Lean Maturity Level Analysis for Industry 4.0

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ABSTRACT

Purpose – This study seeks to identify the ideal moment for the transition from Lean Manufacturing to Industry 4.0, identifying which are the right tools for companies and industries to move towards industrialization evolution.
Methodology – To analyze the maturity of Lean Manufacturing, we developed a survey based on the Lean 4.0 maturity of Matternich *et. al.* [1]. The questions were divided into five groups, based on the lean principles presented in Systematic Literature Review. This survey was applied to small and medium companies from Brazilian Industry.
Findings – With the results in hand, it was possible to verify the relationship between the lean methodology and the technologies of Industry 4.0 and identify the best transition scenario.
Originality – Many references make a theoretical analysis on the relationship between lean and Industry 4.0, while this study makes a more in-depth analysis of companies that have a certain maturity in lean and that are in the process of transition or preparing to implement Industry 4.0, with the objective of analyzing this relationship and the respective maturities and understanding some gaps presented in previous studies.

1. Introduction

Industry becomes more modernized with every passing year. This modernization began in the eighteenth century and brought substantial changes with it [2]. In Europe in particular, there was a large quantity of manual laborers due to the lack of machines available to complete tasks or create certain tools. Until the end of the eighteenth century, a large part of Europe's population lived in the countryside and produced only what they consumed as part of self-sustaining communities. However, a substantial change resulting from the first Industrial Revolution was the shift to salaried and machine-based manual labor.

Though these jobs were performed manually, some European countries already had craft production systems. These systems were large centers where a variety of craftspeople performed activities under inhumane conditions and long shifts. However, this system was about to change. Between 1760 and 1840, England led the changes occurring in industry.

These changes were widespread in the country because of its territorial advantages (coastal waters) and because of the rise of the bourgeois. The textile industry experienced substantial growth due to the use of the power loom. This revolution was marked using steam engines.

In the 1860s and 1870s, electric energy and fossil fuels also came to be used [3]. Germany and France were more closely involved at this time. It was the second Industrial Revolution that gave rise to the Ford and Taylor assembly lines. This method of production allowed for a large volume of cars to be produced in a short period of time. Another important factor is that, with the use of electric light, factories that once had shifts limited by daylight were now able to operate 24 hours a day.

It was in the mid-twentieth century that the third Industrial Revolution began. It was marked using robotics and the internet, which brought significant changes to production. The internet allowed for the exchange of information and data more quickly and accurately [4]. Robotics also revolutionized production in terms of collaboration (aiding workers on the factory floor) and of reallocating manual labor to non-automated activities. In this context (the postwar period), new manufacturing strategies began to develop and distinguish themselves from those of the United States. Japan was the source of the efficiency-based production model that came to be known as Lean Manufacturing or the Toyota Production System. This system has been studied and applied by a variety of companies around the world.

Recent technologies involving cloud computing, the Internet of Things, artificial intelligence, virtual reality, and augmented reality have further revolutionized the methods and models used in current manufacturing. However, this change has not been overnight. Research and investment are necessary for our understanding of the right period in an industry's growth to make a transition into Industry 4.0.

2. Objective

I. To review the literature on Lean Manufacturing and Industry 4.0 and to select the best techniques to study this transition.
II. Start mapping the processes carried out in companies that have some type of serial production (such as the automotive, home appliance and others), identifying the feasibility of applying the selected tools.
III. To perform analyses to determine the level of lean maturity that the companies in question are on, in addition to the level of lean 4.0 maturity and to propose a way they can adopt to efficiently automate their manufacturing processes.

3. A Review of the literature

3.1. Lean Manufacturing

Lean Manufacturing was created and popularized by large automobile companies. In the mid-1990s, Lean Manufacturing techniques were implemented in other industries and fields. The purpose of Lean Manufacturing as created by Toyota in the postwar period was to reduce waste [5]. Another determining factor in Lean Manufacturing is the quest for continuous improvement, an idea which comes from the Japanese word *kaizen*. However, the meaning of the word goes beyond the concept of continuous improvement and includes the idea of involving everyone in these operations. Though Lean Manufacturing philosophies go far beyond the tools used, the authors suggest certain concrete parameters and methods for analyzing lean efficiency, such as:

- ✓ Stock reduction;
- ✓ Reducing batch size;
- ✓ Part transport;
- ✓ Product quality.
- ✓ Just-in-time manufacturing;
- ✓ Multitasking teams;
- ✓ Decentralizing activities.

A new method for analyzing lean maturity was provided by Goodson [6]. This author developed a tool called "the Rapid Plant Assessment (RPA)". The classification system presents eleven categories to assess the consistency of a plant, and the RPA questionnaire provides 20 yes-or-no questions to determine whether the plant uses the best practices in these categories. Below is a list of some of the categories that the author presents in their study.

1. Customer satisfaction – employees know who their clients are, and their main goal is to satisfy them. Another important factor is factory presentation. Clients must be welcome to the factory, and it is therefore important that employees be trained in presenting the factory to them.
2. A safe, clean, and orderly environment – it is easier to work in a clean and organized factory. There is no need to search for a given part, because they've all been duly cataloged and organized.
3. The use of space, movement of materials, and the flow of the assembly line – the most efficient plants are those which use their space efficiently. The materials necessary for manufacturing are transported or moved only once.
4. Teamwork and motivation – Factories must have a team board, a place where employees can leave comments and suggestions, and even clearly displayed safety measures. Information such as the date and price of the last maintenance procedure is also important to demonstrate that the company is investing in keeping the factory running.

3.2. Toyota Production System (TPS)

For a long time, Toyota did not document its manufacturing processes [7]. It was easy for a small business to teach its collaborators and suppliers how its processes worked. As the years passed, the automaker grew, and the task of manually passing on its best practices to all of its plants around the world became impractical. In this context, Taiichi Ono created a representative TPS model (Figure 1).

He wanted to keep his house in order, meaning he had to make sure it was stable and that its columns, foundation, and roof were strong. If any one of these were compromised, the rest would be affected. Following this logic, Taiichi Ono gave each branch and sector of his company all of the tools necessary to sustain the model he'd designed.

The "roof" was high quality, low costs, increased safety, and decreased lead time, which are fundamental features of the TPS. For each of these goals to be reached, Lean Management tools are necessary. To avoid waste, manufacturing must be "pulled," or guided, by demand; this prevents a high volume of stock.

The just-in-time "column" refers to synchronized and efficient processes within the company. For this to be possible, the entire production flow must be mapped out. All the steps must be distinct and well defined for the process to be organized. The right part must arrive in the manufacturing sector necessary at just the right time and in the amount necessary to avoid hiccups or delays in the process.

Another important "column" is the pull system within the TPS. To avoid excess, production is "pulled" by demand. When more parts arrive, productivity increases; when fewer parts arrive, it decreases. This measure triggers a series of benefits, including reduced stock and batch size. The Jidoka column - jikoda or automation, is a term that came about in the twentieth century as part of the TPS. Though it is often associated with machine work, this term is not restricted to mechanical automation. It is important to note that jidoka much more commonly refers to worker autonomy in identifying and solving automation problems. Allowing employees to stop the assembly line if a problem is identified is a fundamental part of the manufacturing process. This avoids a waste of time on reworking and increases product quality. Because it is not only about machines, but automation may also be applied to any type of business or work that involves manual activities. Jidoka is described as a method capable of "humanizing the machine-operator interface" [8].

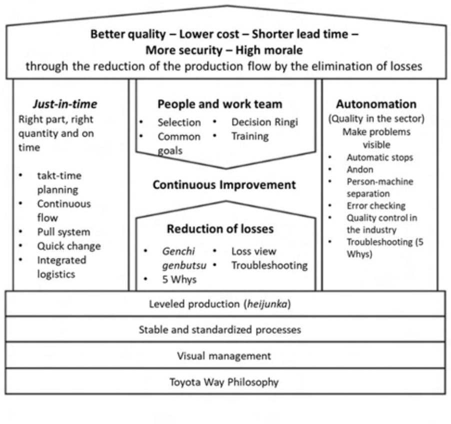

Figure 1. The Toyota Production System (TPS) House Source: Liker [7]

Center - At the center, we have the term kaizen, which, as mentioned previously, refers to the quest for continuous improvement. Trained employees can help identify mistakes or failures in the production process. Workers must be trained to identify the root of the problem to prevent it from happening again. Practices with the 5 Whys are effective in identifying root causes. This practice consists of repeatedly asking about the causes that lead to a given error.

