

Implementation of Lean in Healthcare environments: an update of systematic reviews

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Abstract

Purpose – Even though the implementation of Lean in healthcare environments is relatively recent, it has been receiving a lot of attention in recent years. Partly due to the fact that it is a recent field of practice and research and partly because the number of works developed in this field has grown rapidly, it is important to frequently update the perspectives on this field of investigation. Thus, this article aims to systematically review the implementation of Lean tools and techniques applied to hospital organizational areas in a 5-year period, between 2014 to 2018, complementing some of the most relevant reviews already published. The most important criteria such as tools, methods and principles, hospital areas intervened, improvements and difficulties were assessed and quantified.

Methodology - As starting point for this systematic literature review, a set of selected pre-existing review publications was used to support the current work and as the ground base for the expansion of the studies about Lean Healthcare. The current study contemplated 114 articles from a 5-year period between 2014 and 2018. A subset of 58 of these articles was critically assessed to understand the application of lean tools and methods in different hospital areas.

Findings - The thorough analysis of selected articles show a lack of works in Continuous Improvement approaches when compared to the application of work organization, visual management, and diagnosing and problem-solving tools. The reported improvement results demonstrate alignment with the principles and foundations of lean philosophy, but such results are presented in isolated initiatives and without robust evidence of long-term maintenance. Moreover, this study shows an evolution in the number of articles referring to lean implementation in hospital areas, but in its great majority, such articles report isolated implementations in different areas, not spreading those for the global organization. Thus, some of the main recommendations, are the need to implement studies on complete flows of patients, drugs and materials, instead of isolated initiatives, and strive to promote cultural change of hospitals through structural changes, following new visions and strategic objectives, supported by real models of continuous structural and sustained improvement.

Originality – The current work develops a new perspective of the articles published under the thematic of Lean Healthcare, published in a recent period of 5 years, which are not completely covered by other works. Additionally, it explicitly applied, in an innovative way, an approach that used a set of previous reviews as the starting point for this SLR. In this way, it integrates approaches and categories from different SLRs, creating a framework of analysis that can be used by future researchers. Finally, it shows the most recent implementations of Lean Healthcare, exposing the current trends, improvements and also the main gaps.

Keywords: Lean Healthcare; Operations Management; Systematic Literature Review.

1 Introduction

Health promotion is essential for the well-being of humanity and for sustainable economic and social development, with most countries ranking health as one of their highest priorities (WHO, 2010). Hospitals, in this context, are crucial organizations for the implementation of health policies because they provide various health services to the community. Their activities may include healing, rehabilitation, prevention and promotion of health education (Chaerul, Tanaka and Shekdar, 2008). According to the WHO (2010), there are different levels of government commitment to health. As an

example, from the WHO Regional Office for Europe, which includes countries with different levels of GDP, government commitment to health varies from 4% to 20% of total government spending. More than an investment issue, due to rising costs and poor management, the health system is undergoing financial, social and political pressures, needing to develop a more robust capability of aligning current and future services according to its structure and high demand. Health systems will only succeed if they have the capacity to innovate by crossing organizational, political, geographical and sectoral barriers (Roberts et al., 2016).

According to Vendemiatti et al. (2010) hospital dynamics is composed of complex interrelationships between processes and people working at different levels of hierarchy, specialization and organizational identity. The administrative and nursing groups have a contractual link to the organization and are subject to the authority of the organizational chart of the hospital, while the medical group has high levels of autonomy over the clinical processes. In this sense, hospitals could benefit from a more professional management approach through management systems similar to the ones used in the business world (Matos, 2002). However, hospitals are usually analysed as complex structures that tend to be impervious to change (Santos, 2006). Nevertheless, hospitals require efforts related to continuous improvement culture and operations management, just like any other existing organization.

Based on this interest in considering hospital dynamics as a regular company, hospitals have promoted studies related to strategic planning, informatization, cost reduction, among others, in a context of increasing demand, increasing expenses and competitiveness (Weber & Grisci, 2010). Given this complexity (and inherent taken responsibility to patients), hospital managers need robust management techniques that allow the evaluation and improvement of their processes (de Souza et al., 2009), the increase of quality and efficiency, and to develop a vision of flow/stream.

In order to mitigate the problems and inefficiencies of the hospital world, methodologies and management techniques from manufacturing and operations management have emerged (Kim et al., 2016). Some of these type of improvement methodologies and management techniques are related to Lean Thinking (Graban, 2011). Lean Thinking may be characterized as a philosophy for reducing waste and adding value by improving organizational processes (Womack & Jones, 2003). This approach applied to production systems, has its conceptual basis in the Toyota Production System - TPS (Ohno, 1988). It is relevant to state that, as referred by Sugimori et al. (1977), a key aspect of the Toyota model is the central focus given to human aspects, such as respect for employees and teamwork. The principles of TPS are the result of more than three decades of evolution of Toyota Motor Corporation's production methods developed mainly by Taiichi Ohno (Hines et al., 2004).

According to Womack & Jones (1997), lean thinking is based on five principles: identify value; map the value stream; create continuous flow; promote pull production; and a continuous search for perfection. There are evidences of a trend on Lean application in areas such as construction, insurers, banks, pharmaceutical industries and hospitals (Souza, 2009). From the hospital viewpoint, the term Lean Healthcare has been used to name the use of the Lean philosophy in the context of healthcare. Lean Healthcare can be characterized as a philosophy of improvement, supported by tools, methods and principles that improve the way hospitals are organized, redesigning physical spaces and processes, as well as engaging administrative professionals, nurses and medical staff in the search for continuous improvement (Graban, 2011). In Lean Healthcare the patient should always be the focus

of the study, being the Lean Healthcare goal to provide the right care at the right time, with quality and with the flexibility to keep up with the changing health system environment. Therefore, understanding the value for the patients is the guiding principle that allows defining the necessary changes for hospitals (Weinstock, 2008). Ajmera & Jain (2019) showed in their study that healthcare organizations may capitalize high efficiency earnings by understanding and improving the main factors (and their relative importance, interdependencies and relationships) that influence the implementation of lean principles in the healthcare industry. Factors such as lean leadership, professional organizational culture and teamwork and interdepartmental cooperation are pointed out as the top-level factors influencing adoption of lean philosophy in healthcare organizations.

Bertolini et al. (2001) identified some critical processes in the hospital environment using techniques of Operations Management, such as simulation of processes, which demonstrated to be useful in the definition of scenarios and critical analysis of the organization. Such hypothetical scenarios simulated the use of resources, allowing the analysis and identification of bottlenecks and utilization rates. In the health sector such problems, related to the operations management, are considered complex due to the inherent complex nature of the sector, added with the high management autonomy of doctors, the lack of performance measurements, the customization of treatments and the difficulty to standardize processes. These are just some of the aspects that hinder the adoption of management tools from other areas, like Industrial Engineering.

Although there is research on operations management and planning in hospital context, there are still gaps in the integration of these two areas of knowledge. Hospital administrators aim to improve service quality and reduce costs, which are core issues in the field of operations management. Thus, although being possible to draw positive comparisons between hospitals and industrial sector regarding operational problems, there are fundamental differences. Two of the most relevant differences are the interaction between caregivers and clients (patients), and the large professional and philosophical gap between "business operations managers" (managers/administrators) and "clinical operations managers" (medical staff / doctors). These are critical issues, already presented by Butler et al. (1996), that should be assigned to an operations manager and that should be addressed by the hospital's strategic plan and by its operations management strategy. The application of these tools, brought from other business areas/industries to hospitals, requires in-depth studies and adaptations according to the nature of the care process and the focus on the patient (Evans, Hagar & Nagarajan, 2001).

From the Lean Healthcare's historical perspective, Souza (2009) assumes that a precise date for the first application of lean in health is uncertain and indicates Heinbuch (1995), Jacobs and Pelfrey (1995) and Whitson (1997) as possible first applications of lean concepts in hospitals, even though the authors had not yet coined the term Lean in their research projects. However, Souza (2009) speculates that the first potential publication related to the use of Lean Healthcare appeared in an article by the NHS Modernization Agency in 2001. Daultani et al. (2015), Souza (2009), Mazzocato et al. (2010), Holden (2011), D'Andreanmatteo et al. (2015), Costa & Godinho Filho (2015) and Mousavi Isfahani et al. (2019) expose and explain the state of publications in this theme, using literature review approaches and discussing an evolution over the years. Despite the fact that these works bring a summary of the publications and synthesize in a useful way the knowledge about Lean healthcare, they bring a natural and understandable difficulty when studying the implementation of Lean in hospitals. These were works developed by different researchers in different periods of time and present both, tools, methods

and principles, and hospital organizational areas, with different classifications. This lack of uniformity makes it difficult to understand which tools, methods and principles are applied to different areas and the approaches to different issues (Régis et al. 2018) in Hospitals.

