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The Integration of Six Sigma and Lean Manufacturing

Marcio B. Santos

Abstract

The Lean Manufacturing and Six Sigma methodologies are increasingly being executed together and what we have today is the united work of both, and companies have come to understand that their integration makes it possible to take advantage of the strengths of both strategies, becoming a comprehensive and effective, suitable for solving various types of problems related to the improvement of processes and products. Routine management, process standardization and the study of times and movements to eliminate waste are key features of Lean Manufacturing, while finding the root cause for problem solving requires further deepening and analysis in Six Sigma. The Lean and Six Sigma can be viewed as useful tools for the operation of the systems of improvement, innovation and routine management that integrate the system of business management. The companies have implemented Lean Manufacturing with the aim of improving the elimination of waste in the processes. Companies using Six Sigma have found that by selecting projects and assigning them to teams, after a monitoring, the results would appear. Companies that implement Lean Six Sigma often awareness of the teams, seeking projects from different scopes with the focus of improving the structure of processes and achieve the results.

Keywords: lean manufacturing, reference models, measurement systems evaluation, innovation, reliability, strategies

1. Why integrate?

The Lean Manufacturing and Six Sigma methodologies are increasingly being executed together and what we have today is the united work of both, and companies have come to understand that their integration makes it possible to take advantage of the strengths of both strategies, becoming a comprehensive and effective, suitable for solving various types of problems related to the improvement of processes and products.

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The Lean and Six Sigma can be viewed as useful tools for the operation of the systems of improvement, innovation and routine management that integrate the system of business management. For this reason, they are considered reference models. Santos et al. [1] points out that based on evidence about the potential of best practice approaches, different actors worldwide have been proposing and promoting different reference models. In general, these models serve as references

for decision-makers in establishing practices to be used in operations and organizational processes usually associated with awards, certificates, or consultancies.

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Over time, companies have realized that these methodologies are complementary and since then, much has been written about combining Lean with Six Sigma as a process improvement approach, using best practices from each. For some authors like George [2], the union of these two methodologies maximizes the value of the company.

There are many ways to combine these two methodologies. According to Corrêa and Giansesi [3], in the Western world there has been a growing movement to recognize the strategic role of manufacturing in optimizing the production process and reducing its costs. Bendel [4] says that the way forward for implementing Lean Six Sigma depends primarily on the issues the company is currently facing and the nature of its business, as well as the aspirations of the company and its employees.

For Chaurasia et al. [5], the shift from traditional manufacturing processes to Lean Six Sigma processes (LSS) implies positive results for companies in relation to the generation of revenues, customer and employee satisfaction, increased productivity, reduced waste and design of a quality product at low cost, as shown in **Table 1**.

Features / Method	Six Sigma	Lean
View	Process Improvement	Value Chain Improvement
Approach	Defect Reduction	Waste Reduction
Goal	Decrease variability	Decrease Non-Aggregate Value
Indicators	Effectiveness and efficiency	Efficiency and Effectiveness in time
Structure	Team formed by Belts	Small Group Activities (SGA's).
Nature of work	Projects defined with impact on the External or Internal Customer	Projects defined by observing the Value Chain Flow
Intrinsic Method	DMAIC e DMADV	Use of the 5 Principles
Deployment Strategies	Deploy by strategic projects to the company's business.	Implement improvements in bottlenecks with dissemination of the Kaizen concept.
Model Association	ISO 9000, FMEA, 8D	QFD, Kaizen
Typical Coordination	Quality	Production
Initial Reference	North American Companies (GE, Intel, Auto)	Japanese companies (Toyota and production chain)

DMAIC (measures the current performance of a process): Define, Measure, Analyse, Improve, Control;
DMADV (measures customer specifications and needs): Define, Measure, Analyse, Design, Verify;
FMEA: failure mode and effect analysis;
8D: eight disciplines;
QFD: quality function deployment;
Kaizen: tools that seek to bring about daily improvements, involving all employees of the company and in all existing areas;
5 Principles: specify value, map the value stream, deploy continuous flow, implement pulled production, seek perfection.

Table 1.
Comparative table of methods.

2. Understanding Six Sigma

2.1 The beginning

According to Santos [6],

“The Quality model, which has long constituted a theoretical school as remarkable as the Scientific Administration (F. Taylor and H. Fayol) or the General Theory of Systems (L. Bertalanffy and N. Wiener), preserves singular longevity for decades of evolution and conceptual updates. Far from being a bastion of contemporary truths, rooted in specific epochs, it further molds itself into a great umbrella that, as time passes, grows in size, incorporating and restructuring managerial concepts.

