality improvement is a form of change and innovation that typically requires cultural change in the organization that can only be driven by leadership. The leaders have to guarantee a culture that fosters innovation and the need to make an effort to ensure a positive energy flow, which generates creative ideas on how to improve the process (Bahensky, Roe, and Bolton 2005).

Conclusion

Returning to the authors' research question, "What are the common trends, benefits, and limitations related to implementing the Six Sigma and LSS methodologies within a hospital environment?" this article has shown that there is a great tendency to combine lean and Six Sigma approaches. The results have also shown that Six Sigma and LSS can bring potential benefits to the hospitals where they are properly applied. The best improvements identified by the literature review made were 90 percent reduction of travel time for technicians (Bahensky, Roe, and Bolton 2005), more than 50 percent patient cycle reduction (Bush et al. 2007), 50 percent reduction of excessive laboratory tests (Blick 2013), more than 60 percent reduction of patient waiting time (Gijo and Antony 2014; Taner, Sezen, and Atwat 2012; Bush et al. 2007; Fischman 2010), 32 percent reduction in errors in surgery and medical prescriptions (Chan 2004), 20 percent increase in patient satisfaction (Breslin, Hamilton, and Paynter 2014), and 10 percent increase in daily patient capacity (Aakre, Valley, and O'Connor (2010)).

Chan (2004) emphasizes that Six Sigma methodologies are very important to staff productivity and patient safety since they offer a new structured approach to the improvement of what are often complicated processes in healthcare, and focus on reducing errors. Unlike in manufacturing, where a defective product can normally be rejected without any major consequences, in healthcare, defects and rework most often directly affect the patient and, therefore, the patient's perception of quality (Heuvel, Does, and Verver 2005).

Shorter waiting lists, elimination of unnecessary examinations, reduction of the number of defects, as well as complications, process variability reduction, costs reduction, increased customer satisfaction, increased profits, and increased output of the care process are some of the many benefits of the improvement process, and they obviously contribute to the improvement of the quality in healthcare (Heuvel, Does, and Verver 2005; Taner and Sezen 2009).

The power of Six Sigma lies in its "empirical" data-driven approach (and its focus on using quantitative measures for how the system is performing) to achieve the goal of process improvement and variation reduction (Bertolaccini et al. 2011). Furthermore, Six Sigma also demonstrates how improvements will contribute to the financial goals of the hospital. An evidence-based approach proves to be a strong argument to convince medical specialists to change to a different method of working (Heuvel, Does, and Verver 2005).

The introduction of Six Sigma and LSS in a hospital may also contribute to process maturity by stimulating a culture of awareness of process immaturity. It catalyzes process design and improvement work (Lifvergreen et al. 2010). Furthermore, it brings a cultural change within the organization by involving everyone in the organization in this movement toward excellence (Shreeranga, Gijo, and Jnanesh 2014). The fact that Six Sigma and LSS

successfully combine quality improvement and cost reduction reinforces the concept that it can be one solution to present-day financial problems in healthcare organizations (Heuvel, Does, and Verver 2005).

Most of the limitations mentioned in this article are not directly related to LSS. Rather, they are related to the organizational and infrastructure capabilities of institutions and uniqueness of each healthcare process (Cima et al. 2011; Niemeijer et al. 2012).

The results identified through the analysis of the case studies elucidate that, despite some cultural barriers, Six Sigma and, most often, LSS can bring potential gains to a variety of hospital departments. It appears that the involvement of a multidisciplinary team is a must, keeping the key stakeholders on track and contributing to the project's success. Training is also essential regarding the multidisciplinary improvement team. In a hospital environment, it is not common for employees to have a background in Six Sigma and LSS methodologies. The results show that training employees in Six Sigma methodology in the form of Green Belts or Black Belts provides the needed skills to manage the project, to support the team in terms of resources, to assist the team with data analysis, and to make sure the project is running according to schedule. Several case studies reported a significant investment in training the hospital staff prior to the beginning of the project and, when necessary, external experts were hired to guide and assure the project's success. To train the staff on lean tools is also recommended since both methodologies are normally applied together.

