# DMAIC in improving patient care processes: evaluation based on a systematic review from the perspective of Lean Six *Sigma* in healthcare

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**Abstract**

DMAIC is a Six *Sigma* methodological framework that has attracted the attention of researchers in the field of health (REIS *et al.*, 2021). It is noticed that DMAIC has been used in several processes in health services, such as dispensing medication, hospital discharge and patient admission. Lean Six *Sigma*, based on the association of DMAIC with lean, brought important and valuable results in the context of health care, such as reducing the length of stay (LOS) in services, increasing patient satisfaction and reducing employee satisfaction. This study aims to evaluate how Lean Six *Sigma*/DMAIC has been implemented in the health area and its impacts on patient health care processes.

**Keywords:** Total quality management; Delivery of health care; Process assessment in health care; Quality improvement.

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# DMAIC na melhoria dos processos de atendimento ao paciente: avaliação com base em uma revisão sistemática sob a perspectiva do *Lean Six Sigma* na área da saúde


**Resumo**

O DMAIC é uma estrutura metodológica do Seis *Sigma* que tem atraído a atenção de pesquisadores na área da Saúde (REIS *et al.*, 2021). Percebe-se que o DMAIC tem sido utilizado em diversos processos nos serviços de saúde como dispensação de medicamentos, alta hospitalar e admissão de pacientes. O *Lean Six Sigma*, baseado na associação do DMAIC com o *lean*, trouxe resultados importantes e valiosos no contexto da assistência à saúde, como redução do tempo de permanência (LOS) nos serviços, aumento da satisfação do paciente e redução da satisfação dos funcionários. Este estudo tem como objetivo avaliar como o *Lean* Seis *Sigma*/DMAIC vem sendo implementado na área da saúde e seus impactos nos processos de atendimento à saúde do paciente.



**Palavras-chave**: Gestão de qualidade total; Assistência à saúde; Avaliação de processos em cuidados de saúde; Melhoria de qualidade.


# DMAIC en la mejora de procesos de atención al paciente: evaluación basada en una revisión sistemática desde la perspectiva de *Lean Six Sigma* en el cuidado de la salud


**Resumen**

DMAIC es un marco metodológico *Six Sigma* que ha llamado la atención de investigadores en el campo de la Salud (REIS *et al.*, 2021). Se nota que DMAIC ha sido utilizado en varios procesos en los servicios de salud, como la dispensación de medicamentos, alta hospitalaria y admisión de pacientes. *Lean Six Sigma*, basado en la asociación de DMAIC con *lean*, trajo resultados importantes y valiosos en el contexto de la atención de la salud, como la reducción de la duración de la estadía (LOS) en los servicios, el aumento de la satisfacción del paciente y la reducción de la satisfacción de los empleados. Este estudio tiene como objetivo evaluar cómo se ha implementado *Lean Six Sigma*/DMAIC en el área de la salud y sus impactos en los procesos de atención a la salud de los pacientes.



**Palabras clave**: Gestión de la calidad total; Atención a la salud; Evaluación de procesos de atención de salud; Mejoramiento de la calidad.

## Introduction

Healthcare is a field where "amazing advances in technology and treatment, but is often burdened by inefficiencies, errors, resource constraints and other problems that threaten accessibility and safety of patient care" (TANER; SEZEN; ANTONY, 2007, p. 329). Regarding emergency departments (EDs), Ahsan *et al.* (2019) consider that they have become increasingly congested due, among other factors, to the growing demand, which adversely affects the performance of health services.

Healthcare organizations, as companies in other knowledge areas, do not use all available working time efficiently with an excessive amount of time being spent on non-value-added activities (BLACK; MILLER, 2016).

Santos *et al.* (2021) highlighted the importance of creating a system that involves the continuous improvement cycle in organizations based on the Lean Healthcare approach. According to Santos *et al.* (2021, p. 887), together with the observance of strategic aspects and the "appropriate choice of application of lean tools and methods", significant improvements in production processes can occur.

In this sense, the present study seeks to evaluate the implementation of Lean *Sigma* based on DMAIC in healthcare organizations based on scientific production, evidencing related experiences through a systematic literature review.

This article is structured in these sections: introduction that highlights the background, conceptual basis where concepts involving Lean, Six *Sigma*, Lean Six *Sigma* and DMAIC are presented. Next, the objectives of the study are presented, as well as the research questions and the guide used to develop the research method with presentation of how to conduct the systematic literature review and the categorization of studies. Finally, the results are discussed focusing on the processes, methods/techniques/tools and measures (pre and post implantation scenario) of the studies analyzed and the conclusions of this article are exposed.

## Conceptual basis

### *Lean interventions*

Lean production "significantly altered trade-offs between productivity and quality, but also led to rethinking a wide range of manufacturing and service operations beyond the high-volume repetitive manufacturing environment" (HOLWEG, 2007, p. 420). The Lean Methodology (Lean Methodology) focuses on "elimination waste" (CHEUNG; GOODMAN; OSUNKOYA, 2016, p. 857). In the lean methodology, the use for any purpose other than the creation of value is a waste and must be eliminated (CHAVES *et al*., 2021; LINDEN; UFFORD; LINDEN, 2019).

Al-Araidah *et al*. (2010, p. 59) stressed that "eliminating, combining or simplifying steps reduces process cycle time," which increases the time available for patient care, quality improvement and cost reduction. According to Al-Araidah *et al*. (2010, p. 59), lean in the context of healthcare, "enables to improve patient care by eliminating activities that do not add value and that compromise efficient treatments" and allows to "reduce waits" as well as "accelerate processes".

Cheung, Goodman and Osunkoya (2016, p. 857) stated that "lean tools include workplace organization, identification of wastes in workflow and use of visual controls". The Value Stream Map (VSM), a lean tool, provides the "connection between work, performance data and information flow" and contains the "key steps of a process" (CHEUNG; GOODMAN; OSUNKOYA, 2016, p. 862). Through the map, you can visualize elements that add value and elements that evidence waste, as well as activities that add value and others that are necessary but do not add value. Waste elimination (mute) and value creation are key factors of lean.

The challenge we face is not simply directing executives and managers to implement new production or management techniques, or adopt new principles, but to achieve continual systematic evolution and improvement throughout the organization. This entails the development of repeatedly and consistently applied behavioral routines known as '*Kata*' (SANTOS *et al.*, 2021).

***Six Sigma***

*Sigma*, or standard deviation, represents "a statistical measure of variation" (ARAMAN; SALEH, 2023, p. 338). *Sigma* is represented by a letter of the Greek alphabet that is used to indicate the "amount of variability in a process under analysis" (MOUSLI *et al.*, 2023). Islam (2006, p. 16) highlight that "the more variation there is, the bigger the standard deviation is".

Every process has critical characteristics for quality (CTQ's – critical to quality) that must remain within an established tolerance zone in order to reach the goal (CHIARINI, 2012). Goh *et al.* (2006, p. 236) stated that, when using Six *Sigma* to improve processes, what is sought is "to offer what customers want", which is the basis of CTQ. In this sense, the focus on the customer is crucial for the success of a process (GOH *et al*., 2006). For Taner, Sezen and Antony (2007), the CTQ's in the health context are the attributes that are considered of great value to the patient. The CTQ's deviation is measured by the "*sigma*" (standard deviation) (CHIARINI, 2012), representing the degree of deviation from the mean in a normal curve.

Six *Sigma* is a "methodology for quality improvement" (GOH; XIE, 2003, p. 587). The selection of the Six *Sigma* process for improvement should go through the analysis of what is critical to the success of the organization (DREACHSLIN; LEE, 2007). The "difference investigated with Six *Sigma*, compared with other methods, is the inclusion of statistics to analyze the data" (IMPROTA *et al*., 2017, p. 2). Chiarini (2012, p. 7) argued that "every process ideally has a goal" and is "subject to variability", which subjects it to "moving away from its goal" (CHIARINI, 2012, p. 8).

