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ORIGINAL ARTICLE

Overview of stages of change of lean six sigma programs in organizations from 2005 to 2021

Panorama dos estágios de mudanças dos programas lean six sigma nas organizações de 2005 a 2021

Eduardo Lopes de Sousa[1], Fabricio Viana Andretti[2], Marcelo Tadeu Grimaldi de Castro[3]

[1] Pontifícia Universidade Católica do Rio de Janeiro – PUC/RJ, Instituto de Administração e Gerência – IAG, Rio de Janeiro, RJ, Brasil. E-mail: elsousa1974@gmail.com

[2] Universidade do Estado do Rio de Janeiro – UERJ, Departamento de Engenharia Ambiental – DEAMB, Rio de Janeiro, RJ, Brasil. E-mail: fabricio2906engenheiro@gmail.com

[3] Sr.Consultant, Lean Six Sigma Master Black Belt, Rio de janeiro, RJ, Brasil. E-mail: grimaldi.marcelo13@gmail.com

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Abstract: Quality management can be considered as the set of actions adopted to obtain characteristics of the product or service provided capable of meeting/satisfying needs and even exceeding customer expectations, achieving sustainable results for the organization. In this sense, several improvement programs adopted by organizations have emerged over time, including lean six sigma (LSS). The objective of this research is to establish an overview of the stages of change of the lean six sigma program in organizations in the last 15 years, identifying the critical success factors (CSF) for its implementation before and after these 15 years. The initial panorama was established by carrying out qualitative research with specialists from the LSS program of a service sector organization in 2005, when nine CSF were identified, namely: communication, organizational culture, a commitment of individuals to change, middle managers role, resistance to change, top management commitment, project selection/prioritization, training, and dissemination of results. Then, to analyze the historical evolution, a bibliographic review was carried out on the process of changes in LSS programs in organizations from 2005 to 2021. In this bibliographic review, it was found that the nine CSF identified in the 2005 survey were still relevant in the 15 subsequent years and that technological advances and the digital transformation experienced in various sectors promoted the emergence of three new CSF in the implementation of organizations' LSS programs: big data analytics (BDA), agile manufacturing and innovation.

Keywords: Quality; Management; six sigma; lean; lean six sigma.

Resumo: Gestão da qualidade pode ser considerada como o conjunto de ações tomadas para se atender e superar expectativas dos clientes e se obter resultados sustentáveis. Surgiram com o tempo diversos programas de melhoria nas organizações, entre eles o *lean six sigma* (LSS). O objetivo desta pesquisa é estabelecer um panorama dos estágios de mudanças do LSS nas organizações nos últimos 15 anos, identificando fatores críticos de sucesso (FCS) para sua implantação antes e após estes 15 anos. O panorama inicial foi estabelecido por meio da realização de pesquisa qualitativa com especialistas do programa LSS de uma organização do

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setor de serviços em 2005, quando foram identificados nove FCS: comunicação, cultura organizacional, comprometimento dos indivíduos, papel dos gerentes intermediários, resistências à mudança, comprometimento da alta administração, seleção de projetos, treinamento e divulgação dos resultados. Na sequência, para análise da evolução histórica, foi realizada revisão bibliográfica sobre LSS nas organizações de 2005 a 2021. Nesta revisão constatou-se que os nove FCS identificados na pesquisa de 2005 continuavam relevantes nos 15 anos subsequentes, e que os avanços tecnológicos e a transformação digital promoveram o surgimento de três novos FCS na implantação dos programas LSS: Big Data Analytics (BDA), Manufatura Ágil e Inovação.

Palavras-chave: Qualidade; Gestão; *six sigma, lean*, *lean six sigma*.

1 Introduction

The word quality is usually associated with the satisfaction noticed by customers in relation to their own expectations or with excellence in the performance of products or services. Countless definitions and concepts surround this theme, which has been the object of human attention since the beginning of its history. If, on the one hand, efforts to improve quality have become a common strategic component for many organizations around the world (Antony et al., 2014), the study of quality has undergone many changes, following the evolution of civilizations, adding new attributes, and becoming a key science in the internal and external relations of organizations (Arcidiacono & Pieroni, 2018).

The quality program called lean six sigma (LSS) is recognized in the corporate environment as a successful strategy for sustained improvement of the performance of organizations. Among the authors who analyze this topic, George's (2002) definition can be highlighted that LSS is a methodology that maximizes value by achieving the fastest rate of improvement in customer satisfaction, cost, quality, process speed, and invested capital. The benefits associated with the implementation of LSS projects in organizations are related to cost reduction, reduction in production and service times, reduction in the number of defects in processes, and increased customer satisfaction (Motwani et al., 2004).

Even motivated by the achievement of these benefits, from the beginning of six sigma methodology at Motorola to the current days, organizations have found and still face several challenges in the implementation of LSS programs.