It shows, for example, the change from Quality Inspection to CCQ (Quality Control Circles), from TQC (Total Quality Control), TQC to Total Quality Management (TQM) and to WCM (World Class Manufacturing), pointing to such broad concepts as Quality Management or world-class criteria of excellence. Santos (pg 68, 2011)

Shewhart [7] set the starting point for the pursuit of Quality from 1925, when Bell Telephone Laboratories, New York, served the Western Electric Company (headquarters) in Chicago, where, in the manufacture of telephone sets, there was uniformity. He, analyzing the work process, initially verified the high volume of telephone scraps that were out of specification, found at the end of the production line... Deming [8] met Shewhart in 1927 who, in his view, gave the world a new perspective on science and administration. This professor of the University of New York, in turn, as eminent statistician, was able to implement and amplify, notably, the teachings of his tutor, so much that he was central figure in the uplift of Japan, after 2^a World War, considered one of the greatest expressions of Western and Eastern administration.

In the course of its development, it has been structured in international norms that ensure reliable and expected management practices (ISO 9.000, 14.000, 18.000, TS, CMMI), methods (5 S, FMEA, FTA, MASP, QFD, BSC, TRIZ), techniques (Pareto, Cause–Effect, Histogram, Control Charts, 5W2H, etc.), and even in philosophical-strategic approaches (LEAN Manufacturing, 6 Sigma, Red X, MEG, among others) that for some companies are still another method and for others, another technique or tool, and still some professionals, with disdain, call them pills. As a school or current of the Administration, therefore, Quality has for decades had a non-trivial density of contributions to companies, with a great diversity of researchers, authors, books and works, but being mostly directed to the empirical results of its applications, without methodological concerns in the formulation of hypotheses, control of quantitative and qualitative techniques and broad repetition. For this reason, the marginal penumbra of science or Management Theory is added. Even “insurrections” (reengineering, chaos theory, constraints) have already occurred, which in fact, coeteris paribus, have further strengthened their principles and continuity in the timeline. – Santos ([6], pp. 68–69).

2.2 Precision for large production volumes

With the expansion of the global consumer market in the late 1980s, especially through the breakdown of political barriers (iron curtain), quality no longer operates in thousands or hundreds of thousands, but in millions and hundreds of millions. This explosion imposes a new manufacturing standard on the world's major brand competition.

In addition, a new definition of Quality is focused by Harry and Schroeder [9], who built their 6 Six Sigma concepts from their work with Motorola in the 1980s, which was losing market share to competition for cost and quality reasons. For them, the traditional definition of Quality aims at complying with the standards that companies create for the quality of their products and services, even if this means reworking (raising costs) of a specific part of the product/service due to interaction between standards.

From the beginning, great emphasis was placed on the use of statistical tools for the treatment of variables in problem solving and reduction of process variation. The application of the Six Sigma approach is based on a standardized method for conducting the problem-solving process known as DMAIC, which is the abbreviation of the Define, Measure, Analyze, Improve, and Control phases. In each phase of this method, the use of some tools such as Process Mapping, FMEA, Hypothesis Testing, among others.

Six Sigma's creative management strategy extends the definition of quality by including economic value and practical utility for both the company and the consumer. It is a business relationship, where the incorporated value of the good means, on the company side, a certain expectation of producing quality products/services with the highest level of profits possible; by the consumer side, means that they have an expectation of buying high quality products at the lowest cost. In other words, the quality in the organization is greater when the costs are as low as possible for the company and for the consumer. The business strategy and philosophy built around Six Sigma show how changes in the organization must take place so that it can gain a new level of competitiveness by reducing defects in its industrial and commercial processes.

In traditional terms, 6 Sigma focuses on defect prevention, reduction of cycle times and cost savings. Unlike costly cost cuts, which reduce value and quality, 6-Sigma identifies and eliminates costs of waste, meaning that they do not add value to customers. In general, these costs are extremely high in companies that do not use it.

Companies operating at 3-Sigma or 4-Sigma levels usually spend between 25% and 40% of their revenue to repair or solve problems. This is known as the cost of quality or, more precisely, the cost of poor quality. Companies operating on 6-Sigma generally spend less than 5% of their revenue to fix problems.

