Lean and Six Sigma Philosophies and Organizational Performance: A Study in Portuguese Laboratories

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ABSTRACT

Purpose: This research aimed to make a diagnosis of the implementation of Lean and Six Sigma philosophies in Portuguese laboratories and to evaluate the impact of these philosophies on organizational performance.

Methodology/Approach: A quantitative research methodology was used, based on the survey research strategy, and using as data collection instrument an original online questionnaire, validated and distributed to the Portuguese laboratories via email. The sample was composed by 106 laboratories. Descriptive and inferential statistical analysis were applied to the data, using IBM SPSS software.

Findings: It was found that most laboratories do not know the Lean Approach and/or Six Sigma philosophies, and their implementation occurred in about one tenth of the sample. The laboratories that implemented the philosophies were found to have a larger number of employees and turnover. Finally, regarding organizational performance it was found to be superior in laboratories that implemented at least one of the philosophies when compared to laboratories that did not implement any Lean and/or Six Sigma philosophy.

Research Limitation/Implication: The small sample size, which corresponds to approximately 15% of the population, is the main limitation of the study.

Originality/Value of paper: This study is the first diagnosis on the application of Lean and Six Sigma philosophies made in the Portuguese laboratory market, and may provide relevant inputs for decision-making in this context.

Category: Research paper

Keywords: lean; six sigma; lean six sigma; organizational performance; portuguese laboratories

1 INTRODUCTION

In an increasingly competitive context, companies see the need to implement a culture of continuous improvement as an imperative to cope with the constant volatility of the market. In this sense, Lean and Six Sigma philosophies, widely applied in industry, have been adopted in the services area, given the remarkable results provided in organizations in terms of process improvement (Andersson, Eriksson and Torstensson, 2006; Oliveira, 2013; Dave, Murugesh and Devadasan, 2015; Neto, de Faria and da Silva, 2015; Dinis-Carvalho, Monteiro and Macedo, 2020; Lima et al., 2021).

As in other organizational areas, also in the laboratory market, as a result of its constant evolution, competitiveness and customer needs, there is an urgency to maintain processes with a high level of flexibility and value creation (Berlitz, 2011). Nowadays, laboratories are increasingly faced with greater challenges associated with increasing workload and reducing costs. The need to increase efficiency and quality levels is becoming critical today (Santos and Barbosa 2006; Gras and Philippe, 2007; Sá et al., 2015; Costa et al., 2019; Santos et al., 2019; 2021).

The study of laboratories has greater importance when their role in defining medical diagnosis is perceived. Considering the impact that analytical results may have on human health, elements such as response time and reliability of results are of utmost importance. The implementation of Lean Thinking concepts and Six Sigma tools, with clearly proven benefits in industry and services, has shown significant improvements in several performance indicators, such as the level of productivity, response time, costs, quality of results and customer satisfaction (Doiro et al., 2017; Silva, 2013; Neto, de Faria and da Silva, 2015; Inal et al., 2017; Santos et al., 2017; Malacarne, 2018).

In this context, this research aims to make a diagnosis of the level of knowledge and implementation of Lean and Six Sigma philosophies in Portuguese laboratories, as well as an evaluation of the impact of these philosophies on organizational performance. In addition, it compares the results obtained in Portugal with those described at the international level, since at this level significant and widely important benefits are observed for the area of laboratory diagnostics (Berlitz, 2011; Buljanović, Patajac and Petrovečki, 2011; Moraes et al., 2013; Agarwal et al., 2016; Havinga, 2018).

The following section presents the literature review, followed by the research methodology that support this research. Section 4 provides the results of the study. The final sections present the discussion of the results and the conclusions.

2 LITERATURE REVIEW

2.1 Lean Thinking

“Lean is the term used to describe a management philosophy and set of principles for the continuous improvement of any production process, focusing on eliminating waste and creating a better product from the customer’s point of view” (Collins and Wiersma, 2008, p.1). For the materialization of the Lean Thinking (Womack and Jones, 1996) several tools can be used such as Value Stream Mapping (VSM), Seiri – separate/classify, Seiton – organise/arrange, Seiso – clean, Seiketsu – standardise, Shitsuke-self – discipline/respect (5S), Visual management, Standardised work, Single Minute Exchange of Die (reduction of setup process time) (SMED), Poka-Yoke, One piece flow production, Production balancing, Pull system, Kanban, Heijunka (production levelling), Mizusumashi (internal supply operator), Jidoka (automation), Spaghetti diagram, Gemba (shop floor), Total Productive Maintenance (TPM), Organisation of people in work cells, Visual communication A3 Problem Solving, and Kaizen (continuous improvement) (Liker and Meier, 2006; Neto, de Faria and da Silva, 2015; Oliveira, 2013; Tague, 2005).