Pande, Neuman and Cavanagh (2002) stated that "there will always be some variation in a process: the central question is whether this variation means that its services and products fit or not within the requirements of customers". The variation, in the context of healthcare, means what the "patient sees and feels" (TANER; SEZEN; ANTONY, 2007, p. 333). According to Araman and Saleh (2023, p. 338), "*sigma* can be thought of as a comparison of expected results in a group of procedures, against those that were not successful".

Six *Sigma* translates the variation into a measure that allows you to see whether "a product or service meets the customer's requirements or not" (PANDE; NEUMAN; CAVANAGH, 2002, p. 6) and if it does not, it is called a defect. Dreachslin and Lee (2007, p. 364) revealed that in the health context, "any defect in this customer-seen service process leads to dissatisfaction [which leads to the conclusion that] the consumer's view is critical to success". Pande, Neuman and Cavanagh (2002, p. 4) considers that "the purpose of Six *Sigma* is to reduce variation to obtain very small standard deviations so that almost all of its products or services meet or exceed customer expectations".

The *sigma* level is linked to the number of defects: "the fewer defects, the higher the *sigma* level and the better the quality" (ISLAM, 2006, p. 16). The term *sigma* is a reference to a particular objective of reducing defect to close to 0" (PANDE; NEUMAN; CAVANAGH, 2002, p. 4). The performance of a process can be measured by the *sigma* level (PYZDEK; KELLER, 2010). Mahanti and Antony (2005, p. 741) consider that "*sigma* level of process/product is a business metric used to indicate the performance of a process/product relative to specification".

Often, Six *Sigma* "is presented and developed in the DPMO metric, that is, defects per million opportunities" (GOH; XIE, 2003, p. 587). As one of the approaches used for the *sigma* level, the comparison between the number of defects and the number of opportunities that, in a product or service, something did not go as expected is expected (PANDE; NEUMAN; CAVANAGH, 2002). Pyzdek and Keller (2010) sustained that this standard represents a "response to increased customer expectations and the increased complexity of modern processes and products".

Mahanti and Antony (2005, p. 625) cited that "Six *Sigma* aims at achieving 3.4 defects per million opportunities with an assumption that the process mean shifts by 1.5 standard deviation off the target value". For a process to find the quality Six *Sigma*, cannot produce more than 3.4 defects per million opportunities (CHEUNG; GOODMAN; OSUNKOYA, 2016) and if this occurs, the process is considered capable (GEORGE, 2003).

Six *Sigma* is an approach that aims to improve "an organization's products, services and processes" by continually reducing defects in the organization (KWAK; ANBARI, 2006, p. 708). By default, defect is "something that does not meet consumer requirements" (PANDE; NEUMAN; CAVANAGH, 2002, p. 6). For Dreachslin and Lee (2007, p. 363), in-service companies, represents "a defect in any transaction, service meeting, action, or procedure that does not meet customer expectations." Six *Sigma* aims to "make the process 99.99996% defect-free" (COUGHLIN; POSENCHEG, 2019, p. 1002).

Taner, Sezen and Antony (2007, p. 329) considered that "delays, measurement and medical errors and variability often compromise the provision of safe and effective patient care" and that it is "possible to minimize them by applying Six *Sigma*". Six *Sigma* has been used to reduce time, costs and errors (NIÑEROLA; SÁNCHEZ-REBULL; HERNÁNDEZ-LARA, 2020). Taner, Sezen and Antony (2007) believe that Six *Sigma* can be perceived as a strategy that enables the health sector to provide a service of excellence to patients.

Six *Sigma* and lean are complementary, as both use "data collection and analysis to improve performance" and focus on "eliminating waste and redundancy in operational processes" (DELLIFRAINE; LANGABEER II; NEMBHARD, 2010, p. 214). Snee (2010, p. 10-11) stressed that "processes do not improve by themselves". Raval, Kant, Shankar (2018, p. 413-414) considered that the purpose of using Six *Sigma* lies in "process improvement"; while, in lean, "the focus is on process flow and speed, reducing or removing waste". When used together, the methodology is renamed Lean Six *Sigma* (LSS).

Pereira *et al.* (2022) warn about incidents of non-sequential values recorded on the timeline, highlighting the need to ensure standardized and consistent data collection according to the defined method. This aspect underscores the significance of Lean Six *Sigma* aligned with the DMAIC framework in driving improvements in healthcare processes.

"Lean Six *Sigma* is necessary because organizations and individuals need a methodology for improvement and problem solving" (SNEE, 2010 p. 10). Sunder and Ganesh (2020, p. 93) assessed that "LSS is not merely a combination of Lean and Six *Sigma*", as it enables "transformational change in organizations".

Lean Six *Sigma* proposes in a structured way the achievement of "process efficiency and customer satisfaction by reducing waste and variation" (CHEUNG; GOODMAN; OSUNKOYA, 2016, p. 857). Stamatis (2011, p. 213) stated that "Lean Six *Sigma* incorporates Six *Sigma's* organizational infrastructure and complete diagnostic and analysis tools with lean analysis tools and best practice solutions for problems that deal with unnecessary waste and time consumption".

In the literature, Lean Six *Sigma* methodology is also named Lean *Sigma*, Lean Six *Sigma* DMAIC and LSS DMAIC. DMAIC refers to the five steps of the Lean Six *Sigma* methodology and is similar to the PDCA cycle (Plan-Do-Check-Act) (IMPROTA *et al*., 2017). The initials of the expression Define, Measure, Analyze, Improve and Control, form the term DMAIC.

DMAIC incorporates a clear framework for problem solving into Six *Sigma* (GOH *et al*., 2006, p. 237). It represents a framework used by Six *Sigma* to reduce process variability based on statistics (DELLIFRAINE; LANGABEER II; NEMBHARD, 2010; TLAPA *et al.*, 2020). DMAIC can be considered as a continuous improvement methodology, being considered "a key methodology used in Six *Sigma* projects", which can be used to improve, optimize and reorganize processes" (HENRIQUE; GODINHO FILHO, 2018, p. 14).

In general terms, in each phase of the DMAIC the following activities must be carried out (MITTAL *et al.*, 2023):

- Phase 1 - Define: define the problem and goal of the project.
- Phase 2 - Measure: to examine the current *status* of the problem.
- Phase 3 - Analyze: analyze the current situation and find out the solution to achieve the goal.

- Phase 4 - Improve: implementation of the solution to achieve the goal.
- Phase 5 - Control: make sure that permanent improvement takes place.

Cudney, Furterer and Dietrich (2013, p. 11) stated that "the phases of DMAIC are well defined, but the steps performed in each phase can vary". The execution of DMAIC phases allows improving the quality of all processes at the project level or globally in the organization (NIÑEROLA; SÁNCHEZ-REBULL; HERNÁNDEZ-LARA, 2020).

Uluskan (2016) stressed that during training for future Six *Sigma* practitioners, "systematic classification schemes" should be presented to assist them so that they can know which tools to use in the face of a range of tools available and the relationship between them so that they can implement Six *Sigma*. It is worth noting that there is no standard structure for Lean Six *Sigma*.

Cudney, Furterer and Dietrich (2013) and Antony *et al.* (2018) cited the most common tools used when applying the DMAIC phases. The most relevant techniques to be used during the Phases of DMAIC are process maps and diagrams, cause and effect diagrams and Pareto, techniques of analysis of modes and effects of failure (FMEA), and statistical data analysis (NIÑEROLA; SÁNCHEZ-REBULL; HERNÁNDEZ-LARA, 2020). Prashar (2015) reported that the tools perception analysis, inter-relationship diagram, and Research in *Gemba* (represent an innovation in terms of use when implementing DMAIC). The latter is also known as *Gemba* Walk (*Genchi Genbutsu*).

Despite the existence of "various classification schemes available in the literature" such as those that associate tools with the Phases of DMAIC, "other tool classification schemes that are based on functionality or basic characteristics are needed to better assist practitioners during their Six *Sigma* projects" (ULUSKAN, 2016, p. 414).