The "foundation" consists of all the concepts that solidify the structuring of the company. Once the principles of automation have been applied, employees must be duly trained to allow for sustainability and standardization in the process. Standardization helps maintain good practices and keeps problems from requiring solutions more than once.

Finally, TPS is erroneously seen by some authors as a toolbox – the 5Ss, JIT, the 5 Whys. It is much more than that. It can be seen as a culture in which everyone is engaged in a common purpose. "It's a sophisticated production system in which all of the parts contribute to the whole." [7]. All these measures combined are necessary for Lean Manufacturing to be maintained.

3.3. Lean tools

1. *Kaizen* - As mentioned previously, kaizen is a Japanese term that means continuous improvement. Kaizen may be separated into two different levels [9]:
Flow or system kaizen, which focuses on the flow of value, and which is meant for management;

2. The 5Ss – The 5S are defined as follow [10]:
Seiri – Utility, sorting, organizing, selecting;
Seiton – Order, systemization, classification;
Seiso – Cleanliness and shine;
Seiketsu – Cleanliness, hygiene, health, and integrity;
Shitsuke - Self-discipline, respect, commitment.

3. PDCA (Plan, Do, Check, Act) – As in the case of kaizen, the PDCA method seeks continuous improvement and serves to optimize and standardize processes. A 4 step method (Figure 2).

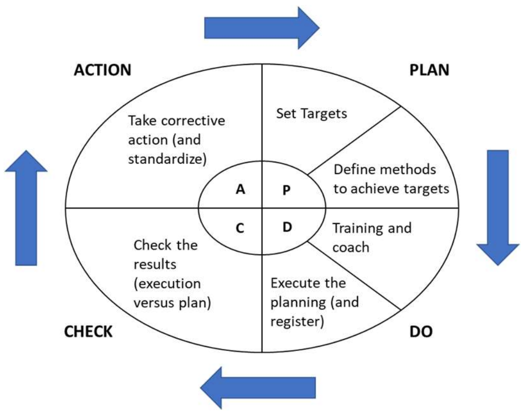

Figure 2. The PDCA method. Source: Campos [11]

4. Visual Management;
5. Total Quality Management (TQM) – It´s as a permanent, long-term system focused on achieving customer satisfaction through continuous improvement in the quality of the company's products and services [12];
6. Total Productive Maintenance (TPM) - "TPM helps to keep the plant and its current equipment at its highest level of productivity possible through cooperation between all functional areas of an organization" [13] [14].

3.4. Industry 4.0

According to the Acatech study [15], the "Industurie 4.0 Maturity Index," many organizations still lack a basic understanding of the main aspects of Industry 4.0. "For example, companies generally incorrectly restrict Industry 4.0 to digitalization or total automation." Furthermore, rather than seeking out a collective sense of change, they focus on isolated changes that have little to no effect. For the benefits of Industry 4.0 to be noticeable, these changes must be applied to all sectors, whether it's a question of customer relations (involving behavioral analysis tools) or industrial process automatization.

According to the study, the main feature of this new era is the speed with which change can occur. The faster organizational changes are made to meet the current needs of the market, the greater the benefits will be. These changes are also related to production and delivery time. Efficient companies that have adapted to new technologies can produce better, more quickly, and at a higher quality and can deliver products in a shorter time.

Each company analyzed in the study had a different final objective. Therefore, a map was created for each of these companies to reach their desired level of maturity. To determine the level of 4.0 maturity that these companies were at, the study was divided into 6 steps (Figure 3):

1. Computerization;
2. Connectivity;
3. Visibility;
4. Transparency;
5. Predictive Capacity;
6. Adaptability.

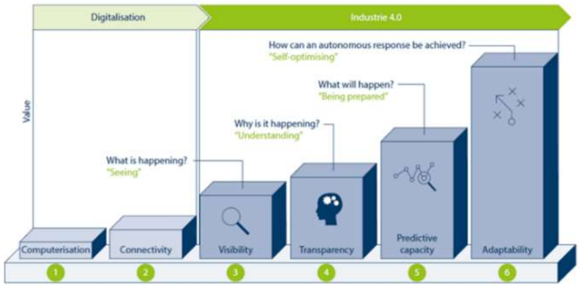

Figure 3. Industry 4.0 Maturity. Source: Schuh *et. al.* [15]

3.5. Lean 4.0

The current literature is structured around two perspectives: Lean Manufacturing is considered a pre-requisite for introducing Industry 4.0 tools, or Industry 4.0 tools are considered promoters of Lean Manufacturing. Digitalization (Figure 3) is part of the first steps toward Industry 4.0. Even so, many scientific works claim that Lean Manufacturing is the basis for Industry 4.0 [16] [17] [18] since Industry 4.0 technologies are supposed to be based on the holistic approach of the Lean Production System [19]. Research by Tortorella & Fettermann [20] confirms that Industry 4.0 is more likely to be introduced if Lean Manufacturing is already implemented. According to the article "Industrie 4.0 meets Lean - Guideline to increase added value holistically", [1], digitalization can be divided into two distinct parts: the digitalization of internal processes, which brings direct benefits to the company, or the digitalization of products and services offered to the customer. Once a product is connected, it guarantees a post-sale relationship between the company and the customer. It becomes the key that opens the company to the user. Along this vein, new and completely digital business models have been developed to connect customers to services linked to a given product.

Another important aspect is the network formed by this new perspective. Relationships are vertical in that the data from the sensors installed on the factory floor go directly to the cloud, and horizontal in that production is client centered. It is important to note that each company has its own path to industrialization, since there is no toolbox capable of being applied in a way that brings instantaneous productivity.

Both Lean Manufacturing and Industry 4.0 are essentially a way to meet the same goals. Both focus on efficient production with higher quality, greater safety, and less time wasted. Industry 4.0 goes one step ahead and addresses the importance of product individualization and the creation of services that may help companies understand the relationship between customer and producer. While Lean Manufacturing uses process standardization to analyze deviations, Industry 4.0 relies on cognitive systems capable of self-optimizing processes.

Another point that has progressed with these changes is one of the main pillars of the Toyota Production System: jidoka. Automation, a concept which includes employee autonomy to stop assembly lines, came to be replaced using algorithms capable of tracing different production paths in a way that minimizes the impacts of interruptions to the flow of production.

It can therefore be said that Industry 4.0 has come to eliminate barriers and reach parameters in a way that the Lean Manufacturing culture would not be able to do alone. As argued by the authors of the article, the following figure (Figure 4) shows, the similarities and differences between Lean Manufacturing and Industry 4.0. The two first rows show differences between Lean Manufacturing and Industry 4.0, while the other rows show consistency between the two models.

	Lean		Indútria 4.0
Approach	Holistic (person + technology + organization)	↔	Technology as an enabler
Philosophy	Respect, problem solving and employee development	↔	Feasibility and self-optimization
Base	Stability and Standardization	+	Integration and adaptability
Principles of Control	Flow and pull production	+	Dynamic and situation dependent
Information Acquisition	Current state (go and see)	+	Real-time processed data
Improvement	Reactive in day-to-day and business through employees	+	Auto optimization, forecasting

Figure 4. Similarities and differences between the models. Source: Adapted from Schuh *et al.* [15]

The main objectives of Lean Manufacturing are to be error proof, to achieve zero waste, and to generate as much product value as possible. For this reason, Industry 4.0 technologies add to this preexisting model by incorporating digitalization without taking away from the original lean objectives. To analyze lean maturity as well as the stages that come before Lean 4.0, according to the article "Industrie 4.0 meets Lean - Guideline to increase added value holistically", [1], 5 steps are necessary (Figure 5).