Some of the Lean tools described have more applicability in the area of industry, while others can be implemented in services. Of these tools, we can highlight VSM, 5S, Visual management and Standardized work that are widely used in the laboratory area and show very positive results in terms of productivity and efficiency, allowing laboratoires to continuously adapt to customer and market demands (Berlitz, 2011).

In general, the aim of Lean thinking can be described in a simplified way as the way of doing more with less (Vaz, Morgado and Lima, 2017; Sá et al., 2020). In the laboratory context the same aims are applied. The objective is to perform a higher volume of analyses, in less time and with less space, i.e., to minimize the consumption of resources that do not add value to the final product, which is expressed in cost reduction and increased productivity (Garikes, 2004; Gonçalves, 2012; Ribeiro et al., 2019).

According to the literature, it is possible to list a set of positive results with the application of the Lean philosophy in laboratories, such as: increase in productivity and efficiency (Graban, 2007; Collins and Wiersma, 2008; Cankovic et al., 2009; Rutledge, Xu and Simpson, 2010; Berlitz, 2011; Campos, 2012; Gonçalves, 2012; Moraes et al., 2013); greater process flexibility (Berlitz, 2011); and reduction in response times (Collins and Wiersma, 2008; Moraes et al., 2013; Cankovic et al., 2009; Graban, 2007; Rutledge, Xu, and Simpson, 2010; Gonçalves, 2012).

In addition to the aforementioned benefits, there are others such as: reduction in costs (Collins and Wiersma; 2008; Graban, 2007; Rutledge, Xu and Simpson, 2010; Gonçalves, 2012); better use of space and reduction in the movement time of collaborators and samples (Graban, 2007; Rutledge, Xu and Simpson, 2010;

Gonçalves, 2012); reduction in the number of equipment (Moraes et al., 2013); increase in the number of samples collected (Cankovic et al., 2009; Rutledge et al., 2010); improvement in the quality of the tests performed (Moraes et al., 2013); increase employees motivation (Collins and Wiersma, 2008; Halwachs-Baumann, 2010; Zayko, 2007; Moraes et al., 2013); increase proximity with customers (Gonçalves, 2012); and improvement of the laboratory's image (Gonçalves, 2012).

Lean process improvements make it possible to do more with less, as a considerable increase in the number of samples may not lead to the need for new recruitment (Cankovic et al., 2009; Rutledge et al., 2010). IT and automation also play a very important role in the overall increase of efficiency in a laboratory, allowing to optimise flows, reduce errors, improve turnaround times and sample traceability and safety (Cankovic et al., 2009; Halwachs-Baumann, 2010).

"Effectively it is found that performance in Lean laboratories is clearly superior to more traditional laboratories", because it is about "using existing resources intelligently, eliminating waste and providing the customer with what they perceive as added value" (Collins and Wiersma, 2008, p.8).

2.2 Six Sigma

Six Sigma corresponds to the ability of a process to produce units within established limits. The objective of this philosophy is to reduce variation in processes through continuous and innovative improvements in order to guarantee customer satisfaction (Andersson, Eriksson and Torstensson, 2006). It is defined by Snee (2004, p.8) as "an improvement approach that seeks to find and eliminate the causes of defects in processes by focusing on the process outputs that are of critical importance to customers".

In fact, the good results obtained with the application of this philosophy in terms of the reduction of defects and improvements in processes are evident (Elder, 2008). Linderman et al. (2003, p.195) describe Six Sigma as "an organised and systematic method for improving strategic processes and developing new products and services, which relies on statistical and scientific methods to drastically reduce the defect rates defined by the client".

Several components are listed as necessary for the implementation of a Six Sigma project, such as the infrastructure, organization, training, statistical tools, highlighting as essential the involvement of the management/administration. In its implementation it is necessary to create an organizational and multidisciplinary structure with delineation of the different responsibilities and functions within the team, which should be hierarchically distributed as follows: Sponsor, Master Black Belt, Black Belt and Green Belt (Andersson et al., 2006; McCarty et al., 2004; Westcott and Duffy, 2014; Winters-Miner et al., 2015). One of the characteristics of Six Sigma initiatives is that they involve intensive training and teams dedicated 50% to 100% of their time to improvement projects (Juran and Godfrey, 1998; Linderman et al., 2003).

The Six Sigma philosophy is supported by a methodology, which is based on five phases: Define, Measure, Analyze, Improve and Control (DMAIC) and focuses on existing processes to improve their performance (Andersson et al., 2006; Silva, 2013; Winters-Miner et al., 2015). A variation on DMAIC is Design for Six Sigma (DFSS), which is intended for the development of new processes, products or services. This methodology is also implemented in five steps: Define, Measure, Analyze, Design and Verify (DMADV) (Linderman et al., 2003; Andersson, Eriksson and Torstensson, 2006; Silva, 2013; Winters-Miner et al., 2015).