Ahmed (2019, p. 1) stated that the "application of DMAIC in a healthcare organization provides a guide on how to maintain a service quality system through patient satisfaction" and "makes it possible to reduce waste, variation and imbalance in work".

Tufail *et al.* (2021) analyzed the implementation of Lean Six *Sigma* during Covid-19 in a hospital in Pakistan after a month of the implementation. The objective of the implementation was to improve the quality of the processes with a view to a month in the period of passive immunization at hospital. VOC, SIPOC, Ishikawa Diagram, Kano Model were used through DMAIC.

Scala *et al*. (2021) reported that the Lean Six *Sigma* DMAIC cycle was adopted in an Italian university hospital to evaluate the effectiveness of DTAP (diagnostic-therapeutic assistance pathway) in order to accelerate the surgical process of the femur. The Ishikawa Diagram, SIPOC and CTQ tools were used in the implementation. A 39% reduction in LoS occurred in the average LOS.

Sordan *et al.* (2022) addressed the implementation of Lean Six *Sigma* in hospitals and healthcare organizations. Descriptive statistics, process mapping, 5S and Spaghetti diagram were the most used tools/method. In projects where DMAIC was used, had "median savings for these projects equivalent to US$ 800,500, ranging from US$ 414,190 to US$ 1,700.00" (SORDAN *et al.*, 2022, p. 12).

In Rosa *et al.* (2023), a Lean Six *Sigma* (LSS) approach was used in the process of managing patients with AMI (death rate due to acute myocardial infarction) in order to decrease the mortality rate. Improving this process is considered fundamental, as it represents one of the main causes of hospitalization and healthcare costs in Italy. In this context, the flow of patients was analyzed, as it intended to reduce the 30-day mortality rate due to AMI registered by an Italian hospital. As for the tools, the VSM and Ishikawa diagrams were used in the implementation. To improve the process, actions such as the activation of a post-discharge outpatient clinic and telephone contacts were carried out. These actions generated a 35% reduction in total time and from 16 to 8%, in a pre- and post-implantation scenario, respectively.

*Method*

This article seeks to understand and analyze the implementation of the Lean Six *Sigma* DMAIC cycle in patient care processes in Hospital and Emergency Units based on the trajectory and results.

The research questions were formulated based on the acronym PCC. In the case of the present study, "P" (Population or problem) are patient care processes, "C" (Concept) refers to interventions based on the implementation of the Lean Six *Sigma* DMAIC Cycle; methods/techniques/tools; measures; effects; pre- and post-implementation scenario; efficiency; and Co (Context) relates to Hospitals and Emergency Units.

Based on this, the following questions were elaborated:

Question 1 - How the Lean Six *Sigma* DMAIC cycle was implemented and what are its effects in the patient care process of hospital and emergency units?

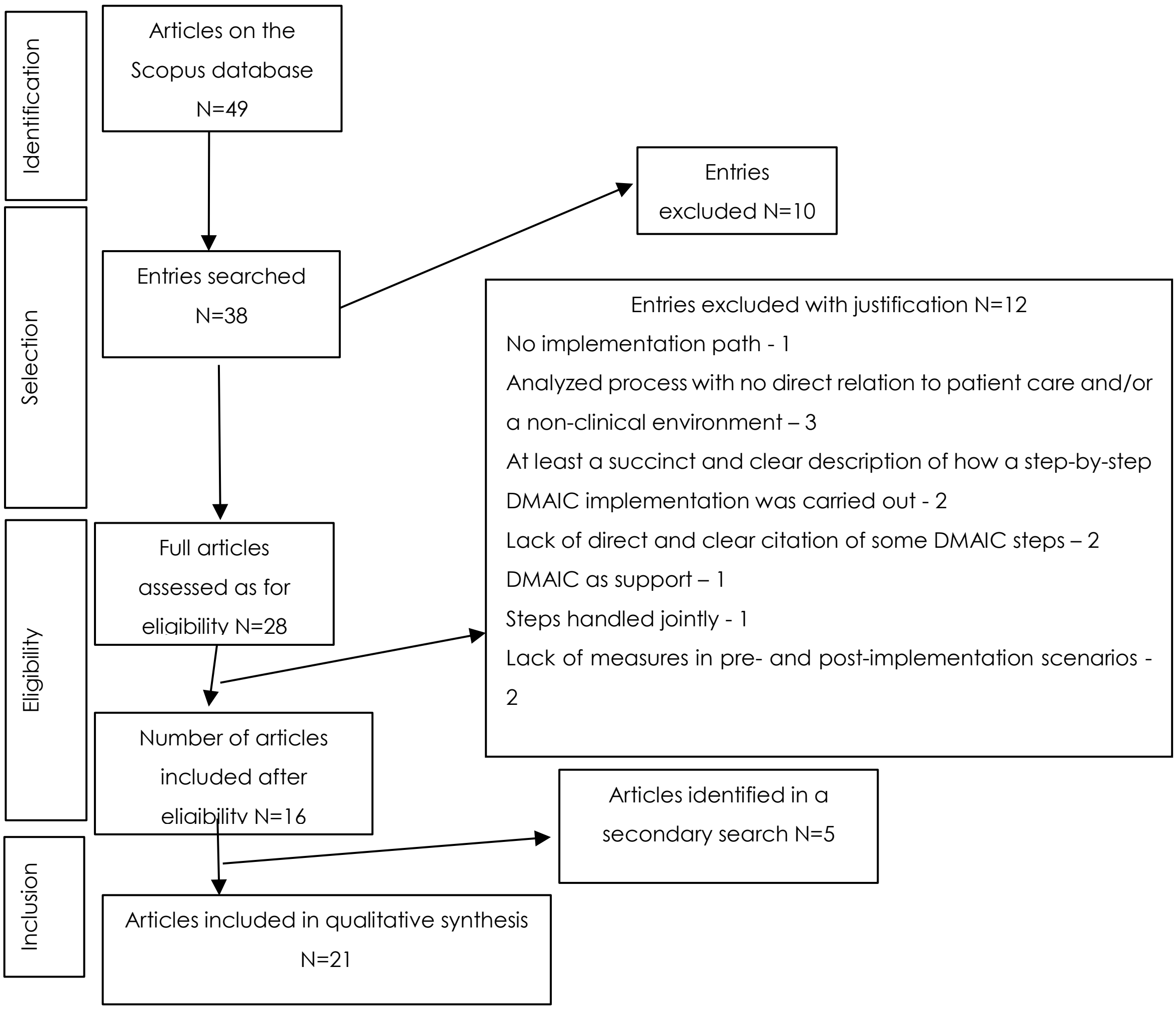
Question 2 - How effective is the implementation of the Lean Six *Sigma* DMAIC cycle in the patient care process of hospitals and emergency units based on a pre- and post-implementation scenario?

The articles were analyzed based on a systematic literature review following the Prisma framework.

4.1. Systematic review

In this article, a systematic review was carried out to evaluate and to achieve its objectives. Therefore, the steps presented by Moher *et al*. (2009) were selected for the present research design, namely: the identification, sorting, eligibility and inclusion of articles. Figure 1 shows the systematic review flowchart. The present research was carried out between August and October 2020. Scopus was the database selected for the present research because it contains the largest database of peer-reviewed abstracts and citations.

Figure 1 - Manuscript Selection Flowchart




Source: REIS *et al.* (2021).

Identification: this article is focused on DMAIC implementations in hospital and emergency health environments. For such a purpose, in the stage of Identification, a simulation of keywords with various terms related to DMAIC was carried out; thus, by investigation, it was found that the term "DMAIC" was not found throughout an article at times, but only expressions such as "define, measure, analyze, improve and control" or "define-measure-analyze-improve-control". Table 1 shows an advanced search performed for each entry. It was also found that the use of variants of terms referring to DMAIC did not affect the search results. Once performed, the term "DMAIC" and its variants were combined, as well as the terms "hospital" or "emergency". For this article, a combination of the following keywords has been used: DMAIC OR "define measure analyze improve control" and hospital OR emergency AND application OR implementation AND patient. As a result, 49 entries were found.