In addition, this article provides some guidance on possible tools that can be used to support the Six Sigma and LSS implementation methodology. Some of those tools appeared in the great majority of the studies, indicating that they are essential for a hospital setting. However, those tools that were applied only in specific case studies might suggest that they can be used for some particular project goals. Hospitals that wish to implement Six Sigma or LSS can use this article as a framework for determining what is applicable and what is outside the scope of their needs.

After applying the string and the exclusion criteria to the literature review, the authors noticed that several case studies implemented lean together with Six Sigma (that is, LSS). The synergies that can be obtained by combining those two methodologies are very strong, as they can be used to complement each other, as described in healthcare examples by Huddle et al. (2016) and Lin et al. (2013). As a suggestion for future research, a special focus should be on LSS and, more specifically, to how it can be integrated to effectively improve healthcare institutions as a whole. In addition, this article is a purely theoretical paper with no new data generated. Its value, in terms of research, is in the systematization of multiple case studies published in academic journals that were analyzed with a structured approach. A limitation of this article is that it did not carry out any actual implementations; rather, it studied those available in the literature, providing a qualitative assessment. Also, as noted earlier, the SLR considered only cases published in two academic databases (Web of Science and Scopus) that were in the English language; other cases may be available with other sources, but were not considered here. Consequently, as potential next steps in the authors' research they could investigate where a practical analysis of the Six Sigma or LSS implementation in a particular hospital area should be conducted, approaching the project with a multidisciplinary team, selecting specific tools to assist the implementation, and considering the barriers and enablers identified in the qualitative analysis.

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References

Aakre, K. T., T. B. Valley, and M. K. O'Connor. 2010. Quality initiatives: Improving patient flow for a bone densitometry practice: Results from a Mayo Clinic radiology quality initiative 1. *Radiographics* 30 (2):309–315. doi:10.1148/rg.302095735.

Arafeh, M., M. A. Barghash, E. Sallam, and A. AlSamhouri. 2014. Six Sigma applied to reduce patients' waiting time in a cancer pharmacy. *International Journal of Six Sigma and Competitive Advantage* 8 (2):105–124. doi:10.1504/IJSSCA.2014.064256.

Bahensky, J. A., J. Roe, and R. Bolton. 2005. Lean sigma—will it work for healthcare. *J Health Inf Manag* 19 (1):39–44.

Bender, J. S., T. O. Nicolescu, S. B. Hollingsworth, K. Murer, K. R. Wallace, and W. J. Ertl. 2015. Improving operating room efficiency via an interprofessional approach. *The American Journal of Surgery* 209 (3):447–450. doi:10.1016/j.amjsurg.2014.12.007.

Bertolaccini, L., G. Rizzardi, M. J. Filice, and A. Terzi. 2011. 'Six Sigma approach'—an objective strategy in digital assessment of postoperative air leaks: a prospective randomized study. *European Journal of Cardio-Thoracic Surgery* 39 (5):128–132. doi:10.1016/j.ejcts.2010.12.027.

Blick, K. E. 2013. Providing critical laboratory results on time, every time to help reduce emergency department length of stay: How our laboratory achieved a Six Sigma level of performance. *American Journal of Clinical Pathology* 140 (2):193–202. doi:10.1309/AJCPNUTIPQTRRG0D.

Breslin, S. E., K. M. Hamilton, and J. Paynter. 2014. Deployment of Lean Six Sigma in care coordination: an improved discharge process. *Professional case management* 19 (2):77–83. doi:10.1097/NCM.0000000000000016.

Bush, S. H., M. R. Lao, K. L. Simmons, J. H. Goode, S. A. Cunningham, and B. C. Calhoun. 2007. Patient access and clinical efficiency improvement in a resident hospital-based women's medicine center clinic. *American Journal of Managed Care* 13 (12):686.