In the process of implementing the Six Sigma philosophy and in each of the phases of DMAIC, various quality techniques and tools are used, in addition to the classic and new quality tools, among which we highlight: Process capability analysis, Critical to Quality tree (CTQ tree), Brainstorming, Deployment diagram, Gantt diagram, Failure Mode and Effects Analysis (FMEA), Six Sigma metrics, Project charter, House of Quality (Quality Function Deployment (QFD)), Sigma-metrics method decision chart, Suppliers, Input, Process, Output, Costumers (SIPOC), Statistical Process Control (SPC), and Measurement Systems Analysis (MSA) (George, 2003; Tague, 2005; Bauer, Duffy and Westcott, 2006; Westcott and Duffy, 2014; Westgard, Bayat and Westgard, 2018).

Several studies on the application of this philosophy in laboratories have shown very positive results in several performance indicators, such as: quality and efficiency improvement (Elder, 2008; Westgard, Bayat and Westgard, 2018; Gaspar et al., 2015; El-hashmi and Gnieber, 2014; Gras and Philippe, 2007); improvement in tests and equipment performance (Jairaman, Sakiman and Li, 2017); reduction in rework (Jairaman, Sakiman and Li, 2017); cost reduction (Jairaman, Sakiman and Li, 2017; Elder, 2008; Westgard, Bayat and Westgard, 2018; Gras and Philippe, 2007); reduction of laboratorial variability and elimination of errors (Gaspar et al., 2015); increase customer satisfaction (Jairaman, Sakiman and Li, 2017); increase competence of collaborators (Jairaman, Sakiman and Li, 2017) and improvement in work organization (Xia et al., 2018).

2.3 Lean Six Sigma

The association of Lean and Six Sigma philosophies enables the monitoring, reduction and elimination of non-value adding activities and errors in an organisation's work and processes (Stankovic and DiLauri, 2008; Pereira et al., 2019). Both philosophies seek to increase efficiency, Lean by eliminating waste in the work performed and Six Sigma by reducing inefficiencies in process variation, so the results obtained are more effective when implemented together (Stankovic and DiLauri, 2008; Pereira et al., 2019) and their importance is growing in the current context of Industry 4.0 (Park, Dhalgaard-Park and Kim, 2020).

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When comparatively analysing the two philosophies, it is remarkable that their integration adds value to quality improvement projects (Andersson, Eriksson and Torstensson, 2006). Pereira et al. (2019) with the implementation of Lean Six Sigma tools in CNC machines, in a Moulding Industry, obtained an improvement of about 20% in the overall OEE. Guleria et al. (2022) obtained excellent improvements in an automobile transmission component manufacturing industry after successive implementation of Lean Six Sigma practices, such as reducing the reject rate (from 10.4% to 3.20%); reducing the shop floor area for processing axes, and improving the sigma level.

The Lean Six Sigma philosophy has been increasingly seen as a philosophy that can also bring great benefits to other areas of organizations, beyond the production process. Sá, Pereira and Almeida (2022), applied the Lean Six Sigma philosophy to the marketing area, and also achieved significant gains, with a reduction in response time of 11%, which was very good.

Some authors have tried to develop other methodologies to integrate Lean with Six Sigma more easily. Ferreira et al. (2019) is one of those cases, in conceived the iLeanDMAIC methodology based on Lean Tools and DMAIC, with the aim of helping organizations to solve their problems more easily and accurately. Recently, green Lean Six Sigma has emerged leading to greater productivity, profitability and environmental sustainability (Kaswan and Rathi, 2021), therefore it is essential that organisations make an assertive selection of projects that maximise organisational sustainability (Kaswan et al., 2023).

In a laboratory, the isolated use of Lean philosophy does not guarantee that processes are in statistical control, just as the implementation of Six Sigma projects not associated with Lean does not benefit from time and cost efficiency in the process flow, so their synergy is expressed in a higher level of quality (Hamilton, 2018).

According to the literature, the integration of Lean and Six Sigma has led to significant benefits for laboratories, of which we highlight: productivity improvement (Stankovic and DiLauri, 2008; Alkunsol et al., 2019); higher quality of the results (Stankovic and DiLauri, 2008; Alkunsol et al., 2019); reduction in the number of defects (Dave, Murugesh and Devadasan, 2015; Neto, de Faria and da Silva, 2015; Oliveira, 2013; Inal et al., 2017); elimination of waste (Dave, Murugesh and Devadasan, 2015; Neto, de Faria and da Silva, 2015; Oliveira, 2013); reduction in the response time (Stankovic and DiLauri, 2008; Damato and Rickard, 2015; Agarwal et al., 2016); and reduction of rework (Damato and Rickard, 2015; Havinga, 2018).