According to Beer (2003), quality management and improvement programs often fail to create sustained change in organizations and become a fad soon replaced by another fad. And failure to institutionalize a quality program can be attributed to gaps in understanding and managing the factors that are critical to its success (CSF).

Furthermore, when analyzing the past and envisioning the future, one can see emerging trends that put pressure on organizations with improvement needs related to new unstructured, and more complex problems. This suggests that LSS deployment has become increasingly demanding for all involved (Singh & Singh, 2020).

There are studies in the literature that identify and prioritize the CSF of quality programs, however, there is a gap or a knowledge gap regarding the evolution of these factors over the years.

This article seeks to fill this knowledge gap and has as its main research question the query: have the critical factors for success in the implementation of LSS programs remained the same in recent decades or would they have changed significantly,

following the speed of digital transformation and the fast evolutionary process of organizations?

Thus, the objective of this research is to establish an overview of the stages of change of lean six sigma programs in organizations in the last 15 years, identifying the critical success factors (CSF) for implementation, capable of helping organizations and researchers interested in the LSS approach.

In section 2, based on the bibliographic review, the origin and foundations of lean manufacturing and lean six sigma, which were consolidated in the LSS, are presented. Still, in section 2, the aspects that facilitate and/or hindered the implementation and success of LSS programs in the last 15 years are listed and discussed.

The research methodology, detailed in section 3, was structured in three blocks: (i) carrying out, the authors themselves, qualitative research with specialists from the LSS program of a service sector organization in 2005 to identify the CSF for LSS programs at that time; (ii) bibliographic review on the change process of LSS programs in organizations between 2005 and 2021, to identify the historical evolution of CSF to LSS programs; and (iii) comparison of the results of the 2005 applied research with the analysis of the historical evolution of LSS based on the bibliographic review of the period between 2005 and 2021. This comparison culminated in the identification of the evolution of the critical success factors (CSF) for the implementation of lean six sigma programs, that is, in the panorama of the stages of change in organizations in the last 15 years.

Finally, in section 4 the results are presented, and in section 5, the conclusions of the research are detailed.

2 Literature review

This section presents in subsections 2.1 to 2.5 a synthesis of the history of the quality movement from its origin, through the beginning and evolution of lean six sigma until the arrival of the so-called fourth industrial revolution and its consequences. Then, in subsection 2.6, a review of the literature on the critical success factors for lean six sigma programs over the last 15 years is presented.

2.1 Origins and evolution of the quality movement

Throughout the 20th century, the concept of quality underwent an evolution process, adding new attributes and becoming a key element in the internal and external relations of organizations. In recent decades, several approaches have been proposed regarding the theme of quality that have been presented to organizations.

According to Juran (1989), before the 20th century, quality management was based on two basic principles: the inspection of products by consumers themselves; the confidence that consumers placed in the craftsmen's skills and reputation. In the 18th century, the industrial revolution began to interfere with the labor relations prevailing until then. The factories gradually suffocated the guilds, while the craftsmen, seeing themselves without alternatives, became workers in the factories. Standardization, the use of measuring instruments and laboratory tests and written specifications for raw materials, processes, and finished products started at this time (Juran, 1989).

Under the influence of the principles of scientific management, based on the separation between planning and execution of work, the industry experienced an

increase in productivity that had negative effects on the quality of products. To restore the balance between productivity and quality, the solution found by managers at the time was the creation of inspection departments after production.

The arrival of the 20th century brought an increase in the complexity of products, as well as an explosion in the demand and supply of services. This movement found strength in the growing demand to produce high-quality military equipment under tight deadlines during World War II and, after the war, continued with the large-scale use of statistical process control by USA companies.

Equipped with the experiences they had during this period, North American and European consultants went to Japan to collaborate in the reconstruction of the country's economy after the second war. Among these consultants, William Edwards Deming and Joseph M. Juran were recognized for their contributions to the quality movement.

Total Quality Management (TQM) originated between the 1950s and 1960s when Japan started a revolution in the quality of its products and services, which until then were recognized for being cheap and of poor quality. Deming (2000) redefined concepts in Japanese organizations through his philosophy that quality is a concern for everyone in the organization. The aim was to make quality an element of the organization's culture, rather than a job for a few people. Edwards Deming's experience in similar projects in the United States in the post-war period showed that quality lost importance when consumer demand exploded, repressed during the war years (Kenneth & Marshal, 1994).

Juran was another prominent consultant who participated in the Japanese quality movement. Basu & Wright (2003) state that Juran was the first to emphasize communication as a relevant aspect of quality. Juran's concepts and work, which had the planning, control, and improvement trilogy as a support pillar, can be related to the fundamentals of six sigma.

According to Juran (1989), the success of the Japanese in the implementation and maintenance of TQM was due to the use of some decisive strategies: senior managers took charge of leading the quality movement; training all employees at all levels of the organization; continuous and peaceful effort; adoption of the concepts of quality circles.