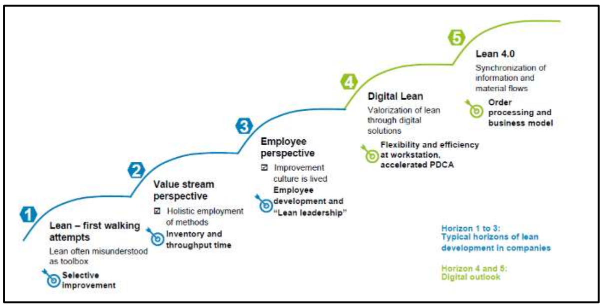

Figure 5. Typical horizons of lean development in companies and digital outlook: Matternich *et al.* [1]

1. The first steps of Lean Manufacturing: Many companies that begin to implement Lean Manufacturing see it as a toolbox. Many of these companies use the tools listed in this article to solve individual project issues. However, if the Lean Manufacturing culture is applied only to isolated projects, it will not produce sustainable results.
2. A "value flow" perspective: the way in which we address chains of activities directly affects company expenses and profits. With its objective to make production flow and to reduce processing time, value stream management (VSM) helps to develop a lean value perspective. The result of VSM is often improved quality and reduced processing time.
3. Employee Perspectives: To ensure the success of the principle of continuous improvement, employees must be trained to identify deviations from patterns. In this step, employees require support and management from company leadership, who must indicate the correct way to achieve improvement. As mentioned previously, Lean Manufacturing must be applied both vertically—from the factory floor to the corporate office—and horizontally, so that it may reach customers and suppliers.
4. Digital Manufacturing: Once a certain level of maturity is reached, some processes can be digitalized. To identify which manufacturing steps may be digitalized and improved, the authors suggest the use of questions such as, "which machines are essential to product quality?" "Which processes have yet to be improved?" "Which sectors rely on flexible manufacturing that is capable of personalizing products in accordance with customer demand?"
5. Lean 4.0: In this stage, the lean system changes from a factory floor model and becomes a managerial approach applied to the entire company. The first step is to connect the supplier's IT system to customer requests. Each time a new order is made, the supplier is notified, and a series of interconnected processes are set into motion.

According to the current state of existing literature, there is a positive correlation between Lean Manufacturing and Industry 4.0, called Lean 4.0 [1] [21]. Lean 4.0 describes the adaptability of a manufacturing company to progress technological and digital, considering the Lean Manufacturing. In this context, Lean 4.0 improvements need to be be aligned with the company's goals and have a holistic effect and consider humans, technology, organization and their interactions [22] [23].

4. Research Methods

The present research is based on the relevant literature through a Systematic Review of Literature and a Content Analysis through case-study of a combined quantitative and qualitative approach that allows a more effective understanding of the problem explored, based on a statistical analysis of the data collected (quantitative analysis) in the context of the literature regarding the maturity of lean and the relationship between Lean Manufacturing and Industry 4.0 (qualitative analysis). Regarding the domain of Industry 4.0 the following models and tools for assessing readiness or maturity have been published (Table 1).

Table 1 - Industry 4.0 readiness and maturity models. Source: Adapted from Schumacher, Erol and Sihn [24]

Model Name	Institution	Assessment Approach
The Connected Enterprise Maturity Model (2014)	Rockwell Automation	Maturity model as part of a five-stage approach to realize Industry 4.0; technology focused assessment in 4 dimensions; no details about items and development process offered (white paper)
IMPULS – Industrie 4.0 Readiness (2015)	VDMA, RWTH Aachen, IW Consult	Assessment in 6 dimensions including 18 items to indicate readiness in 5 levels; obstacles to advancing to the next step are defined
Empowered and Implementation Strategy for Industry 4.0 (2016)	Lanza et al.	Industry 4.0 maturity assessment with a quick check and part of a process model for realization; gap analysis and toolbox to overcome maturity obstacles are suggested
Industry 4.0 / Digital Operations Self Assessment (2016)	PriceWaterhouseCoopers	Online self-assessment in 6 dimensions; focus on digital maturity on 4 levels; application as a consulting tool as assessment rate is required in 3 of the 6 dimensions
Industrie 4.0 meets Lean - Guideline to increase added value holistically (2018)	VDMA Industrie 4.0 Forum	This guideline shows how the Lean approach can be systematically connected with the new opportunities of digitalization and Industrie 4.0. It presents typical lean development horizons in companies, from lean to industry 4.0.
Industrie 4.0 ACATECH Study (2020)	Acatech - National Academy of Science and Engineering	Assessment through a survey to assess 4 structuring areas of an organization; maturity level divided into 6 levels

To do this maturity analysis, the research was based on Matternich *et al* [1] model by presenting an approach to the model based on a succession of maturity steps, that is, value-based levels of development that help organizations navigate all steps transformation, from basic requirements for Industry 4.0 to full implementation. This model was used as a reference, due to the objective of analyzing the relationship between lean and Industry 4.0.

4.1. *Developing the Methodology*

A Systematic Literature Review process was used as a first step in building the basis for this study, using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology, thus allowing an investigation on the subject, analyzing studies already published, to justify the research gap [25]. Following this PRISMA methodology, the research objectives were defined, then the database to be used to perform the search for published articles (Web of Science), after that the filters were defined (number of citations, date, starting from the most recent, and available in English language) and the search terms (key words: Lean Manufacturing and Industry 4.0; Industry 4.0; Industry 4.0 maturity). Based on this, a preliminary search was carried out in the database, reaching a total of 775 identified articles. Subsequently, duplicated articles were eliminated. Of the remaining articles, a selection was made based on pre-defined filters and reading the abstracts which resulted in a total of 72 pre-selected articles. After that, a complete reading of the articles was carried out to select those that were aligned, eligible, with the topic to be addressed, resulting in the inclusion of 57 articles in the research (Table 2). The selected articles were references for defining the topics to be addressed, as well as for preparing the questions for each group of the questionnaire, in addition to helping in the analysis of the results obtained.

Table 2 - Systematic Literature Review. Source: Authors

Definition of Goals	Data Base	Keywords	Filters Definition	Pre selection	Final Selection
- Lean Manufacturing and Industry 4.0 relationship - Lean Maturity and Industry 4.0	Web of Science	- Lean Manufacturing and Industry 4.0 - Industry 4.0 - Inudtry 4.0 maturity	- Higher numbers of citation - Date: >2015 - Language: English - Free access file	- Reading Titles - Reading Abstracts	- Full reading of pre selected articles
	Initial Search: **775 Articles**		Selection: **72 Articles**		Final: **57 Articles**

4.2. *Survey*

A series of lean tools were presented in the applied survey, based on each of the referenced authors. Since TPS is not treated as a toolbox in this study, the quantity and quality of each tool mentioned together produce parameters for analyzing the maturity of the companies analyzed herein. Companies are considered prepared to take the next steps toward an Industry 4.0 system once the 5 steps of Lean 4.0 development have been followed. Each of these steps is fundamental to guarantee the stability and sustainability of the changes.

In this study, the questions utilized in the survey were separated into five groups based on the five steps of Lean 4.0 presented in the article "Industrie 4.0 meets Lean - Guideline to increase added value holistically" [1]. The goal is to identify whether each of the companies of the survey is mature in terms of its lean principles and whether the company can move on to Lean 4.0, thus incorporating all the innovations that make up Industry 4.0. As cited in the reference, for each of the TPS pillars, there is a limitation that can be overcome using digitalization, interconnectivity, and machine learning.

4.3. *Company Analysis*

Small and Medium companies in the automotive sector, home appliance, electronics and metallurgical manufacturers were considered for the data collection through a questionnaire, given the relevance they have in the Brazilian economic scenario and with the constant implementation of new technologies and continuous improvement programs in their production lines.

The survey used to analyze companies' lean maturity was created using a Likert scale, which evaluates the subject's agreement with a given item. A 5-point Likert scale was used herein in which 1 meant "completely disagree" and 5 meant "completely agree." Each of the survey questions represented lean culture tools or practices that helped us researchers to identify each of the companies' level of lean maturity.