2.4 Organisational Performance

Organisational performance is associated with the results achieved by an organisation. The results are assessed by indicators and these have associated goals and objectives, so that the organizational performance assessment is carried out by comparing the results obtained with the established goals (Brandão, Borges-Andrade and Guimarães, 2012).

Organizational performance is a multidimensional concept that includes, in addition to the financial dimension, considered as the narrowest view of the concept, the social/environmental and workers/community dimensions (Dess and Robinson, 1984). According to Venkatraman and Ramanujam (1986), organizational performance is a concept of extreme importance and has three levels, gradually more comprehensive, namely:

- financial performance
- financial and operational performance
- organizational efficiency.

One of the organisational strategies is to divide the performance indicators into four perspectives that influence each other:

- economic-financial perspective
- customers perspective
- internal processes perspective
- knowledge and growth perspective (Brandão, Borges-Andrade and Guimarães, 2012).

According to the literature, the following performance indicators are commonly considered in laboratories: turnover, market share, quality control, response time, customer satisfaction, motivation and number of employees, costs, rework, nonconformities, productivity and efficiency, among others (Zayko, 2007; Gras and Philippe, 2007; Elder, 2008; Stankovic and DiLauri, 2008; Halwachs-Baumann, 2010a; Silva, 2013; Agarwal et al., 2016; Jairaman, Sakiman and Li, 2017; Havinga, 2018; Westgard, Bayat and Westgard, 2018; Alkunsol et al., 2019).

In a laboratory, analytical quality is validated by the results obtained in quality control (internal and external) of each of the assays, determining whether the assay is in statistical control. In this context, quality control parameters can be adjusted to optimise performance metrics. At this level there are several quality control tools that may vary according to the type of test to be performed (Schmidt and Pearson, 2019).

One of the tools that has been used at the level of quality control, both internal and external, in clinical laboratories are the Six Sigma metrics that allow the evaluation and comparison of the performance of assays and laboratories on the Six Sigma scale (Sciacovelli, Aita and Plebani, 2017; Westgard, Bayat and Westgard, 2018).

The accreditation and certification of laboratories also play an important role in the definition of performance indicators insofar as the implementation of the respective standards imposes the fulfilment of several requirements that aim for superior performance in terms of the quality of the tests performed (Sciacovelli et al., 2019).

3 METHODOLOGY

To achieve the objectives of this study, a deductive research approach was adopted (Saunders, Lewis and Thornhill, 2009). A quantitative research methodology was used, based on the survey research strategy (Coutinho, 2014; Saunders, Lewis and Thornhill, 2009). In addition to collecting primary data from the sample, which aimed to establish relationships among the variables (Coutinho, 2014; Saunders, Lewis and Thornhill, 2009), this study allowed to obtain relevant information about the laboratory area at a national level regarding the implementation of Lean and Six Sigma philosophies.

As an instrument of data collection, an online, validated questionnaire was used (Saunders, Lewis and Thornhill, 2009) which was developed on the Goggleforms platform and distributed to the Portuguese laboratories via email. In order to guarantee a higher percentage of valid questionnaires, facilitate data analysis and increase the objectivity of the answers, it was decided to formulate mostly closed and mandatory questions (de Marconi and Lakatos, 2003). A five-point Likert scale was used for most of the questions (Passmore et al., 2002).

Considering that “the quality of the data obtained depends on how well respondents understand the questionnaire items or questions” and the clarity of the questions (Passmore et al., 2002, p.281; Saunders, Lewis and Thornhill, 2009), the questionnaire was submitted to validation by four laboratories (pre-test), with identical characteristics to the laboratories in the population, in order to assess its adequacy and consistency, as well as to appreciate the correct wording of the questions. None of the laboratories included in the pre-test was part of the final sample (de Marconi and Lakatos, 2003).

The questionnaire was structured into three groups: Group A, referring to general company data such as geographical location, size and turnover, analytical and accreditation/certification scope and evolution in some performance indicators, Group B, directed at practices related to the Lean philosophy and Group C, directed at practices related to the Six Sigma philosophy.

According to the research objectives, the population consists of a total of 695 Portuguese laboratories. Of these 9 are accredited clinical laboratories (ISO 15189), 343 are accredited testing laboratories (ISO/IEC 17025), 58 are accredited calibration laboratories (ISO/IEC 17025), 120 are certified laboratories (e.g. ISO 9001 or ISO 14001). The remaining 165 laboratories are non-accredited or certified, of which 156 belong to national and regional health systems and 9 operate in the veterinary clinical area.

The questionnaire was applied using the Goggleforms platform. The response period was four weeks, during October and November 2019.