2.2 Six sigma

Within the process of evolution of the quality movement, studies indicate that the origins of six sigma date back to the 1970s, when large American corporations began to experience the threat of the invasion of Japanese products in the world market resulting from the revolution of the quality promoted by TQM (Larson, 2003).

At this time, a large company electronics segment, Motorola, had its leadership position in the pagers and semiconductors market in the United States of America threatened by the entry of Japanese electronics. In 1979, under the management of Bob Galvin, Motorola developed a renewal and growth plan, based on four pillars: (i) guarantee of global competitiveness; (ii) participatory management; (iii) tenfold increase in quality (in this initiative lean the roots of six sigma); (iv) creation of the education and training center. The initiative to increase quality by ten times went beyond the manufacturing area and involved all aspects of management and all departments of the company, mainly engineering, responsible for product design (Barney & McCarty, 2002).

According to Barney & McCarty (2002), the benefits of this initiative were only obtained thanks to the involvement of everyone with the objectives of improving the

quality of the business and improving consumer satisfaction. In search of a metric that could reflect the quality of its various processes, Motorola's quality teams developed a program called Design for Manufacturability (DFM) in which the so-called six sigma quality was sought. All efforts to improve quality began to be measured in sigma (or standard deviation) and the pursuit of the objective of achieving six sigma quality in all processes mobilized the entire company.

Six sigma was introduced in Brazil a few years after its appearance in the United States of America, with the implementation and conduction of the program in the Brasmotor Group (Embraco and Multibrás) by the then Fundação Desenvolvimento Gerencial (FDG), in 1997 (Aguiar, 2002).

In the 2000s, six sigma produced financial results and significant impacts in the areas of manufacturing, design, finance, and health, among others. Later, new opportunities explored would allow for an even greater impact, such as the creation of the design for the six sigma (DFSS) method, which aims to maintain quality in new product designs and can be applied to production processes so that, when they come into operation, already reach six sigma quality (Antony et al., 2017).

From the perspective of the quality movement, from the 2000s, the six sigma approach gained the complementarity of the lean manufacturing approach, which originated in Toyota, to become what we know today as lean six sigma. The origins of lean manufacturing and the characteristics that made LSS possible will be detailed in items 3.3 and 3.4 below.

2.3 Lean manufacturing

Lean manufacturing has had a history of development tangential to six sigma. The Toyota Production System (TPS) provided the foundation for what became known as lean thinking. The development of this approach began shortly after World War II, initiated by Taiichi Ohno and associates while employed by the Toyota Motor Company. Forced by the scarcity of capital and resources, Toyota workers were instructed to eliminate all waste, defined as anything other than the minimum amount of equipment, materials, parts, space, and time essential to add value to the product. TPS became the dominant production model with several concepts emerging, including USA and European companies beginning to adopt TPS under the name of just-in-time (JIT) to remain competitive with the Japanese industry. (Pepper & Spedding, 2010).

2.4 Lean six sigma

The term lean six sigma (LSS), which stands for the integration of lean manufacturing and six sigma, was first introduced into the literature around 2000 and LSS teaching was established in 2003 as part of the evolution of six sigma. Since then there has been a notable increase in the popularity and deployment of LSS in the industrial world. In the 2010s, LSS became one of the most popular and proven business process improvement methodologies that organizations had ever seen (Antony et al., 2017).

Integrating six sigma and lean manufacturing into a broader approach has enabled many organizations to be able to solve problems and improve financial results faster. Therefore, it could be considered the state of the art in improvement at the end of the 2010s (Antony et al., 2017). When an organization uses lean and six sigma

simultaneously, improvements throughout the corporation are achieved much faster with higher success rates (George, 2002).

Analyzing the limitations of using lean and six sigma separately, Nash et al. (2006) highlighted that the speed and flexibility provided by lean manufacturing methods require strong engagement of the entire workforce and a high understanding of the Kaizen methodology. These characteristics associated with the six sigma structure and statistical knowledge base can provide even greater results and improvements in the long term. These authors pointed out practical limitations of the separate use of lean manufacturing and six sigma: (i) limitations of lean manufacturing: the method can run into problems that are not solvable without the application of advanced statistics. In addition, engineering and finance departments of organizations typically demand robust datasets and analyses from improvement projects to be approved, which may not be fully satisfied by lean projects; (ii) limitations of six sigma: the time required to identify the root causes of defects/problems can increase the cost of improvement projects and even make smaller projects unfeasible. The segmentation of training can also give rise to resistance from the organization in relation to the program, given that a smaller part of the employees is trained in six sigma skills.

2.5 Industry 4.0, Big Data Analytics and Agile Manufacturing

The so-called fourth industrial revolution and the term Industry 4.0 have origins in the German government's high-tech strategy project, which has been working since 2013 to bring its production to complete independence from human labor. Since then, these concepts have fundamentally changed society (Schwab, 2016).