The dollar cost of this difference can be enormous. General Electric estimates that the difference between 3-Sigma or 4-Sigma and 6-Sigma cost \$8 billion to \$12 billion a year. To achieve this goal, we use a set of proven techniques together with a cadre of well-trained, well-trained technical leaders known as black-belts to achieve a high level of efficiency in applying these techniques.

In other words, the number of Sigmas is a measure of process performance. The greater the number of Sigmas, the lower the variability of the process, the greater the process, the higher the probability of obtaining products that do not meet the customer's specification. Processes with little variability: More products complying with the specifications, as shown in **Figure 1**.

In short, the definition of the term Six Sigma contains three distinct elements [10]:

1. **A Measure:** The term derives from the statistical concept of standard deviation that shows how much a process deviates from perfection;
2. **One Target:** Refers to a fixed rate of 3.4 defects per million opportunities;
3. **Philosophy:** Six Sigma is a long-term business strategy to reduce costs by reducing the variability of products and processes.

But, we can add another fundamental element:

4. **Method:** the use of a critical path (DMAIC/DMADV) that will show and facilitate the use of statistical techniques in each of the stages.

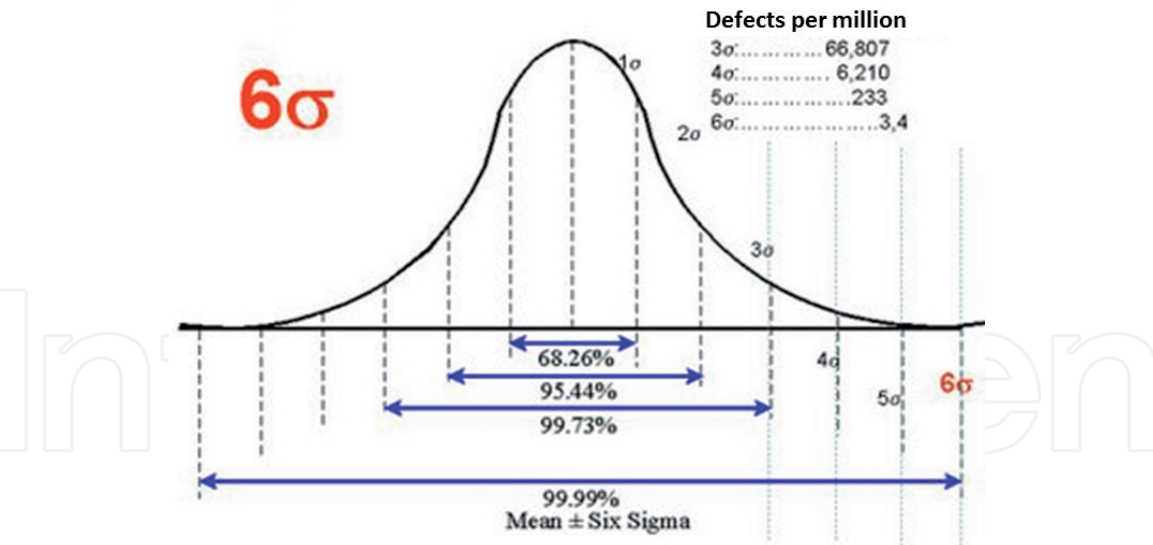


Figure 1.
Confidence levels in normal processes.

2.3 Team

The incorporation of the rigor and discipline of the martial arts in the learning of the personnel, as far as the statistical techniques are concerned, is of singular performance the involvement of the people (green belts, black belts, master black belt and collaborators), in the specific projects and general process of obtaining Quality 6 sigma.

Team building presents a differential compared to other approaches, considering the growing burden of statistical studies that participants should be trained. From basic statistics to models and simulations, from Green Belts to Master Black Belts respectively.

In this, the trainings of the specialists are divided by area and degree of knowledge. The success of Six Sigma is subject to the existence of persons with the appropriate profile and who will be transformed, according to **Figure 2a** and **b**.

2.4 DMAIC and DMADV

Six Sigma uses a variety of descriptive and inferential statistical techniques applied to the best performance of the process. It has intrinsic methods (**Table 2**) that allow it to establish a critical path in the use of these techniques, guaranteeing the best result.

