An overview of key methodologies employed in continuous quality improvement: applicability and trends

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Abstract. Pursuing excellence in testing and calibration laboratories is a constant challenge to ensure the quality and reliability of results, guaranteeing customer satisfaction. In this context, continuous improvement methodologies have been widely applied to increase the efficiency of processes, reduce costs and minimise errors. This article aims to conduct a state-of-the-art analysis on applying the main methodologies associated with continuous improvement in testing and calibration laboratories, highlighting the main contributions and challenges faced. Recent studies and practical examples of its application are presented, and trends are discussed. The results show that Kaizen, Lean, Six Sigma are usually applied, with Kaizen in industrial applications and Lean Six Sigma tending to industrial applications and Lean Six Sigma emerging as a future trend.

1. Introduction

In a world where services compete for space, any differential can define success or failure. This competition demands dynamism between the consumer and supplier markets, with a focus on the agility and efficiency of service delivery. On the other hand, the financial impact achieved through the implementation of strategies, both for waste reduction and quality maintenance, has increased interest in research describing different tools, methodologies, and application niches [1-3].

In this scenario of increasing demand for high-quality services and products [3,4], there is great interest in implementing continuous quality techniques and quality management in various fields of operation [5], particularly in the industrial sector [6-8].

Methodologies such as Lean and Six Sigma, as well as the hybridisation formed by their respective combination, Lean Six Sigma (LSS), directly contribute to quality maintenance [3, 9-10]. Another approach that emerged in Japan, initially targeting the automotive industry [2-3, 11-12], aims at waste reduction and efficiency improvement through continuous small actions [13-15].

Although initially conceived for industrial applications, these methodologies have gradually been adopted by other fields of operation, such as healthcare [3, 14, 16-17], education [18-20], and those associated with accredited or non-accredited laboratories [21]. Particularly in this domain, while there are concerns about equipment, supplies, and facilities, one factor that is sometimes overlooked is the

human factor, which can have a negative impact on testing operations, leading to increased time for completion and higher levels of waste [22-23].

An alternative to this issue consists of increasing the involvement of different collaborators working within a particular enterprise in discussions about improvements and quality maintenance, thus promoting continuous quality control. In this regard, approaches such as Kaizen and Lean Six Sigma stand out as methodologies that aid in quality maintenance by ensuring that testing and calibration laboratories comply with normative requirements. This is achieved through the promotion of employee and leadership training, collaborative activities, and the implementation of scientific and organisational mechanisms.

These actions facilitate decision-making, enhance operational efficiency, and reduce waste and process variability, thereby improving laboratory management by developing employees and researchers [1, 3, 10, 14, 20, 24-30].

This work aims to review research on continuous quality improvement, the main methodologies employed and their application.

The present work is structured into five sections. In addition to this introduction, Section 2 describes the main tools applied in continuous quality improvement. Section 3 describes the methodology applied on the literature review, while the results are presented in Section 4. These results are discussed in Section 5, including the conclusion and suggestions for future work.

2. Tools for Continuous Quality Improvement

In this section, some of the main tools/methodologies associated with continuous quality improvement will be presented.

2.1. Kaizen

Kaizen is a globally renowned and applied methodology, created by the Japanese Masaaki Imai to improve manufacturing quality in Japan, with its core principle being the involvement of all company collaborators [24]. The objective of this methodology is continuous improvement in the quality of products and/or services to meet customer demands [4]. Implementing continuous improvement practices is based on three key points: involving all people, every day, and in all areas [22].

According to [31], there are ten commandments developed by [32] that should be followed in the Kaizen methodology: (i) eliminate waste; (ii) make continuous incremental improvements; (iii) involve all employees in the process (from managers to the operational base); (iv) increase productivity without significant investments; (v) apply the methodology within and beyond the Japanese culture; (vi) ensure complete transparency of procedures, processes, and values, making waste and problems visible to everyone; (vii) focus on the areas that generate profitability, such as the factory floor; (viii) orient towards processes; (ix) prioritise people by guiding personnel towards quality, teamwork, nurturing wisdom, boosting morale, self-discipline, quality circles, and encouraging individual or group suggestions; (x) the essence of organisational learning lies in learning by doing.

2.2. Lean

Lean is a methodology created in Japan by Taiichi Ohno, an engineer and production manager at Toyota [33]. It is used by companies across all sectors with the objectives of waste and inventory reduction, cost reduction, production improvement and flexibility, process enhancement, and associated logistics improvement [8, 24, 34-36].

According to [7, 20, 36-37], the success of Lean implementation depends on the involvement of all employees through training and organizational change within the company, using improvement tools to achieve success in the effective and enduring implementation of this quality tool.

2.3. *Six Sigma*

The Six Sigma method was developed by engineer Bill Smith at the American company Motorola during the 1980s [35, 39], a period of intense competition, especially from Japan [40]. Its initial purpose was to improve businesses by eliminating errors in production processes and defects in products. To achieve this, statistical data collection was used, which proved essential in resolving issues related to poor quality and ultimately satisfying customers [9, 40-44].