Partly due to the fact that the implementation of lean in healthcare environments is a recent field of practice and research and partly because the number of works developed in this field has been rapidly growing, creates the need to answer to the following question: What are the Lean tools, methods and principles applied to hospital organizational areas in recent years and what could be seen as missing? As the previous review works are relevant and useful, the authors of the current work decided to use them as the basis for answering to this question, enlarging the knowledge about the theme being studied, and additionally creating a uniform framework of analysis depicted from their works.

Thus, this study aims to systematically analyse articles for understanding the implementation of Lean principles, tools and techniques applied to hospital organizational areas in a 5-year period, between 2014 and 2018. This objective is materialized through the identification of the main tools, methods and principles applied in Lean Healthcare studies, the identification of the main hospital organization areas and related to these two subthemes, what are the main improvement results and difficulties identified in the reviewed articles. Linked to the above stated objective, there is another equally relevant objective, which is related to the identification of Lean tools, methods and principles applied to hospital organizational areas in recent years that could be seen as missing.

2 Systematic Literature Review Methodology

Linde & Willich (2003) argue that a systematic literature review (SLR) can be useful to identify emerging themes for future research and can also be useful for synthesizing information from a set of studies carried out separately on a given subject. The studies may present results that may, or may not, coincide with each other. Considering these arguments, the selection of SLR as a research approach is adequate to analyse and synthesize a perspective on the implementation of Lean tools, techniques and principles applied to hospital organizational areas in a 5-year period, between 2014 and 2018. A critical analysis of those works will also allow to identify potential gaps and propose them as a possible target for future research.

Systematic review is a type of scientific research presented in the form of retrospective observational studies and critical literature review. These reviews aim to identify, group, critically analyse and synthesize the results of several primary studies (Briner & Denyer, 2012; Galvão & Pereira, 2014).

Systematic reviews should include a research question, a systematic and comprehensive study analysis, an explicit and reproducible data extraction process, an adequate and critical data presentation and interpretation, and may suggest future research related to the synthesis of the analysis (Ravindran & Shankar, 2015).

2.1 Method

The current work adapted the design proposed by Tranfield et al. (2003), which describe a structure for systematic reviews based on three main phases:

- Phase 1 – Planning of the Review: Identification of the need for the review; Proposal preparation for review; Development of the review protocol.
- Phase 2 - Conduct the Review: Identification of the research; Selection of studies; Assessment of study quality, Data extraction, Data synthesis.
- Phase 3 - Report and Disseminate: Results and recommendations, Expose practical evidences.

Phase 1 of the study, as described by Tranfield et al. (2003), may not be a closed sequence of steps, and, instead, it may be developed iteratively. In the case of the current work, during the initial iteration on Phase 1, for establishing the need of the study and the purpose, an initial analysis of pre-existing review publications was developed. These review publications include, extensively, the analysis of publications mainly prior to 2014. Thus, they are used as a ground basis of this study, which expands the review timespan to the period 5-year period from 2014 to 2018, overlapping temporally a few articles from 2014 and 2015 of previous works. As those previous review works are considered highly relevant for the area, it was considered appropriate to define a method based on the analysis of a subset of existing systematic reviews and update them with more recent data and an analysis supported by a new integrated framework of criteria and categories. This approach intends to contribute to the integration of different categories that could be used by other researchers and practitioners, making this and future perspectives on Lean healthcare more uniform. Nevertheless, such framework of analysis cannot be considered static and future researchers may, and should, update it as needed, either due to the evolution of the theme or to bridge gaps not covered by this work. This framework of analysis is presented in section 2.2. During this iteration was possible to close the research question, presented in the introduction section.

In the second iteration of phase 1, a deeper analysis of the pre-existing review works was developed as a contribution for the definition of the review criteria to be used in the analysis of the articles. This part of the process was based in seven systematic review studies (Table 1) considered highly relevant for the purpose of this article.

Table 1. Systematic review articles used as basis for this study

Authors	Title	Review Period
Souza (2009)	Trends and approaches in lean healthcare.	2002 to 2008
Mazzocato et al. (2010)	Lean thinking in healthcare: a realist review of the literature.	1998 to 2008
Holden (2011)	Lean thinking in emergency departments: a critical review.	2005 to 2010
D'Andreamatteo et al. (2015)	Lean in healthcare: A comprehensive review.	2003 to 2013
Daultani et al. (2015)	A decade of lean in healthcare: Current state and future directions.	2002 to 2014
Costa & Godinho Filho (2015)	Lean healthcare: review, classification and analysis of literature.	2008 to 2014
Mousavi Isfahani et al. (2019)	Lean management approach in hospitals: a systematic review.	2010 to 2015

During this phase two highly recent review works were analysed, but they are not able to fully answer to our research question. The work from Mousavi Isfahani et al. (2019) includes articles until august 2015 and for that reason it does not allow to answer to our research question. Moreover, due to a more focused research objective the analysis includes a small number of works from 2014 (10 articles) and 2015 (3 articles) then the current work. Additionally, a recent review from Ramori, Cudney, Elrod & Antony (2019) also cover a small number of papers from the 5-year period considered here, but due to a much more focused thematic (“Lean business models in healthcare”) objective compared to the one used in the present work, it does not allow to answer to the research question of the current study and was not included in the subset of review papers used to support the current work. The criteria of

analysis of the selected review studies partially overlap and may be considered as complementary. Thus, it was decided to analyse, integrate and extend the criteria of these articles in order to increase its scope and usefulness. The definition of the criteria of analysis and the way it would be applied is also part of phase 1, as defined by Tranfield et al. (2003), and the details are described in the following section 2.2.

Still in Phase 1, a set of keywords were defined by intersecting the keywords used by the authors of the review articles mentioned in Table 1 and adding up relevant keywords considered by the researchers involved in the current study. Souza (2009) evaluated 90 articles using keywords such as "lean healthcare", "lean hospital", "lean health", and "lean medical" in the period between 2002 and 2008. D'Andreamatteo et al. (2015) conducted a literature review based on 243 articles selected between 2003 and September 2013 exploring the Scopus and Pubmed databases using keywords such as "Lean healthcare", "Lean six sigma", "Toyota management system", "Kaizen", "Rapid improvement event", "health system", "hospital". Mazzocato et al. (2010) performed a systematic review between January 1998 and February 2008, initially finding 1,000 publications of which 112 were identified as potentially relevant to the study, and from these (after the bibliometrics analysis) the authors defined 33 publications to analyse. Costa & Godinho Filho (2016) analysed 107 articles using the keywords "lean health", "lean healthcare" and "lean hospital" between March 2008 and November 2014, exploring the Engineering Village, Web of Knowledge, Scopus and Google Scholar databases. Daultani et al. (2015) applied a systematic review between 2002 and 2014 using the keywords "lean", "healthcare", "hospital" in international databases, finding 335 potential articles and, after discarding 211 articles with no relevance to the topic, 124 articles were kept. Mousavi Isfahani et al. (2019) used a search strategy that included the terms "Lean principles", "Lean Six Sigma", "Lean Process", "Lean thinking", "Lean Methodology", "Toyota Production System lean processing", "Lean techniques", and "hospital". This search strategy resulted in 967 articles, from which 48 were finally selected and analysed.

After analysing the keywords used in the selected review articles, the researchers of the current study have decided for broad search terms during the definition of the search procedure, resulting in the following search query: TITLE-ABS-KEY ("lean healthcare" OR "lean hospitals") OR TITLE-ABS-KEY ("lean thinking" AND (hospitals OR healthcare)).

At this point, it is possible to *conduct the review*, Phase 2 according to Tranfield et al. (2003). Thus, the search query was applied to two index databases, Scopus and the Web of Knowledge. Considering that the number of results of the first one (Scopus) included the great majority of the results of the second one (Web of Knowledge), it was decided to use the list of results obtained in the Scopus database search, resulting in a total of 366 articles found prior to 2019. Then, as a quality criterion of inclusion, these articles were filtered by selecting journal publications only, resulting in a total of 245 articles. Considering the period of time delimitation of this study, the search included articles in the years 2014 to 2018, resulting in 136 articles.

In this phase, the articles' files were downloaded, and, after a first screening process based on the title and abstract, 22 articles were excluded: three due to different scope of the study and 19 due to lack of access to full text, resulting in a total of 114 final articles, as illustrated by Figure 1.

