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The Development of an Excellence Model Integrating the Shingo Model and Sustainability

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Abstract: Companies are continuously looking to improve their production systems using excellence models, with lean thinking, the Shingo model, six sigma and lean six sigma being the most comprehensive and applied. It is expected that the initial focus for the survival of companies is their economic profitability, but when economic needs are met, the next step is to achieve operational excellence. For this, in addition to economic objectives, it is necessary to include social and environmental objectives, i.e., the other two pillars of sustainability. This study aims to propose a conceptual model identifying the tools that can help achieve the desired results in the three pillars of sustainability aligned with operational excellence. The design of the conceptual model was based on a bibliometric analysis of the literature that relates the concepts of lean thinking, six sigma, lean six sigma and the Shingo model. The Web of Science was the platform selected for the collection of data, and the timeframe considered was 2010 to 2021. A total of 125 articles were analyzed using the VosViewer software, through which it was possible to analyze different topics of study related to the literature. The bibliometric analysis allowed for the identification of the temporal distribution of publications, the categorization of topics, different areas of application and the importance of the tools used in different practical cases. This study points out that companies have at their disposal several tools to achieve economic objectives. On the other hand, there is a set of more restricted tools that are used to meet the objectives of the social and environmental pillars. Future research should focus on identifying tools that meet social and environmental goals in order to strengthen these pillars that are essential for operational excellence and for the sustainability of companies.

Keywords: sustainability; Shingo model; lean six sigma; lean thinking; six sigma; DMAIC

1. Introduction

Existing global competition has led to significant changes in the market, with a considerable increase in the variety of increasingly complex products with ever shorter and uncertain life cycles [1]. The current problem for manufacturers is how to deliver their products or materials quickly at a low cost and with good quality [2].

In recent years, continuous improvement and operational excellence programs have played an important role in the success and sustainability of organizations, allowing companies to achieve high grades of competitiveness [3]. Lean thinking, the Shingo model, the Toyota way, six sigma and lean six sigma are some examples of applied models. These models guide companies to maintain consistent practices with sustainable development strategies, and, as such, they control waste, reduce production variability and implement practices that are environmentally and socially responsible [4,5].

Organizations have been pressured by stakeholders to adopt not only economic but also social and environmental objectives [6,7]. The growth of ecological consumerism, climate change and the latest government legislation are some of the reasons why companies have improved their performance in all components of sustainable development [8–10]. This growing trend of companies in responding to the challenge of sustainability has resulted in the emergence of the concept of corporate social responsibility, which focuses on creating value that promotes harmony between economic development, social progress, equity and respect for the environment [11].

Lean six sigma (LSS) is one of the excellence models that helps companies improve operational efficiency, reduce costs and increase effectiveness, especially when they need to operate in a highly competitive globalized market [12]. It allows companies to increase the speed of waste elimination, reducing the processes variation as well by integrating the best methodologies and tools associated with lean thinking and six sigma [2,5].

LSS, like other excellence models, has undergone evolutions towards sustainability. First, there was integration between LSS and Green Technology, resulting in GLS (green lean six sigma) methodology that incorporates two dimensions of sustainability (economic and environmental). Recently, sustainable green lean six sigma has emerged, which incorporates all the dimensions of sustainability (economic, environmental and social) and an inclusive approach that makes industries more resilient and promotes a healthier society, meeting Corporate Social Responsibility [13].

The lean six sigma philosophy promotes process and product innovation and has the potential to influence radical innovation in the industry worldwide. To achieve long-term success, organizations need to focus on continuous improvement and problem-solving approaches by changing the organizational culture. Thus, it is possible to adopt these new philosophies, including sustainability, Industry 4.0 and the Circular Economy [14,15].

An important component of this work is to research and categorize the different operational excellence tools used on DMAIC methodology applications, allowing for readers to easily understand the best ones to act in each pillar of the conceptual model under development. In fact, their suitability to act economically, environmentally and socially are different and promotes different effects in achieving operational excellence. The model developed allows for easy perception about what tools can be used to improve each pillar. This categorization of the tools regarding each pillar toward operational excellence is the main novelty presented by this paper, representing an important contribution to the sustainability of companies regarding different pillars. Indeed, if companies improve their performance considering the DMAIC methodology and excellence tools, their sustainability also increases, leading to a better economic, environmental and social performance.

The investigation was based on a literature review in the areas of lean thinking, six sigma, lean six sigma and the Shingo model, through which a bibliometric analysis was performed. The main contribution of this research is the development of a conceptual model that relates excellence tools with the different pillars of sustainable development, in which the DMAIC plays the role of structured methodology, allowing for a strategic direction for improvement. This article is divided into the following sections. First, a theoretical review of the lean thinking literature, six sigma, lean six sigma and the Shingo model is presented. Second, the methodology and research criteria that enabled the treatment of information are presented. Third, the results of the bibliometric analysis are presented. Fourth, the information of the analyzed publications is discussed. Finally, the main findings of the research are revealed.

2. Literature Review

2.1. Lean Philosophy

Production systems have undergone several evolutions throughout history. First, production was essentially handmade, and then it was replaced by mass production with assembly lines. From the middle of the 20th century, the lean approach has increasingly replaced mass production until today [16]. Lean philosophy, or lean thinking, inspired by the Toyota Production System, can be considered as a philosophy that helps in the identification and elimination of waste. In practice, lean philosophy helps maximize product value by minimizing waste [17–20].

Taiichi Ohno, the pioneer of the Toyota Production System (TPS), described the following: "All we are doing is looking at the timeline from the moment a customer gives us an order, to the point when we receive the money. In addition, we are reducing the timeline by reducing waste activities that do not add value" [18].

The objectives of the lean philosophy are: to reduce waste in human efforts, stock, the time of marketing and production space to become agile-looking for the customer while producing quality products more efficiently and economically [21]. This production approach consists of determining the value of each activity and distinguishing the activities that add value from activities that do not add value. The latter has been worked on in order to reduce or even eliminate them [22,23]. Lean philosophy is "a way to do more with less and less human effort, less equipment, less time and less space as it comes closer to providing customers with what they want" [24].

Lean thinking is a critical concept in which value creation and waste reduction are interrelated with each other. Value creation is defined as meeting customer requirements by understanding requirements, mapping the process, promoting value flow to and from stakeholders, extracting customer value and driving toward perfection [25]. In order to reduce or even eliminate waste in the production system, organizations need to follow five key principles, as follows: Define "Value" from the customer's point of view, Identify the "Value Stream", Create a "Continuous Flow", Create "Pull Flow" and "Seek Perfection" [26]. The lean philosophy suggests that, in order to create capacity in the workplace, it is better to identify areas where there is waste and to work in these areas in order to eliminate them from processes [27].