In the maturity analysis, each of the five groups of questions was associated with one of the five steps required to achieve Lean 4.0. The higher the score for the question groups addressing Lean Manufacturing 4.0 systems, the higher the company's degree of maturity. The higher the score for the question groups addressing Lean Manufacturing as a toolbox, the lower the company's degree of maturity. The former group is associated with the first stage of maturity, while the latter group is associated with more advanced stages of maturity. The first group of questions was given a weight of 1, followed by the second group of questions, which was given a weight of 2, and so forth (Figure 6). The survey was made available as an online form.

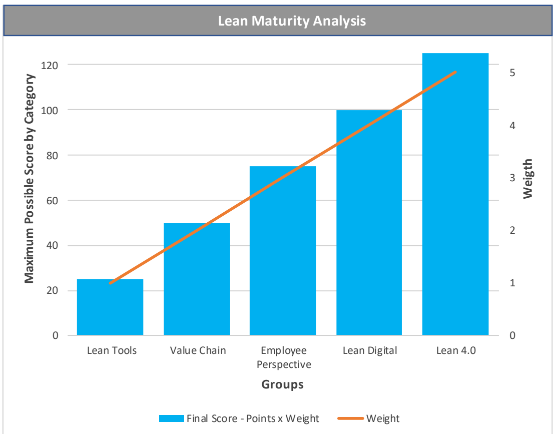

Figure 6 - Lean maturity Analysis. Source: Authors

The survey consists of 25 questions with a maximum possible score of 375 points. This score is based on the product of the points obtained on the questionnaire multiplied by the weight given to each of the groups of questions. The companies that completed the questionnaire were categories as follows:

281 - 375 points: Outstanding Companies. The leaders and employees alike understand and apply more than 80% of the lean tools. They understand that the concept of Lean Manufacturing goes far beyond a toolbox and may be applied to all sectors, whether operational or strategic.

187 - 280 points: Above-Average Companies. Many of the lean tools are applied, though there may be some sectors that have not yet adopted lean culture. Many employees understand the importance of progressing toward Industry 4.0, but there are some barriers to its application and/or development.

93 - 186 points – Average Companies. In this category, many manufacturing and customer relations practices follow old-fashioned management models. There is no solid

connection with distributors, and few lean practices are applied.

0 - 92 points – At-Risk Companies. These companies use few or none of the tools or cultural elements presented in this study. Neither company leadership nor employees comply with the lean practices outlined herein. Companies with this score were at risk for problems in their attempts to implement Industry 4.0 practices. They are bound to automate inefficient processes.

This scale has been used to score companies on their maturity levels within each of the question group categories. The questions were answered on a 5-point Likert scale, and the relevant weights were then applied to calculate the final score (Table 3).

Table 3 - Lean maturity assessment survey. Source: Authors

Tool Lean	The production process is chained. (One-piece-flow)	1	2	3	4	5
	The equipment is organized. (5S)	1	2	3	4	5
	All new projects go through the planning, action and verification phases. (PDCA)	1	2	3	4	5
	Every process improvement is standardized, documented, and all important information is available and up-to-date. (Standardization and Visual Management)	1	2	3	4	5
	Machines and equipment are periodically inspected. (TPM)	1	2	3	4	5
Value Chain	The batch size produced is scaled based on demand. (Leveled production)	1	2	3	4	5
	The production system is pulled. (Pulled production)	1	2	3	4	5
	There is a continuous production flow. (JIT)	1	2	3	4	5
	Production is balanced, that is, it is always limited as much as possible. (Takt-time)	1	2	3	4	5
	The value chain is mapped identifying its bottlenecks and improvement points. (VSM)	1	2	3	4	5
Employee Perspective	Employees are encouraged to propose improvements. (Autonomy)	1	2	3	4	5
	Employees are recognized for improvement proposals. (Motivation)	1	2	3	4	5
	Employees meet periodically to analyze the results obtained. (Team work)	1	2	3	4	5
	The company trains its suppliers, resellers and employees so that everyone can take part in the improvement process. (Kaizen)	1	2	3	4	5
	Leadership indicates the guidelines for changes and supports its employees. (Leadership)	1	2	3	4	5
Lean Digital	Processes are digitized and can be obtained in real time. (Transparency)	1	2	3	4	5
	Digitized jobs that have similar processes are modularized. (Modularization)	1	2	3	4	5
	Idle workstations pull new production orders. (Flexibility)	1	2	3	4	5
	The data generated during the processes are used to schedule preventive maintenance. (Preventive maintenance)	1	2	3	4	5
	Product quality flaws can be identified through the data. (Traceability)	1	2	3	4	5
Lean 4.0	Data generated throughout the processes are used for optimization (Machine learning)	1	2	3	4	5
	Algorithm systems trace alternative production paths. (Big data / Analytics)	1	2	3	4	5
	Automated vehicles Take the necessary material to the workstation. (Automation)	1	2	3	4	5
	The products produced are connected to the network. (Vertical integration)	1	2	3	4	5
	The factory is connected to the supplier's IT system (Horizontal Integration)	1	2	3	4	5

Using the survey, we were able to determine which tools companies were using, as well as the degree of maturity each of these tools exhibited in each company. The maturity has been analyzed in such a way that companies have received a higher score for question groups that address the company's proximity to Lean 4.0 processes. Some of the survey questions address lean culture in general, which helped us to determine whether the companies are ready to move on to new systems or whether certain modifications will first be necessary.

In the survey, questions related to pull production (question 7), value stream mapping (question 10), production leveling (question 6), one-piece-flow (question 1), kanban and Just in Time (question 8) and load balancing production line (question 9), according to Sundar, Balaji and Kumar [26] and Liker [7] these points are fundamental for the effectiveness of Lean Manufacturing maturity. About Kaizen (question 14), according to Knechtges and Decker [67] and Singh and Singh [27], these are events often associated with waste reduction techniques, lead time and workstation balancing, as well as 5S according to Mayr *et. al.* [28] and Lapa [10] is a basic concept in the elimination of waste (question 2), therefore, important tools in the continuous improvement process, a basic principle of the lean methodology. According to Bicheno and Holweg [29], continuous improvement is essential for any organization that wants to remain competitive and Kaizen is based on the PDCA cycle (question 3). The visual representation of process conditions and performance (question 4), according to Matternich *et. al* [1], Sjödin *et. al* [30] and Liker [7], offers employees and management the opportunity to recognize deviations immediately, enabling quick decision-making, therefore, it is considered fundamental within the lean methodology and consequently within the I4.0.

According to Prinz, Kreggenfeld and Kuhlenkötter [65], in lean manufacturing, the improvement process is very present in the hands of employees, therefore, autonomy (question 11) is an important characteristic in this process. According to Matternich *et. al* [1], Coffey and Thornley [31] if recognition, motivation (question 12), are not present, any improvement process is not sustainable, it is lost over time. For Pinheiro and Toledo [32], Rodrigues and Cecconello [33] and Bortolotti, Boscari and Danese [34], teamwork (question 13), as well as strong leadership that motivates the team (question 15), provide the group with a stimulus to improve performance, it is essential to reach new levels of optimization and supports it in the long term.

A dynamic process with a continuous capacity for improvement, in the search for optimization, for Womack and Jones [35], Mayr *et. al.* [28] and Buer *et. al* [36] needs transparency through real-time data and information quality (question 15). For a concept of product variety, with the aim of having customization based on customer expectations, Brettel *et. al.* [37] point out that modularization (question 17) is an important feature in this process, as well as for Oliveira and Simões [38] and Vaidyaa, Ambadb and Bhoslec [39] the flexibility of mass production processes is also a fundamental characteristic for a high customization of the product. According to Lee, Kao and Yang [64], machines capable of evaluating their own health and degradation as well as for Haddara and Elragal [40] the integration between machine data, ERP data, sensory data and predictive algorithms, are technologies fundamental for efficient predictive maintenance, increasing equipment availability (question 19). For Nicoletti [41] workpiece-machine communication, improved man-machine interfaces and process tracking, integration and management ensure that defect-free products are produced and sold to customers (question 20).

Pfeiffer [42] emphasizes that Machine Learning is one of the key technologies driving the progress of the Industry 4.0 revolution (question 20). According to Bevilacqua, Ciarapica and Antomarioni [43], Roy and Roy [44] and Deng *et. al.* [45], Big Data analysis proved to be potentially important in the concept of I4.0 (question 21) and this analysis can be used to create new production routes.