2.4. *Lean Six Sigma*

The Lean Six Sigma (LSS) methodology is a term formed by the combination of two quality methodologies, Lean and Six Sigma, to reduce production costs, enhance an organisation's capability, improve the quality of products and services [8, 34], and thus reducing customer waiting time [45].

3. Research Methodology

A systematic literature review (SLR) was conducted as a structured, robust, repeatable, and transparent process to investigate the existing literature [46] analytically. This type of research has been widely used by many authors to organise the main contributions in different areas of knowledge, such as in fields related to the automotive industry [2, 3, 11-12] education [18-20], food industries [36], and healthcare [3, 17]. It helps synthesise research and provides valuable insights for future studies. The following section will detail the methodology employed for the SLR.

3.1. *Research Planning*

The study aims to understand how the combined use of Lean, Six Sigma, Lean Six Sigma, and Kaizen methodologies can contribute to the continuous improvement of quality management in different areas, especially in testing and calibration laboratories.

Four groups of interest were defined and are associated with the proposed theme, namely: (i) Quality; (ii) Tools; (iii) Standards; and (iv) Location. For each group, a set of keywords was identified based on the terms and keywords found in the literature when researching continuous quality (Table 1).

Table 1 – Keywords selected according with the work's scope.

Group	Keyword
Quality	"Continuous Quality Improvement" OR "Quality Improvement" OR "Quality Management" OR "Quality Assurance" OR "Quality" OR " Quality Control" OR "Quality Management System"
Tool	"kaizen" OR "lean" OR "lean six sigma" OR "pdca" OR "six sigma"
Norm	ISO/IEC 17025 OR "17025 " OR "ISO standards " OR " iSO"
Site	"Testing and Calibration Laboratories" OR "Laboratory accreditation" OR "Calibration laboratories"

Research papers, review articles, and conference proceedings indexed in 3 important databases were searched: Google Scholar, Scopus, and Web of Science. Language filters (English language only) and temporal filters (works published between 1994 and 2022) were applied. The temporal cutoff was justified since the vast majority of works have been published after 1994 (Figure 1).

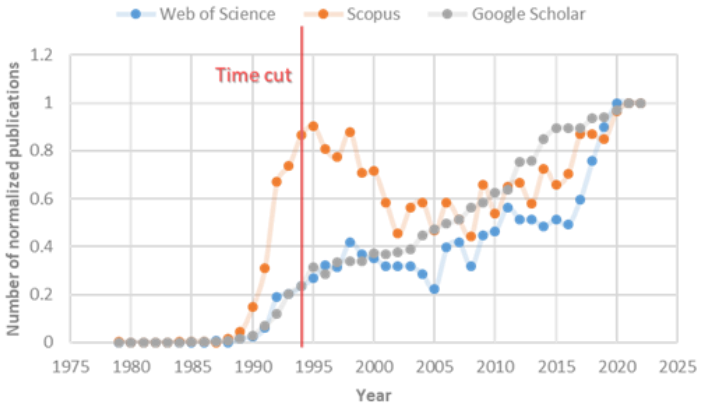

Figure 1 – Normalization number of publications searched in Google Scholar, Scopus and Web of Science databases.

Once the described filtering was performed, intersections were made with the keyword groups (Table 1), evaluating the overlap of articles obtained between the 4 groups. Finally, the titles and abstracts of the identified articles were read, and 41 articles that best related to the purpose of this study were selected.

4. Results

In this section, the main results of the conducted literature review are presented.

The number of articles found when different keyword intersections were performed in 3 datasets (Google Scholar, Scopus and Web of Science) is shown in Table 2.

Table 2 - Result of the search strategy in Google Scholar: 1994 - 2023

#	Key words	Web of Science	Scopus	Google Scholar
1	Kaizen	988	1911	182000
2	Lean	86190	119091	3870000
3	Six Sigma	4544	8913	201000
4	Lean Six Sigma	1444	2314	50800
5	Continuous Quality Improvement	3019	4748	116000
6	Testing and Calibration Laboratories	104	179	12300
7	#1 AND #2	412	875	5700
8	#1 AND #3	88	184	25800
9	#1 AND #4	42	74	15100
10	#1 AND #5	7	21	3400
11	#1 AND #6	0	0	65
12	#1 AND #2 AND #3 AND #4	42	74	15100
12	#1 AND #2 AND #3 AND #4 AND #5	0	14	889
13	#1 AND #2 AND #3 AND #4 AND # 5 AND #6	0	0	3

In Figure 2, the information on publications that used each of the 4 quality tools investigated is summarised. In Figure 2(a), the number of publications over time is shown, and in Figure 2(b), the most used tools are indicated by the application area.