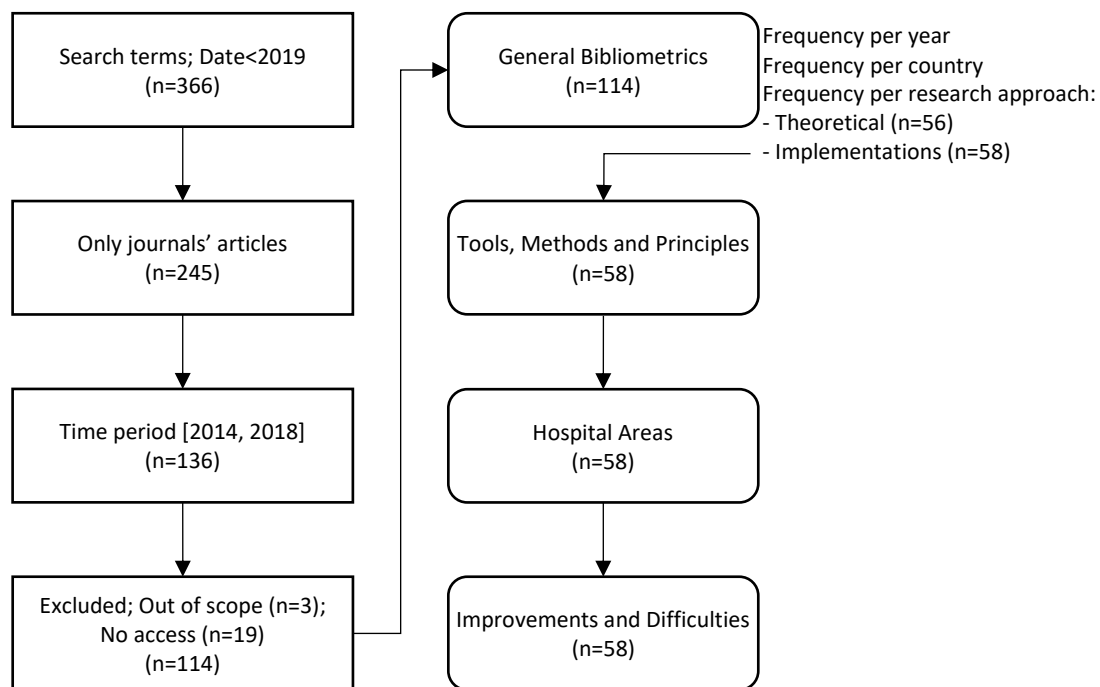


Figure 1 – Structure and organization to conduct the review

As stated by Easterby-Smith, Thorpe, Jackson and Jaspersen (2018, p.46), the critical phase of the assessment “follows the criteria and (emerging) themes of the review”. These criteria and themes, described in the next section, were a result of integrating and expanding the criteria from the works referred in Table 1. Moreover, their meaning and interpretations were debated and clarified among all researchers and subsequently applied by one of the researchers to all articles. Whenever doubts arose, they were clarified among all the researchers and a decision was made by consensus among them. These criteria are described in detail in the next section.

Finally, after conducting the review, the work enters in phase 3, *report and disseminate*, where results and recommendations are presented, in addition to the practical evidence exposed. The analysis and synthesis of the articles are reported using a structure based on the review criteria defined in section 2.2, followed by discussion, recommendations and conclusion. Finally, the complete list of articles and the relation with the criteria identified is presented in the appendix.

2.2 Review Criteria

As explained in the previous section, the first filter applied in this study was the selection of the most relevant reviews in the study’s field of knowledge (Table 1). After selecting the reviews, the criteria were chosen according to Costa & Godinho Filho (2016) and were crosschecked for each article. Costa & Godinho Filho (2016) classified the articles according to six criteria, and this study adapted and updated five of those criteria by crossing with the other selected systematic reviews. The criteria applied were:

1. Year, number of publications per year by Souza (2009), D'Andreamatteo et al. (2015), and Daultani et al. (2015).
2. Country, also analysed by Souza (2009).
3. Research approaches, also analysed by Souza (2009), Mazzocato et al. (2010), D'Andreamatteo et al. (2015), and Daultani et al. (2015).

4. Tools, Methods and Principles, also studied by Souza (2009), Mazzocato et al. (2010), D'Andreamatteo et al. (2015), Daultani et al. (2015) and Mousavi Isfahani et al. (2019); including principles and techniques related to Lean Healthcare.
5. Hospital areas, also studied by Mazzocato et al. (2010), Daultani et al. (2015), Holden (2011) and Mousavi Isfahani et al. (2019).
6. Improvements and difficulties, also studied by Mazzocato et al. (2010), Daultani et al. (2015), Holden (2011) and Mousavi Isfahani et al. (2019).

2.2.1 General Bibliometrics

The first three criteria identified above are mainly related to the analysis of the frequency of the number of published references, grouped by year, country and type of research approaches used in each study. These analyses, entitled as *general bibliometrics*, present an overview about the recent history around this theme.

Regarding the research approaches used in Lean Healthcare articles, Souza (2009) addressed his analysis in two categories: theoretical and case studies, in which theoretical studies would not demonstrate a real implementation, while case studies would do. D'Andreamatteo et al. (2015) used the criteria of Souza (2009) to divide the articles into two types of clusters: Empirical and Theoretical. Costa & Godinho Filho (2016) analysed the articles as Theoretical-conceptual (TC), Action research (AR), Case study (CS), Survey (S), and Ethnography (E).

After reading the abstract and, if needed, other parts of the article, they were assessed according to the methodological approach, using the classification of Costa & Godinho Filho (2016), as theoretical-conceptual (TC), survey (S), action-research (AS), case study (CS) and ethnography (E). None of the articles was classified as using ethnography (E). Fifty-eight (58) articles were assessed as case studies and action-research, with the application of lean tools and methods in healthcare contexts. These 58 papers were qualitatively analysed, with the objective of developing a critical assessment of implementation of lean tools and methods in empirical works, encompassing a timeframe of 5 years.

Furthermore, considering the objective of understanding tools and techniques applied to Lean Healthcare, the 58 articles categorized as case studies and action-research were analysed in detail according to the criteria 4 to 6, as described below.

2.2.2 Tools, Methods and Principles

Daultani et al. (2015) analysed a wide range of tools and techniques, and their combinations applied in lean healthcare and show that VSM (Value Stream Mapping) is one of the most frequent tools cited, but without a complete demonstration of its potential. Costa & Godinho Filho (2016) also identify tools and techniques applied to Lean Healthcare with a classification previously proposed by Radnor et al (2012) where these tools are divided into three main classifications: Assessment; Improvement; and, Monitoring. Within these main general classifications, Mazzocato et al. (2010) included tools, methods and principles based on their review. Mousavi Isfahani et al. (2019) classified studies in ten generic terms with different levels of aggregation. Examples of terms used are Lean tools, Lean Six Sigma, Lean Methodology or Lean Principles.

According to the list of tools and techniques presented in the studies by Daultani et al. (2015), Costa & Godinho Filho (2016) and Mazzocato et al. (2010), the current study compiled and synthesized a list of tools, methods and principles from the selected articles and divided it into five classes, as shown in Table 2. These classes are a result of a debate between three Lean experts regarding the six review

articles used to support the current work, and considering their experience, both in research and in practical developments with industries and hospitals. The main objective of this classification is to present a more useful result for practitioners and for other research works.

The classes refer to two Lean principles, “Production Flow” and “Continuous Improvement”, and other dimensions transversally related to Lean, “Work Organization and Visual Management”, “Diagnosing and Problem Solving” and “Complementary Management Approaches”.

Table 2 – List of tools, methods and principles

I. Production Flow	IV. Diagnosing and Problem Solving
T1 Continuous Flow	T30 5 Whys
T2 Heijunka (Levelling)	T31 A3 reports
T3 Just in Time	T32 ABC Analysis
T4 Kanban	T33 Ishikawa Diagram (Cause and effect/Fishbone diagram)
T5 One-piece-flow	T34 Kobetsu
T6 Pull System	T35 OEE (Overall Equipment Effectiveness)
T7 Quick Changeovers (SMED - Single Minute Exchange of Die)	T36 Process mapping, Process redesign
T8 Takt time	T37 Risk Analysis (FMEA - Failure Modes, Effects Analysis)
T9 Work Cells	T38 SIPOC (Suppliers, Inputs, Process, Outputs, Customer)
T10 Workload balancing	T39 Spaghetti diagram
	T40 Statistical Process Control
II. Continuous Improvement	T41 Value stream mapping
T11 Continuous Improvement Teams	T42 Wastes Analysis
T12 DMAIC (Define-Measure-Analyse-Improve-Control)	V. Complementary Management Approaches
T13 Go to Gemba	T43 Benchmarking
T14 Hoshin Kanri	T44 Lean Six Sigma
T15 Kaizen/Rapid Improvement Event	T45 Project Management
T16 Kata	T46 SCRUM
T17 KPIs (Key Performance Indicators) Monitoring	T47 Simulation/Systems Approach
T18 PDCA/PDSA (Plan, Do, Check, Act / Plan, Do, Study, Act)	T48 Theory of Constraints (TOC)
T19 VOC, VOB, CTQ (Voice of Business, Voice of Customer, Critical to Quality)	T49 Total Productive Maintenance (TPM)
	T50 Total Quality Management (TQM)
III. Work Organization and Visual Management	
T20 5S (Seiri, Seiton, Seiso, Seiketsu, Shitsuke)	
T21 Andon (Patient safety alert system and 'Stop the line')	
T22 Daily Meetings / Rounds	
T23 Jidoka	
T24 Mistake-proofing (Poka-yoke)	
T25 Multidisciplinary task training	
T26 Physical work setting redesign	
T27 Standardized work	
T28 Teamwork	
T29 Visual management	

2.2.3 Hospital Areas

Among the articles containing implementation studies, the main hospital areas were found according to the authors Mazzocato et al. (2010), D'Andreamatteo et al. (2015), Costa & Godinho Filho (2016), Daultani et al. (2015), Mousavi Isfahani et al. (2019). Mazzocato et al. (2010) listed the 16 main areas and clinical specialties in which Lean was applied. These areas were divided into: "Clinical Specialties"; "Diagnostic Services"; and "Other". Costa & Godinho Filho (2016) present 23 hospital areas by adapting the proposals by Mazzocato *et al.* (2010). In addition to these authors, D'Andreamatteo *et al.* (2015) indicate that the main studies appear in areas such as Surgery and Emergency. Thus, it was not possible to find a consensus for classifying Hospital Areas.