Lean thinking practitioners traditionally focus on what they refer to as the seven forms of waste: Overproduction, Waiting Time, Transportation, Improper Processing, Inventory, Defects and Movements [4,15,28]. Recently, the authors have suggested two more types of waste that should be considered: the Underutilization of People's Creativity and Environmental Waste [29]. The departure of individuals from companies with a certain set of skills and the non-use of talent results in losses of competitiveness and productivity for companies [15].

2.2. Six Sigma

The six sigma philosophy embarks on organized and systematic methodologies that do not have, as their sole purpose, the improvement of a strategic process, but it also allows for the design of new products and services. It achieves significant reductions in defect rates and frequently uses statistical and scientific methods [30]. Essentially, an approach that improves productivity, quality and reduces operating costs is traditionally used to measure and reduce process variability [31]. It is a philosophy of continuous improvement aimed at increasing efficiency and customer satisfaction and reducing operating costs [29]. In general, it is a business improvement strategy, focused on processes to improve the profit yield by eliminating waste, reducing the cost of non-quality and improving the effectiveness and efficiency of the entire system in order to achieve or even exceed the stakeholders' needs and expectations [32].

The six sigma philosophy has two methodological branches: DMAIC (Define, Measure, Analyze, Improve, and Control) and DMADV (Define, Measure, Analyze, Design, Verify). The first focuses on existing products and processes. The second focuses on new products and processes [33,34]. The main differences between the DMAIC and DMADV methodologies are in the objectives and results of the project. DMADV has a more tangible result; however, both methods have better quality, efficiency, more production, profits and greater customer satisfaction as their common goals [35].

The DMAIC methodology provides organizations with a rigorous and disciplined structure [36]. It is used for process improvement and, more recently, for project management. It enables the finding of solutions and opportunities based on decisions supported by data and management standards, and it also provides formal procedures for the implementation of solutions [37,38].

The path of the different DMAIC phases is then described succinctly [39–41]:

- Define: The identification of the problem, the determination of objectives and the appropriation of the relevance of the objectives.
- Measure: The translation of the problem in a measurable way through the observation and research of knowledge.
- Analysis: Making a diagnosis by identifying the factors and causes of influence that determine certain behaviors, and using the aggregated data in the Measurement phase.
- Improve: Implementation of measures that have been designed to improve performance and achieve the desirable state.
- Control: Adjustments to process management and system control; therefore, the results are sustainable.

2.3. Lean Six Sigma

The lean six sigma (LSS) philosophy emerged in the early 2000s and is a hybrid philosophy built from the combination of lean methods and principles with DMAIC [1,42]. Being considered a differentiating philosophy of management and improvement, its acceptance in the generality of the industry has grown rapidly, causing significant improvements in the performance of organizations [43]. These improvements are based on reducing costs, reducing lead time and increasing quality through the elimination of waste and process variation, thus enabling organizations to achieve competitive prices and thereby ensuring customer satisfaction [44–46]. The consistent practice of methodologies such as LSS allows companies to embark on a sustainable development strategy and to be socially and environmentally responsible for their practices, achieving a desirable control that enables them to gain a competitive advantage [47].

The combination of lean thinking and six sigma allows companies to capitalize on the best of both worlds in order to achieve operational excellence [5]. The LSS philosophy "uses tools from both toolboxes to get the best of both philosophies, increasing speed while increasing accuracy" [48]. Lean philosophy, as mentioned above, increases productivity by eliminating waste, such as activities that do not add value, with the goal of achieving the continuous flow of production smoothly and uninterruptedly, producing only what the customer requires. The six sigma philosophy increases productivity by reducing product variations and increases the quality of production processes [49,50]. In addition to that, it also provides methodologies for solving problems in a structured way, which allows a strategic direction for improvement [48].

2.4. The Shingo Model

The Models of Operational Excellence began to emerge around the late 1980s and early 1990s, with the aim of supporting organizations to overcome challenges, to improve the level of performance and to achieve results that are sustainable in the long term [51]. The Models of Operational Excellence, today, are also identified as a potential support for corporate sustainability through the integration of sustainable development criteria in traditional business models. Corporate sustainability is a concept that incorporates areas such as long-term focus, stakeholder needs and the foundations of sustainable development (social responsibility, environmental responsibility and economic responsibility) [52].

In order to achieve operational excellence, there is a panoply of methodologies that can be applied, as is the case of the Shingo model. It was conceived by Japanese industrial engineer Shigeo Shingo, who highlighted the importance of organizational and behavioral culture along with the integration of lean culture; therefore, transformation and development can occur with the desired results [53].

The Shingo model allows for the symbiosis of the multiple strands of a lean management system in a strand of operational excellence, i.e., it is not only focused on the customer (results) and tools but also covers systems, culture and guiding [54]. Organizations design systems with the intention of achieving specific results and select tools to support these systems. However, the tools do not run a business. The behaviors of people in an organization can influence the sustainability of results, and therefore, this model argues that the search for improvement can not only be limited to the application of a new tool or method but should also focus on organizational culture [53]. Organizational culture is the system of principles that members of the organization share, including ways of working, traditions, histories and methods capable of achieving goals [55]. The cultural perspective is important in models of excellence, since it influences the actions and behaviors of people. From the perspective of business excellence, it helps organizations find a motivating context for change and achieve higher performance levels. It is through culture that organizations are able to build systems and processes that are strong and stable to meet the market's needs [56].

The Shingo model presents guiding principles and connects them with systems, tools, results and culture, integrating these five elements around the relationships illustrated in Figure 1.

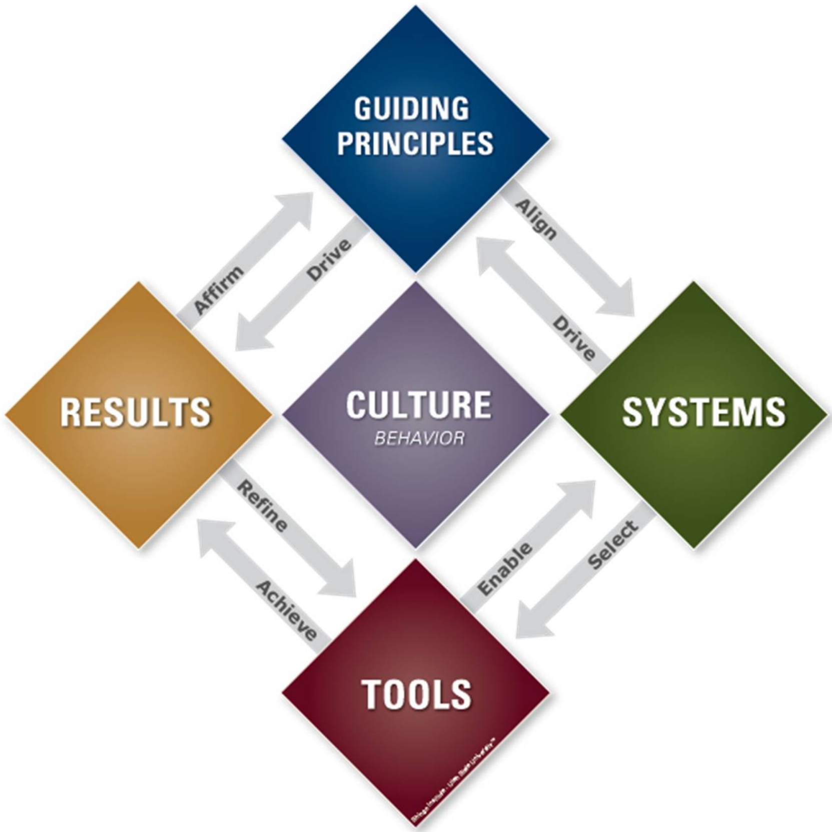

Figure 1. Shingo model parameters (Shingo Institute, 2022).