Table 1 - Advanced search on the Scopus Database

| **Search Entries** | **Documents** |
|---|---|
| TITLE-ABS-KEY ("dmaic") | 1400 |
| TITLE-ABS-KEY ("define measure analyze improve control") | 337 |
| TITLE-ABS-KEY ("define-measure-analyze- improve-control") | 339 |
| TITLE-ABS-KEY ("define, measure, analyze, improve, control") | 339 |
| TITLE-ABS-KEY (dmaic *OR "define measure analyze improve control")* | 1449 |
| TITLE-ABS-KEY (dmaic OR "define measure analyze improve control") AND TITLE-ABS-KEY (hospital) | 132 |
| TITLE-ABS-KEY (dmaic OR "define measure analyze improve control") AND TITLE-ABS-KEY (emergency) | 20 |
| TITLE-ABS-KEY (dmaic OR "define measure analyze improve control") AND TITLE-ABS-KEY (hospital OR emergency) | 137 |
| TITLE-ABS-KEY (dmaic OR "define measure analyze improve control") AND TITLE-ABS-KEY (hospital OR emergency) AND TITLE-ABS-KEY (application OR implementation) | 69 |
| TITLE-ABS-KEY (dmaic OR "define measure analyze improve control") AND TITLE-ABS-KEY (hospital OR emergency) AND TITLE-ABS-KEY (application OR implementation) AND TITLE-ABS-KEY (patient) | 49 |

Source: The authors (2021).

Selection: table 2 shows details about the search carried out on the Scopus Database regarding search filters. In the Screening Stage, as a result of using search filters through the entries found in the previous stage, only published articles in journals in English have been considered. The "year" search filter was not considered; therefore, the search covered an analysis of all years, which resulted in a range between 1997 and 2020 (10/12/2020). By inserting the search filters, 38 articles remained, of which 10 were excluded (unavailability, poster and abstract reading). Thus, 28 articles were selected for the stage of eligibility.

Table 2 - Search filters

| Search filters | Advanced search | Manuscripts |
|---|---|---|
| **1: Document Type** | TITLE-ABS-KEY (dmaic OR "define measure analyze improve control") AND TITLE-ABS-KEY (hospital OR emergency) AND TITLE-ABS-KEY (application OR implementation) AND TITLE-ABS-KEY (patient) AND DOCTYPE ("air") | Result 1: 38 manuscripts |
| **2: Type Source** | TITLE-ABS-KEY (dmaic OR "define measure analyze improve control") AND TITLE-ABS-KEY (hospital OR emergency) AND TITLE-ABS-KEY (application OR implementation) AND TITLE-ABS-KEY (patient) AND DOCTYPE ("air") AND SRCTYPE(j) | Result 2: 38 manuscripts |
| **3: Language** | TITLE-ABS-KEY (dmaic OR "define measure analyze improve control") AND TITLE-ABS-KEY (hospital OR emergency) AND TITLE-ABS-KEY (application OR implementation) AND TITLE-ABS-KEY (patient) AND DOCTYPE ("air") AND SRCTYPE(j) AND LANGUAGE (English) | Result 3: 38 manuscripts |

Source: The authors (2021).

Eligibility: in the stage of eligibility, full articles were selected through an extensive in-process intervention through the DMAIC steps based on an empirical research method carried out in a clinical environment focusing on direct patient care. The 28 articles were examined based on the criteria shown in Table 3.

Table 3 **-** Inclusion and exclusion criteria

| **Criteria** | |
|---|---|
| **Inclusion criteria** | **Exclusion criteria** |
| Database: Scopus | *Conference papers* |
| Published in peer-reviewed journals | *Books* |
| Language: English | *Reports* |
| Articles published before October 2020 | *Editorial letters* |
| Research method: empirical - case study (single/multiple)/action research | Reviews |
| Focus on patient care in a clinical setting | Poster |
| A clear focus on implementing DMAIC Six *Sigma* | Outside the clinical setting |
| Extensive in-process intervention through DMAIC | Lack of focus on direct patient care |
| Exposure to pre-implementation and post-implementation measures | DMAIC adaptation |
| Articles adopting an empirical approach | DMAIC as a support tool |
| | Some stages are not directly cited |
| | No implementation path |

Source: The authors (2021).

Inclusion: twelve out of the 28 articles were excluded, and 16 articles remained. In addition, a secondary search based on the criteria shown in Table 3 was performed, and five articles were identified in the reference sections of selected articles (secondary search) that started to comprise the list of articles that would be used. Thus, the research to be carried out in the next stages was based on 21 articles.

Subsequently, the articles included in the systematic review were categorized according to the articles by Fernandes *et al.* (2020) and Zimmermann, Siqueira and Bohomol (2020). For categorization, the following content of articles was considered: title, authors, year, country, intervention, processes, health institution, Methods/Techniques/Tools by DMAIC phase, measures in pre- and post-implementation scenario. Data were recorded in Excel electronic forms as recommended by (PEREIRA; GALVÃO, 2014).

## Results

In this section, the results of the evaluation based on the systematic literature review are presented. As stated above, analyses related to the following aspects are going to be presented: process, methods/techniques/tools and measures (pre and post implementation scenario).

### *Processes*

Table 4 shows different addressed processes, such as depression screening, prevention of inpatient falls, discharge, patient admission, and transfer, pain management, sample collection, surgery, febrile neutropenia treatment, and outpatient department service. The processes with the highest number of occurrences were patient discharge (3), femur surgery and knee and hip replacement surgery (2). Medication errors were addressed in articles published by Singh *et al*. (2021), Al Kuwaiti (2016) and Yamamoto, Abraham and Malatestinic (2010).

Table 4 - Process and authors of the articles included

| Processes | Authors |
|---|---|
| Prevention of in-patient falls | Al Kuwaiti and Subbarayalu (2017) |
| Process of depression screening | Aleem *et al*. (2015) |
| Patient discharge | Allen *et al*. (2010), Arafeh *et al*. (2018), Vijay (2014) |
| Outpatient department service | Bhat and Jnanesh (2014) |
| Registration process | Bhat, Gijo, Jnanesh (2014) |
| Musculoskeletal procedures | Cheung, Goodman, Osunkoya (2016) |
| Care for febrile neutropenic patients | Dang *et al*. (2018) |
| Sample collection | Gijo *et al*. (2013) |
| Knee replacement surgery | Improta *et al*. (2017), Ricciardi *et al*. (2020) |
| Hip replacement surgery | Improta *et al*. (2015), Improta *et al*. (2019b) |
| Femur surgery | Improta *et al*. (2019a), Ricciardi *et al*. (2019) |
| Dispensing prescription drugs | Al Kuwaiti (2016) |
| Transferring patients | Silich *et al.* (2012) |
| Medication delivery | Singh *et al.* (2021) |
| Dispensing of medicines | Trakulsunti *et al.* (2021) |
| Insulin administration and dispensing | Yamamoto, Abraham, Malatestinic (2010) |

Source: The authors (2021).

**Methods/techniques/tools**

The tools cited by stages are shown in Table 5. Next, some caveats will be exposed to clarify the compilation of Table 4. Cheung, Goodman and Osunkoya (2016) have not considered training, form, and standardization in a figure that summarized the tools used in the pilot test, however, for achieving the purposes of the present work, a thoroughly comprehensive search was carried out by considering possible limitations of all tools presented along with the articles. In Al Kuwaiti and Subbarayalu (2017), an improvement of a bed alarm system was considered to prevent falls. Thus, it was observed that the andon would be regarded as a corresponding tool in terms of classification in this work. In Al Kuwaiti and Subbarayalu (2017), orange stickers/fall risk signs were regarded as *poka-yokes* by the authors of the present study. Debriefing was selected as a tool by (AL KUWAITI; SUBBARAYALU, 2017). Although Descriptive Statistics has not been named as a tool by several studies, the articles that use median, mean, standard deviation, and rate, i.e., those that described the data of variables of a sample or population, were selected. The tools "Training, Education Plan and Training, and Education" were found in selected articles. For the present work, it was opted to cluster them into the category "Education and Training".