Considering the areas referred above from the several review works, the current study compiles and synthesizes the main areas and fields of study in Lean Healthcare, which are presented in Table 3. The refinement was based on the differentiation between hospital areas and hospital medical specialties. However, as some specialties may use certain areas, it was decided to define more generic areas instead of detailing it by specialty. The reasoning is that there could be duplication of references (in

terms of areas and medical specialties), for example: when an article refers to the "Surgery" specialty, the "Operating Room" area was the classification assigned. Operating Room is also the terminology adopted by Mousavi Isfahani et al. (2019).

Table 3 – List of Hospital Areas

A1	Emergency Department
A2	General (for studies that do not specify the studied area)
A3	General Hospital
A4	General Outpatient Clinic
A5	Hospital Laundry
A6	Information Department
A7	Intensive Care
A8	Laboratory
A9	Mental Health Centre
A10	Nursing Department
A11	Oncology
A12	Operating Room
A13	Pathology
A14	Pharmacy
A15	Primary healthcare
A16	Radiology
A17	Specialties
A18	Sterile Services Department
A19	Support activities

All areas identified in Table 3 were extracted and refined from the selected review works, except the "Primary healthcare" area, which emerged from the analysis of the following two papers: Drotz & Poksinska (2014) and Poksinska, B., Fialkowska-Filipek, M., Engström, J. (2017). These articles refer to case studies related to care centres that provide primary healthcare services in Sweden. Thus, this area was added to the list presented in Table 3.

2.2.4 Improvements and Difficulties

The improvements and difficulties were qualitatively assessed in the selected articles and a list of the main improvements and difficulties (regarding to the scope of the study) was developed. The development of this analysis was made by two researchers, which identified the main improvements and difficulties and reported it as a synthesis of the analysis. This analysis allows Lean Healthcare practitioners and researchers to identify the main risks and plan actions to overcome eventual difficulties. Additionally, practitioners and researchers may become aware of the potentially positive results from the application of Lean Healthcare.

3 General Bibliometrics

This section presents the main results of the analysis regarding the number of published references, grouped by year, by country and by type of research approach used in each study.

Figure 2 presents an updated scenario of the number of journal articles published per year. There is an evolution on the number of publications between the years 2000 and 2015, with a trend to stabilize in the following years. Instead of showing just a 5-year period of publications, this analysis includes all the 245 journal articles found, covering the period from 1994 to 2018, for a broader perspective on the evolution publications per year.

Souza (2009) identified the first publication related to Lean Healthcare as being from 1995. In the current work one publication from 1994 was identified (Pfaff, 1994). This work already referred the

term Lean Production and discussed if it could be considered a model for hospitals. Aligned to the lean principles, it argued that lean at the hospitals should promote the participation of the patients.

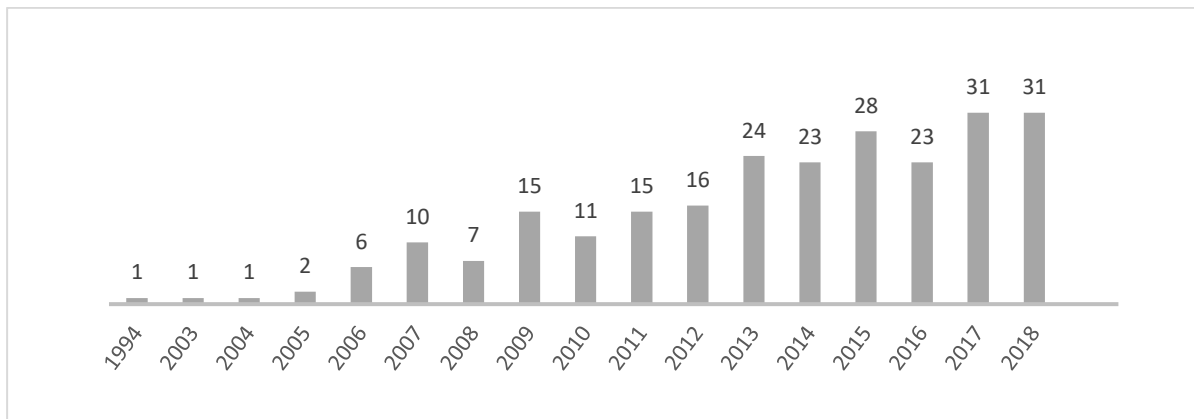


Figure 2. Evolution of the number of publications per year

As a result of his work, Souza (2009) shows that 57% of the analysed articles are originated in the private sector in the USA, 29% in the public sector in the UK, 4% in Australia and 9% in other countries. Costa and Godinho Filho (2016) confirmed that most of the studies are still from authors of the USA and UK, and observed the emergence of a third country, the Netherlands, which stood out in the number of publications in relation to other countries.

Figure 3 reveals the top 15 countries with the higher number of Lean Healthcare articles published in journals, previous from 2019. This result confirms a tendency similar to previous review studies, revealing USA as the top country in Lean Healthcare journal publications per year. UK, Sweden, Australia, Canada and Netherlands also appear, as in previous studies. Notably, in the 5-year period from 2014 to 2018, the countries with a higher number of publications are respectively USA, Italy and Brazil. It should be noted that, in the update provided by this study, other countries (like Italy and Brazil) emerge with a great number of publications occupying the third and sixth places in the ranking, respectively (Figure 3).

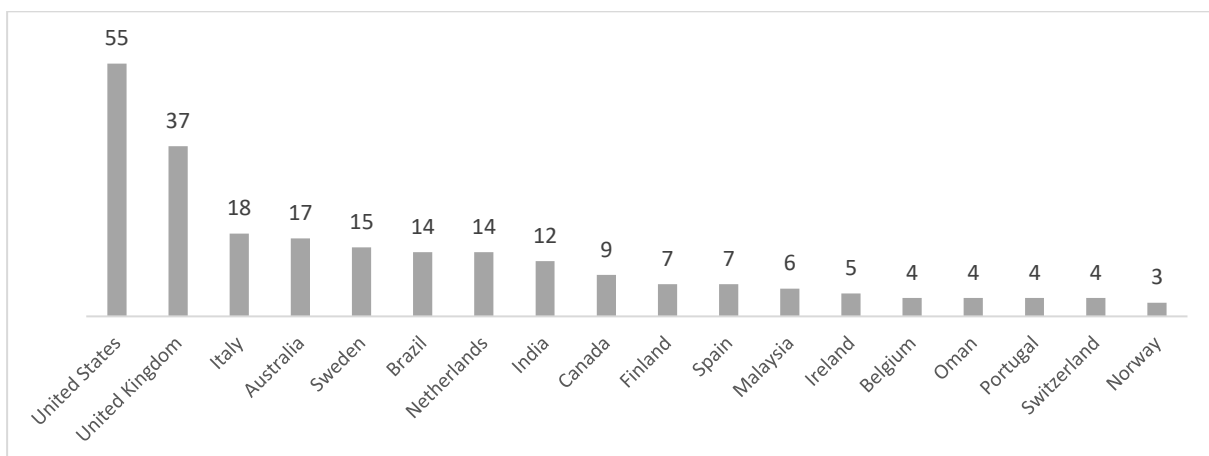


Figure 3 – Number of articles per country

Previous reviews on Lean Healthcare classified the majority of articles as being theoretical, stating that more empirical studies with evidences to the management results are missing (Souza, 2009; D'Andreamatteo et al., 2015). From the 114 articles analysed in detail in the current study, Figure 4 shows that 44 articles were identified as theoretical-conceptual, 12 as surveys, 29 as action-research

and 29 as case study. As case studies and action research works represent in the current study the works reporting implementations, this may indicate an increasing attention to implementation works of Lean in healthcare environments. This is a trend that could not be identified neither from the works of Souza (2009) nor D'Andreamatteo et al. (2015).