The parameters present in Figure 1 correspond to [53]:

- Guiding Principles: Shingo's guiding principles are the basis for a sustainable organizational culture of excellence. They indicate rules that enable the understanding of the consequences of behaviors and, therefore, enable decision making to be conscious and to meet the ideal results;
- Tools: Tools that allow operational execution to be carried out in order to achieve the purpose of the system. Therefore, they must be carefully selected in order for the tools to be aligned with the system;

- Systems: These are sets of processes, persons or procedures that are interconnected and allow the realization of guiding principles;
- Results: The consequence of leadership capacity, behaviors and routines. Ideal results are all those that are sustainable in the long term and that require leadership capacity to create cultures in which behaviors and routines are practiced;
- Culture: The center of the Shingo model, which represents the manifestation of the behaviors and actions of the organization's elements;

The Shingo model presents ten guiding principles that are organized in three dimensions: cultural enablers, continuous improvement and enterprise alignment (Figure 2).

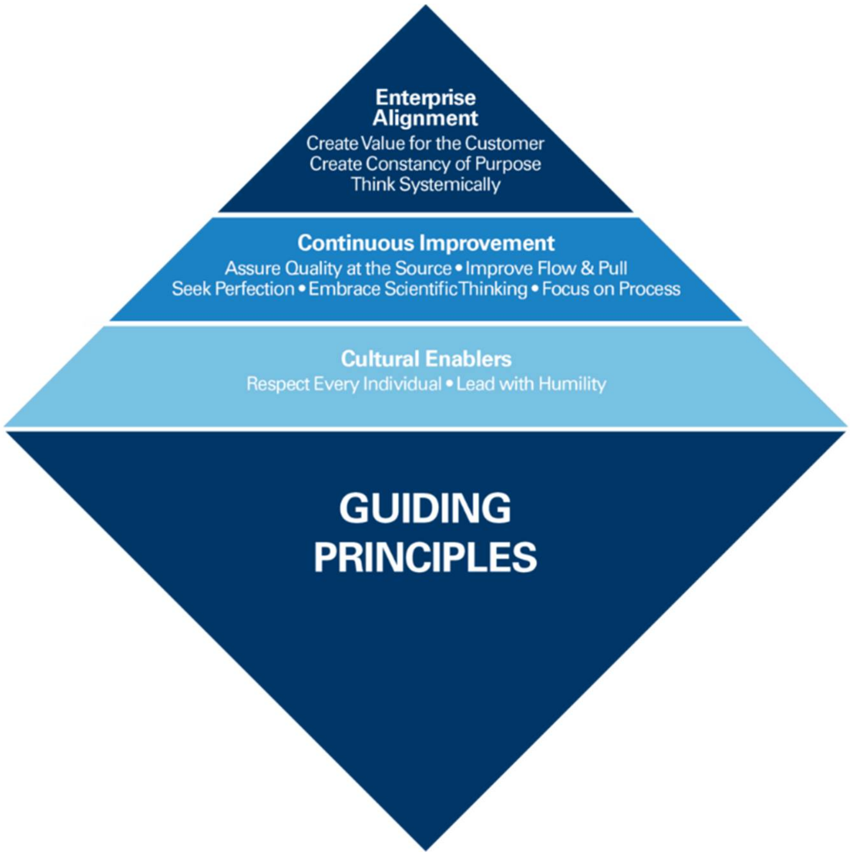

Figure 2. Dimensions of the Shingo model (Shingo Institute, 2022).

Guiding principles are used to align behaviors and actions, a process that is improved by selecting specific tools used to achieve results, where the results then affirm the guiding principles. In the opposite direction, the Shingo model indicates that the guiding principles can generate results in the form of performance indicators and impacts from which the company can obtain interpretations and predictions that can help in the refinement of the tools used to improve the systems that, in turn, direct principles that are anchored in the core values of the company [57].

The principles of the Shingo model are universal and timeless, and therefore, they do not vary in different cultures and eras, although they may manifest themselves differently [57]. Table 1 shows the principles corresponding to the Shingo model's dimensions.

As already referenced, it is known that the Shingo model can help organizations search for optimal results in various dimensions, as long as it is implemented appropriately [57]. Briefly, the model argues that the involvement of all elements of the organization is essential for significant and sustainable improvement and that it is only possible when people's behaviors are aligned with ideal behaviors based on principles.

Table 1. Shingo's model guiding principles [55].

Dimensions	Guiding Principles
Cultural Enablers	Respect each individual
	Lead with humility
Continuous Improvement	Seek perfection
	Adopt scientific thinking
	Focus on processes
	Ensuring quality at the source
	Improve flow and pull
Enterprise Alignment	Thinking systematically
	Create continuity of purpose
	Create value for the customer

3. Methodology

This research was conducted from the Web of Science (WoS) database, and since its scientific quality is internationally recognized, it covers a wide range of publications, a robust citation index as well as other features such as interesting and effective analytical tools. The bibliometric analysis of the referenced articles aims at evaluating the scientific activity of a field of study and performing a meta-analytical evaluation of the literature.

3.1. Database Selection

The Web of Science (WoS) database includes the most important journals in this field of knowledge, such as: Production Planning and Control, Materials Today: Proceedings, the International Journal of Production Research, the International Journal of Productivity and Performance Management, the Journal of Cleaner Production, the International Journal of Advanced Manufacturing Technology, Total Quality Management and Business Excellence, the International Journal of Lean Six Sigma, Clean Technologies and Environmental Policy, the International Journal of Sustainable Engineering, and Sustainability, among others. Moreover, due to restricted access to other databases, this has been the main source of information used by many research groups, being one of the most reputed databases as well because it is linked to Clarivate.