According to Kagermann, Wahlster and Helbig [46], the mature Industry 4.0 results in a dynamic production line, with supplies through autonomous vehicles. For Dombrowski, Richter and Krenkel [16] and Wyrwicka and Mrugalska [17] vertical and horizontal integration allows for better integration of customers and suppliers in the process, adding even more value. In vertical integration, according to Sony [47], the main objective is to meet customer expectations with minimal resources (question 24), yet for Sony [47] in horizontal integration, all organizations that participate in the value chain play a role role to meet customer needs, in addition to, according to Ivanov *et. al.* [48], huge opportunities to design innovative supply chain models (question 25).

4.4. Data Collection

The Survey was sent by e-mail directly to 255 companies from Brazil participating in the Lean Management Research Group of the Federal University of ABC (2021) and also some direct contacts with managers of some large companies to carry out the survey. The emails were sent to the employees indicated as the company's contact at the time of enrollment in the research group, usually industrial managers. Microsoft Forms was used so that companies could answer the questionnaire online, and the link was sent by email to registered contacts. The questionnaire was answered by 108 companies. This amount represents a coverage of approximately 42%, given that we have 255 companies initially identified as relevant.

5. Results and Analysis

5.1. Survey Answers

To verify the significance between the survey questions, the ANOVA method was applied, testing the null hypothesis that states that samples in all groups are extracted from populations with the same mean values. ANOVA produces an *F-statistic*, which is the ratio of calculated variance between means to within-sample variance [49]. A higher proportion therefore implies that samples were taken from populations with different mean values [50]. According to the figure, for the maturity result in the item Value Chain there was a significant interaction with the questions of Lean Tools, in the same way, there was a significant interaction between the questions of Lean Tools with the questions of Lean Value in the result of the maturity of the item Perspective of the Employee, as well as the interaction between the questions of the first three items influenced the maturity of the item Lean Digital and this, in the interaction of all other items, influenced the maturity of the item Lean 4.0, as well as the interaction between all items influenced the global maturity of the companies. ANOVA results also indicated that all six interactions showed significant differences in means (p values < 0.05).

	SS	Mean	F-value	P-value
Global Maturity	5.46	8.14	41.7	<0.01
Lean 4.0	3.18	6.77	3.78	<0.01
Lean Digital	44.6	1.44	6.54	<0.01
Emplyee Perspective	187.79	14.45	6.58	<0.01
Value Chain	1584	527.9	50.1	<0.01
Lean Tools	2.77	6.29	21.7	<0.01

Figure 7 - ANOVA. Source: Authors

About the companies that answered the survey, the average time working with lean concepts was 8.9 years, represented by the dotted line as shown in the graph in Figure 8.

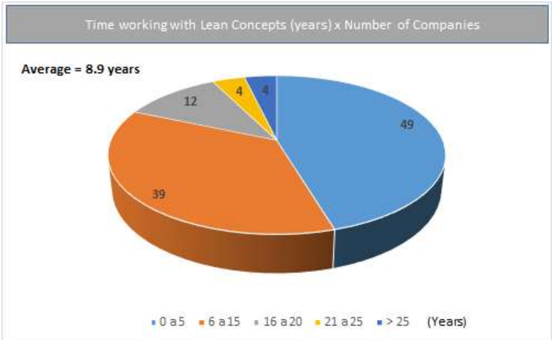

Figure 8 - Average working time with lean concepts. Source: Authors

Table 4 shows the average value of each of the survey questions. Analyzing the answers, it is possible to deduce that the questions related to Big Data/ Analytics and Automation were the ones with the lowest average. This is in line with the expected result, as these are advanced concepts of Industry 4.0. In contrast, the highest scores were obtained in basic lean concepts such as employee autonomy and leveled production.

Table 4 - Average value per questionnaire statement. Source: Authors

Tool Lean	The production process is chained. (One-piece-flow)	1	2	3	4	5	3.62
	The equipment is organized. (5S)	1	2	3	4	5	4.18
	All new projects go through the planning, action and verification phases. (PDCA)	1	2	3	4	5	4.16
	Every process improvement is standardized, documented, and all important information is available and up-to-date. (Standardization and Visual Management)	1	2	3	4	5	3.98
	Machines and equipment are periodically inspected. (TPM)	1	2	3	4	5	3.90
Value Chain	The batch size produced is scaled based on demand. (Leveled production)	1	2	3	4	5	4.19
	The production system is pulled. (Pulled production)	1	2	3	4	5	4.03
	There is a continuous production flow. (JIT)	1	2	3	4	5	3.78
	Production is balanced, that is, it is always limited as much as possible. (Takt-time)	1	2	3	4	5	3.78
	The value chain is mapped identifying its bottlenecks and improvement points. (VSM)	1	2	3	4	5	3.83
Employee Perspective	Employees are encouraged to propose improvements. (Autonomy)	1	2	3	4	5	4.10
	Employees are recognized for improvement proposals. (Motivation)	1	2	3	4	5	3.74
	Employees meet periodically to analyze the results obtained. (Team work)	1	2	3	4	5	3.61
	The company trains its suppliers, resellers and employees so that everyone can take part in the improvement process. (Kaizen)	1	2	3	4	5	3.44
	Leadership indicates the guidelines for changes and supports its employees. (Leadership)	1	2	3	4	5	3.84
Lean Digital	Processes are digitized and can be obtained in real time. (Transparency)	1	2	3	4	5	3.46
	Digitized jobs that have similar processes are modularized. (Modularization)	1	2	3	4	5	3.38
	Idle workstations pull new production orders. (Flexibility)	1	2	3	4	5	2.81
	The data generated during the processes are used to schedule preventive maintenance. (Preventive maintenance)	1	2	3	4	5	3.37
	Product quality flaws can be identified through the data. (Traceability)	1	2	3	4	5	3.96
Lean 4.0	Data generated throughout the processes are used for optimization (Machine learning)	1	2	3	4	5	3.14
	Algorithm systems trace alternative production paths. (Big data / Analytics)	1	2	3	4	5	2.58
	Automated vehicles Take the necessary material to the workstation. (Automation)	1	2	3	4	5	2.58
	The products produced are connected to the network. (Vertical integration)	1	2	3	4	5	2.81
	The factory is connected to the supplier's IT system (Horizontal Integration)	1	2	3	4	5	2.72

In Table 5, we have the average value separated by each of the group levels of analysis. It can be seen that questions related to Lean Digital and Lean 4.0 were the ones with the lowest overall average. However, the analyzed companies obtained a reasonable average in the categories of Lean Tools, Value Chain and Employee Perspective.

Table 5 - Average value of questionnaire by group. Source: Authors

Ferramentas Lean	Cadeias de Valor	Perspectiva do Funcionário	Lean Digital	Lean 4.0
3.97	3.92	3.75	3.40	2.77

To analyze lean maturity as well as the stages that come before Lean 4.0, the authors of the Industrie 4.0 meets Lean - Guideline to increase added value holistically, [1], argue that 5 steps are necessary. First, lean concepts must be implemented in all sectors of the company. In this case, the companies included in the study received high scores on their implementation of fundamental lean concepts such as the 5Ss, PDCA, TPM, and visual management. Table 6 details the average scores for each question within question group 1.

Table 6 - Average value per tool (group 1). Source: Authors

One-Piece-Flow	3.62
5S	4.18
PDCA	4.16
Visual Management	3.98
TPM	3.90

The second step analyzed in this research is the importance of knowing about the value chain as shown on Table 7. “In order to let products flow and reduce processing time, Value Stream Management helps to develop a vision of lean value” [15]. In this group, the participating companies obtained almost the same average of the scores of the previous group. In this group, the concepts of Just in time, Leveled Production and VSM were analyzed.