The sample consists of 106 laboratories, which corresponds to a response rate of 15%. According to Saunders, Lewis and Thornhill (2009) in survey research strategy, the response rate to questionnaires tends to be around 10-20%.

For the results to be generalisable it is crucial that the sample be representative of the population (de Marconi and Lakatos, 2002; Saunders, Lewis and Thornhill, 2009). As can be seen in Table 1, the sample is similar to the population, since it has laboratories from all strata of accreditation/certification and analytical scope and presents an equivalent data distribution.

In terms of accreditation/certification, 86% of the laboratories in the sample (n = 91) are accredited and/or certified, of which 82% are accredited to ISO/IEC 17025 (n = 75). With regard to the size of the laboratories, it can be seen that 52% of the laboratories have up to 10 employees.

Table 1 – Comparative Table of Sample and Population Distributions by Accreditation/Certification and Analytical Scope

Laboratories	**Population**		**Sample**	
Accredited clinical Laboratory (ISO 15189)	1.3%	9	0.9%	1
Accredited testing laboratory (ISO/IEC 17025)	49.4%	343	63.2%	67
Accredited calibration laboratory (ISO/IEC 17025)	8.3%	58	7.5%	8
Certified laboratory (ISO 9001, ISO 14001, and others)	17.3%	120	14.2%	15
Laboratory not accredited or certified	23.7%	165	14.2%	15
Totals	100%	695	100%	106

Descriptive and inferential statistical analyses were performed using IBM SPSS Statistics software.

4 RESULTS

The results section are divided into two parts: characterisation of the sample with regard to the level of knowledge and application of Lean and Six Sigma philosophies; and analysis of the relationship between the implementation of Lean and Six Sigma philosophies and laboratory performance.

4.1 Level of Knowledge and Application of Lean and Six Sigma Philosophies

Concerning the level of knowledge of the Lean philosophy, it was found that 52% of the sample laboratories had no knowledge of the philosophy (n = 55). The distribution of the sample by type of laboratory with regard to the level of knowledge/application of the Lean philosophy is shown in Table 2.

Table 2 – Distribution of the Sample by Type of Laboratory and Level of Knowledge of the Lean Philosophy

Level of knowledge and application	**Total laboratories**	**Clinical Laboratories (certified/ accredited)**	**Clinical Laboratories (not certified/ accredited)**	**Calibration Laboratories**	**Testing Laboratories**
Does not know	55 (52%)	9 (64%)	10 (67%)	1 (12%)	35 (51%)
Known and not applied	38 (36%)	4 (29%)	4 (27%)	6 (76%)	24 (35%)
Know and applied	13 (12%)	1 (7%)	1 (6%)	1 (12%)	10 (14%)

As can be seen, the lack of knowledge of the Lean philosophy is higher than 50% in clinical and testing laboratories. In the calibration laboratories this percentage is much lower (12%), but a higher level of knowledge of the philosophy in these laboratories (76%) did not lead to its implementation.

In relation to the level of knowledge of Six Sigma philosophy, it was also found that most laboratories do not know Six Sigma (n = 59) and only 9% (n = 10) have implemented this philosophy. The distribution of the sample by type of laboratory with regard to the level of knowledge/application of the Six Sigma philosophy is shown in Table 3.

Table 3 – Distribution of the Sample by Type of Laboratory and Level of Knowledge of the Six Sigma Philosophy

Level of knowledge and application	**Total laboratories**	**Clinical Laboratories (certified/ accredited)**	**Clinical Laboratories (not certified/ accredited)**	**Calibration Laboratories**	**Testing Laboratories**
Does not know	59 (56%)	7 (59%)	11 (64%)	1 (9%)	40 (61%)
Known and not applied	37 (35%)	4 (33%)	3 (18%)	7 (64%)	23 (35%)
Know and applied	10 (9%)	1 (8%)	3 (18%)	3 (27%)	3 (4%)

As with the Lean philosophy, it can be seen that the lack of knowledge of the Six Sigma philosophy is also higher than 50% in clinical and testing laboratories. In the calibration laboratories this percentage is much lower (9%).

Of the total sample, only 16 laboratories implemented at least one of the philosophies, and 44% of these implemented both philosophies.

Regarding the analytical sector, it was found that of the laboratories under analysis (n = 16), 69% are testing laboratories, 25% are clinical laboratories and 6% are calibration laboratories. It was also found that, with the exception of the clinical laboratory, all other laboratories are accredited and/or certified. Of the 16 laboratories, 11 (69%) are accredited to ISO/IEC 17025.

As for the number of employees, 50% of the laboratories that have implemented at least one of the philosophies have more than 30 employees. Laboratories that have implemented Lean and Six Sigma philosophies are, on average, larger than those that have not implemented any philosophy.