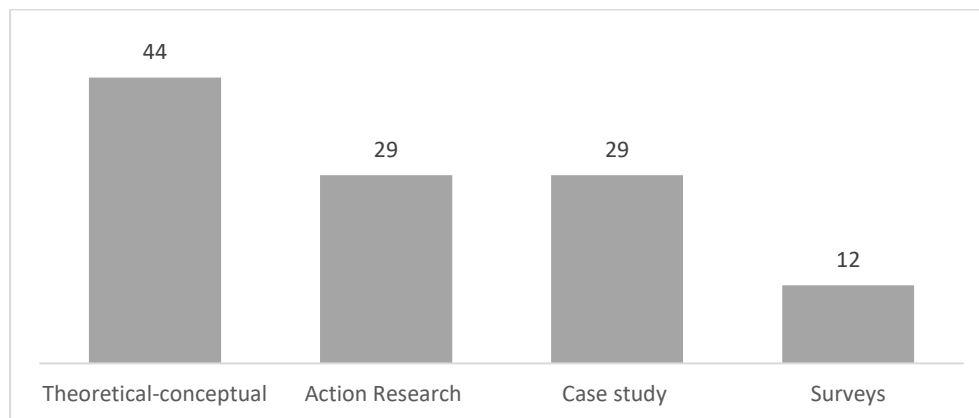


Figure 4 – Number of papers per research approach

4 Tools, Methods and Principles

Régis et al. (2018) evaluated the implementation of Lean Healthcare in three Brazilian hospitals and found similarities between the use of tools and methods, and identified the motivation for the implementations as being derived from strategic planning. The use of methods such as PDCA and DMAIC, value stream mapping and kaizen were found similar in all cases. Mazzocato et al. (2010) present the most frequent methods in their study: process vision; team approach to problem solving and rapid improvement events; visual management; Value Stream Mapping (VSM); and, standard procedures. Costa & Godinho Filho (2016) stated in their study that the most used tools were VSM, Ishikawa Diagrams and the DMAIC method. Daultani et al. (2015) presented the main tools and methods used in studies as being VSM; process mapping and standardization; Kaizen events; root-cause analysis (five Whys, A3 reports, Cause and effect / Fishbone diagram); and 5S applications. In the current study, the Value Stream Mapping, 5S, Standardized Work and Visual Management are the tools identified as the most frequent (Figure 5), corroborating the most used tools cited by previous authors.

According to Henrique et al. (2016) a key tool for lean implementations is Value Stream Mapping (VSM). However, VSM models used in healthcare are simple adaptations of the original manufacturing models and do not always represent important activities regarding the flow of patients. In this context, Henrique et al. (2016) present a new approach to VSM for hospital environments, focusing on activities that directly affect treatment time and, consequently, value-added. As stated by Souza (2009), frequently, studies entitled as “Lean” do not show an appropriate level of systemic view, approaching Lean by the simple application of one or two tools or lean principles.

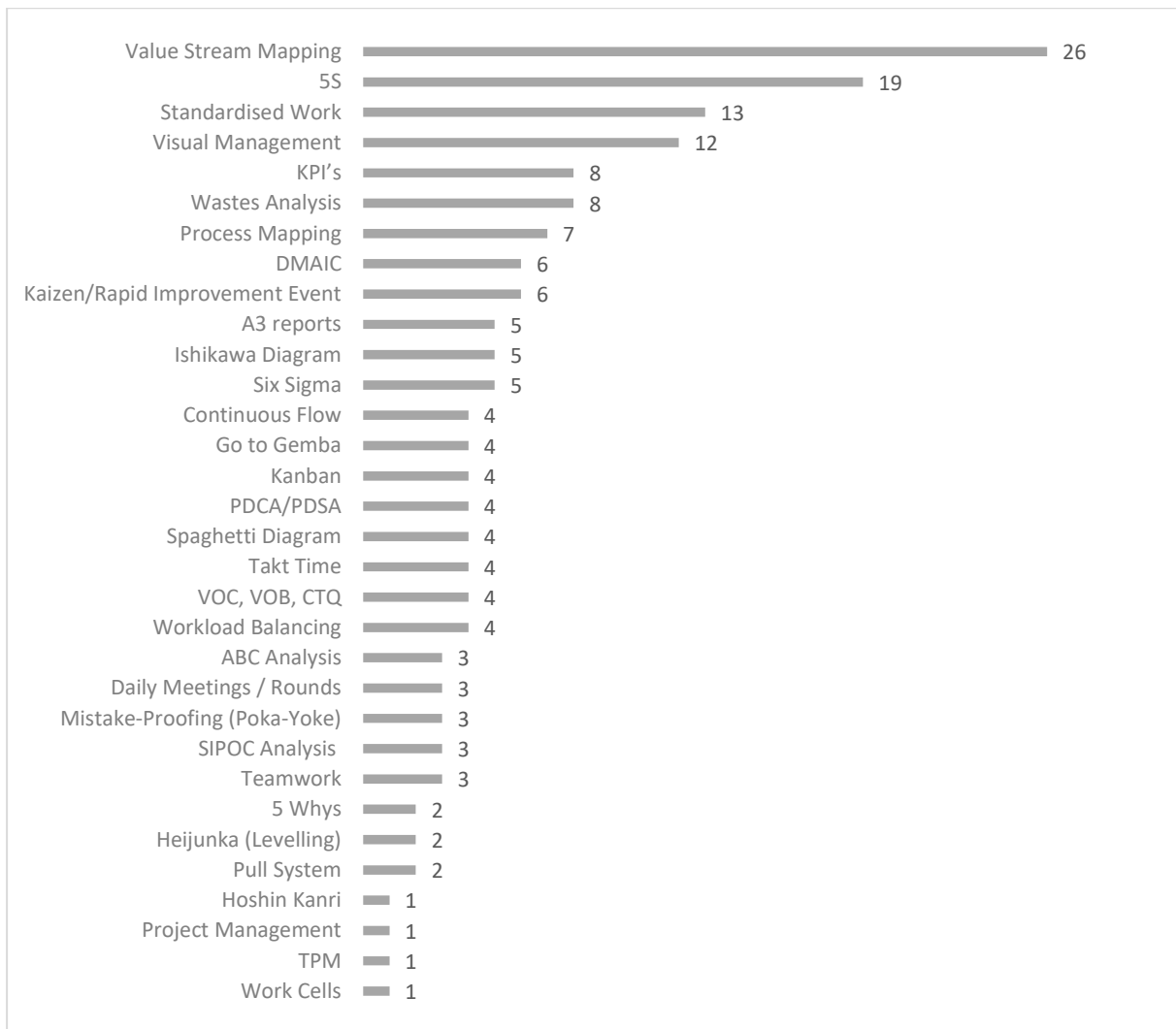


Figure 5 – Tools, Methods and Principles in Lean implementations

In the current study, the tools, methods and principles in Lean Healthcare were categorized (see categories in Table 2), and Figure 6 depicts their compilation and distribution by the defined categories. It is possible to observe that there are much more publications assigned to the categories "Diagnosing and Problem Solving" and "Work Organization and Visual Management", due to the use of the principles, tools, methods and techniques identified in the articles and represented in Figure 5.

The vision of flow encompassed by the "Production Flow" class and the long-term improvement culture represented by the "Continuous Improvement" class appear with fewer publications. It is possible to analyse and speculate, that these results may be justified by the use of tools in an isolated manner rather than in a global approach, in which the focus would be on priority flows and driven by a long-term improvement vision.

One additional discussion that could arise is that most referred lean tools are solutions developed in the context of Toyota plants. The referred lean tools try to materialize the lean or TPS principles and concepts. It could be argued that these lean tools may not be the most appropriate solutions in hospital environments. One type of flow in hospital context that is somehow similar to industry is the flow of materials, such as medicines, medical material, cleaning products, gauze, hygiene products, sheets and towels. The principles of flow and pull flow may be pursued by using similar tools as the ones originated in Toyota plants, however other medical activities and the flow of people may require the development

of specific tools for hospital environments. Value Stream Mapping appears as the most referred tool (Figure 5) and its use is mainly effective in streams of materials, which is a small subset of hospital activities.

The following three items in the list are 5S, Visual Management and Standard Work. The 5S technique is very effective and needed in hospitals since it brings efficiency, safety and quality to the activities in hospitals. Visual management allows transparency and simplifies the management work, contributing for a higher performance. The Standard Work is also an important concept to create consistency and predictability to hospital tasks. Tasks in hospitals are performed by nurses, doctors and other personnel, many times according to their own way of working, allowing different ways of performing the same task and therefore bringing inconsistency in results, time spent and quality.

One recommendation that could be given at this point is that more effort should be applied in continuous improvement integrated systems designed for hospitals, with *Hoshin Kanri* strategic deployment, as proposed by Barnabè & Giorgino (2017). This would seriously change the hospital structure by encouraging everyone to contribute to small improvements every day. These improvements should be focused on how the work could be performed in an easier way with better results for patients and hospital staff.