Due to the technologies that emerged, there was a significant evolution of many continuous improvement methodologies, such as lean six sigma. Customer engagement, for example, is becoming increasingly relevant given the continuous feedback facilitated by IoT (Internet of Things), social networks, etc. It brings profound real-time impacts on production, product design customization, and after-sales service (Arcidiacono & Pieroni, 2018).

Arcidiacono & Pieroni (2018) summarized the relationship of mutual importance between lean six sigma and Industry 4.0 in the following aspects:

(i) Industry 4.0 helps collect more real-time data across the entire value chain with the support of lean six sigma tools.

(ii) Lean six sigma empowers process operators/owners.

(iii) The IoT allowed different processes to feed a cognitive algorithm in real-time.

(iv) Lean six sigma analytical tools allow you to better extract important insights from Big Data.

Additionally, the literature of the last 15 years reveals interesting studies on the relationships and synergies between lean six sigma and the characteristic concepts of the Industry 4.0 era such as Big Data Analytics (BDA), Agile Manufacturing, and Innovation. These relationships will be explored later in this article.

2.6 Aspects that facilitate and/or hinder the implementation and success of LSS programs in the last 15 years

Among the studies on lean six sigma, it can be noted that some address the critical factors for the implementation of this LSS program. As an example, Singh & Singh (2020) proposed a list of vital factors for the success of LSS programs in organizations, citing, among others, the commitment of top management, training, communication, etc. Raval et al. (2018), in turn, highlighted the most relevant CSF for the implementation of quality improvement programs, namely: senior management commitment, leadership, communication, training, and project management.

The following topics detail the CSF that stands out the most in the specialized literature, prioritizing the period between 2005 and 2021, and addressing aspects of how they influence the failure or success of programs such as LSS.

2.6.1 Communication

The issue of communication in organizations is the phenomenon that, according to the approach of the social construction of changes adopted by Ford & Ford (1995), creates and sustains the process of changes. Communication management in a way capable of motivating the participation of individuals in the change process is one of the most complex challenges faced by organizations today. According to Silva & Oliveira (2003), the constant changes in companies create a growing need to obtain the involvement and intense contribution of employees.

In the 2000s, Coronado & Antony (2002) brought to light the finding that communication has the power to reduce resistance to the implementation of quality programs, showing how a process of change works, how it is related to people's work, and the benefits it can bring. They concluded that it is important to have a communication plan that involves employees with the six sigma initiative.

This panorama is confirmed by the research by Kumar (2007), which states that medium and small companies starting LSS programs can show advantages over large organizations because they have more effective and open communication channels, and the research by Singh & Singh (2020), which point out that the success of LSS requires a strong and effective communication system within the company.

2.6.2 Organizational culture

Since the beginning of the 21st century, Beer (2003), focusing on the processes of change that originated interventions for total quality management, stated that the change in the organization's culture is the basis for success, although this aspect is little discussed and sometimes underestimated. Since then, efforts have been observed to better understand aspects related to change management that are involved in the application of LSS approach in organizations, in the interrelationship of the program with the culture of companies and with individuals. According to Lang Cheng (2012), six sigma practices can create a culture that encourages the employee to work through the company, increasing personal responsibility and improving the sense of accomplishment in their work tasks.

Lean six sigma has a positive impact on employee morale, inspiring changes in organizational culture, as teams can see the results of their work put into practice almost immediately (Lang Cheng, 2012). When it comes to lean six sigma initiatives,

studies confirm that if the need for cultural change is not properly addressed at the beginning of the initiative, the initiative will possibly disappear over time since lean six sigma can only be successful if accompanied by changes in culture, structure and processes of an organization, in addition to the mindset of the workforce (Brewer & Eighme, 2005).

In a study dedicated to analyzing the implementation of LSS in US healthcare organizations, Knapp (2015) highlighted the cultural factor as CSF. The study found that, without creating an atmosphere embedded in the organizations' culture, LSS programs become merely routine activities carried out by unconcerned employees.

Understanding each type of organizational culture helps leadership achieve effective implementation of quality programs such as lean six sigma from a holistic perspective, both in terms of quality management and culture (Zu et al., 2010).

2.6.3 The commitment of individuals to change

Kets de Vries & Balazs (1999) developed a view of organizational change closely related to the individual's change process. These authors characterize resistance to change as a natural response of human beings to the transformation that involves them. This argument is based on the premise that organizations are made up of groups of people and, by not considering the personal experiences of individuals, aspects that hinder the process of change can be introduced. They also argue that, like the changes of everyone, the change of the organization is a process that involves a certain level of stress. People from the organization, in addition to relying on the hope that changes will bring positive aspects in the future, need to be prepared for the fact that changes are inevitable.

People facing a cultural change and challenges arising from the implementation of six sigma need to understand what the change is about, making it essential to have a communication plan and educate leadership, employees, and customers on the benefits of its implementation (Kwak & Anbari, 2006).