4.2 Implementation of Lean and Six Sigma Philosophies and Organisational Performance

This research aimed to verify whether there is a relationship between the implementation of Lean and Six Sigma philosophies and laboratory performance.

It is known that performance is a multidimensional concept. As such it was measured on a scale of 1 to 5 (1 – decreased a lot, 2 – decreased, 3 – maintained, 4 – increased and 5 – increased a lot), using the following variables: number of employees; turnover; market share; quality control performance; number of tools used in quality control; response times; customer satisfaction and staff motivation. For each variable, the main descriptive statistics are presented in Table 4.

Table 4 – Descriptive Statiscs for the Performance Indicators

Variables	**Mean**	**Standard deviation**	**N**	**Min**	**Max**
Number of employees	3.06	0.701	106	2	5
Turnover	3.43	0.676	106	2	5
Market share	3.36	0.620	106	1	5
Performance achieved in quality control	3.37	0.652	106	1	5
No. of tools used in quality control	3.43	0.648	106	1	5
Response times	2.99	0.697	106	1	5
Customer satisfaction	3.30	0.588	106	2	5
Staff motivation	2.83	0.774	106	1	5

The performance indicators “Turnover” and “Number of tools used in quality control” are those with the highest mean ratings. The indicator “Staff motivation” is evaluated in a less positive way.

For the eight indicators, the results of laboratories that did not implement any philosophy (n = 90) were compared with laboratories that implemented at least one of the philosophies (n = 16). The Table 5 illustrates this comparison.

Table 5 – Descriptive Statistics for Performance Indicators

Variables	**Implementation of Lean and/or Six Sigma philosophies**	**N**	**Mean**	**Standard deviation**	**Standard error of the mean**
Number of employees	without	90	3.03	0.661	0.070
	with	16	3.19	0.911	0.228
Turnover	without	90	3.37	0.661	0.070
	with	16	3.81	0.655	0.164
Market share	without	90	3.31	0.593	0.062
	with	16	3.63	0.719	0.180
Performance achieved quality control	without	90	3.36	0.624	0.066
	with	16	3.44	0.814	0.203
No. of tools used in quality control	without	90	3.38	0.628	0.066
	with	16	3.75	0.683	0.171
Response times	without	90	2.96	0.652	0.069
	with	16	3.19	0.911	0.228
Customer satisfaction	without	90	3.26	0.591	0.062
	with	16	3.56	0.512	0.128
Staff motivation	without	90	2.82	0.758	0.080
	with	16	2.88	0.885	0.221

It was found that laboratories that have implemented Lean and/or Six Sigma philosophies show better performance in all performance indicators.

In order to verify whether the difference in the results of the performance indicators between the two groups of laboratories – laboratories that implemented at least one of the philosophies and laboratories that implemented none of the philosophies - is statistically significant, non-parametric Mann-Whitney U Tests were performed, since they appeared to be the most appropriate to the nature of the data. The following hypotheses were formulated:

H1: The level of performance, measured through the variable “Number of employees”, is different between the two groups of laboratories.

H2: The level of performance, measured through the variable “Turnover”, is different between the two groups of laboratories.

H3: The level of performance, measured through the variable “Market Share”, is different between the two groups of laboratories.

H4: The level of performance, measured through the variable "Performance achieved quality control" is different between the two groups of laboratories.

H5: The level of performance, measured through the variable "Number of tools used in quality control" is different between the two groups of laboratories.

H6: The level of performance, measured through the variable "Response times" is different between the two groups of laboratories.

H7: The level of performance, measured through the variable "Customer Satisfaction" is different between the two groups of laboratories.

H8: The level of performance, measured through the variable "Staff motivation" is different between the two groups of laboratories.

Table 6 – Mann-Whitney U-test

Variables	**Hypotheses**	**Sig.**[1]	**Decision**
Number of employees	H1	0.530	Hypothesis not supported
Turnover	H2	0.022	Hypothesis supported
Market share	H3	0.051	Hypothesis not supported
Performance achieved in quality control	H4	0.932	Hypothesis not supported
Number of tools used in quality control	H5	0.049	Hypothesis supported
Response times	H6	0.465	Hypothesis not supported
Customer satisfaction	H7	0.024	Hypothesis supported
Staff motivation	H8	0.717	Hypothesis not supported

Notes: [1] Asymptotic significances are displayed. The significance level is 0.05.

As can be seen in Table 6, for the indicators "Turnover", "Number of tools used in quality control" and "Customer satisfaction" it can be stated, with a confidence level of 95%, that the performance levels are statistically different between the two groups of laboratories. In these indicators, the group of laboratories that implemented Lean and/or Six Sigma philosophies presents higher performance levels than the group of laboratories that did not implement any of the philosophies.