3. Lean manufacturing

The concept of Lean Production emerged in Japan after World War II created by Japanese Toyota's Eiji Toyoda and Taiichi Ohno, aiming to overcome the challenge of cutting costs while producing small quantities of many types of cars [11].

The definition of the Lean Production system is given by Ohno (1988) as:

"The elimination of waste and unnecessary elements in order to reduce costs; the basic idea is to produce only what is necessary at the necessary moment and in the quantity required." Ohno (1988, p.23)

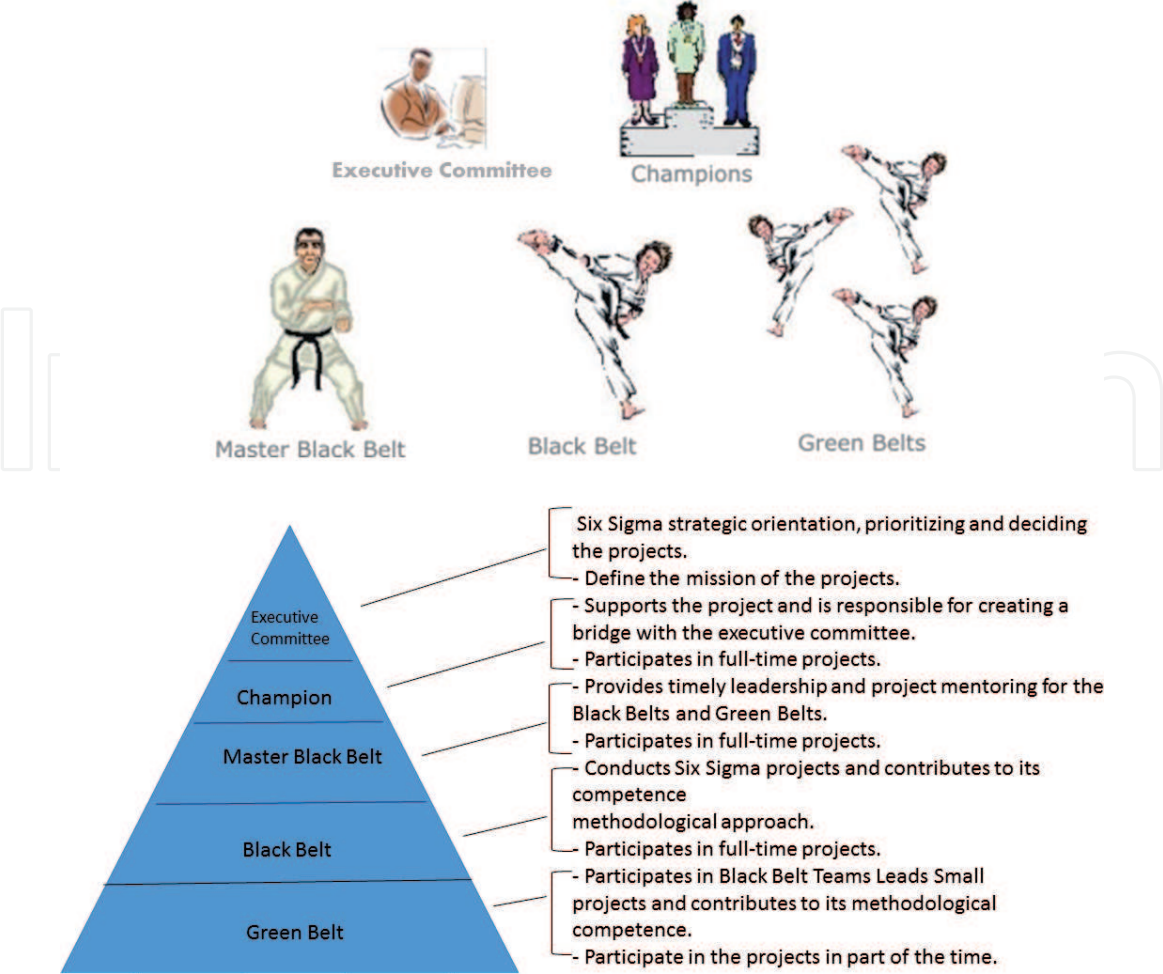


Figure 2. 6-sigma team roles (a) and responsibilities (b).