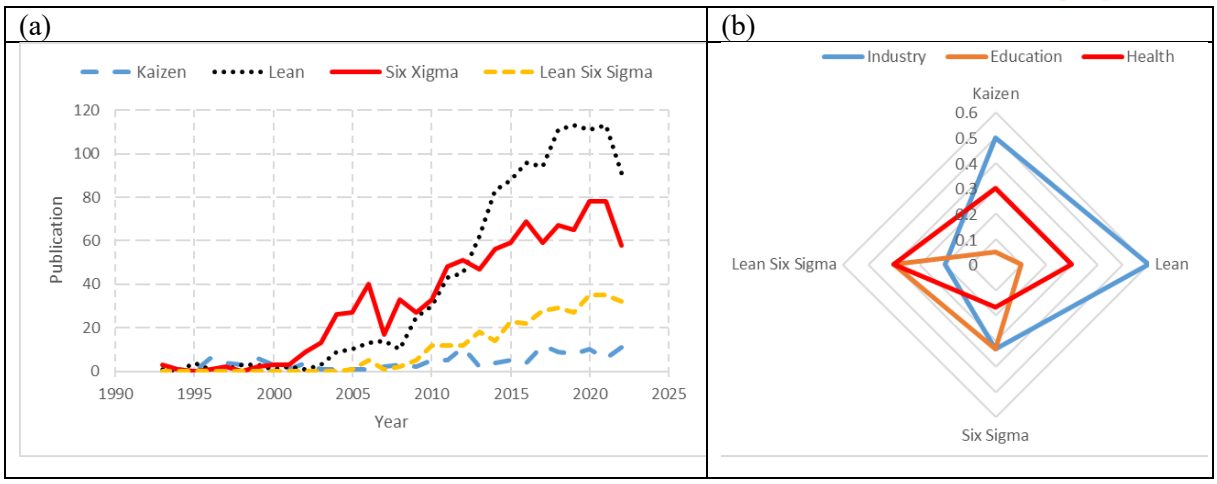

Figure 2 – (a) Evolution of publications by tool over time; (b) Main applications by industry sector and tool.

Table 3 Presents the identification of the methodologies and their applications according to the authors of the 41 articles identified as most relevant for this research.

Table 3 – Relevant aspects of the selected articles.

Methodology	Year	Authors	Application
Kaizen	1994	Imai	Industry
	1997	Eidgahy	Education
	1999	Ennis	Health
	1999	Richardson et al.	Health
	2000	Mckinley et al.	Laboratory
	2003	Brunet e New	Industry
	2006	Briales e Ferraz	Industry
	2006	Rebechi	Industry
	2016	Raiser et al.	Industry
	2016	Oliani	Industry
	2016	Lucio	Laboratory
	2016	Dinis	Industry
	2018	Loureiro	Pharmacy
	2018	Gumba	Health
	2019	Kumar	Industry
	2019	Sladen et al.	Health
	2019	Zocca et al.	Industry
	2021	Lordelo et al.	Health
	2021	Yogeswary et al.	Industry
	2022	Flug et al.	Health

Table 3 – Relevant aspects of the selected articles (*cont*).

Methodology	Year	Authors	Application
Lean	1997	Womack	Industry
	2008	Silva	Industry
	2010	Trilling et al.	Health
	2012	Radnor e Holweg	Health
	2016	Dora et al.	Industry
	2018	Blouin-Delisle	Health
	2018	Mendes et al	Education
	2018	Ng e Ghobakhloo	Industry
	2020	Saetta e Caldarelli	Industry
	2022	Yilmaz et al.	Industry
Six Sigma	2000	Henderson e Evans	Industry
	2004	Antony	Education
	2011	Antony	Education
	2016	Hassan	Computing
	2019	Vetter e Morrice	Health
	2010	Taghizadegan	Industry
Lean Six Sigma	2016	Antony	Education
	2017	Antony	Education
	2018	Guo et al.	Health
	2018	Ahmed	Health
	2019	Parmar e Desai	Industry

5. Discussion and Conclusion

The results indicate a more intense use of Lean over the years, followed by Six Sigma, and the least utilization of the Kaizen methodology. There is also an observed increasing trend in the use of all four methodologies, which supports the premise of this research. Among the 41 selected articles, Lean and Kaizen are the most commonly employed in the industry, followed by Six Sigma, with very little application of Lean Six Sigma. However, there were very few studies related to the use of such methodologies in testing and calibration laboratories. This finding motivates us to propose future research on the implementation of continuous quality methodologies in testing and calibration laboratories.

In this work, research related to the topic of continuous improvement and the methodologies Kaizen, Lean, Six Sigma, and Lean Six Sigma were conducted. In the state-of-the-art survey, solutions employed by various authors in the industrial, healthcare, and educational sectors were identified, highlighting the gap regarding applying the continuous improvement theme and the main methodologies in testing and calibration laboratories.

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