Chan, A. L. 2004. Use of Six Sigma to improve pharmacist dispensing errors at an outpatient clinic. *American Journal of Medical Quality* 19 (3):128–131. doi:10.1177/106286060401900306.

Chiarini, A. 2012. Risk management and cost reduction of cancer drugs using Lean Six Sigma tools. *Leadership in Health Services* 25 (4):318–330. doi:10.1108/17511871211268982.

Cima, R. R., M. J. Brown, J. R. Hebl, R. Moore, J. C. Rogers, A. Kollengode, G. J. Amstutz, C. A. Weisbrod, B. J. Narr, and C. Deschamps. 2011. Use of lean and Six Sigma methodology to improve operating room efficiency in a high-volume tertiary-care academic medical center. *Journal of the American College of Surgeons* 213 (1):83–92. doi:10.1016/j.jamcollsurg.2011.02.009.

Cima, R., E. Dankbar, J. Lovely, R. Pendlimari, K. Aronhalt, S. Nehring, R. Hyke, D. Tyndale, J. Rogers, and L. Quast. 2013. Colorectal surgery surgical site infection reduction program: a national surgical quality improvement program–driven multidisciplinary single-institution experience. *Journal of the American College of Surgeons* 216 (1):23–33. doi:10.1016/j.jamcollsurg.2012.09.009.

Coronado, R. B., and F. Antony. 2002. Critical success factors for the successful implementation of Six Sigma projects in organizations. *The TQM Magazine* 14 (2):92–99. doi:10.1108/09544780210416702.

de Koning, H., J. P. S. Verver, J. V. D. Heuvel, S. Bisgaard, and R. J. M. M. Does. 2006. Lean Six Sigma in healthcare. *Journal for Healthcare Quality* 28 (2):4–11. doi:10.1111/j.1945-1474.2006.tb00596.x.

Dobrzykowski, D. D., K. L. Mcfadden, M. A. Vonderembse. 2016. Examining pathways to safety and financial performance in hospitals: A study of lean in professional service operations. *Journal of Operations Management* 42–43 (1):39–51. doi:10.1016/j.jom.2016.03.001.

Drenckpohl, D., L. Bowers, and H. Cooper. 2007. Use of the Six Sigma Methodology to reduce incidence of breast milk administration errors in the NICU. *Neonatal Network: The Journal of Neonatal Nursing* 26(3): 161–166.

Drohomeretski, E., S. E. Gouvea da Costa, E. Pinheiro de Lima, P. A. D. R. Garbuio. 2014. Lean, Six Sigma and Lean Six Sigma: an analysis based on operations strategy. *International Journal of Production Research* 52 (3):804–824. doi:10.1080/00207543.2013.842015.

Fischman, D. 2010. Applying Lean Six Sigma methodologies to improve efficiency, timeliness of care, and quality of care in an internal medicine residency clinic. *Quality Management in Healthcare* 19 (3):201–210. doi:10.1097/QMH.0b013e3181eece6e.

Foster, T, Jr. 2007. Does Six Sigma improve performance? *Quality Management Journal* 14 (4):7–20. doi:10.1080/10686967.2007.11918043.

Gayed, B., S. Black, J. Daggy, I. A. Munshi. 2013. Redesigning a joint replacement program using Lean Six Sigma in a Veterans Affairs hospital. *JAMA surgery* 148 (11):1050–1056. doi:10.1001/jamasurg.2013.3598.

George, M. L. 2003. *Lean Six Sigma for Service*. 1st ed. New York: McGraw-Hill.

Gijo, E. V., A. Jiju, J. Hernandez, S. Johny. 2013. Reducing patient waiting time in a pathology department using the Six Sigma methodology. *Leadership in Health Services* 26 (4):253–267. doi:10.1108/LHS-02-2012-0004.