Given the above, the analysis shown in Table 5 was carried out. In the step of "Defining", the tools "Project Opening Term, SIPOC, CTQ, and Voice of the Customer" were frequently found. In the step of "Measuring", process map, data collection plan, and statistical tools such as Descriptive Statistics (mean and standard deviation, for instance) were frequently identified. A mind map was identified once only in the step of "Defining", as well as "Benchmarking, *Gemba*, Kano Model, Input-Output Process Analysis, Communication Plan, Time Series Graph, and I-MR Control Graph (IMR-chart), and Dashboard". "Operational Definition" was found as a tool twice in this step.

In the step of "Measuring", "Data Collection/Data Collection Plan" was often used as a tool. Descriptive Statistics and Capability Analysis have been widely used. Detailed Process Map, Swin Lane Map and Value Flow Map were also addressed. Statistical tests such as normality tests also appeared rather often. Audit, Flowchart, Stratification, Protocol, Standard Operating Procedure, Sampling, Time Series Graph, Time Study, Training and Responsibility Matrix were seldom used.

In the step of "Analyzing", "Brainstorming and Ishikawa Diagram" were frequently used. "FMEA, Validation Studies, Analysis of Variance (ANOVA), *Gemba*, Basic Flow

Map, 5 Whys" were addressed less frequently. "Communication Complexity Diagram, Meeting, Root Cause Analysis, Cause-Effect Matrix, Multi-voting and Linear Regression" were the least used tools. Value stream mapping, Swin lane map, and statistical tests such as the F test and the Student's t-test were addressed in articles in this step.

In the step of "Improving", "Recommendations for improvements/Implementation and standardization" were widely used as tools. *Poka-Yoke*, Andon, *Kanban*, 5S, Dot Plot, Box Plot, Meetings, Solution Matrix, Simulation of Discrete Events, Simplification of procedures, Checklist, Meetings, FMEA, Form, Swin lane map, among others, were used often less as tools. "Education and Training" were cited in several articles.

In the step of "Improving", tests such as the Student's t-test, chi-square test, and Mann-Whitney U test were used. The tools "Descriptive Statistics, Reaction Plan, Monitoring Plan, and Control Charts such as the I-MR and the Time Series chart" were used, among others. Table 5 presents the tools by authors of each article found through the systematic review. According to Table 5, among the 97 tools found in the articles, 38 appeared only once. The 10 most commonly addressed tools (Table 5) were Brainstorming, CTQ, Data collection/Data collection plan, Ishikawa diagram, Education and training, Descriptive statistics, Time series chart, SIPOC, Project charter term, Student's t-test, and Brainstorming.

Table 5 - Tools found by DMAIC Steps

| Authors | Sets | Measure | Analyze | Improve | Control |
|---|---|---|---|---|---|
| 1. Aleem *et al*. (2015) | Project charter term | Swin Lane Map | Brainstorming | Frequency-impact matrix | Control chart (p-chart) |
| | Voice of the customer | Data collection plan | Ishikawa Diagram | *Swin Lane* Map | Time series chart |
| | Affinity diagram | Control chart (p-chart) | | Improvement recommendations | Student's t-test |
| | Mind map | Time series chart | | Implementation plan | FMEA |
| | CTQ | | | Standardization | Monitoring plan |
| | | | | Training | |
| | | | | Communication | |
| 2. Allen *et al*. (2010) | Project charter term | Process map | Pareto Chart | Improvement recommendations | Audit |
| | Voice of the customer | Standard operational procedure | Cause and effect matrix | Form | Spreadsheet |
| | | Protocol | | Pilot test | |
| | | Data collection | | | |

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| Authors | Sets | Measure | Analyze | Improve | Control |
|---|---|---|---|---|---|
| | | Shewhart's Control chart (ImR chart) | | | |
| 3. Arafeh *et al*. (2018) | Project charter term | Detailed process map | Ishikawa diagr am | Discrete-event simulation | Control plan |
| | SIPOC | Data collection | Communicatio n complexity diagram | Improvement recommendations | Stakeholder analysis |
| | | Descriptive statistics | Brainstorming | Pareto Chart | RACI Matrix |
| | | Histogram | | Capability analysis | Shewhart's Control chart (ImR chart) |
| | | Shewhart's Control chart (ImR chart) | | Descriptive statistics | |
| | | Capability analysis | | | |
| 4. Bhat, Gijo, Jnanesh (2014) | Project charter term | Data collection plan | Value stream mapping | Value stream mapping | *Poka-Yoke* |
| | SiPOC | Flowchart | Brainstorming | Discrete-event simulation | 5s |
| | CTQ | Time-motion Study | Ishikawa Diagram | Action plan | Standard operational procedure |
| | | Responsibilit y assignment matrix (RACI Matrix) | Validation study | Student's t-test | Control chart (X-bar and R) |
| | | Capability analysis | *Gemba* | | Normality test |
| | | Descriptive statistics | Analysis of variance (ANOVA) | | Capability analysis |
| | | | Box plot | | Descriptive statistics |
| | | | Student's t-test | | |
| | | | Pareto Chart | | |
| | | | Multi-Vari Chart | | |
| 5. Bhat and Jnanesh (2014) | Project charter | Random sampling | Ishikawa Diagram | Risk assessment analysis | Control plan |
| | SiPOC | Normality test | Validation study | Implementation plan | Standard operational procedure |
| | Simulation | Shewhart's Control chart (ImR chart) | Student's t-test | Kanban | Awards and recognition |
| | CTQ | Capability analysis | *Gemba* | Control chart (I-chart) | Meeting |

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| Authors | Sets | Measure | Analyze | Improve | Control |
|---|---|---|---|---|---|
| | | Data collection plan | Brainstorming | Capability analysis of the process | Time series chart |
| | | | Pareto Chart | | Training |
| | | | | | Documentation |
| | | | | | 5s |
| | | | | | Reaction plan |
| 6. Cheung, Goodman, Osunkoya (2016) | Project charter | Descriptive analysis | Value stream mapping | Brainstorming | VOC |
| | VOC | Swin Lane Map | Ishikawa Diagram | Pilot tests | Remeasurements |
| | Affinity chart | Data collection spreadsheet | Dispersion plots | Standardization | Box Plot |
| | | | | Education | Storyboard |
| | SIPOC | | | Form | |
| 7. Dang *et al.* (2018) | Process map | Data collection | Process map | Implementation plan | Time series chart |
| | SIPOC | Time series chart | Ishikawa Diagram | Education and training | *Huddles* |
| | CTQ | Shewhart's Control chart (ImR chart) | FMEA | Standardization | Reeducation |
| | VOC | Descriptive analysis | Brainstorming | Descriptive statistics | |
| 8. Gijo *et al.* (2013) | Project charter | Data collection | Ishikawa Diagram | Implementation solutions | Monitoring |
| | CTQ | Systematic sampling | Detailed process map | Checklist | Time series chart |
| | Operational definition | Time series chart | Validation study | Capability analysis | Reaction plan |
| | SIPOC | Normality test (Anderson-Darling) | F test | Dot plot | Descriptive statistics |
| | | Descriptive analysis | Student's t-test | | |
| | | Capability analysis | Box plot | | |
| | | | Brainstorming | | |
| | | | *Gemba* | | |
| 9. Improta *et al.* (2015) | Project charter | Data collection | Value stream mapping | Procedure/process simplification | Student's t-test |
| | SIPOC | Histogram | Brainstorming | Standardization | Chi-square Test |
| | CTQ | Normality test (Shapiro-Wilk) | Ishikawa Diagram | Periodical meetings | Periodical meetings |
| | | Time series chart | Analysis of variance (ANOVA) | Box-Plot | Internal audit |
| | | Run tests | Student's t-test | Capability analysis | Checklist |
| | | | Validation study | | Time series chart |
| | | | Descriptive statistics | | Descriptive statistics |
| | | | | | Capability analysis |