Intrinsic Method	General Feature	Phases	Specific Characteristics
DMAIC	Optimize existing processes by getting improvements in a business process to reduce or eliminate defects.	1) Define	Define the objectives of the improvement activity. Project aligned with corporate strategy. Define team.
		2) Measure	Establish metrics, measurement system, and current performance levels.
		3) Analyse	Identify differences between the current system performance and the desired goal; analyze the causes of defects and sources of variation.
		4) Improve	Improve the process to eliminate variations. Get responses from stakeholders by assessing the benefits
		5) Control	Plan to monitor process performance by controlling its variations, ensuring that improvements are maintained.
DMADV	Develop an appropriate business model to meet customer requirements, or design new product / process.	1) Define	Establish realistic and measurable goals important to the organization and its stakeholders.
		2) Measure	Critical factors for the quality should be measured as well as the requirements of the metrics.
		3) Analyse	What is the best design to achieve the goals? Analyze the project cycle
		4) Design	Develop project prototype or detail
		5) Verify	Make sure the design is acceptable. Conduct pilot studies and production scale.
Techniques of the Phases: 1) Brainstorming, Team Formation, Flowchart, PERT, QFD 2) Pareto Chart, Histogram, Normal Curve Analysis (a3, a4), Stratification 3) Diagram Cause Effect, Prioritization Matrix, FMEA, Experiment Design, Hypothesis Testing 4) Action Plan (5W2H), Dispersion Graph, Regression Analysis 5) Control Letters, FMEA, International Standards (ISO 9000, 14000, 18000)			

Table 2. Six Sigma and its intrinsic methods.

The general view of the cited author is that he considers seven types of production losses:

1. overproduction,
2. wait,
3. transport,
4. superprocessing,
5. handling,
6. defective products, and
7. stock.

Although initiated in manufacturing, the Lean concept can also be deployed in several organizational areas [12].

By aligning activities that create value by eliminating waste, the value stream is advanced smoothly and quickly according to the customer's request and not according to the producer.

Lean Manufacturing seeks process improvement by streamlining its flow, eliminating waste and emphasizing gains in speed and efficiency.

Womack et al. [11] present the five basic principles that can be used as a framework for an organization to implement the Lean methodology, these being:

1. **Value:** Precisely specifying the value is the starting point for Lean thinking. The value is defined only by the end customer. However, it is the organization that must identify what generates this value for the customer. Determining the value and defining the product, the next step is to specify the target cost based on the resources needed to manufacture the product with the specific characteristics;
2. **Value flow:** The value stream or value chain is the path traveled from the beginning of production to delivery to the end customer. Each step involved in the process is mapped on the premise that activities that cannot be measured cannot be managed and those that are not precisely identified cannot be analyzed and improved. With the mapping of the value stream it is possible to identify and eliminate activities that contain waste through waste elimination techniques;
3. **Continuous flow:** From the analysis and mapping of the value flow, it is necessary to make the activities that generate value can flow through the process without interruptions. The best way to make products flow is to stream them wherever possible by rearranging the sequence and equipment so that it does not act on waiting and inventory between activities;
4. **Pulled production:** Pulled production aims to decrease the lead time for the consumer. Implementing the pulled system means producing a good or service only when the request is made by the customer and not pushing the product to the consumer;

5. **Perfection:** When the four principles are followed clearly, that is, the organization declares the value accurately, maps the flow of value so that products flow continuously or when customers pull these products, it is possible to achieve perfection of processes by eliminating losses and waste. Continuous improvement must always be sought to achieve this perfection. To the Lean Thinking, the most important thrust to perfection is to maintain transparency among everyone involved in the system so that it is easier to identify ways to create value.

The main management techniques used to implement the Lean principles are: Value Stream Mapping, Evaluation System with well-defined metrics, 5S, Kaizen, Kanban, Standardization, Visual Management and TPM (Total Productive Maintenance).

4. LSS: the Lean and Six Sigma integration

Before beginning the integration between Lean and Six Sigma, it is prudent to understand their similarities and divergences, according to Antony [13], to enhance the work of the team in the reality of the organization:

1. Similarities:

- Core processes in the organization,
- Applicable not only in manufacturing activities,
- Management support is essential,
- It has customer focus,
- They are made up of multifunctional teams, and.
- The tools are complementary to each other.