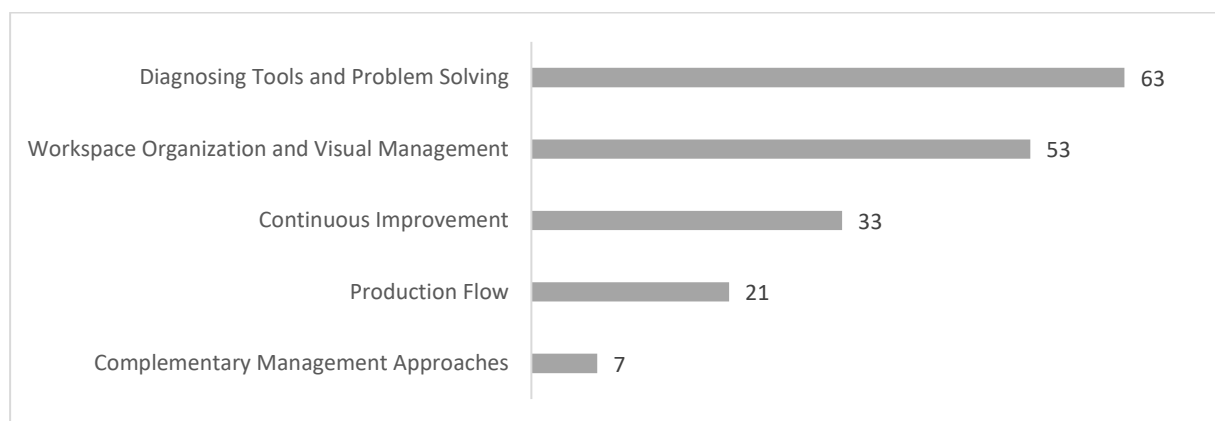


Figure 6 – Categories of Tools, Methods and Principles in Lean implementations

In summary, this way of categorizing the Tools, Methods and Principles presented in Figure 6, allowed to clearly illustrate that much less effort is made in more systemic implementations of lean. Considering that Lean implementations that are focused in the application of tools for improving a subsystem, may, in some cases, “have a negative impact on the wider system” (Papadopoulos, Radnor, & Merali, 2011, p. 171), and as advocated by lean thinking, more effort should be made on studying lean implementations focused in complete process flows, and sustainable systems for continuous improvement.

5 Hospital Areas

Costa & Godinho Filho (2016) and D'Andreamatteo et al. (2015) identified the Emergency Department and Surgical Centre as the main areas of implementation of Lean Healthcare. Daultani et al. (2015) indicate the same areas and added the General Hospital area, as the more frequent areas in the studies. In the current study, as can be seen in Figure 7, general (for areas not specified), general hospital, emergency department, information department, specialties, oncology, operating room and pharmacy were the main areas in terms of Lean implementation. This update confirms some of the

previously identified main areas cited by other authors of reviews and demonstrates two emerging areas related to drug flow (Pharmacy) and the information flow (Information Department). Despite the fact that more areas of the hospital are being referred, this analysis show that studies of the application of Lean in all hospital areas are missing and are required in order to have broader and systemic implementations of lean in hospitals.

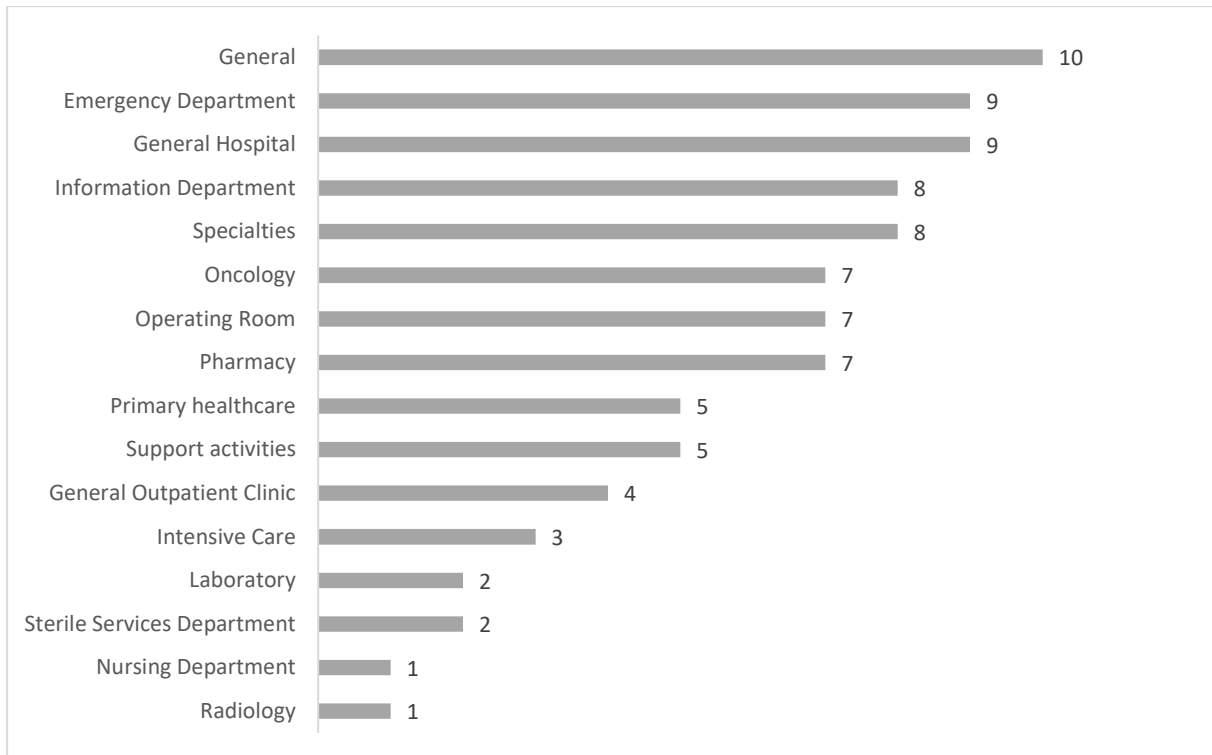


Figure 7 – Lean implementation by Hospital Areas

The pharmacy area has a considerable number of published articles, maybe because it is the area that most closely resembles the Toyota plant activities with the flow of physical materials between stock areas. The tools and knowledge that comes from industry is quite easily applicable in this area because it deals with stock management, material handling and material flow. It should be also noted that the detailed analysis of the 58 articles did not find works related to the following three areas: Hospital Laundry, Mental Health Centre, and Pathology. These three areas, and the ones above with less references (radiology and nursing department) should be object of future implementations in order to extend the knowledge of application of Lean thinking to health organizations.

6 Improvements and Difficulties

D'Andreamatteo et al. (2015) indicate that the main results of Lean Healthcare implementations have positive impact on productivity and cost efficiency. The most common results found in the study performed by Mazzocato et al. (2010) include gains in time and service punctuality, cost reductions or improvements in productivity and quality, as well as processes for reducing errors and defects, improving staff and patient satisfaction. Mousavi Isfahani et al. (2019) analysed 48 articles and their improvements, determining that 69 out of 150 assessed indicators were meaningfully improved.

In the current study, the option was to develop an aggregated analysis, which inform researchers and practitioners about types of improvements and the corresponding published studies. In this way, it would make it possible for them to investigate the works specifically related to their objectives.

Moreover, this approach allows to identify an important part of the overall picture of research in Lean Healthcare.

In the current study, the improvements results are listed below:

I1 - Time gains, reduction of lead time, reduction of patient waiting time, improvement of cycle time, improvement of hospitalization time, reduction of waiting lists - 22 articles.

I2 - Reduction of errors, identification and reduction of waste, reduction of stocks, reorganization of physical space, and reduction of costs - 19 articles.

I3 - Improved organizational culture, increased team spirit and communication, employee and supplier satisfaction, improved workload for nurses, and reduced overtime - 18 articles.

I4 - Efficiency and productivity gains, bottleneck identification, improved patient and information flow, capacity levelling - 17 articles.

I5 - Positive impact on quality and safety indicators, reduced number of complaints, increased customer satisfaction (patient) - 7 articles.

Albliwi et al. (2014) expose some common factors as a threat to Lean application, such as lack of commitment and involvement of management, lack of communication, lack of training of stakeholders, and limited resources. In relation to the difficulties observed in the implementation studies analysed in the current work, it is possible to highlight the following:

D1 - Lack of training of teams linked with scepticism and distrust in lean practices, which may create obstacles to reach sustainable Lean implementations in the long term - 6 articles.

D2 - The focus on the flow and the overall vision of the process is limited, predominating isolated initiatives ("local vision") - 6 articles.

D3 - Low involvement between stakeholders and operational team resulting in demotivation and undesired team performance - 6 articles.

D4 - Difficulty in collecting data and building reliable information - 2 articles.

D5 - Failure of communication between lean professionals and other professionals, especially care professionals (nursing and clinical staff) and traditional managers - 2 articles.

D6 - Excess of bureaucracy in the hospital field due to regulations, protocols and legislation often used ineffectively and as a mean of "blocking" (compromising) lean applications - 1 article.