Gijo, E. V., and J. Antony. 2014. Reducing patient waiting time in outpatient department using Lean Six Sigma methodology. *Quality and Reliability Engineering International* 30 (8):1481–1491. doi:10.1002/qre.1552.

Heineke, J., and M. M. Davis. 2007. The emergence of service operations management as an academic discipline. *Journal of Operations Management* 25 (2):364–374. doi:10.1016/j.jom.2006.11.003.

Heuvel, J. V. D., R. J. M. M. Does, J. P. S. Verver. 2005. Six Sigma in healthcare: Lessons learned from a hospital. *International Journal of Six Sigma and Competitive Advantage* 1 (4):380. doi:10.1504/IJSSCA.2005.008504.

Huddle, M. G., A. Tirabassi, L. Turner, E. Lee, K. Ries, S. Y. Lin. 2016. Application of lean sigma to the audiology clinic at a large academic center. *Otolaryngology – Head and Neck Surgery* 154 (4):715–719. doi:10.1177/0194599815627774.

Kitchenham, B., and S. Charters. 2007. *Guidelines for performing systematic literature reviews in software engineering. EBSE 2007–001*. Keele University and Durham University Joint Report.

Lifvergren, S., I. Gremyr, A. Hellstrom, A. Chakhunashvili, B. Bergman. 2010. Lessons from Sweden's first large-scale implementation of Six Sigma in healthcare. *Operations Management Research* 3 (3–4):117–128. doi:10.1007/s12063-010-0038-y.

Lin, S. Y., D. Gavney, S. L. Ishman, J. Cady-Reh 2013. Use of lean sigma principles in a tertiary care otolaryngology clinic to improve efficiency. *The Laryngoscope* 123 (11):2643–2648. doi:10.1002/lary.24110.

Linderman, K., R. G. Shroder, S. Zaheer, and A. S. Choo. 2003. Six Sigma: A goal-theoretic perspective. *Journal of Operations Management* 21 (2):193–203. doi:10.1016/S0272-6963(02)00087-6.

Martinez, E., R. Chavez-Valdez, N. Holt, K. Grogan, K. Khalifeh, T. Slater, L. Winner, J. Moyer, and C. Lehmann. 2011. Successful implementation of a perioperative glycemic control protocol in cardiac surgery: barrier analysis and intervention using Lean Six Sigma. *Anesthesiology Research and Practice* 26 (4): 1–10. doi:10.1155/2011/565069.

Minami, C. A., C. R. Sheils, K. Y. Bilimoria, J. K. Johnson, E. R. Berger, J. R. Berian, M. J. Englesbe, O. D. Guillamondegui, L. H. Hines, J. B. Cofer, et al. 2016. Process improvement in surgery. *Current Problems in Surgery* 53 (2): 62–96. doi:10.1067/j.cpsurg.2015.11.001.

New England Healthcare Institute. 2008. *Waste and Inefficiency in the U.S. Health Care System. Clinical Care: A comprehensive Analysis in Support of System-Wide Improvements*. Accessed January 1, 2018. http://media.washingtonpost.com/wp-srv/nation/pdf/healthreport_092909.pdf

Niemeijer, G. C., R. J. M. M. Does, J. De Mast, A. Trip, J. Van den Heuven. 2011. Generic Project definitions for improvement of health care delivery: a case-based approach. *Quality Management in Health Care* 20 (2):152–164. doi:10.1097/QMH.0b013e318213e75c.

Niemeijer, G. C., A. Trip, L. J. de Jong, K. W. Wendt, and R. J. M. M. Does. 2012. Impact of 5 years of Lean Six Sigma in a university medical center. *Quality Management in Health Care* 21 (4):262–268. doi:10.1097/QMH.0b013e31826e74b7.