Knapp (2015) points out that managers of organizations that emphasize group culture are more likely to have quality initiative successfully implemented, and that group culture favors flexibility, cohesion, and a sense of unity. Teamwork and participation are encouraged in this environment. Employee involvement is emphasized and decision-making is transferred to the individual performing the work. These individuals' engagement characteristics are consistent with the fundamental assumptions of LSS.

2.6.4 Role of middle managers

By the end of the 20th century, it was estimated that many initiatives had been implemented and a lot of effort was spent, mainly on ineffective quality management or reengineering programs. However, little had been done to understand the effects of such initiatives on those who are usually responsible for implementing them and who are the link between the authors of the initiatives and the employees: the middle managers (Turnbull, 1999).

Organizations often expect middle managers to be able to keep control of their own emotions and prioritize the organization's problems over private ones while simultaneously displaying enthusiasm for the rest of the organization.

According to this point of view, issues such as the lack of human resources in both quality and quantity aspects to execute lean six sigma projects can represent an important barrier to the success of the initiative. In most cases, it is a great challenge to carry out projects and manage day-to-day roles and responsibilities in the workplace at the same time (Brewer & Eighme, 2005).

2.6.5 Resistance to change

Several authors who represent a traditional controlling view of change management have addressed the issue of resistance to change as a characteristic of the transformation process that must be avoided or overcome. However, this view is criticized by authors who follow a constructivist perspective, since the so-called resistance can bring up discussions arising from unforeseen controversies in the change planning, in addition to being an opportunity to explore and better understand the change process itself (Ford & Ford, 1995).

When researching quality management processes in industrial organizations, Ambroz et al. (2004) pointed out that people are the fundamental and most important basis of the relationship between the individual and collective perception of the concept of quality, and that the human side of quality programs is frequently ignored or given insufficient attention. According to this author, changing quality standards implies changing the way people perceive quality in tasks and that means change. And when changes are imposed, there is expected to be resistance and a desire for things to go back to the way they were before.

In a study on the implementation of lean six sigma in the public sector, some of the fundamental challenges presented by Antony et al. (2014) are related to resistance to changes inherent to the process, citing some main elements: (i) LSS is seen as a quick fix, possibly labeled as another management fad; (ii) judgment of the initiative as a way of quickly cutting costs to meet budget deficits, without achieving real benefits; (iii) the difficulty in understanding the concept of customers and their voices; (iv) alleged lack of financial and human resources, time, etc. and (v) resistance to learning the method and statistical concepts.

Implementing any new concept like LSS is usually a complex task. For successful implementation, resistance forces must be recognized and debated (Raval et al., 2018).

2.6.6 Top management commitment

Top management commitment is seen as one of the most significant critical success factors for LSS implementation, as top leadership needs to be involved in all stages of implementation, from the concept of management processes at a strategic level to project individual monitoring at the business unit level (Julien & Holmshaw, 2012). Management at all levels needs to provide resources and training (Henderson & Evans, 2000). Silva *et al*. (2018), in research on the critical success factors for the implementation of LSS in Brazilian companies, emphasize that support and managerial leadership are fundamental to dealing with cultural issues and organizational conflicts related to the implementation of LSS. They also state that the involvement of top leadership is essential since it makes decisions related to the guarantee of resources, adaptation of the organizational system (structure, policy, and processes) and cultural change.

For Brewer & Eighme (2005), committed leadership is a critical factor for the implementation of LSS programs because it gives a clear direction on the general

strategy of the program, allows allocation of time and the best human resources, and reinforces clear communication to all, showing the priority of the initiative.

2.6.7 Selection and prioritization of projects aligned with the strategy

Since the beginning of LSS, the issue of a careful selection of projects and people to be trained has gained strong relevance to obtain the desired changes in the business, whether short or long-term. Thus, the identification of high-impact projects in the initial stage of the program plays an important role in causing the necessary ruptures in a quick window of time (Kumar et al., 2009).

Kumar et al. (2009) also claim that the proper selection of projects induces confidence in management and employees about the effectiveness of LSS initiative, promoting investment and future efforts in the initiative and winning the minds of all those involved. They also state that projects cost money, take time and influence normal operations and standard routines, and for these reasons, they need to be focused on the strategic objectives of any business.

The failure of LSS projects can mean a major setback in the initiative, since the projects are its core activity, materialize the application of the method and obtain the expected significant returns. Brewer & Eighme (2005) provided ingredients that are necessary for the successful development of LSS initiative in the financial services sector and among them, they highlight the selection of short projects to maintain the momentum of the initiative in the first two years of the initiative. Senior management staff in many organizations loses interest in projects lasting longer than six months.