Previous review works (Mazzocato et al., 2010; D'Andreamatteo et al., 2015) stressed the fact that most of the research developed under this theme report mainly positive results, and failure results could also contribute for the advancement of knowledge. The current review work did not look for failure projects but instead, focused on the identification of difficulties and obstacles reported by published articles. This identification adds a set of categories of difficulties found by researchers when implementing Lean in healthcare environments, which may be of special help for practitioners and researchers when addressing new implementations of Lean or even researching this subtheme.

7 Discussion, Recommendations and Conclusion

The adoption of Lean thinking to the hospital context has transformative potential in the reengineering of health services, focusing on improvements in quality, safety, efficiency and standardization (Kim et al., 2006). Despite the growing academic assessment of Lean Healthcare, there is still a lack of research to explore in detail the implementation of Lean and its interaction with existing care practices (Waring & Bishop, 2010). These authors indicate that the application of Lean in health systems is likely to be a highly contested process, since it is reinterpreted by different actors from a social environment full of conflicts and disagreements, evidencing a traditional management vision.

The current study concludes that there has been an evolution of Lean Healthcare in the last years, but with a trend of stabilization in the publications. The United States, Italy and Brazil are the countries with the highest number of journal publications in the 2014-2018 period. In terms of tools, methods and principles, Value Stream Mapping, 5S, Visual Management and Standardized Work appear as the most used, which may reveal non-systemic approaches for lean development and application. Thus, one of the most important conclusions that can be drawn from this study is that in most cases the introduction of lean thinking in hospitals is performed through the application of lean tools, in specific areas with little structural changes in hospitals' management and organization structure.

Considering the hospital areas with high number of works reported in previous review studies, there is still a tendency to develop works in Emergency Department and Surgical Centre. Nevertheless, in contrast with other studies, the current work found a new trend of ascending number of works related to the Information Departments and Pharmacy. Another trend identified by this study is the lack of studies related with Hospital Laundry, Mental Health Centre, Pathology, Radiology and Nursing department.

One important conclusion that can be drawn is that unfortunately, very few or non-existing works were published reporting some of the most critical factors contributing to the success of Lean implementations. These factors are related to the invisible part of Lean as called by Rother (2010) and as the Key Behavioural Indicators or the social science side of lean as mentioned in the Shingo Model (Miller, 2018). Those are the same critical factors that are missing in most lean implementation failures. The missing factors are some of the key principles of the Shingo Model (Shingo Institute, 2019) and the Toyota Way (Krijnen, 2007). Regarding the Enterprise Alignment (from Shingo Model) and "Long-term philosophy" (from Toyota Way) only one publication was found referring *Hoshin Kanri* strategic deployment. Moreover the focus on patients is not properly addressed in terms of value added, which is related to the "Create Value for the Customer" Shingo principle and the first principle of Lean thinking. Also missing from the large majority of the work published is the reference to the Cultural Enablers "Respect Every Individual" and "Lead with Humility" (from Shingo Model) and "Add Value to the Organization by Developing Your People" group of principles (from Toyota Way). Those aspects are so important that they were already referred by Sugimori et al. (1977) as "treat the workers with respect as human beings and with consideration" as being one of the two TPS basic concepts. In the publications considered in this literature review there is a lack of works focusing on motivation and work satisfaction, which is not properly addressed when referring to hospital staff (e.g. nurses, doctors, support personal, managers, administrative personal and technicians). In summary, the Continuous Improvement set of principles still seems to be poorly understood in most lean implementations in hospitals. Although the Toyota Way principle "Go and see for yourself to thoroughly understand the

situation” is referred frequently, another principle of the same group of principles “Become a learning organization through relentless reflection (hansei) and continuous improvement” is missing. Most published work reports improvements and problem solving but the sustainability of the continuous improvement system is seldom addressed.

With regard to main improvement results reported, lead time improvement, increased productivity and efficiency, waste reduction, improved team spirit, and quality assurance demonstrate alignment with the principles and foundations of lean philosophy, but such results are presented in isolated initiatives and without robust evidence of long-term maintenance. Among the difficulties encountered, the lack of communication between the multidisciplinary teams, the low involvement of the management staff and the high bureaucracy in the hospital field emerged as frequent difficulties, which may explain the lack of works related to cultural change factors referred above. Moreover, another important difficulty identified in the current work, is the difficulty in collecting data and the lack of communication between teams, which opens an excellent opportunity to apply current trends of data analytics and business intelligence in selection, processing and driving that data into the teams and other stakeholders, in ways meaningful for them. This seems to be a potential opportunity to improve the impact of lean implementations in the future, simultaneously bridging gaps between different stakeholders.

Souza (2009) stated that Lean healthcare was still at an early stage of development when compared to the implementation of lean principles in the automotive industry, and the review presented in this study shows an evolution of the implementations, but still with a small number of publications, which report isolated applications in different hospital areas, and are developed locally instead of globally. Other authors suggested that Lean should be developed holistically in healthcare (Matthias & Brown, 2016; Mazzocato et al., 2010) exploring creativity and innovation-related approaches (Hoerl & Gardner, 2010). Thus, as future recommendations for studies, it would be important to develop works related to different dimensions and type of hospitals in different world regions, as these characteristics may affect the nature of the process and the demand for health care, thus guiding different approaches for continuous and sustained improvement interventions. In addition, it is recommended to develop applied studies on end-to-end (global) flows rather than isolated initiatives, bringing more robustness and proof of lean results.

Based on what is published about lean implementation in hospitals, one additional recommendation to be made is that hospitals should be culturally reshaped through structural changes, following new visions and strategic goals, supported by real models of structural and sustained continuous improvement. The structure could be based on teamwork, with daily improvement, targeting specific objectives aligned with the appropriate strategic vision of top management. Senior management's vision should emphasize value addition from the patient's point of view and clearly emphasize worker motivation and well-being. The proper focus on the value added to patients and the well-being improvements among hospital workers, created by a well-designed sustainable continuous improvement system, would certainly represent an enormous contribution to society.

Acknowledgments

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Appendix – List of 114 articles