3.2. Publication Search Criteria

The criteria selected with the research are ordered chronologically in Figure 3. First, after the selection of the database (Web of Science), documents written in English and peer reviewed were exclusively considered. Second, the restricted time space between 2010 and 2021 was considered; therefore, the matters that are regarded are current and valid. Data collection was finalized in May 2022. Third, four distinct combinations of keywords ("lean methodology" or "lean manufacturing" or "lean tools", "six sigma" or "DMAIC", "lean six sigma", "sustainability" or "Shingo's model" or "excellence models") were used. This research covered the theme, which included the title, summary and keywords of each post. After these first three steps, articles from the database were randomly selected for each combination of keywords. Finally, a manual selection of publications was carried out on the publications that were selected randomly, and they were fully read. This procedure resulted in the selection of 67 publications based on the theme "Lean", 40 publications based on the theme "Lean Six Sigma", 12 publications based on the theme "Six Sigma" and 6 articles based on the theme "Shingo's Model". A total of 125 publications were consulted, for which a quantitative and qualitative analysis was carried out.

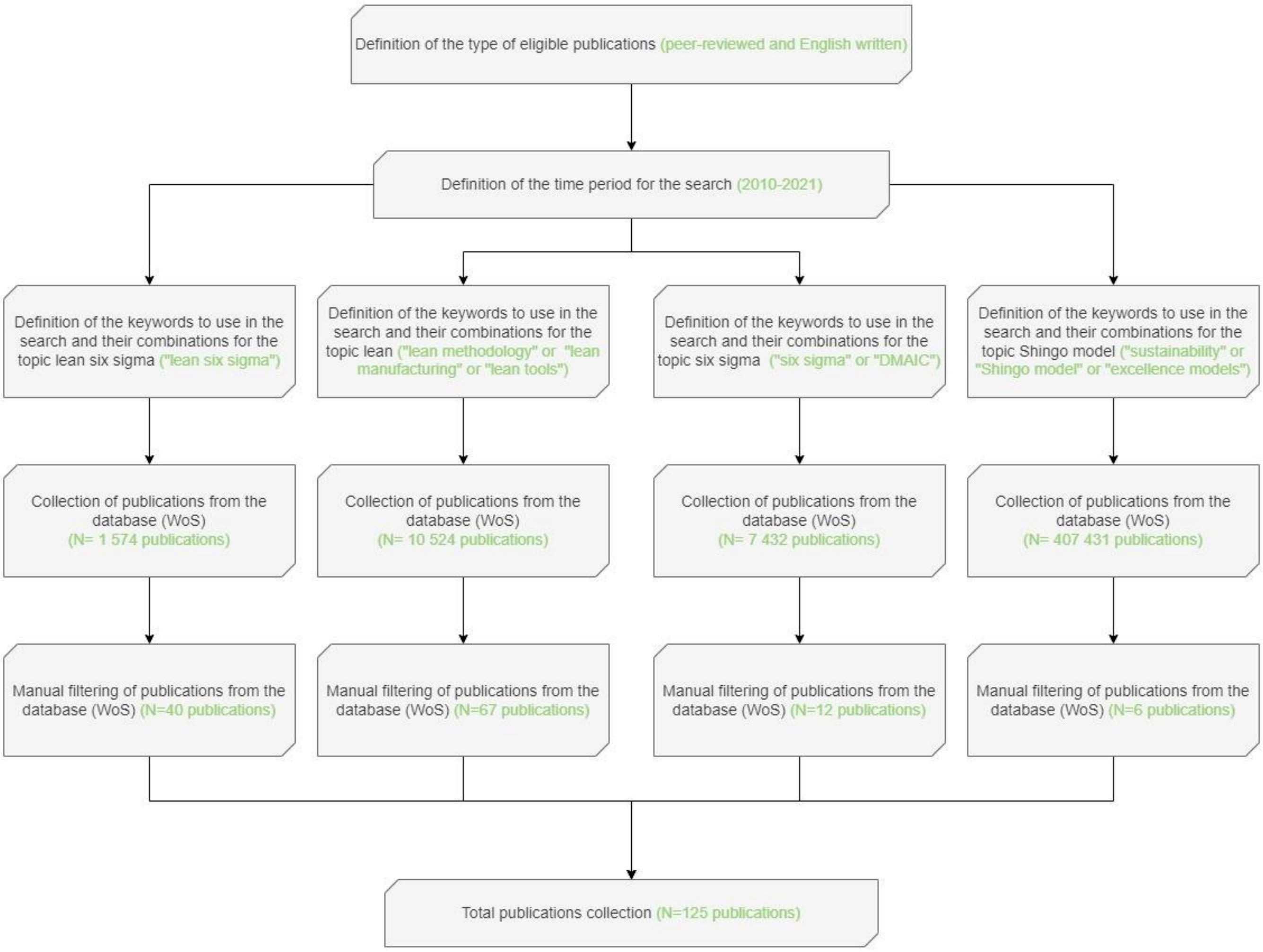

Figure 3. Research strategy steps.

In order to design the respective publication analyses, a database was constructed in an MS Excel® data sheet based on data obtained from the Web of Science, such as the title of the publication, the average number of citations per year and the journal name. Additionally, after reading and analyzing each document, the MS Excel® data sheet was complemented with the area of the application, research objectives, main contributions and suggestions for future research mentioned by the authors of the publications. Finally, these documents were classified into four groups based on research themes, as follows: "Lean", "Six Sigma", "Lean Six Sigma" and "Shingo's Model".

3.3. Bibliometric Analysis

The design of the bibliometric analysis was supported by VosViewer software (version 1.6.17) (Universiteit Leiden, Leiden, The Netherlands) through which it was possible to obtain a network visualization map with key concepts of greater relevance of the various publications.

4. Results of the Bibliometric Analysis

4.1. Distribution of Publications

With the support of WoS, the publications referenced for several years (Figure 4) were made. It was found that the oldest publications were from the year 2011, with 7 (5.6%) publications, whereas the most recent publications were from 2021, with 14 (11.2%) publications. The years 2017 and 2019 had the most publications, with each having 16 (12.8%)

and 19 (15.2%) publications, respectively. It was noted that there is a growing trend of publications analyzed from more distant years to the most recent.

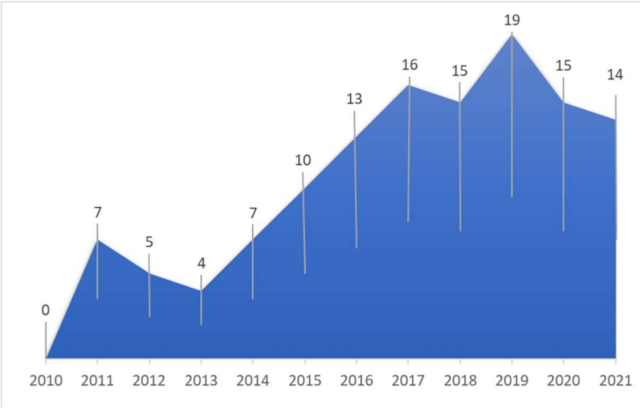

Figure 4. Distribution of publications found under this scope by year of publication.