2. Divergences:

- Six Sigma requires more intensive training compared to Lean Manufacturing,
- Lean Manufacturing focuses on waste reduction while Six Sigma in reducing variability,
- Six Sigma requires more investment compared to Lean Manufacturing,
- Lean Manufacturing aims to streamline the flow of processes while Six Sigma seeks to increase capacity,
- Lean Manufacturing does not present a systematic methodology for implementation, and
- Six Sigma presents specific designations as team empowerment.

It should be noted that Six Sigma supports Lean Manufacturing while it does not have a structured critical path (intrinsic method) for troubleshooting. But Six Sigma, in turn, does not focus on improving process speed, reducing lead time and eliminating waste, which are aspects of Lean Manufacturing.

4.1 Roadmap

The strong point for company culture is that statistical tools assist in the work of methodologies, reducing variability and making processes more stable and reliable.

According to Werkema [14, 15] there are steps for organizations to follow, aiming at the union of Lean and Six Sigma. It is a roadmap for an integrated implementation:

1. **Assess performance:** Establish the need for change and assess how well the organization is prepared to make that change.

Results: Initial list of opportunities, including financial benefits, for subsequent prioritization and implementation.

2. **Plan the improvements:** Establish and communicate the goals of the implementation of Lean Six Sigma (LSS).

Results: LSS Steering Committee, Method for selection and prioritization of projects, Standard for calculation of financial gains, Procedure for selection and training of LSS sponsors and specialists.

3. **Enable execution:** Develop, disseminate and implement procedures and policies to establish the infrastructure for change.

Results: Training of sponsors and specialists, Establishment of internal communication channels for the dissemination of LSS, Integration of other improvement programs in force with LSS.

4. **Execute the projects:** Execute the projects (DMAIC and Kaizen) prioritized.

Results: Achievement of financial gains (validated by the controllership), Development of the “hard and soft skills” of the sponsors and specialists, Replication of projects.

5. **Maintain improvements:** Ensure the perpetuation of the gains achieved and the consolidation of “LSS Culture”, conducting periodic audits and re-energizing the program.

Results: Continuous improvement of LSS.

4.2 Strategies for integration

Therefore, it is necessary to keep in mind the importance of choosing the Lean Six Sigma implementation strategy that best suits the characteristics of the company and its business.

Lean and Six Sigma to be integrated into a broader system of organizational improvement, the potential of which would be far greater than the sum of these two initiatives. In this line, some companies have already created their own integrated systems, called business improvement systems.

Thus, according **Table 3**, some authors cited Busso and Miyake [16, 17], emphasize the importance of adopting strategies to implement the Lean Six Sigma methodology, so that it is aligned with strategy and strategic manufacturing decisions, in order to more effectively harness the potential of both methodologies for improvement of the company business.

The strategy of manufacturing/services and its strategic decisions with the business strategy positively impacts the performance of the company improving productivity and profitability, when the organization has a management model. It is possible to say then that for the competitiveness of the company, it is important that the choices made in the production of goods or services in relation to the use of resources, skills and improvement methodologies, for example, should be guided by business strategies and selected reference models.

Author	Implementation Strategy	Features
Elliot (2003) There are 4 ways to implementation of Lean Six Sigma as a strategy for manufacture	Lean before Six Sigma	It eliminates unnecessary complexity and establishes a starting point. Manufacturing is the main problem and does not focus on solutions to variation problems.
	Six Sigma before the Lean	Eliminates variation and establishes process capability by creating focus. The problems are not need to be necessarily of manufacture. Care must be taken not to optimize processes that do not add value.
	Lean and Six Sigma separately	Comprehensive solution to solve all kinds of problems, the organization must be able to tailor the right methodology to the problem and take care that it does not resource competition.
	Lean and Six Sigma combined	Comprehensive solution to solve all kinds of problems when there is a map application of each tool.
George (2002) Companies that do not have neither methodologies. The methodology is chosen after identification of the problem and alignment with the objectives of the company.	Lean and Six Sigma combined	a) Start: Involvement of leadership, definition of goals that are related to the company's objectives and exposure of possible gains from the implementation and launch of the project, thus involving all employees. b) Selection of Project and Resource: selection of pilot projects that will serve as examples for the development of culture in all areas. One of the necessary resources is people specialized and trained for the development of activities. c) Implementation and Evolution: implementation of the project solutions. The author states that the Lean tools are part of the solution implementation and the mapping to discover opportunities. The Six Sigma methodology is based on organization of work and processing of data and information, in addition to problem analysis tools.

Table 3.
Strategies for Lean and Six Sigma.

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