2.6.8 Qualification/training

In the literature on quality, a lot of importance is given to the issue of qualification/training within LSS approach. Training is considered crucial in the implementation of LSS, as in addition to the belts, everyone in the organization must receive some training to be able to become familiar with the concepts and contribute to the growth of the program; training in LSS should start with top management and then be deployed by the hierarchy; although only a few people become green belts, black belts or master black belts (belt is related to the level of training and experience, in other words, practitioners receive a belt title after receiving training and, generally, demonstrating experience through practical application in projects). This does not mean that they are the only ones to carry the philosophy in the organization, but that they are multiplying agents (Coronado & Antony, 2002).

According to Singh & Singh (2020), the success of LSS depends on the frequency with which training programs are offered to employees to adapt the employee's proficiency to the company and to develop the necessary skills. The lack of training in the methodology, on the other hand, is identified as one of the main barriers capable of leading to the failure of LSS programs, according to a review of academic research on LSS conducted by Raval et al. (2018).

2.6.9 Disclosure of results

When studying the reasons that led corporations like Dow Chemicals to exceed all strategic and financial expectations in relation to six sigma, Motwani et al. (2004)

highlighted, among other aspects, the dissemination and storage of data generated by projects and sharing of acquired knowledge.

The positive impact of successful lean six sigma projects is the fuel that helps companies to institutionalize the cultural change that is configured in the adoption of lean six sigma. As this change does not occur in the short term, the dissemination of frequent positive results can motivate individuals who are mere observers to become more actively involved with lean six sigma and thus reinforce the process of transforming the organization's culture.

2.6.10 Big Data Analytics (BDA)

Brewer & Eighme (2005) highlighted that one of the challenges in applying LSS methodology in the context of financial services has always been the accessed to sufficient data. According to the authors, the collection and quantification of human-centered service process data during project execution are the specific problems with which organizations have to deal. In addition, processes are implemented in heterogeneous IT (Information Technology) systems, which has made the data collection process even more difficult.

With LSS widely used and recognized in the 2010s, many companies were already experiencing the impact of the fourth revolution, pointed out by Brewer & Eighme (2005), with exponential data growth that quickly made traditional information systems and techniques insufficient and ineffective.

Big data analytics (BDA), a term used to characterize the analysis of large sets of data that are difficult to examine due to their complexity and variability, has made it possible to uncover hidden patterns, market trends, and correlations between different parameters in a context where data sources are multiple and are in different forms ranging from text, numerical, weblogs, videos, tweets, etc. (Gupta et al., 2020).

The benefits of joining BDA in LSS projects did not take long to be identified, since the structured methodology of LSS began to gain greater capacity to predict and analyze business problems in a more agile way, fostering better insights, innovation, and process improvement (Gupta et al., 2020).

According to Gupta et al. (2020), companies need to create a structure that can help align BDA capabilities, LSS, project objectives, company goals, customer demand and the agreement of the different stakeholders involved.

Since 2014, research on this relationship has taken a significant leap, mainly in the areas of decision sciences, engineering, informatics, business management and accounting. The continued interest in research and application of BDA in LSS aims to demonstrate how storing, mining, integrating, interpreting, and modeling big data can lead to practical solutions to today's business problems (Gupta et al., 2020).

2.6.11 Agile manufacturing

Agile methods, originating in the area of software development and adopted in several areas in recent decades, are based on an incremental and iterative approach, open to changes in requirements over time, instead of the classic planning model at the beginning of the project. This methodology encourages constant feedback from end users.

Agile manufacturing was thought of as the manufacturing model of the 21st century, based on the concepts of agile methods. It is a more flexible approach that encourages cooperation and the development of creative skills in management and the workforce.

According to Alipour et al. (2018), in a steady state world, the creation of stable and robust structures to eliminate nonconformities observed in LSS approach would be enough to guarantee the resilience of organizations. But in the face of unpredictable events, processes also need to be agile and respond quickly.

2.6.12 Innovation

Studies suggest that LSS is an element that promotes innovation, although it is necessary to specify that the term innovation refers to process innovation, incremental innovation, or innovation capacity. On the other hand, the relationship between LSS and the so-called disruptive innovation is controversial, with some authors defending that LSS is not the best method to identify disruptive innovation opportunities, while others claim that it has the potential to influence radical and revolutionary innovation. (Antony et al., 2014).

Innovation, especially disruptive innovation, is sorely needed for companies to be successful in the long term. However, a myopic focus on innovation, without balancing it with the need for basic and ongoing problem-solving, is a road to financial disaster (Hoerl & Gardner, 2010).

According to Antony et al. (2017), emerging trends will place greater demands on organizations to improve and innovate, including globalization and its competitive pressures, customers demanding more in terms of quality, service, and lower costs, as well as improvements related to complex and unstructured problems.

3 Methodology

In this section, the research methodology is presented. The methodology used to collect primary data was qualitative research using a script of semi-structured questions carried out by the authors with specialists from the LSS program in a service sector organization in 2005. According to Denzin and Lincoln (2006), qualitative research involves an approach to the interpretation of the world, that is, it means that its researchers study things in their natural settings, trying to understand phenomena in terms of the meanings that people give to them. Furthermore, another important feature of the qualitative methodology is the heterodoxy at the time of data analysis. The variety of material obtained qualitatively requires the researcher to have an integrative and analytical capacity which depends on experience with the subject and the development of a creative and intuitive capacity.