Regarding the average number of citations per year (Figure 5), there is also an increasing trend. In addition to the upward trend in the number of publications, there is also an upward trend in the number of citations. This shows the increasing interest of the scientific community in studying the concepts lean, six sigma, lean six sigma and the Shingo model in recent years. The publications of the years 2020 and 2021 were the most cited, with each surpassing the barrier of 500 citations.

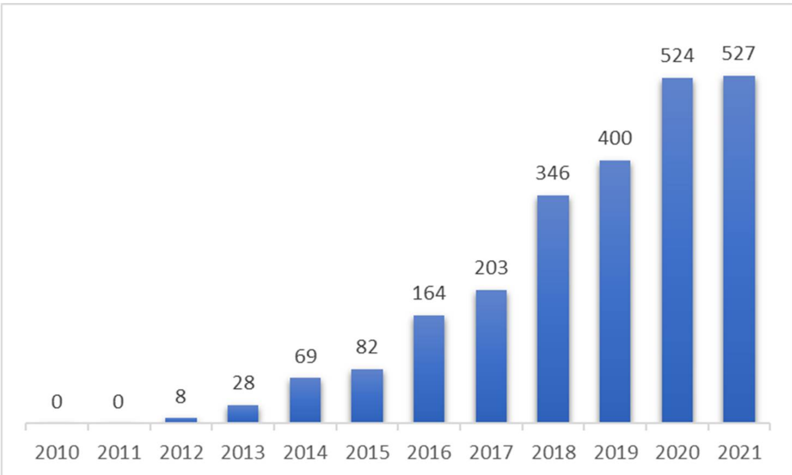

Figure 5. Distribution of citations by year of publication.

In relation to the journals used as sources of information (Figure 6), it was verified that Production Planning and Control and Materials Today: Proceedings were the most common, with a total of 9 and 7 publications, respectively. The following was Total Quality Management and Business Excellence, with 5 publications. The International Journal of Production Research, the International Journal of Productivity and Performance Management, the Journal of Cleaner Production and the International Journal of Advanced Manufacturing Technology completed the group of journals with the most publications associated with, respectively, 4 publications each. Regarding the axis identified as "Other", it represents the journals that had fewer than 4 publications associated with the work. Making a total of 88 journals on the "Other" axis, this group includes journals such as the Central European Journal of Operations Research, the International Journal of Lean Six Sigma, the International Journal of Sustainable Engineering, Quality Engineering and Trends in Food Science and Technology, among others. The high number of associated journals in the distribution of publications based on the concepts "Lean", "Six Sigma", "Lean Six Sigma" and "Shingo's Model" highlights the scope and diversity of the fields of study related to those subjects.

Figure 6. Distribution of Publications by Scientific Journal.

4.2. Cluster Identification

The construction of the clusters was based on the intersection of articles based on the topics "Lean", "Six Sigma", "Lean Six Sigma" and "Shingo's Model". The first cluster consisted of 17 terms. The second cluster consisted of 14 terms. The third and fourth clusters were composed of 11 terms. The fifth cluster consisted of 10 terms. The sixth and seventh clusters were composed of 8 terms. The eighth cluster consisted of 7 terms. The ninth cluster consisted of 6 terms. The tenth and eleventh clusters were composed of 4 terms, summing up a set of 100 study topics.

By observing the map presented in Figure 7, it seems that the ten most mentioned topics are: "manufacturing, technology, lean manufacturing, productivity, management, lean, efficiency, work, DMAIC and sustainability". The ten topics less mentioned are: "responsibility, leadership, SMED, workstation, rework, variation, automation, energy, VSM and flow".

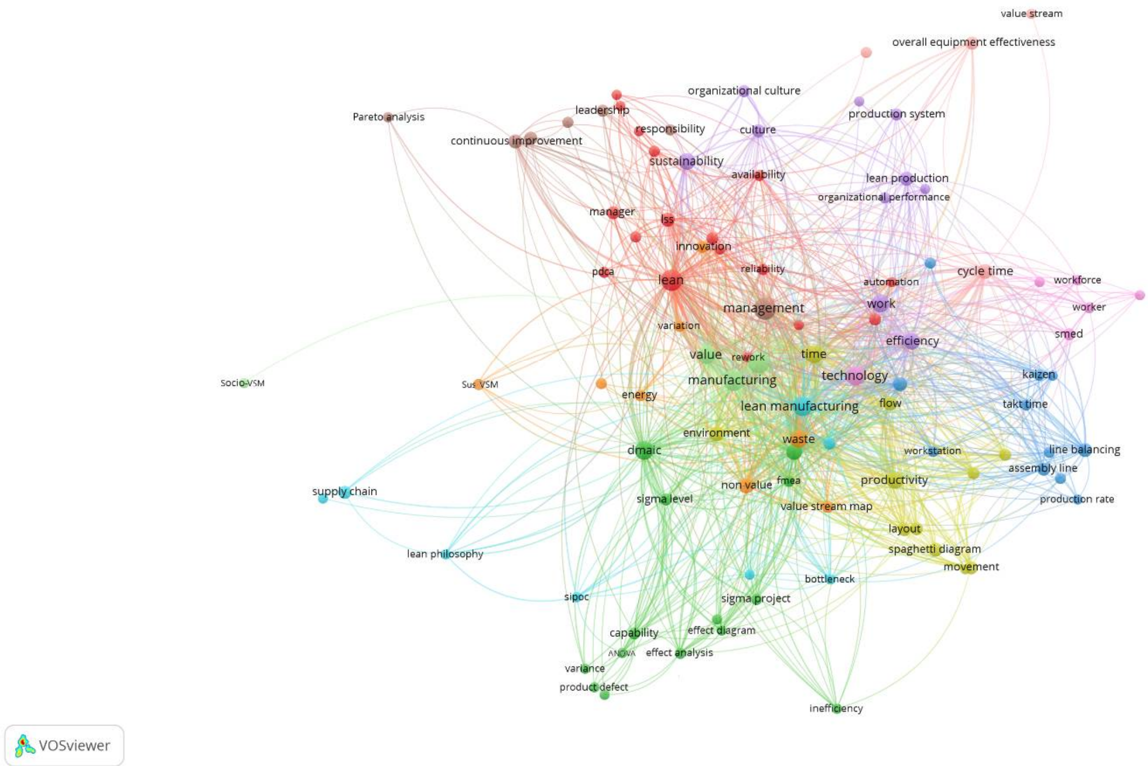

Figure 7. Most important study areas for lean, six sigma, lean six sigma and the Shingo model.

By analyzing Figure 7, it is possible to observe that the most dispersed areas encompass topics such as: "value chain, production rate, movements, bottleneck, sigma design, capability, logistics chain, Sus-VSM and OEE". Later, some of these topics are studied in greater detail.

Following the network visualization map (Figure 7), the constitution of each of the eleven clusters is presented in Table 2.