Niemeijer, G. C., E. Flikweert, A. Trip, R. J. Does, K. T. Ahaus, A. F. Boot, and K. W. Wendt. 2013. The usefulness of Lean Six Sigma to the development of a clinical pathway for hip fractures. *Journal of Evaluation in Clinical practice* 19 (5):909–914.

Ortiz Barrios, M., and H. Felizzola Jiménez. 2016. Use of six sigma methodology to reduce appointment lead-time in obstetrics outpatient department. *Journal of Medical Systems* 40 (10):293–302.

Parks, J. K., J. Klein, H. L. Frankel, R. S. Friese, and S. Shafi. 2008. Dissecting delays in trauma care using corporate Lean Six Sigma methodology. *Journal of Trauma and Acute Care Surgery* 65 (5):1098–1105. doi:10.1097/TA.0b013e318188e8ad.

Petticrew, M., and H. Roberts. 2006. *Systematic Reviews in the Social Sciences*. Malden, MA: Blackwell Publishing.

Polk, L. D. 2011. Lean Six Sigma, innovation, and the change acceleration process can work together. *PEJ* 37 (1):38–42.

Rai, A., M. Smith, S. Boo, A. Tarabishy, G. Hobbs, and J. Carpenter. 2016. The 'pit-crew' model for improving door-to-needle times in endovascular stroke therapy: A six-sigma project. *Journal of Neurointerventional Surgery* 8 (5):447–452.

Sabry, A. 2014. Factors critical to the success of Six Sigma quality program and their influence on performance indicators in some of Lebanese hospitals. *Arab Economic and Business Journal* 9 (2):93–114. doi:10.1016/j.aebj.2014.07.001.

Shreeranga, B., E. V. Gijo, N. A. Jnanesh. 2014. Application of Lean Six Sigma methodology in the registration process of a hospital. *International Journal of Productivity and Performance Management* 63 (5):613–643. doi:10.1108/IJPPM-11-2013-0191.

Sutphin, P., S. Reis, A. McKune, M. Ravanzo, S. Kalva, and A. Pillai. 2015. Improving inferior vena cava filter retrieval rates with the define, measure, analyze, improve, control methodology. *Journal of Vascular and Interventional Radiology* 26 (4):491–498.e1.

Stanton, P., R. Gough, R. Ballardie, T. Bartram, G. J. Bamber, and A. Sohal. 2014. Implementing lean management/Six Sigma in hospitals: Beyond empowerment or work intensification? *The International Journal of Human Resource Management* 25 (21):2926–2940. doi:10.1080/09585192.2014.963138.

Taner, T., M. B. Sezen, and K. M. Atwat. 2012. Application of Six Sigma methodology to a diagnostic imaging process. *International Journal of Health Care Quality Assurance* 25 (4):274–290. doi:10.1108/09526861211221482.

Taner, T., M. B. Sezen. 2009. An application of Six Sigma methodology to turnover intentions in health care. *International Journal of Health Care Quality Assurance* 22 (3):252–265. doi:10.1108/09526860910953520.

Tranfield, D., D. Denyer, P. Smart. 2003. Towards a methodology for developing evidence-informed management knowledge by means of systematic review. *British Journal of Management* 14 (3):207–222. doi:10.1111/1467-8551.00375.

Verbano, C. and M. Crema. 2013. Guidelines for overcoming hospital managerial challenges: A systematic literature review. *Therapeutics and Clinical Risk Management* 9:427–441.

Warner, C. J., A. J. Horvath, R. J. Powell, J. A. Columbo, T. R. Walsh, P. P. Goodney, D. B. Walsh, and D. H. Stone. 2015. Endovascular aneurysm repair delivery redesign leads to quality improvement and cost reduction. *Journal of vascular surgery* 62 (2):285–289. doi:10.1016/j.jvs.2015.02.054.

Zucchi, P., C. Del Nero, A. M. Malik. 2000. Health expenditures: demand and supply factors in health services. *Saúde e Sociedade* 9 (1–2):127–150. doi:10.1590/S0104-12902000000100010.