Table 7 - Average value per tool (group 2). Source: Authors

Leveled Production	4.19
Pulled Production	4.03
JIT	3.78
Takt-time	3.78
VSM	3.83

The next step is related to the employee perspective (Table 8). In order for the changes made so far to be sustainable, all employees must understand the value of lean concepts. With an average of 3.75, most companies encourage their employees to propose improvements within their individual areas of activity (Autonomy). This point, with an average of 4.10, (the highest score of the group) is essential for improvements to be implemented in all spheres, from the operational level – shop floor to the most strategic level.

Table 8 - Average value per tool (group 3). Source: Authors

Autonomy	4.10
Motivation	3.74
Team Work	3.61
Kaizen	3.44
Leadership	3.84

The next group is related to Digital Lean, the concepts of traceability, preventive maintenance and transparency were analyzed (Table 9). On the aspect of traceability, the participating companies obtained the best score of the group. However, with a score of 2.81, idle workstations are not or very little monitored by sensors capable of monitoring production avoiding idle machine time. Within Lean Digital, the use of sensors is fundamental for process monitoring. They help not only to map the process as a whole, but even to predict wear and tear on tools and machinery.

Table 9 - Average value per tool (group 4). Source: Authors

Transparency	3.46
Modularization	3.38
Flexibility	2.81
Maintenance	3.37
Traceability	3.96

Finally, the last group analyzed is related to the final stage of the maturity scale (Table 10). Questions related to Lean 4.0 had the lowest average. This was already expected, since, in order to reach maturity in this group, it is necessary to develop an even greater maturity in the previous groups. With an average of 2.77, some companies said that the data collected is used for automatic optimization of the value chain. However, few of them use the concepts of Big Data and Analytics capable of creating variable algorithms allowing the creation of new production flows.

Table 10 - Average value per tool (group 5). Source: Authors

Machine Learning	3.14
Big Data / Analytics	2.58
Automation	2.58
Vertical Integration	2.81
Horizontal Integration	2.72

Based on the data collected and the levels of maturity that companies reach in the later categories as they reach a higher level in the previous ones, it reinforces the idea that Lean Digital and Lean 4.0 present better results when Lean Manufacturing is a cultural methodology within the organization [36]. Despite some indications on this path, there are not enough studies that point out to the facilitating role of lean implementation before a transformation to I4.0. However, some studies have shown that the combination of Lean Manufacturing with I4.0 helps companies achieve lean automation (Lean 4.0), and this aims at greater adaptability and shorter information flows to meet future market demands [51] [52] [49]. Additionally, I4.0 technologies introduce automation and interconnectivity that can mitigate pre-existing management pain points. Some brazilian companies participating in the research also said during the data collection, that projects where they implement I4.0 technologies in processes already optimized with lean, have lower costs than an implementation completely from scratch, which facilitates the justification of the implementation, where, the very high cost of implementing smart factories, particularly during the early years, exacerbates uncertainty as the benefits of the investment will accrue at an uncertain time in the future [30]. But here is a lack of studies that empirically present a successful relationship in the implementation of I4.0 elements in an empirical way. successive to a mature Lean Manufacturing implementation, so that this research has demonstrated in the companies studied precisely that digitization maturity is a consequence of a well-implemented lean methodology, with strong correlation between the categories focused on I4.0 with the categories of Lean Manufacturing [20] [51] [66] [53].

The average score obtained by the companies, based on the methodology, was 252.40 (Figure 9). This places them within the range of companies considered optimal. Most of them obtained good grades in the groups related to the basic principles of lean, however, on average, the participating companies have not yet reached the expected level of maturity to be considered excellent companies. For this, there is still a journey to be followed so that the tools related to Industry 4.0 can be absorbed by each of the companies.

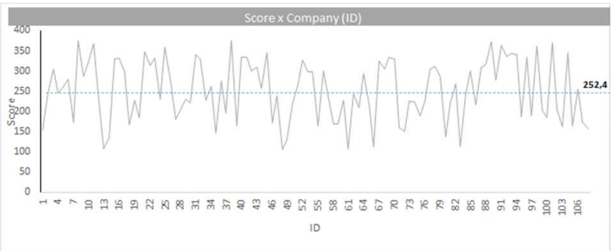

Figure 9 – Score chart by company. Source: Authors

In table 11 we can see the number of companies per range.

Table 11 - Number of companies by group of category on lean maturity. Source: Authors

Intervalo de Pontos	Quantidade de Empresas
375 a 281	45
280 a 187	37
186 a 93	26
92 a 0	0

The percentagem of companies in each of the analyzed category is reflected in Figure 10.

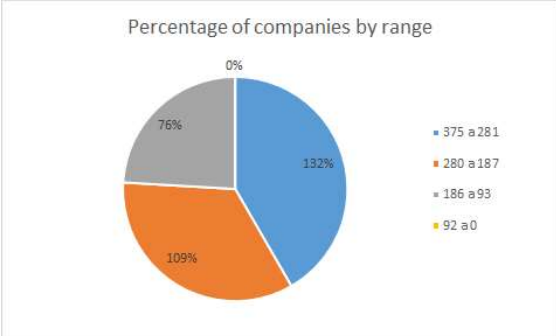

Figure 10 – Percentage of companies by group of category on lean maturity. Source: Autthors

The average score obtained by companies by branch of activity is shown in Figure 11. The automotive industry, the birthplace of the lean production methodology and where industry 4.0 technologies are being implemented, had the best score, followed by the electronics industry, a branch that is very focused on technology implementation. Next, we see the chemical/pharmaceutical industry, as they are companies that need a high level of process control, followed by the white goods industry, then companies such as the textile, furniture and services industries, characterized as others. In the sequence, metallurgical and food and beverage industries, which are usually less concerned with the implementation of methodologies such as lean and with investments in new technologies, as they are usually smaller companies and implementations and investments depend a lot on the availability of people resources and support from institutions government agencies such as, for example, the BNDES for investments (Brazilian bank for investments).

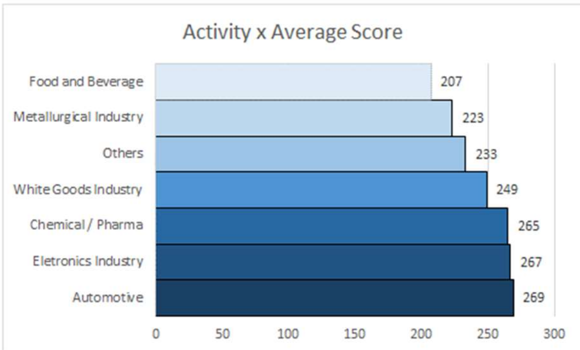

Figure 11 – Average score x activity. Source: Autthors

5.2. *Critical analysis of results*

First, a reliability analysis of the questionnaire was applied to validate the questionnaire. The test results in Cronbach's Alpha index is categorized as reliable at a minimum value of 0.7 [54] [55]. The index was tested using the IBM SPSS Statistics software considering each of the 5 research categories and in each category a set of 5 items (questions) as shown in Table 12.

Table 12 - Cronbach's Alpha Index. Source: Authors

Search Reliability		
Categories	Cronbach´s Alpha standardized items	Number of items
Lean Tools	0.849	5
Value Chain	0.854	5
Employee Perspective	0.918	5
Lean Digital	0.887	5
Lean 4.0	0.923	5

Still regarding reliability, an analysis was carried out in each of the categories to identify the items (questions) with the highest index of relationship between them, as a way of testing that there is indeed a reliable interaction between the questions.

In the Lean Tools category, as shown in Table 13, we see a strong relationship between questions 3 and 4 of the questionnaire, with question 3 being related to the PDCA cycle, while question 4 is related to the Visual Management. The result showing a relationship between these 2 questions reflect that all improvements/changes in the process using the PDCA cycle are documented and standardized, ensuring that everyone has access and knowledge through effective sight management.

Table 13 - Correlation matrix among lean Tools items. Source: Authors

	Quest1	Quest2	Quest3	Quest4	Quest5
Quest1	1.000	0.482	0.439	0.278	0.403
Quest2	0.482	1.000	0.712	0.672	0.636
Quest3	0.439	0.712	1.000	0.716	0.581
Quest4	0.278	0.672	0.716	1.000	0.537
Quest5	0.403	0.636	0.581	0.537	1.000

In the Value Chain category, according to Table 14, there is an expressive relationship between questions 6 and 7, the first being related to the Leveled Production and the second about Pulled Production and in fact, when the batch size produced is based on demand, the pull production system becomes more efficient, with previously defined process times, production time is better planned and inter-process inventories are avoided or even eliminated.