Table 2. Most important clusters on lean, six sigma, lean six sigma and the Shingo model.

Clusters	Items
Cluster 1 (17 items)	Automation, availability, competitive advantage, green lean, infrastructure, lean, lean six sigma, maintenance, manager, SMEs, operational excellence, PDCA, production cost, reliability, rework, commitment of top management, training;
Cluster 2 (14 items)	ANOVA, "Capability", cost, DMAIC, effect analysis, effect diagram, FMEA, inefficiencies, product defect, product quality control, sigma level, sigma method, sigma design, variance;
Cluster 3 (11 items)	Production line, kaizen, kanban, lead time, line balancing, production rate, takt time, waste reduction techniques, labor standardization, workstation, yamazumi;
Cluster 4 (11 items)	Environment, flow, inventory, layout, lean principle, lean thinking, movements, productivity, spaghetti, staff, time;
Cluster 5 (10 items)	Culture, efficiency, environmental management, lean production, lean production system, organizational culture, organizational performance, production system, sustainability, work;
Cluster 6 (8 items)	Bottleneck, customer satisfaction, inventory management, lean manufacturing, lean philosophy, OEE, SIPOC, logistics chain;
Cluster 7 (8 items)	Energy, innovation, non-value, Sus-VSM, sustainable manufacturing, VSM, variation, waste;
Cluster 8 (7 items)	Business excellence, continuous improvement, leadership, management, Pareto analysis, quality management, responsibility;
Cluster 9 (6 items)	Time set-up, human factor, SMED, technology, worker, workforce;
Cluster 10 (4 items)	Cycle time, OEE, project management, value chain;
Cluster 11 (4 items)	Industry, manufacturing, Socio-VSM, value;

As shown in Table 2, it is possible to identify 11 clusters in relation to the intersection of concepts among lean, six sigma, lean six sigma and the Shingo model. In cluster 1, it shows the correlation between different philosophies, strategic methodologies and critical success factors for the improvement of key indicators. Cluster 2 focuses on the weight of certain tools and methodologies in controlling waste and defects. Cluster 3 shows tools capable of generally improving the operation of production lines. Cluster 4 depicts the connection of some classic waste scum of lean thinking and tools capable of diminishing its effects on organizations and their eventual connections to the environment. Cluster 5 lists concepts such as sustainability, lean and the relevance of culture to the success of these concepts. Cluster 6 describes productivity and flow-related tools that can help meet customer needs. Cluster 7 describes the need to reduce the environmental impact of organizations, more critical areas related to sustainability and some tools capable of helping in this direction. Cluster 8 indicates some critical success factors and support areas for achieving excellence. Cluster 9 contains factors and techniques capable of reducing non-productive times for organizations. Cluster 10 shows classic production and tools capable of increasing the efficiency of production systems. Cluster 11 essentially focuses on the importance that social factors should have in organizations for the production of widespread value.

5. Structural Analysis

5.1. Distribution of Publications by Search Topic and Application Area

Through this analysis, the publications were categorized according to four research topics, which were: lean, six sigma, lean six sigma and the Shingo model (Figure 8). Through this categorization, it was possible to observe that the lean topic was the one with the most associated publications, with a total of 67 (54%). Next, the lean six sigma topic had about 40 (32%) associated publications. The six sigma topic had 12 (9%) associated publications. Finally, the Shingo model topic had 6 (5%) associated publications. This discrepancy in the number of six sigma publications in relation to lean and lean six sigma is explained by the fact that the focus was on the research of methodical structures and not six sigma tools. These data reveal that lean has had greater prominence and importance in studies in the area of industry and whose tendency is to increase the relevance of lean six sigma by being able to adopt concepts and methodologies of both lean and six sigma areas. The Shingo model allows us to relate these concepts to operational excellence.

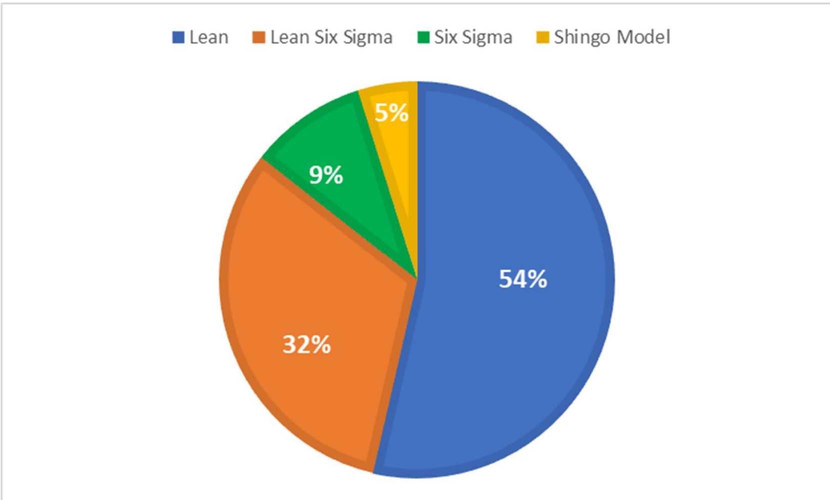

Figure 8. Categorization of publications for each topic.

Table 3 shows a categorization of the papers consulted, taking into account the topic and quantifying the number of papers consulted under each topic.

Table 3. Categorization of the analyzed publications.

Topic	Publications	Total
Lean	[2,4,16–18,21–23,26–28,58–112]	67; 54%
Six Sigma	[3,30–33,35,40,41,113–116]	12; 9%
Lean Six Sigma	[1,5,12,14,15,24,25,29,34,36–39,42–50,117–134]	40; 32%
Shingo Model	[51,52,54–57]	6; 5%

Additionally, a graph (Figure 9) is displayed from which publications are distributed throughout their years and search topics. From this chart, it is possible to verify that publications related to the lean topic were in primacy from the year 2016, with a total of 48 publications until 2021. This corresponds to about 71% of the total publications with the lean topic. Publications with the topic lean six sigma began to gain prominence from the year 2017, with a total of 29 publications by 2021. This is about 72% of the total publications with the topic lean six sigma. Publications with the topic six sigma were dispersed in a constant way over the years while never surpassing the two associated publications per year. The years 2013 and 2021 were the exceptions that did not present any publications associated with the theme six sigma. Publications with the Shingo model topic were concentrated in the years 2015, 2017, 2018 and 2019. The year 2018 contained half of the publications under this topic, with about 3 publications.