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| Authors | Sets | Measure | Analyze | Improve | Control |
|---|---|---|---|---|---|
| 10. Improta *et al*. (2017) | Project charter | Data collection | Value stream mapping | Procedure/process simplification | Mann-Whitney U Test |
| | | Normality test (Shapiro-Wilk) | Brainstorming | Standardization | Periodical meetings |
| | Gantt Chart | Time series chart | | Periodical meetings | Internal audit |
| | Input-process-output analysis | Run tests | | | Time series chart |
| | CTQ | Mann-Whitney U test | | | Descriptive statistics |
| | | Descriptive statistics | | | |
| 11 Improta *et al*. (2019a) | Project charter | Data collection | Basic value stream mapping | Clinical pathway | Student's t-test |
| | CTQ | Normality test | Descriptive statistics | Standardization | Chi-square Test |
| | SiPOC | Run test | Student's t-test | Education | Meeting |
| | | Time series chart | Analysis of variance (ANOVA) | | Audit |
| | | | Periodical Meetings | | Checklist |
| | | | Ishikawa Diagram | | Time series chart |
| | | | Validation study | | Box Plot |
| | | | | | Descriptive statistics |
| 12. Improta *et al*. (2019b) | CTQ | Data collection | Basic value stream mapping | Clinical pathway | Box plot |
| | Operational definition | Histogram | Histogram | | Student's t-test |
| | SIPOC | Time series chart | Ishikawa Diagram | | Chi-square Test |
| | Project charter | Run test | Box plot | | Time series chart |
| | | Normality test (Jarque-Bera Test) | Student's t-test | | Descriptive statistics |
| | | Descriptive statistics | | | Reaction plan |
| 13. Al Kuwaiti (2016) | CTQ | Data collection spreadsheet | Pareto Chart | Brainstorming | Control plan |
| | VOC | Audit | FMEA | Action Plan | *Poka-yoke* |
| | SIPOC | Capability analysis | | 5S | |
| | | | | Education and training | |
| | | | | Standardization | |
| | | | | Capability analysis | |
| | | | | Procedure | |

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| Authors | Sets | Measure | Analyze | Improve | Control |
|---|---|---|---|---|---|
| 14. Al Kuwaiti and Subbarayalu (2017) | Shewhart's Control chart (ImR chart) | Data collection plan | Pareto Chart | Solutions implementation | Control plan |
| | Time series chart | Data stratification | Ishikawa Diagram | Training | Shewhart's Control chart (ImR chart) |
| | VOC | Descriptive statistics | Root cause analysis | Protocol | Communication plan |
| | CTQ | | Brainstorming | Andon | Debriefing |
| | | | | *Poka-yoke* | |
| 15. Ricciardi *et al.* (2019) | SIPOC | Data collection | Value stream mapping | Clinical pathway | Student's t-test |
| | Project charter | Histogram | Descriptive statistics | | Chi-square Test |
| | | Normality test (Shapiro–Wilk) | Ishikawa Diagram | | Box-plot |
| | | Descriptive statistics | Brainstorming | | Descriptive analysis |
| | | | | | Time series chart |
| 16. Ricciardi *et al.* (2020) | Project charter | Data collection | Basic value stream mapping | Clinical pathway | Jarque-Bera test (normality test) |
| | Input-process-output analysis | Normality test (Jarque-Bera Test) | Brainstorming | | Student's t-test |
| | CTQ | Time series chart | Validation study | | Chi-square test |
| | | Run tests | | | Time series chart |
| | | | | | Visual control |
| | | | | | Descriptive statistics |
| 17. Silich *et al*. (2012) | Project charter | Data collection plan | Ishikawa Diagram | Pilot test | Capability analysis |
| | SIPOC | Capability analysis | FMEA | | Documentation |
| | | | Analysis of variance (ANOVA) | | Monitoring |
| | | | Student's t-test | | Descriptive statistics |
| | | | Linear regression analysis | | |
| 18. Singh *et al.* (2021) | Project charter | CTQ | Ishikawa Diagram | Cause/Solutions Matrix | Implementation plan |
| | Voice of the Customer | Data collection | Data collection | Brainstorming | Brainstorming |
| | Benchmarking | Descriptive statistics | Analysis of variance (ANOVA) | 5S | |
| | Kano Model | | Descriptive statistics | | |
| | Operational definition | | Capability analysis | | |
| | SIPOC | | | | |

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Conclusão

| Authors | Sets | Measure | Analyze | Improve | Control |
|---|---|---|---|---|---|
| | Basic value stream mapping | | | | |
| 19. Trakulsunti *et al.* (2021) | Project charter | Data collection | Brainstorming | Brainstorming | Standard operational procedure |
| | *Gemba* | CTQ | Ishikawa Diagram | Monitoring plan | Control chart (p-chart) |
| | | Training | Multi-voting | | Wilcoxon signed-rank test |
| | | Control chart (p-chart) | 5 Whys | | |
| 20. Vijay (2014) | Project charter | Capability analysis | 5 Whys | Improvement recommendation | Control Plan |
| 21. Yamamoto, Abraham, Malatestinic (2010) | Project charter | Operational definition | Swin lane map | FMEA | Control Plan |
| | Sipoc | Descriptive statistics | Ishikawa Diagram | Improvement recommendations | Implementation plan |
| | Communication plan | | Analysis of Variance (ANOVA) | | Monitoring plan |
| | Risk assessment analysis | | Student's t-test | | Standard operational procedure |
| | | | Effort/Impact-benefit Matrix | | Documentation |
| | | | | | Education and Training plans |

Source: The authors (2021).

It was noticed that perhaps some tools might not have been nominally explained in previous studies. Thus, some inferences were made by the authors of the present study to verify if any tool could have been used and not been formally explained in the text. These possibilities are set out below.

Allen *et al.* (2010) mention that to choose the target process of the improvement project, patients' complaints and patient satisfaction surveys regarding hospital discharge were considered. This was considered raw material for the decision, so it is suggested that the client's Voice tool was used without this being explained nominally.

Silich *et al.* (2012) reported that the capture of the perception of companions about the time of patients transfer to critical care areas of the Hospital, may indicate that the Client's Voice tool was used.

Cheung, Goodman and Osunkoya (2016) indicated that to perform the detailed process map, they walked through the flow of patients and radiology staff, concerning the musculoskeletal procedures analyzed, during the application of the DMAIC. This indicates the use of the *Gemba** Investigation tool, although it has not been explained nominally. The use of the whiteboard related to the screening of exams with exposure of information e.g. of exam schedule *per* room pieces of evidence the use of Visual Management. In addition, the Training and Control Manuals and continuous monitoring plan.

**Measures (Pre- and post-implementation scenario)**

There is a large variety of measures used in the analyzed processes, ranging from rework (for lost insulin vials), average waiting time, queue size (number of patients), failure rate, the average length of stay, *sigma* level, and lack of medical record data, dispensing errors, among others. Table 6 presents the measures related to the processes present in the analyzed articles found through the systematic review, and a few examples are going to be cited as follows. In Silich *et al.* (2012), the average transfer time (for intensive care units) ranged from 214 minutes to 84 minutes and achieved an improvement of 60.7%. Bhat and Jnanesh (2014) cited a reduction in the average cycle time of outpatient service from 4.27 minutes to 1.5 minutes and had an improvement of 64.9%, in addition to queue size (number of patients) reduction from 11 to 1 and 90.9% improvement. Improta *et al*. (2019b) reported that, concerning femur surgery at Hospital Antonio Cardarelli, the length of stay during preoperative periods (days) of femur surgery was reduced from 6.9 days to 3.15 days and achieved an improvement of 54.3%. In addition, they reported that there was an improvement of over 60% regarding patients undergoing surgery within 48 hours of admission. In Table 5, these exceptions are highlighted in red with a negative sign. For instance, Yamamoto, Abraham and Malatestinic (2010) reported that there was a worsening in some measures (such as several IMs and ADEs) due to attempts to improve patient safety, but these remained within the target established a *priori*. In Cheung, Goodman and Osunkoya (2016), among all measures under analysis, 1 worsened as regards the average time of discharge which increased from 6.43 minutes to 9.75 minutes with a reduction of 51.6%, and the authors found that the cause for such was considered non-apparent, which suggests process instability and requires further investigation.