Article	Methodology	Areas	Tools	Improvements	Difficulties
(Aleem, Torrey, Duncan, Hort, & Mecchella, 2015)	AR	A15	T33; T12; T44; T36	I4	D1;D3
(Andersen & Røvik, 2015)	CS	A19;A3	N/A	N/A	D1
(Bal, Ceylan, & Taçoğlu, 2017)	AR	A1	T41; T29; T9	I3; I4	D6
(Barnabè & Giorgino, 2017)	AR	A2	T17; T14	N/A	N/A
(Barnabè, Giorgino, Guercini, Bianciardi, & Mezzatesta, 2017)	CS	A3	T41;T30	I3	N/A
(Barnabè, Giorgino, Guercini, Bianciardi, & Mezzatesta, 2018)	CS	A2;A6	T41;T30; T29; T33; T15; T31; T24; T39; T8	I4;I5	N/A
(Bittencourt, Verter, & Yalovsky, 2017)	AR	A3;A6	T17	N/A	N/A
(Blouin-Delisle et al., 2018)	AR	A12	T41; T15; T4; T12; T44; T6	I1	D2;D4
(Boronat, Budia, Broseta, Ruiz-Cerdá, & Vivas-Consuelo, 2018)	AR	A17	T18; T17; T45; T11	I3;I5	N/A
(Chaurasia, Garg, & Agarwal, 2017)	AR	A11	T41; T33; T19; T18; T36; T38	I1;I2	N/A
(Cheng, Bamford, Papalexi, & Dehe, 2015)	AR	A6	T41; T38	I1;I3	D4
(Clark, Moller, & O'Brien, 2014)	CS	A10	N/A	I3;I4	N/A
(Collén, Gremyr, Hellström, & Sporraeus, 2017)	CS	A17	N/A	N/A	N/A
(Costa, Filho, Rentes, Bertani, & Mardegan, 2017)	CS	A11;A12;A14;A18	T41; T15; T31; T12; T39	I1;I2;I4	D1;D3
(Dannapfel, Poksinska, & Thomas, 2014)	CS	A2;A11	T29; T27; T42; T17; T10	N/A	N/A
(Delisle & Freiberg, 2014)	AR	A19	T30; T29 T27; T19; T36; T38; T17	I1;I4	N/A
(Drotz & Poksinska, 2014)	CS	A3;A15;A17	T30; T29; T27; T1; T22	I3	N/A
(Efe & Efe, 2016)	AR	A1		N/A	N/A
(Eiro & Torres-Junior, 2015)	CS	A3;A11	T30; T15; T31; T18; T32	N/A	N/A
(Fisher, Ding, Hochheiser, & Douglas, 2016)	AR	A14;	T41	I2;I3	N/A
(Godinho Filho, Boschi, Rentes, Thurer, & Bertani, 2015)	AR	A12	T41;T30; T29; T27; T15; T4; T1; T2; T6; T10	N/A	N/A
(Gupta, Kapil, & Sharma, 2018)	AR	A8	T41; T13	I1;I2;I4	D2
(Haddad, Zouein, Salem, & Otayek, 2016)	CS	A6	T41;T30; T27; T24; T39	I1	N/A
(Halm et al., 2018)	AR	A2	T13	I1;I4	D2
(Henrique, Rentes, Filho, & Esposto, 2016)	AR	A6;A8;A12; A15;A19	T41	N/A	N/A
(Hutton, Vance, Burgard, Grace, & Van Male, 2018)	AR	A3	T27; T19; T36; T11	I1;I2;I4;	N/A
(Hwang, Hwang, & Hong, 2014)	CS	A2;A6;A17	T42; T29; T28; T20	N/A	N/A
(Improta et al., 2018)	AR	A1	T41;T30; T27; T1; T8	I1;I3	N/A
(Lot et al., 2018)	AR	A4	T41; T29; T13; T4; T31; T30	I2;I3;I5	N/A
(Mannon, 2014)	CS	A2;A3;	T29; T27; T13	I1	N/A
(Matt, Rauch, & Franzellin, 2015)	AR	A2	N/A	I2;I3;I5	D3
(Mehdi & Al Bahrani, 2017)	CS	A11	T39; T8; T17	I1;I2;I3;I4	N/A
(Miller & Chalapati, 2015)	CS	A4	T41; T30	I3	D1;D3
(Nanda, Rybkowski, Pati, & Nejadi, 2017)	CS	A3	T31; T22	N/A	N/A
(Narayanamurthy, Gurumurthy, & Lankayil, 2018)	CS	A4;A14	T33; T2; T32; T49; T10	N/A	N/A
(Nayar, Ojha, Fetrick, & Nguyen, 2016)	AR	A2	T12; T44; T36	I3;I4	D5
(P. Simons et al., 2017)	CS	A11	T41;T30; T22; T17	N/A	N/A
(Pineda Dávila & Tinoco González, 2015)	AR	A7	T30; T4; T42	I1;I2;I4;I5	N/A
(Poksinska, Fialkowska-Filipek, & Engström, 2017)	CS	A15	T41;T30; T27	I2	D2
(Rees, 2014)	CS	A1	T41;T30; T18	I1;I3	N/A
(Regattieri, Bartolini, Cima, Fanti, & Lauritano, 2018)	AR	A14	T29; T32	I2;I4	D5
(Régis, Gohr, & Santos, 2018)	CS	A11;A6;A14 ;A16	T41;T30; T29; T27; T15; T10	I2;I4	N/A
(Reijula, Karvonen, Petäjä, Reijula, & Lehtonen, 2016)	AR	A17;A19	T19; T42	I1	D3
(Ruohoaho et al., 2018)	AR	A12;A17	T41	I2	N/A
(Salam & Khan, 2016)	CS	A15	T41; T33; T24; T42; T36	I1;I2;I3;I4;I5	N/A
(Sánchez, Suárez, Asenjo, & Bragulat, 2018)	AR	A1	T41;T30; T27; T42	N/A	N/A
(Shakoore, Abu Jadayil, Jaber, & Jaber, 2017)	CS	A1	T8	N/A	N/A
(Steere, Rousseau, & Durland, 2018)	AR	A14	T12; T44; T42	N/A	N/A
(Tay, Singh, Bhakoo, & Al-Balushi, 2017)	CS	A6;A11; A12;A14	T41; T42; T36	I1;I2;I4;I5	D1;D2
(Tejedor-Panchón et al., 2014)	AR	A1	T41	I1	N/A
(Tortorella et al., 2017)	AR	A18	T41; T13; T1	N/A	N/A
(Trzeciak et al., 2018)	AR	A7	T12; T42	I2	N/A
(Ulhassan, Von Thiele Schwarz, Westerlund, Sandahl, & Thor, 2015)	CS	A1;A17	T29	N/A	N/A
(Kanamori et al., 2015)	CS	A2	T20	I1	N/A

(Holden, Eriksson, Andreasson, Williamsson, & Dellve, 2015)	CS	A1;A7;A12	T44	I1;I2;I3;I4	D2
(Reijula, Reijula, & Reijula, 2016)	CS	A3	T20	I1;I2	N/A
(Van Leijen-Zeelenberg et al., 2016)	CS	A4	T42	I3	D1;D3
(Fournier & Jobin, 2018)	CS	A2	N/A	I1;I2;I3	N/A
(Aij & Teunissen, 2017)	TC	-	-	-	-
(Aij, Aernoudts, & Joosten, 2015)	TC	-	-	-	-
(Al Farsi, Al Abri, Al Hajri, & Al Balushi, 2014)	TC	-	-	-	-
(Al-Balushi et al., 2014)	TC	-	-	-	-
(Alshahrani, Rahman, & Chan, 2018)	S	-	-	-	-
(Andersen, Røvik, & Ingebrigtsen, 2014)	TC	-	-	-	-
(Anuar & Sadek, 2018)	TC	-	-	-	-
(Anuar, Saad, & Yusoff, 2018)	TC	-	-	-	-
(Booker, Turbutt, & Fox, 2016)	TC	-	-	-	-
(Bruno, 2017)	TC	-	-	-	-
(Chakraborty & Gonzalez, 2018)	TC	-	-	-	-
(Costa & Godinho Filho, 2016)	TC	-	-	-	-
(Crema & Verbano, 2015)	TC	-	-	-	-
(Crema & Verbano, 2017)	TC	-	-	-	-
(D'Andreamatteo, Ianni, Lega, & Sargiacomo, 2015)	TC	-	-	-	-
(Daultani, Chaudhuri, & Kumar, 2015)	TC	-	-	-	-
(DiGioia, Greenhouse, Chermak, & Hayden, 2015)	TC	-	-	-	-
(Ferreira, Silva, Costa, & Pádua, 2018)	TC	-	-	-	-
(Filsler, da Silva, & de Oliveira, 2017)	TC	-	-	-	-
(Gershengorn, Kocher, & Factor, 2014)	TC	-	-	-	-
(Habidin et al., 2015)	TC	-	-	-	-
(Habidin, 2017)	S	-	-	-	-
(Habidin, Shazali, Ali, Khaidir, & Jamaludin, 2014)	S	-	-	-	-
(Hallam & Contreras, 2018)	TC	-	-	-	-
(Jiang & Malkin, 2016)	S	-	-	-	-
(Jorma, Tiirinki, Bloigu, & Turkki, 2016)	TC	-	-	-	-
(Kahm & Ingelsson, 2017)	S	-	-	-	-
(Kasivisvanathan & Chekairi, 2014)	TC	-	-	-	-
(Knapp, 2015)	S	-	-	-	-
(Kovacevic, Jovicic, DJapan, & Zivanovic-Macuzic, 2016)	TC	-	-	-	-
(Li & Johnson, 2015)	TC	-	-	-	-
(M. White & Waldron, 2014)	TC	-	-	-	-
(M. White, Butterworth, & Wells, 2017)	S	-	-	-	-
(M. White, Wells, & Butterworth, 2014)	TC	-	-	-	-
(Maijala, Eloranta, Reunanen, & Ikonen, 2018)	TC	-	-	-	-
(Mark White, Wells, & Butterworth, 2014)	S	-	-	-	-
(McCann, Hassard, Granter, & Hyde, 2015)	TC	-	-	-	-
(Moraros, Lemstra, & Nwankwo, 2016)	TC	-	-	-	-
(Narayanamurthy & Gurumurthy, 2018)	TC	-	-	-	-
(P. A. Simons, Benders, Marneffe, Pijls-Johannesma, & Vandijck, 2015)	TC	-	-	-	-
(Patri & Suresh, 2018)	TC	-	-	-	-
(Ponanake, Limnarat, Pithuncharurnlap, & Sangmanee, 2014)	TC	-	-	-	-
(Rees & Gauld, 2017)	TC	-	-	-	-
(Rewa, Mottes, & Bagshaw, 2015)	TC	-	-	-	-
(Richards & Mellott, 2014)	TC	-	-	-	-
(Romano, Guizzi, & Chiocca, 2015)	TC	-	-	-	-
(Sarantopoulos, Spagnol, Newbold, & Li, 2017)	TC	-	-	-	-
(Schonberger, 2018)	TC	-	-	-	-
(Stelson, Hille, Eseonu, & Doolen, 2017)	S	-	-	-	-
(Swartz, Davis, & Graban, 2015)	TC	-	-	-	-
(Terra & Berssaneti, 2018)	TC	-	-	-	-
(van Rossum, Aij, Simons, van der Eng, & ten Have, 2016)	S	-	-	-	-
(Vavrušová, 2015)	S	-	-	-	-
(Vitásková, 2015)	S	-	-	-	-
(Williams & Radnor, 2018)	TC	-	-	-	-
(Yaduvanshi & Sharma, 2017)	TC	-	-	-	-

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