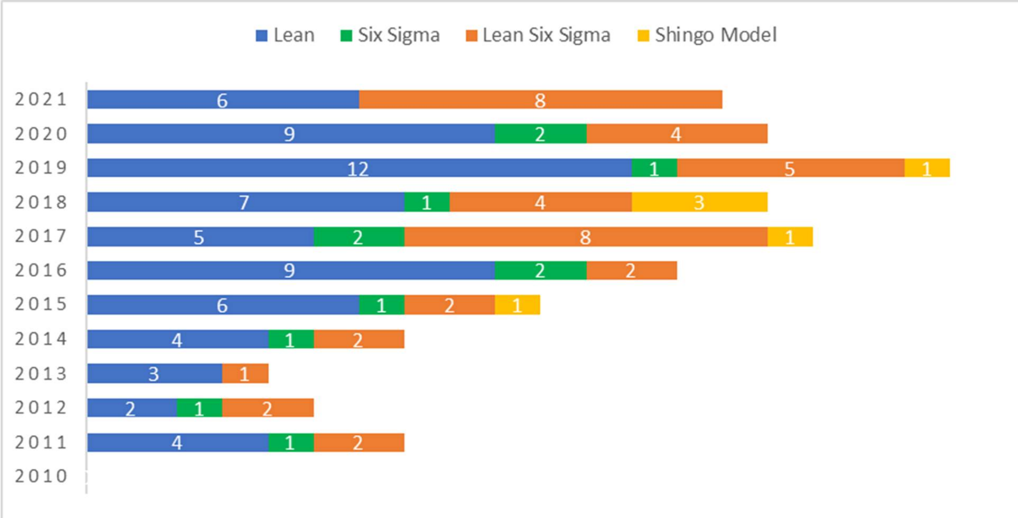

Figure 9. Distribution of publications analyzed by topic.

The publications were also distributed depending on the area of application (Figure 10). From this distribution, it was possible to notice that the most referenced areas were theoretical, automotive and metallurgical, with a total of 30, 17 and 13 publications, respectively. Unsurprisingly, lean dominated the automotive area, whereas lean six sigma began to gain prominence in the theoretical and metallurgical area. The areas that completed the most outstanding ranges were health, multisector, food and textile, with a total of 10, 7, 6 and 5 publications, respectively. In the area classified as “Others”, there were documents with areas of application presenting fewer than 5 references, such as services, agriculture, aerospace, electronics, pharmaceuticals and logistics, among others.

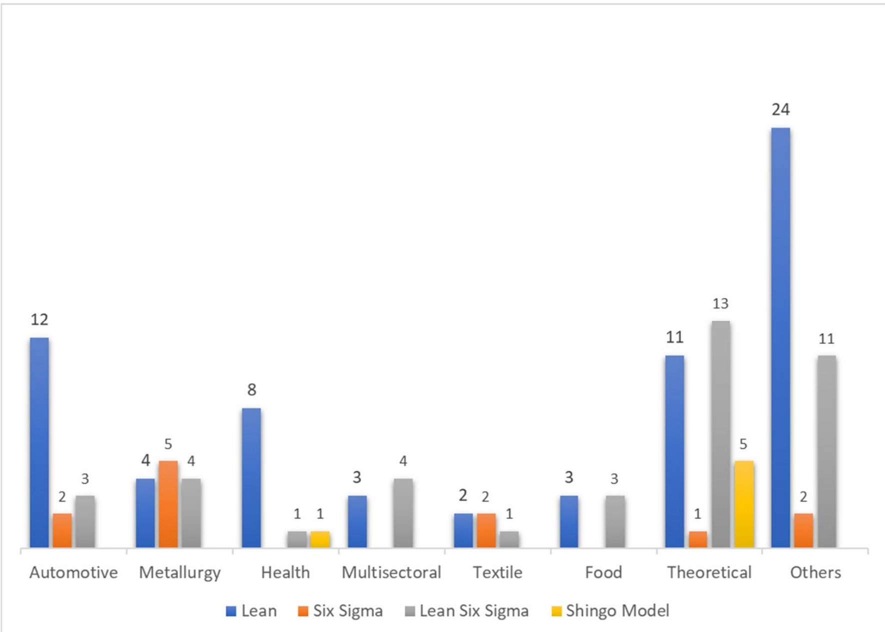

Figure 10. Classification of publications by application area.

5.2. Presentation of Case Studies

Some case studies are presented from the publications analyzed in this research (see Table 4).

Table 4. Description of case studies of the publications analyzed.

Authors	Application Area	Description
[66]	Manufacturing	In this work, the focus was on the implementation of the Work Standardization tool on a production line. The implementation of the tool resulted in a 37.5% decrease in work at one of the workstations and an increase of 304.7% for the daily income at the workstation that was the bottleneck of the production line.
[67]	Car industry	Labor Standardization was applied in several operations of the production line, resulting in a decrease in cycle time by 350 s and reducing setup time by 1500 s. Working procedures were built and placed on all machines in the line; therefore, they were easily accessible to all operators.
[70]	Manufacturing	In this work, the focus was on the Standardization of the Work of a manufacturing company in India, resulting in a decrease of 31.6 s in product cycle time and a production increase to 58 parts that initially floated around 45–50 parts in a 7 h shift. It should be noted that production improvements were achieved without the need for investment in machines or tools by the company.
[71]	Printing Shop	In this work, the focus was on optimizing resources in a small printing shop in order to be able to satisfy requests. To this end, a study was conducted on the times of the processes, the movements of the operators and the respective layout of the production process, identifying sources of waste and opportunities for improvement. Finally, Work Standardization occurred with the help of Process Charts and visual help of the execution of operations, allowing for a reduction in unnecessary movements by 66%, and the standard time on the workstation decreased from 244 to 199 s for each product, increasing the production rate by 63.2% as well.
[72]	Health	In this work, the focus was on improving the processing efficiency of patients in a hospital's emergency department. In order to reduce patient waiting times, two tools were developed that allowed for the standardization of the admission processes of patients in the hospital. After the implementation of the tools, the admission time decreased from 154 to 144 min, although it did not significantly improve the time of admission, but it improved the patients' transfer times (from 30.5 to 21.7 min) and the time required to receive or deliver medical reports (from 3.8 to 2.8 min). Thus, there was a significant improvement in the flow of patients.
[68]	Manufacturing	In this work, the focus was on the implementation of a methodology developed by the author for micro and small enterprises that allowed for the improvement of the OEE index of an operation. After an initial analysis, a set of lean tools was recommended to correct inefficiencies. The practical case presented demonstrated that, after observing the data, availability was the main cause of overall efficiency loss. When applying the Pareto diagram, it was observed that the change in tools was the highest stopping time. The application of SMED was suggested, and, after its implementation, a significant increase in the availability of the machine was observed, increasing the OEE from a range between 70% to 75% to an interval between 81% to 85%.
[69]	Plastic Extrusion	In this work, the focus was to increase the efficiency of an extrusion process of a company in the plastic industry. After the collection and analysis of the process data, it was found that the main cause of the low OEE indicator was the long downtime without producing. To this end, an innovative proposal was developed that involved the use of SMED and preventive maintenance techniques. For the validation of this model, arena simulation software was used to analyze what results this model may lead to, showing that the proposals could result in a reduction in non-productive times by 36.67% and an improvement in the OEE by 9.02%.
[85]	Semiconductor industry	In this work, the author developed an innovative model that allows for a systematic approach to improve the OEE of a system, a framework that incorporates the advantages of OEE with conventional improvement models. It was validated with a 38-week study case by a semiconductor company in Malaysia. The production system had a low OEE of 73.4%, caused by the loss of availability (76.5%). The application of the model developed by the author resulted in an improvement of the OEE and availability to 76.5% and 80%, respectively. In financial terms, it resulted in savings of about 565,000 USD for each conversion of the production line. It should be noted that this model was subject to a single case study. Therefore, it is necessary to test it in different scenarios to prove its robustness.
[86]	Manufacturing	The authors developed a method capable of combining SMED with preset systems (tool anticipation or device adjustments) in order to improve the productivity of production systems. It was validated with a study case in the industry that allowed the following results to be recorded: an 87% reduction in the setup times of the bottleneck resource (labelling machine), a 33.8% increase in the OEE of the labelling machine, a 17% increase in the OEE of the production line and a 45% reduction in lot size.
[87]	Machining	In this work, the objective was to improve the OEE of the CNC machines of a company of the mold industry in Portugal. Initially, they had an OEE value of about 50%. Through the application of tools such as 5S, SMED, Visual Management and Work Standardization, it was possible to improve the performance of the machines. Overall, the OEE was improved by about 20%.