Table 6 - Measures

| Authors | Indicator | Target | Pre-interventions | Post-interventions | Percentage of improvement |
|---|---|---|---|---|---|
| Aleem *et al*. (2015) | Number of sessions for depression screening (%) | Increase to > 50 | 17 | 75.9 | 346.5% |
| | Duplication of PHQ-2 (%) | Keep < 5 | 0.6 | 4.7 | -683.3% |
| | Visits of patients with a PHQ2 score of at least 3 and documented PHQ-9 (%) | > 90 | 100 | 94.70 | -5.3% |
| Allen *et al*. (2010) | Average discharge time (h.) | | 3.3 | 2.8 | 15.2% |
| | Missing medical record data | | - | - | 62% |
| Arafeh *et al.* (2018) | *Sigma* level | | 0.72 | 2.67 | |
| | Average discharge time | | 215.7 | 98.2 | 54.5% |
| Cheung, Goodman, Osunkoya (2016) | The average length of stay (min.) | | 68.2 | 52.18 | 23.5% |
| | Average waiting time *per* room (min.) | | 28.82 | 15.29 | 48.3% |
| | Average accommodation time (min.) | | 6.63 | 7.12 | -7.4% |
| | Average consent time (min.) | | 4.8 | 2.82 | 41.3% |
| | Average procedure time (min.) | | 21.51 | 17.82 | 18.2% |
| | Average discharge time (min.) | | 6.43 | 9.75 | -51.6% |
| Improta *et al*. (2019a) | Average hospital length of stay in days (considering all patients) | | 10.76 | 7.8 | 27.5% |
| | Standard deviation in days | | 1.79 | 1.74 | |
| Ricciardi *et al.* (2020) | Average hospital length of stay (days) | | 8.34 | 6.68 | 19.9% |
| | Standard deviation from to days (%) | | 2.41 | 1.99 | –17.1 |
| Silich *et al.* (2012) | Average transfer time (to intensive care units) in minutes | < 90 | 214 | 84 | 60.7% |
| | Standard deviation (min.) | | 170 | 35 | 79.4% |
| | DPMO | | 242.000 | 10.700 | |
| | *Sigma* level | | 2,2 | 3,8 | |
| | Yield (%) | | 75.80 | 98.93 | |

*Continua*

| Authors | Indicator | Target | Pre-interventions | Post-interventions | Percentage of improvement |
|---|---|---|---|---|---|
| Al Kuwaiti and Subbarayalu (2017) | Failure rate (%) | | 6.57 | 1.91 | 70.9% |
| Gijo *et al*. (2013) | Average waiting time for sample collection (min.) | | 23.96 | 11 | 54.1% |
| | Standard deviation | | 17. 5 | 10.04 | 43.4% |
| | PPM (30 min. of upper specification limit) | | 440,000 | 17,391 | 96.0% |
| Bhat, Gijo, Jnanesh (2014) | Average cycle time (s) | < 120 | 178,99 | 88,63 | 50.5% |
| | Standard deviation of average cycle time (s) | | 61 | 29.21 | 52.1% |
| | DPMO | | 833,222.57 | 141,481.45 | |
| | *Sigma* level | | 0.53 | 3.69 | |
| | Average waiting time (min) | | 21.10 | 1.19 | 94.4% |
| | Queue length (nº) | < 5 | 12 | 1 | 91.7% |
| | Percentage of scheduled utilization of staff | | 94 | 48 | 48.9% |
| Yamamoto, Abraham, Malatestinic (2010) | Number of insulin-related medication incidents (MIs) | | 7.5/quarter | 12 | -37.5% |
| | Number of insulin-related medication incidents (ADE) | | 0.375/quarter | 28 | -98.7% |
| | MI+ADE | 35 to 75/quarter | | 40/quarter | |
| | Amount of patients with abnormal limits of blood glucose levels (%) | > 180 mg/dL= < 20% | >180 mg/dL=23.2% | >180mg/dL=20.4% | 12.1% |
| Trakulsunti *et al*. (2021) | Dispensing errors (No. of incidents *per* 20,000 inpatient days *per* month) | Reducing dispensing errors | 6 | 2 | 66.7% |
| Singh *et al*. (2021) | Average medication turnar ound time | ≤ 60 min | 1h 23 min | 48 min | 43.0% |
| | DPMO | | 6,10,000 | 3,10,000 | |
| | Yield (%) | | 39 | 69 | |
| | Six *sigma* level | | 1.22 | 2 | |
| Ricciardi *et al*. (2019) | Average length of stay (days) | < 10 | 13.14 | 9.21 | 29.9% |
| | Standard deviation (min) | | 5,10 | 4,25 | 16.7% |
| Vijay (2014) | Average patient discharge time (min) | 135 | 234.35 | 143 | 38.9% |

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| Authors | Indicator | Target | Pre-interventions | Post-interventions | Percentage of improvement |
|---|---|---|---|---|---|
| Bhat and Jnanesh (2014) | Average cycle time of outpatient department service (min) | < 2 | 4.27 | 1.5 | 64.9% |
| | Standard deviation (min) | | 2.02 | 0.43 | 78.7% |
| | Average waiting time in the system | | 32 | 1 | 96.9% |
| | Queue size (number of patients) | | 11 | 1 | 90.9% |
| | *Sigma* level | | 0.38 | 3.11 | |
| Dang *et al*. (2018) | Average time taken to administer screening antibiotics to patients suffering from neutropenic fever (min) in the ER | < 60 | 100 | 27 | 73.0% |
| | Febrile neutropenia patients with an ESI (emergency severity index) of 2 and documentation (%) in the ER | 100 | 11 | 89 | 709.1% |
| | Neutropenic fever patients on the oncology floor (%) | 100 | 74 | 88 | 18.9% |
| Improta *et al*. (2017) | Hospital length of stay (days) | < 14 | 14,2 | 8,3 | 41.5% |
| | Standard deviation (days) | | 5,2 | 2,3 | 55.8% |
| Improta *et al*. (2015) | Hospital length of stay (days) | < 14 | 18,9 | 10,6 | 43.9% |
| | Standard deviation (days) | | 2,9 | 1,8 | 37.9% |
| Improta *et al*. (2019b) | Preoperative length of stay (days) | | 6,9 | 3,15 | 54.3% |
| | Standard deviation (days) | | 3,02 | 2,91 | 3.6% |
| | Patients undergoing surgery within 48 hours of admission (%) | | 4 | | Over 60% |
| Al Kuwaiti (2016) | Yield (Prescription/data entry error) | | 94,40% | 99,50% | |
| | PPM (Prescription/data entry error) | | 56000 | 5000 | |
| | *Sigma* level (Prescription/data entry error) | | 3,09 | 4,08 | |

*Continua*

| Authors | Indicator | Target | Pre-interventions | Post-interventions | Percentage of improvement |
|---|---|---|---|---|---|
| | Yield (Medication delivered with manufacturer's defect) | | 96,40% | 99% | |
| | PPM (Medication delivered with manufacturer's defect) | | 36000 | 10000 | |
| | *Sigma* level (Medication delivered with manufacturer's defect) | | 3,6 | 3,83 | |
| | Yield (Medication not properly labeled) | | 96,80% | 99,50% | |
| | PPM (Medication not properly labeled) | | 32000 | 5000 | |
| | *Sigma* level (Medication not properly labeled) | | 3,35 | 4,08 | |
| Dang *et al*. (2018) | Average time taken to administer screening antibiotics to patients suffering from neutropenic fever (min) in the ER | < 60 | 100 | 27 | 73.0% |
| | Febrile neutropenia patients with an ESI (emergency severity index) of 2 and documentation (%) in the ER | 100 | 11 | 89 | 709.1% |
| | Neutropenic fever patients on the oncology floor (%) | 100 | 74 | 88 | 18.9% |
| Improta *et al*. (2017) | Hospital length of stay (days) | < 14 | 14,2 | 8,3 | 41.5% |
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| | Standard deviation (days) | | 2,9 | 1,8 | 37.9% |
| Improta *et al*. (2019a) | Preoperative length of stay (days) | | 6,9 | 3,15 | 54.3% |
| | Standard deviation (days) | | 3,02 | 2,91 | 3.6% |
| | Patients undergoing surgery within 48 hours of admission (%) | | 4 | | Over 60% |