Table 14 - Correlation matrix among Value Chain items. Source: Authors

	Quest6	Quest7	Quest8	Quest9	Quest10
Quest6	1.000	0.773	0.507	0.513	0.440
Quest7	0.773	1.000	0.445	0.436	0.368
Quest8	0.507	0.445	1.000	0.692	0.549
Quest9	0.513	0.436	0.692	1.000	0.704
Quest10	0.440	0.368	0.549	0.704	1.000

Regarding the Employee Perspective category, as shown in Table 15, the relationship is stronger in questions 12 and 13, the first dealing with employee motivation and the second with the results obtained with teamwork. In fact, the culture of teamwork brings important process information to the group for the presentation of improvement proposals with their proper implementation, consequently bringing motivation to the group and making this process a continuous cycle.

Table 15 - Correlation matrix among items Employee Perspective. Source: Authors

	Quest11	Quest12	Quest13	Quest14	Quest15
Quest11	1.000	0.752	0.724	0.674	0.708
Quest12	0.752	1.000	0.781	0.620	0.638
Quest13	0.724	0.781	1.000	0.680	0.697
Quest14	0.674	0.620	0.680	1.000	0.700
Quest15	0.708	0.638	0.697	0.700	1.000

In the Lean Digital category, the most expressive relationship was between questions 16 and 17, as shown in Table 16, the first dealing with transparency and the second with the modularization processes. With processes where data are obtained in real time, decision-making is better, facilitating new production orders to be allocated to idle stations, due to the modularization of processes.

Table 16 - Correlation matrix among Lean Digital items. Source: Authors

	Quest16	Quest17	Quest18	Quest19	Quest20
Quest16	1.000	0.787	0.638	0.589	0.614
Quest17	0.787	1.000	0.616	0.578	0.546
Quest18	0.638	0.616	1.000	0.646	0.495
Quest19	0.589	0.578	0.646	1.000	0.621
Quest20	0.614	0.546	0.495	0.621	1.000

Finally, in the Lean 4.0 category, the strongest relationship was between questions 22 (Big Data) and 23 (Automation), as shown in Table 17. In fact, with the process increasingly connected, horizontally and vertically, [47], the relationship between available information is becoming more evident, connected products bring information that lead to new development and in the process, the available data adjust the production to avoid failures, improving productivity and minimizing or even eliminating production stops.

Table 17 - Correlation matrix among Lean 4.0 items. Source: Authors

	Quest21	Quest22	Quest23	Quest24	Quest25
Quest21	1.000	0.729	0.622	0.691	0.628
Quest22	0.729	1.000	0.790	0.745	0.649
Quest23	0.622	0.790	1.000	0.800	0.693
Quest24	0.691	0.745	0.800	1.000	0.709
Quest25	0.628	0.649	0.693	0.709	1.000

Furthermore, in Figure 12 we can see a relatively weak correlation when we consider the evolution of the score as a function of the time of performance with lean, with an R coefficient of 0.306. Taking as an example, a respondent company in the automotive industry with 20 years of experience in lean, had a total sum of 291 points, while another company, in the same industry, with 10 years of experience in lean, had a total sum of 366 points.

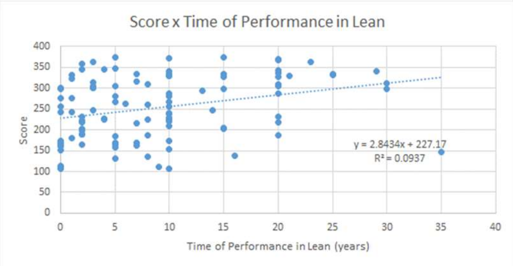

Figure 12 – General correlation among Total Score and Experience Time of Lean. Source: Authors

Even when we look at the categories of the questionnaire, it is possible to verify the correlation between them with the objective of validating the relationship between Lean Manufacturing categories, as well as helping to understand the relationship of the Industry 4.0 categories with lean, since there is still no consensus on the relationship between these concepts [36], there is an inherent need to investigate whether the implementation of Industry 4.0, following lean or should be treated independently. However, in the correlations presented previously, we see that lean has been a very important basis for the implementation of the elements of Industry 4.0.

In Figure 13 we see the correlation between Value Chain and Lean Tools, showing an R coefficient of 0.787 which shows the importance of lean tools such as 5S, PDCA, One-piece-flow for a more optimized process, balanced and on demand. 5S is an important basic tool even before the implementation of any other lean tool and when culturally implemented, it maintains a characteristic of continuous improvement, as well as PDCA is an important tool in process optimization.

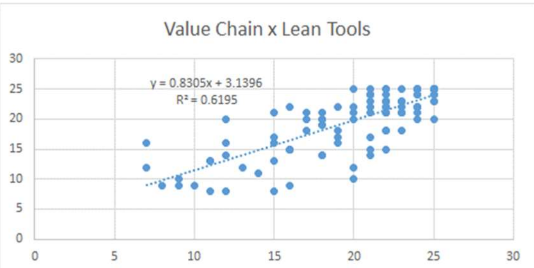

Figure 13 - Value Chain x Lean Tools Correlation. Source: Authors

In Figure 14, it shows the correlation between Employee Perspectives and Lean Tools, showing an R coefficient of 0.681, slightly below the 0.700 expected as a minimum that represents a strong correlation. Which shows how important it is that lean concepts are implemented in a way that becomes cultural in the company. The establishment of a culture of continuous improvement is what prepares the entire organization for major changes [56], the successful implementation of any management practice often depends on organizational characteristics and all employees of all the levels are the key pieces to this success [17].

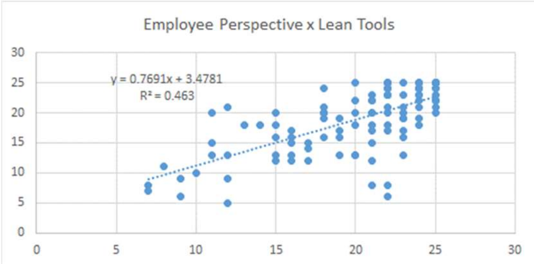

Figure 14 - Employee Perspective Correlation x Lean Tools. Source: Authors

In Figure 15, we see the correlation between Employee Perspective and Value Chain with an R coefficient of 0.583, below the expected 0.700, indicating a weak relationship, which also demonstrates, as in the previous correlation, a weak adherence of employees to the culture of Lean Manufacturing which reflects on the maturity of the companies of the survey.

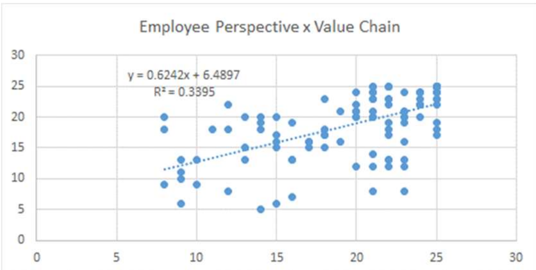

Figure 15 - Employee Perspective x Value Chain Correlation. Source: Authors

In Figure 16, it is possible to verify the first correlation between technologies that move towards Industry 4.0 with lean concepts, with na R coefficient of 0.729 for the correlation between Lean Digital and Lean Tools, which means that tools such as 5S and PDCA in a cycle of continuous improvement, brings positive results, for example, in modularization and flexibility of processes. There is a relationship between Lean Manufacturing and Industry 4.0 that reflects in the increase of process flexibility [57], which helps to elucidate that the implementation of Industry 4.0 elements can be facilitated inaan organization where lean is already implemented and with a certain maturity [36] [51].