Then, to analyze the historical evolution, a bibliographic review was carried out on the process of changes in LSS programs in organizations from 2005 to 2021.

With the result of the 2005 applied research and the conclusion of the analysis of the historical evolution based on the bibliographic review, it was possible to draw an overview of the stages of changes that LSS programs in organizations have undergone in the last 15 years.

3.1 Qualitative research

The research carried out is part of the type of qualitative methodology (André & Ludke, 1986). Having as a reference the typologies indicated by Gil (1987) and Vergara (1997), regarding the objectives or purposes, the research can be classified as exploratory in nature, as it seeks to identify the main factors that facilitated and hindered the process of change in the company. The management of the organization was previously consulted and authorized the conduction of this research, but without disclosing the name of the organization. Data collection took place through documentary research, interviews with employees and consultants from January to December 2005. Fourteen semi-structured interviews were conducted with employees representing different hierarchical groups and areas of the organization involved with the lean six sigma program, as well as with outsourced consultants who were hired to support the implementation of the program.

The interviews had a script of semi-structured questions. The questions were developed considering the relevant aspects identified in the literature review, seeking to capture: the intention of the change (Silva, 2001; Beer, 2003); the stage of change and the critical success factors (Silva, 2001; Coronado & Antony, 2002; Antony, 2004; Motwani et al., 2004; Larson, 2003; Anderson, 2005; Basu & Wright, 2003); how the communication around the change occurred (Ford & Ford, 1995); the behavior of individuals in the context of change (Ford & Ford, 1995; Hernandez & Caldas, 2001; Kets de Vries & Balazs, 1999; Ambroz et al., 2004; Kotter, 1997); the relationship between change and the organization's culture (Ambroz et al., 2004; Silva & Oliveira, 2003; Leitão & Rousseau, 2004); the impacts of change on the organization (Antony, 2004; Silva, 2001); the main barriers to implementation (Beer, 2003; Bellanca, 2005; Coronado & Antony, 2002; Antony, 2004; Motwani et al., 2004); the participation of managers and directors (Ford & Ford, 1995; Turnbull, 1999; Young, 2000; Beer, 2003); the aspects considered positive and the interviewee's main criticisms of the company's experience.

All interviews were transcribed and, with the help of ATLAS-TI software, the contents were classified into different themes and grouped according to the concepts highlighted by the literature review, as well as emerged during the reading of the transcripts.

3.2 Literature review

The formulation of a theoretical framework as a basis for establishing an analysis of the historical evolution of LSS programs in organizations resulted from a bibliographic review of LSS theme and the various aspects related to the implementation, sustainability, and evolution of programs in organizations, having been consulted books, scientific articles and technical documents, among LSS project reports. Searches were carried out in the main scientific databases such as Science Direct, Web of Science, Scopus, Periodicals CAPES, among others. The searches were carried out using the following descriptors: six sigma, lean six sigma, six sigma programs in organizations, and DMAIC (Define, Measure, Analyze, Improve, Control cycle in organizations. Searches were also carried out on sites specializing in lean six sigma.

3.3 Overview of adaptations/changes of lean six sigma programs in organizations in the last fifteen years

In the analysis of the data from the 2005 applied research results and in the conclusion of the analysis of the historical evolution based on the bibliographic review, an attempt was made to establish a conceptual reference panorama on the stages of change in the last 15 years and the alterations in the critical factors of success related to the implementation of LSS programs in organizations.

Several critical factors were evaluated, such as the financial benefits of the projects; newly incorporated methodologies; internal/external communication process; short-term culture; leadership sponsorship; program continuity; prioritization and selection of projects; resistance; dedication of resources to projects; staff turnover; training of belts, among others.

4 Results

In this session, the result of the qualitative research carried out by the authors with specialists from the LSS program in a service sector organization in 2005 is presented, listing the CSF for LSS programs identified by them at the time.

Next, the result of the bibliographic review for the period between 2005 and 2021 with the mapped CSF is presented, which already allows comparison with the research carried out with specialists in 2005.

4.1 Impact of critical success factors (CSF) for implementing lean six sigma programs in 2005

The aspects that facilitate or hinder the implementation of an LSS approach in an organization, analyzed in the case study developed in 2005, found support in the literature on quality and change that time. The analysis of the CSF related to the implementation of LSS from the perspective of change management was often responsible for creating new interpretations of the already known problems and was perhaps one of the greatest contributions of this research.

The factors revealed and investigated from the analysis of the series of interviews led us to a selection of the nine CSF listed in Table 1:

Table 1. CSF (Critical Success Factors) identified in the 2005 survey.