*Continua*

Conclusão

| Authors | Indicator | Target | Pre-interventions | Post-interventions | Percentage of improvement |
|---|---|---|---|---|---|
| Al Kuwaiti (2016) | Yield (Prescription/data entry error) | | 94,40% | 99,50% | |
| | PPM (Prescription/data entry error) | | 56000 | 5000 | |
| | *Sigma* level (Prescription/data entry error) | | 3,09 | 4,08 | |
| | Yield (Medication delivered with manufacturer's defect) | | 96,40% | 99% | |
| | PPM (Medication delivered with manufacturer's defect) | | 36000 | 10000 | |
| | *Sigma* level (Medication delivered with manufacturer's defect) | | 3,6 | 3,83 | |
| | Yield (Medication not properly labeled) | | 96,80% | 99,50% | |
| | PPM (Medication not properly labeled) | | 32000 | 5000 | |
| | *Sigma* level (Medication not properly labeled) | | 3,35 | 4,08 | |

Source: The authors (2021).

## Discussion

This section discusses the main results of the systematic literature review and indicates directions for further research. The present work comprised the analysis of 21 articles through the Scopus database. The findings will provide valuable insights for the health care practitioners regarding methods/techniques/tools and performance measures.

Firstly, its results have been discussed, which are: Path (processes, tools, measures). Discharge of femur, knee and hip replacement surgeries were the most recurrent topics in the analysis of articles. Samanta, Varaprasad and Gurumurthy (2023) revealed that, among the various clinical departments analyzed, the radiology and emergency departments were the most frequent in terms of Lean Six *Sigma* implementation.

The articles yielded significant improvements in process measures (a few worsened concerning the pre-implementation scenario) in patient care process. McDermott *et al.* (2022) emphasized the time element from the point of view of its waste in terms of the user (waiting) and the system (crowding and overload) in healthcare environments. Several articles included in the systematic review of the present study highlighted time as an important measure in the implementation of the Lean Six *Sigma* cycle in processes. In Silich *et al.* (2012), the average transfer time (for intensive care units) improved by 60.7%. Bhat and Jnanesh (2014) cited an improvement in the average cycle time of outpatient service of 64.9% and queue size achieved a 90.9% improvement. Improta *et al*. (2019b) reported that length of stay during preoperative periods (days) for femur surgery achieved an improvement of 54.3%, which was over 60% in patients undergoing surgery within 48 hours of admission. It is worth highlighting the importance of this since the authors cited the fact that the best treatment for such patients is to be admitted during this time interval.

Samanta, Varaprasad and Gurumurthy (2023) argued, in a review study of case studies, that organizations seek in different ways to achieve the objectives of implementing Lean Six *Sigma*. Based on this study, it was noticed how DMAIC is adopted in LSS interventions.

Therefore, integrating the DMAIC approach with Permanent Health Education can be an effective strategy to improve the quality and efficiency of patient care processes, demonstrating the potential of Lean Six *Sigma* in health contexts (LIMA *et al.*, 2022).

In the integrative review carried out by de Barros *et al.* (2021), a large use of DMAIC was evidenced. It should be noted that, unlike the present work, the authors consider DMAIC as a lean tool. The present study considers DMAIC as a structure related to Lean Six *Sigma*.

Thus, thinking about the present article and as quoted by de Barros *et al.* (2021), positive effects were generated when using DMAIC as "more time dedicated to direct patient care and reduction of unnecessary procedures".

There is no benchmark for the Lean Six *Sigma* methodology (PEPPER; SPEDDING, 2010), which can be confirmed by the variety of tools that have been used in the DMAIC steps found in the analyzed articles. Statistical tools, for example, have been quite often used in the steps of measuring, analyzing and controlling of the DMAIC cycle. It is also worth mentioning that among the 98 tools found in articles, 38 appeared only once.

Bhat *et al.* (2020) evaluated that, in the improvement of health systems based in the use of Lean Six *Sigma* through DMAIC in multiple case studies. The following tools are the most used: control charts, cause and effect diagram, 5S, *gemba*, two-sample t test, standardization, waste analysis and flow mapping of value are some of the common tools used to improve health systems. The authors highlighted the tools such as VSM, SIPOC, Ishikawa Diagram and 5S are also widely used (BARROS *et al.*, 2021). Ishikawa diagram, process map, hypothesis test, SPC, SIPOC, VSM, Project Chart and Brainstorming were among the most used tools/techniques (SAMANTA; VARAPRASAD; GURUMURTHY, 2023).

In this article, the tools that were most often cited in articles were Project Charter, Data Collection/Data Collection Plan, Ishikawa Diagram, Brainstorming, SIPOC and Descriptive Statistics. If the present study is compared to articles by Bhat *et al.* (2020), by Barros *et al*. (2021) and Samanta, Varaprasad and Gurumurthy (2023); as the most used tool, in common, there is the Ishikawa Diagram. Considering the *gemba* tool, it was used in four of the 21 studies analyzed in the present work and was only cited by Bhat *et al.* (2020). In nine of the 21 included in this systematic review, standardization was addressed as cited by Bhat *et al.* (2020). Thus, as Samanta, Varaprasad and Gurumurthy (2023), the brainstorming tool was used in several studies of this article.

In the present study, *poka-yoke* was used in three articles: Bhat, Gijo and Jnanesh (2014); Al Kuwaiti (2016); Al Kuwaiti and Subbarayalu (2017). *Kanban* was applied in one study: Bhat and Jnanesh (2014). Benchmarking had its use considered in one study, Samanta, Varaprasad and Gurumurthy (2023) regarding the low use of QFD, *poka-yoke*, *kanban* and benchmarking tools in healthcare environments.

In the study conducted by Zimmermann, Siqueira and Bohomol (2020), the applicability of Lean Six *Sigma* in various health environments was highlighted, with positive effects related to reducing waiting time and increasing user satisfaction, in addition to process improvements regarding assistance indicators and error reduction. Considering the financial aspect, there was a reduction in care and operation costs, an increase in productivity and in bed and surgical center turnover.

## Conclusions

To answer Question 1, the path of implementation in the organizations in question was identified, considering where (process), how (methods/techniques/tools) and measures. In response to Question 2, the impact and effectiveness of the implementation of the Lean Six *Sigma* cycle in the context in question was evaluated based on different processes through different combinations of methods/techniques/tools through a comparison between measures in the pre and post implementation. The study made it possible to present results of the development of Six *Sigma*/Lean Six *Sigma* improvement projects based on the DMAIC cycle in different healthcare processes through articles found in the literature. Its importance has been highlighted in the context of healthcare and how it can be applied in different healthcare service processes. Consistent improvement results of key processes showed how useful and valuable Six *Sigma*/Lean Six *Sigma* implementations are through the DMAIC cycle in healthcare services. This study can help practitioners to, among several alternatives, find a suitable tool for executing a project involving the Lean Six *Sigma* cycle in the context of care processes. This work generated knowledge about tools related to the intervention of the Lean Six *Sigma* DMAIC cycle in health environments and the places where they can be applied, in addition to providing an evaluation of the implementation of the cycle. It is hoped that the present work can encourage future practitioners to implement the Lean Six *Sigma* cycle in healthcare environments beyond the environments presented here.

It is recommended that practical studies with Lean Six *Sigma* evidencing the implementation of DMAIC in a more detailed way be disclosed in view of the importance of this topic for the improvement of health processes.

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