Subsequently, organisational performance was considered as a composite variable, resulting from the aggregation of the 8 variables previously analysed. Reliability tests were performed for this new variable and a Cronbach's alpha value greater than 0.60 (0.713) was obtained, thus none of the variables was excluded from the study (Pestana and Gageiro, 2014). The Table 7 shows the descriptive statistics for the composite variable.

Table 7 – Descriptive Statistics for the Composite Variable "Organisational Performance"

Implementation of Lean and Six Sigma philosophies	Mean	N	Error Deviation	Min	Max
Without implementation	3.185	90	0.372	1.750	4.125
With implementation	3.430	16	0.418	2.875	4.375
Total	3.222	106	0.387	1.750	4.375

It was found that the organisational performance is higher in laboratories that have implemented at least one of the philosophies.

Similar to the previous study, the Mann-Whitney U-test was used to check the differences in performance between laboratories that implemented Lean and/or SixSigma philosophies and laboratories that did not implement any philosophy. The following hypothesis was formulated:

H9: The organizational performance is different between the two groups of laboratories.

Table 8 – Mann-Whitney U-Test - Composite Variable "Organisational Performance"

Variables	Hypotheses	Sig.[1]	Decision
Organisational performance	H9	0.039	Hypothesis supported

Notes: [1] Asymptotic significances are displayed. The significance level is 0.05.

It can therefore be stated, with a confidence level of 95%, that the organizational performance is statistically different between the laboratories that have implemented at least one of the Lean or Six Sigma philosophies and those that have not carried out any implementation (see Table 8).

5 DISCUSSION OF RESULTS

The literature review points to a greater success in organisations when they apply Lean and/or Six Sigma philosophies. In this study conducted in Portuguese laboratories it was possible to corroborate the literature, since it was concluded that overall performance is higher when Lean and Six Sigma tools are adopted in the laboratories. However, when analysing performance in its various dimensions, only three indicators stand out as relevant for identifying different levels of performance among laboratories, namely: "Turnover", "Number of tools used in quality control" and "Customer satisfaction".

Evaluating these three indicators the question may arise as to whether or not they are related to the good results described as derived from the implementation of Lean or Six Sigma philosophies (Womack and Jones, 1996; Andersson, Eriksson and Torstensson, 2006; Klefsjo, Bergquist and Edgeman, 2006; Womack, Jones and Roos, 2007; Collins and Wiersma, 2008; Oliveira, 2013; de Neto, de Faria and da Silva, 2015).

The “Turnover” indicator results from the multiplication of the prices applied by the quantities supplied to customers, so it is a variable that increases as a result of an increase in prices and/or an increase in quantities. Taking into account that Lean and Six Sigma philosophies aim at an improvement in efficiency, we can consider, the better performance in turnover of the laboratories. Thus, those that have implemented Lean and/or Six Sigma philosophies may be indirectly related to an improvement in efficiency promoted by such philosophies, which leads to an increase in the quantities produced (Gras and Philippe, 2007; Silva, 2013; Neto, de Faria and da Silva, 2015; Inal et al., 2017; Malacarne, 2018; Alkunsol et al., 2019).

As for the indicator “Number of tools used in quality control”, its increase may or may not prove to be a positive factor. On the one hand, an increase in the number of tools used in quality control may indicate a higher level of quality of the laboratory tests. On the other hand, a process that is in statistical control and with a high level of performance, enables the reduction of the number of controls applied (IPAC, 2018; NP EN ISO/IEC 17025, 2018; Westgard, Bayat and Westgard, 2018).

As mentioned in the literature, it was possible to evidence in this study that the “Customer Satisfaction” is a performance indicator with direct relation to the implementation of Lean and Six Sigma philosophies, since these originate an improvement in efficiency, quality and response times (Gras and Philippe, 2007; Silva, 2013; Neto, de Faria and da Silva, 2015; Inal et al., 2017; Malacarne, 2018; Alkunsol et al., 2019).

For the remaining performance indicators, when analysed individually, although the differences between the means did not prove to be statistically significant, it was observed that the means of the laboratories with at least one of the philosophies were higher than those of the laboratories without the philosophies.

Regarding the indicator related to the performance achieved in quality control, the results of the two groups of laboratories proved to be very close. The sample consisted mostly of accredited and/or certified laboratories, which in themselves already need to have very demanding internal procedures for quality control (IPAC, 2018; NP EN ISO 9001, 2015; NP EN ISO/IEC 17025, 2018).