#[1]	Critical Success Factors (CSF)
1	Communication
2	Organizational culture and the depth of change
3	The commitment of individuals to change
4	Role of Middle Managers
5	Resistance to change
6	Senior Management Commitment
7	Project Selection and Prioritization
8	Training
9	Disclosure of results

[1]The # symbol in the table represents the list of Critical Success Factors identified in the 2025 survey.

4.2 Impact of critical success factors (CSF) for the implementation of lean six sigma programs from the current scenario

In the literature review of the last 15 years, it was noticed that the nine CSF that already stood out in the 2005 survey continued to be relevant in the current context. It is evident from the results presented in Table 2 that technological advances and the digital transformation experienced in all sectors of society have added three new critical factors for the success of LSS programs in organizations: big data analytics, agile manufacturing, and innovation.

Table 2. CSF (Critical Success Factors) identified in the survey from 2005 to 2021.

#[1]	Critical Success Factors
1	Communication
2	Organizational culture and the depth of change
3	The commitment of individuals to change
4	Role of middle managers
5	Resistance to change
6	Top management commitment
7	Project selection and prioritization
8	Training
9	Disclosure of results
10	Big Data Analytics (BDA)
11	Agile Manufacturing
12	Innovation

[1]The # symbol in the table represents the list of Critical Success Factors identified in the survey from 2005 to 2021.

Decisions based on facts and data using BDA have assumed a critical role in the successful implementation of LSS projects in the last decade, as a new frontier of knowledge has opened up with the possibility of analyzing large volumes of data generated on different platforms and from different forms (structured, semi-structured and unstructured), enhancing analyzes and solutions within projects.

The synergy between Agile Manufacturing and LSS lies in the understanding that, together, they allow increased control over the operation and maintenance systems and enable the ability to change production as needed, in order to neutralize any disruptive events. In a scenario where machine-to-machine communication and the analysis of continuously generated data are already a reality, current lean six sigma projects conducted in the industry will necessarily be dialoguing with the concepts of Agile Manufacturing in its various stages, from data analysis to the formulation of solutions and control of expected results.

Finally, the innovation factor deserves special mention, considering the increasing protagonism conquered in the agenda of organizations in the current times. The critical analysis of the specialized literature brought us insights that LSS and innovation do not conflict but rather intertwine and support each other. Although superficial evaluations may suggest that the discipline and methodological rigor characteristic of LSS may inhibit innovation, a more attentive reflection on the subject and the recent experiences studied confirm that creativity is necessarily present in all stages of LSS method, which makes it an innovation facilitator approach, to be it incremental or larger scale.

5 Conclusion

Considering the central objective of this research is to establish an overview of the stages of change of lean six sigma programs in organizations in the last 15 years to identify whether or not there were changes in the critical success factors (CSF) for LSS between the year 2005 and the year 2021, the methodological approach used made it possible to ratify that: (i) the factors that in the 2000s were seen as critical to success (CSF) in the implementation of quality improvement programs have continued to be relevant to the present day; (ii) factors related to human beings and their role in organizations, such as communication, change management, leadership, and others, already showed in the 2000s and continue to show their relevance in the work environment today. Such factors, therefore, deserve to continue occupying a central place in the plans and actions of organizations and, above all, the attention of leaders who wish to obtain sustainable results from their LSS programs; (iii) over the last 15 years, attention to factors associated with technology, such as the use of Big Data Analytics and the connection with the concept of Agile Manufacturing, has gained relevance for the success of the implementation of quality improvement programs, as well as attention to factors linked to innovation and digital transformation, following industry 4.0 trends. The consideration of these factors, represents the new frontier and has increasingly influenced the success of LSS programs in organizations in recent years.

The theoretical contributions of this study are based on the analyzes and reflections derived from the data described in the results. Regarding practical contributions, the study sought to offer solutions to real problems found in the concrete world, promoting a reflection on the changes in LSS program in organizations through the identification and analysis of critical success factors (CSF).

The sample space of the initial study was a limitation of the research as it was restricted to only one company and to the telecommunications sector.

This study does not exhaust the theme of change with a focus on quality and lean six sigma and it is not intended that its results are proven to be generalizable to all organizations, but rather that they are useful as a reference for companies involved in similar processes and for research on common nature. Thus, it is suggested that future studies on the subject carry out qualitative research to evaluate the CSF of LSS programs in other segments/sectors such as the mining, oil and gas sector, industries, technology companies, start-ups, etc.

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Authors contribution

Eduardo Lopes de Sousa was responsible for planning this study, for carrying out the research, collecting, analyzing, interpreting data, writing and preparing the manuscript for publication. Fabricio Viana Andretti acted as a collaborator of the research group, participating in the conceptualization and theoretical-methodological approach, in the writing and in the final revision of the referred manuscript for its publication. Marcelo Tadeu Grimaldi de Castro participated in the conceptualization and theoretical-methodological approach and acted in the theoretical review, as well as in the data analysis, writing and final revision of the referred manuscript for its publication.