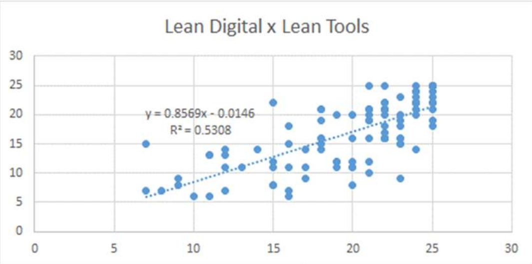

Figure 16 - Lean Digital Correlation x Lean Tools. Source: Authors

In Figure 17, we have the correlation between Lean Digital and the Value Chain, with an R coefficient of 0.728, slightly above the expected minimum of 0.700, that is, as in the previous correlation, tools such as VSM that map the process, its bottlenecks and improvement points, also reflect positively for modularization and flexibility, for example. Value stream mapping (VSM) is a fundamental lean tool [36] and is often seen as a starting point in a continuous improvement cycle. Process digitization can improve the VSM through real-time data collection [17].

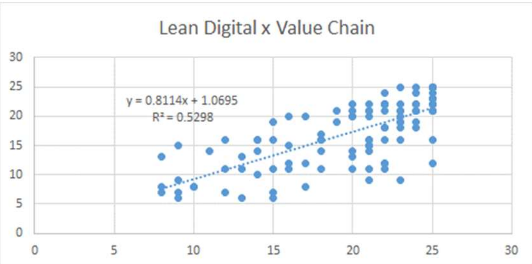

Figure 17 - Lean Digital x Value Chain Correlation. Source: Authors

In Figure 18, we have the correlation between Lean Digital and Employee Perspective, with an R coefficient of 0.684, which shows that, despite the value being a little below the expected 0.7, the culture of teamwork, motivation and continuous improvement, present a positive relationship in the preparation of the entire organization to accept and encourage major changes [56], as in the case of Industry 4.0, from the managerial to the operational level. In addition, it helps to elucidate the impacts of Industry 4.0 on the analytical-behavioral practices of Lean Manufacturing, since this is currently a gap [36] [58], which does not show in a representative way how the relationship between Lean Manufacturing and Industry 4.0 can influence the results of the organization, but we see here that positive results of a lean culture implemented in the organization, with a certain maturity, it has positive effects on its preparation for the implementation of new elements, as in the case of digitization. We can also understand these results that Lean Manufacturing is the basis for the introduction of Industry 4.0 and that the second increases the effectiveness of the first [16], further reinforcing that Industry 4.0 tends to stabilize and support lean manufacturing principles [59].

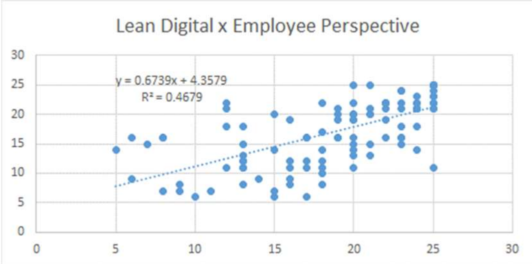

Figure 18 – Lean Digital x Employee Perspective. Source: Authors

Finally, in Figure 19, we see the correlation between Lean 4.0 and Lean Digital, with an R coefficient of 0.738, showing that there is a relationship between the implementation of process digitization technologies, vertical and horizontal integration, as well as more autonomous processes in a more transparent factory with data being obtained in real time, ensuring that product failures can be identified through data and consequently the identification of their root cause. Several companies have difficulty understanding the real effectiveness of Industry 4.0 concepts and with this correlation we can verify that the data are more accessible, giving an effective view in real time, enabling faster and more assertive decision making [24] [58].

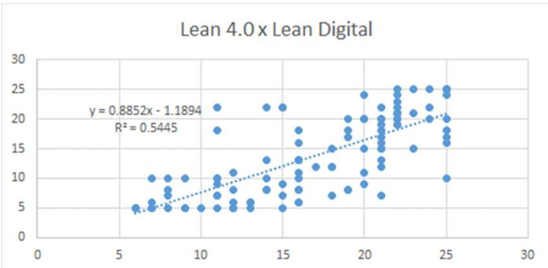

Figure 19 - Lean 4.0 x Lean Digital Correlation. Source: Authors

The fact is that, as already mentioned, although several studies are already being carried out, there is still no consensus on the implementation of the elements that correspond to Industry 4.0, how they should be implemented, what relationship exists between them and where these concepts should be implemented [60] [37] [61] [62]. However, in the companies studied in this research, it appears that with the implementation of a more digitized factory, there is a better access to information, making it possible to further optimize processes. Lean Manufacturing has been an important basis in this transformation, that is, the maturity of lean in the organization, is reflected on the maturity of the implementation of Industry 4.0. The implementation of Industry 4.0 elements does not eliminate Lean Manufacturing, but helps to increase its maturity [63].

6. Conclusion

The Lean maturity analysis of the companies participating in the research is of great importance to verify which stage of maturity each of these companies are. The aim is to show that, in order to reach higher levels of maturity, it is necessary to go through previous stages. Understanding the concepts of lean as a culture and not as a toolbox is critical. The answers obtained in the questionnaire, prepared based on Matternich *et. al.* [1] and the systematic literature review, showed that 76% of the participating companies are in the range of excellent or great companies, which means that most of the lean tools are applied, although there may be some sectors that have not yet adhered to the lean culture. Many companies understand the importance of advancing towards Industry 4.0, but there are some barriers for its application and evolution. Within the five stages of maturity that were developed in this research, based on Matternich *et. al*. [1], companies obtained good results in the first three. This indicates that both the leadership and the operational collaborators understand the importance of the concepts of continuous improvement. In these companies, lean is not seen as a toolbox, but as a culture.

Another important aspect is that, not necessarily the longer they worked on lean implementation, the closer to the range of "excellent companies" they were, but how this time was properly used in the implementation of the tools and their consequent adherence to the culture. To implement a culture it takes time and total understanding in all spheres of work, however this needs to be led by the strong leadership and teamwork. The changes taken towards industry 4.0 only become sustainable when treated in this way.

Based on the data, many companies still do not invest in Big Data and Analytics. The digitization phase precedes any automation process. What to do with the data collected is the differentiator in the transition process from Lean Digital and Lean 4.0. It is important to point out that Industry 4.0 technologies are expensive and must be analyzed so that they serve according to the needs of each one of them.

Finally, it was possible to verify with this study, an important relationship between the categories of Lean Manufacturing, reaffirming the idea of being interconnected tools and that should not be treated individually. In addition, they showed an important reflection in the implementation of Industry 4.0 technologies, which can represent that lean is an important basis for the implementation of these new technologies and these can reflect in an improvement in the effectiveness of lean tools. Also considering that for Brazilian companies, the value of the investment is a decisive factor, implementing technologies step by step in processes optimized with lean seems to be the best path to take.

So considering the insights of this research, following are the contributions to the academic and industry fiels:

Academic contribution – this study contributes to bridge a literature gap about the correlation between Lean Manufacturing and Industry 4.0. It also helps to understand what level of maturity Brazilian companies are within lean manufacturing methodology and Industry 4.0 technologies. In addition, it was possible to verify that Brazilian companies are opting for an implementation of industry 4.0 technologies in processes where lean is well implemented and with a certain level of maturity (browfield), therefore, these are not implementations that start completely from scratch (greenfield). Based on a systematic literature review, it was developed na integrated lean and Industry4.0 maturity level survey which can be replicated to others research.

Industry contribution – this study highlights the importance of Lean Manufacturing to sustainable implementation of Industry 4.0. Companies aiming to implement digitization tools must first organize their shopfloor and build a lean culture, so that entire organization is working on continuous improvement using new digitization tools. Therefore, this study helps companies understand where efforts and investments should be applied to have an improvement in the maturity level of lean manufacturing and consequent implementation of industry 4.0 technologies.

As limitations of this research, we can highlight that the sample size was not larger due to the fears that respondents have in relation to the new Brazilian data protection legislation (General Data Protection Law) and that a large majority of companies that respondents to the survey are from the automotive sector (64%), the birthplace of lean manufacturing and where efforts to implement industry 4.0 technologies are known.

As a suggestion for future work, to have a better parameter of how Brazilian companies in other sectors are doing, the survey can be applied to a larger number of companies outside the automotive sector, as well as an *in loco* assessment of the various branches to attest to what was answered in the survey.

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