It is also important to highlight the indicator “Staff motivation”, whose difference between the means is also very small and not statistically significant. According to several authors (Andersson, Eriksson and Torstensson, 2006; Collins and Wiersma, 2008; Cankovic et al., 2009; Antony and Kumar, 2012) for the success of the implementation of Lean and/or Six Sigma philosophies it is necessary, namely, training, dedicated teams and involvement of employees. It is also important the commitment of the leadership in the creation of an organisational and multidisciplinary structure, with delineation of the different responsibilities (Juran and Godfrey, 1998; Linderman et al., 2003; McCarty et al., 2004; Andersson, Eriksson and Torstensson, 2006; Zayko, 2007; Collins and Wiersma, 2008; Cankovic et al., 2009; Halwachs-Baumann, 2010a; Antony and Kumar, 2012; Moraes et al., 2013; Westcott and Duffy, 2014; Santos, 2014; Winters-Miner et al., 2015). In view of the above, it seems possible to state that in the laboratories that implemented the philosophies there may have been some failure in terms of training and team involvement.

Similarly to what happens in the corporate environment, in which these philosophies primarily developed in large industrial companies, this study also found that, of the laboratories that implemented the philosophies, only one does not belong to a larger corporate structure and 44% have a turnover greater than 1 million euros. Additionally, with regard to the indicator "Number of employees", there is a significant difference between the laboratories that implemented Lean and/or Six Sigma philosophies and those that did not, with the average number of employees of those that implemented almost double that of those that did not implement.

6 CONCLUSION

The literature review highlights the positive results obtained in terms of organisational process improvement with the implementation of Lean and Six Sigma philosophies, both at company and laboratory level. Both philosophies promote an increase in efficiency, Lean by eliminating waste and Six Sigma by controlling process variability with a reduction in the number of defects.

This study presents the results obtained in a representative sample of the Portuguese laboratory market. In general, most laboratories are not aware of Lean and Six Sigma philosophies, with only around one tenth of the sample having implemented them. It is also worth mentioning that the lack of knowledge of these philosophies is clearly higher in clinical and testing laboratories when compared with calibration laboratories. In this way, there seems to be some differentiation of this calibration business area in relation to the others, namely at the level of the relationship with the industrial area.

It was also concluded that, similarly to what is mentioned in the literature, the laboratories with implemented Lean and/or Six Sigma philosophies are the ones that present a higher number of employees and higher turnover. Likewise, with regard to performance, the results are higher in the laboratories that implemented at least one of the philosophies when compared with the laboratories that did not implement any philosophy.

Of the performance indicators analysed, "Turnover", "Number of tools used in quality control" and "Customer satisfaction" are the three indicators that best distinguish the laboratories. Practically all the laboratories that implemented Lean and/or Six Sigma philosophies are accredited and/or certified may condition the observation of discrepant results in the performance indicators. As previously mentioned, the fulfilment of the normative requirements already presupposes good results in some indicators given that it implies a set of process measurement and quality tools that, when already implemented in a laboratory, allow an easier integration of improvements.

This study contributes to characterise the Portuguese laboratories regarding the level of knowledge and implementation of Lean and Six Sigma philosophies and to assess the impact of these philosophies on performance indicators. Given the scarcity of literature at the level of the laboratory context, this study contributes significantly to the increase of knowledge production, since it portrays the Portuguese reality and contributes to decision-making.

This study also contributes with the creation of an original measuring instrument (questionnaire) that can be applied in future works within the scope of Lean and Six Sigma philosophies.

Finally, it is intended that this study may promote the implementation of Lean and Six Sigma philosophies in laboratories, resulting in an improvement of the services provided by them, in terms of response time, productivity, results quality, reduction of rework, among others.

The limitations of the study include the size of the sample, which corresponds to approximately 15% of the population, although it is accepted that it is usual in studies that use the survey research strategy to obtain samples of between 10% and 20%. The statistical analysis of a small sample may not allow for the highlighting of some results.

Additionally, although the study presents an original measuring instrument (questionnaire) that may be applied in future work within the scope of Lean and Six Sigma philosophies, it is considered that it may be improved, namely by incorporating information relative to the date of implementation of the philosophies in order to assess the degree of maturity.

Although this study is comprehensive and portrays the Portuguese reality, on the other hand, it does not have the desired depth. Thus, in future work, it is suggested that case studies be carried out for laboratories with Lean and/or Six Sigma philosophies implemented at a national level, so as to perceive the philosophies' implementation mode, the advantages and disadvantages, the benefits and difficulties. This complementary methodological approach will enable a more descriptive analysis, offering a different perspective and a better understanding of the problem under study.

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Conceptualization, A.C., V.L., and M.L.; Methodology, A.C., V.L. and M.L.; software, A.C. and V.L.; Validation, J.C.S., G.S. and J.D.C.; Formal analysis, J.C.S. and G.S.; Data curation, A.C. and V.L.; Original draft preparation, A.C., V.L. and M.L.; Review and editing, J.C.S., G.S. and J.D.C.; Funding acquisition, V.L.

CONFLICTS OF INTEREST

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