Table 4. *Cont.*

Authors	Application Area	Description
[88]	Pipe Manufacturing	In this work, the authors highlighted the importance of a new indicator capable of combining OEE and Sustainability. This new indicator was designated as Overall Environmental Equipment Effectiveness (OEEE). In order to assess its impact, the authors conducted a case study at a pipe manufacturing company. By analyzing the application of this indicator on a production line, it concluded that the raw material of the product analyzed would have to be replaced by another one in order to comply with the sustainability requirements. Other modifications were also performed, such as the elimination of excessive stocks of raw materials and increased flexibility of the production line (from 2301 to 685 s for the production time of the first part in the line) in order to respond in a timely manner to the customer's needs. With these changes, the cost of production decreased by 6.2%, highlighting the company's increased competitiveness with respect to price, flexibility and sustainability.
[89]	Cellulose	The authors developed an integrated model based on six sigma and TPM in order to improve the performance indicators of the production systems. The model was applied in a manufacturing cell consisting of two machines from a pulp company. The goal of the study was achieved with the application of multiple tools, such as Brainstorming Sessions, Pareto Diagram, Ishikawa Diagram, histograms, FMEA and control charts, among others. At the end of the project, there was a significant improvement in the OEE, which was in a range between 50% and 54% for a range between 76% to 83%, also reducing rework from 22% to 10% and the defect rate from 24.82% to 5%, leading to financial savings of around 2 million USD per year.
[90]	Car industry	In this work, the focus was on the integration of the production teams linked to an assembly system with the measuring system performance indicators in real time. The validation of this system took place in a factory of the automotive industry in Spain. The goal of this system was to focus the organization on value chains and to improve their performance based on the OEE. The system provided real-time OEE values from value chains and allowed production teams to use meetings to discuss and improve the provided indicators. Thus, greater relevance was directed to key points that had a critical impact on production volume. The solution presented allowed for a significant improvement of OEE values in general between 5 and 10% from January 2009 to January 2012 in the case study. It should be noted that this model has been validated with only one practical case. It is necessary to test it in different scenarios to prove its veracity.
[100]	Food industry	In this work, there was a lean implementation in a food company with the help of two tools (SMED and VSM). VSM allowed for the identification of the different wastes associated with the production line (84% of the total production). Then, with the help of SMED, it was possible to reduce setup times by 34% and to promote an increase in line productivity by 11%, allowing the company to avoid the use of temporary workers in periods of high demand.
[101]	Food industry	In this work, there was a lean implementation in a set of companies in the wine sector. VSM was used as the main tool for the determination of waste and points of improvement for the production process. From the VSM information, some tools were selected that were capable of solving the problems found. In the end, it was possible to reduce the lead time between 50% and 65% and to induce a reduction in raw materials between 8% and 16%.
[102]	Logistics	In this work, the focus was on improving the logistics processes of a military unit. VSM and VSD (Value Stream Design) served as the basic tools for improving the processing of item orders, allowing for eliminating or reducing activities that did not add value and improved order processing procedures. The results that were obtained in a simulation showed that the "future state map" could allow for increases in activities that add value, from 44% to 70%, and a reduction in lead time of 69.6% was achieved.
[103]	Car industry	In this work, the focus was on improving the productivity of a production line of an automobile company. For this, VSM and the simulation approach were adopted to validate the improvements. It was observed that it was possible to reduce cycle time by 87.59%, to reduce WIP inventories by 76.47%, to reduce lead time by 95.41%, to reduce the number of operators by 57.14% and to reduce setup times by 70.67%.
[104]	Services	In this work, the focus was on improving the efficiency of services provided by a maintenance team and repairing buildings of a public university. VSM was used as a basis for the identification of waste and improvement points. Then, the simulation was used to validate the proposals. The changes made, based on the simulation, allowed for a reduction in lead time by 26.8% and a reduction in waiting times by 33.6%. This case highlights the increased difficulties of implementing lean concepts in the area of services. However, they can be implemented and provide very good results.
[36]	Theory	In this work, a VSM model focused on sustainability was used, designating it as *Sus-VSM*. It emerged with the emergence of sustainable manufacturing systems. The particularity of this model is that, in addition to evaluating the classic VSM metrics such as cycle time, lead time and material cost, it also analyzes a set of metrics related to the environment and the social environment. For example, it analyzes chemical consumption, water consumption, energy consumption, noise level and the ergonomics of jobs. Thus, the *future state map* is not only aimed at improving the product and process flow, but it also improves environmental performance and work conditions.

Table 4. *Cont.*

Authors	Application Area	Description
[128]	Theory	In this work, a VSM model focused on energy was developed. The authors' model was designated as Lean Energy Six Sigma Value Stream Mapping (LESSVSM) and was based on Energy Value Stream Mapping (EVSM). It has emerged to combat waste existing in the energy area. It evaluates consumption along the manufacturing system chain and identifies foci where consumption can be eliminated or managed more efficiently. The design of the future state map from this model aims to achieve sustainable manufacturing by reducing energy and waste costs, increasing efficiency in their jobs.
[16]	Theory	In this work, a model was proposed that integrates the Eco-Function Matrix with VSM. The process starts with the construction of the current state map in which it identifies and categorizes waste. Areas classified as more critical are configured as requirements in the Eco-Function Matrix. Brainstorming sessions are then held building proposals and improvements that can be designated as attributes. Then, the conventional Procedure of QFD (Quality Function Deployment) begins to consider the environmental perspective in the construction of the matrix and its interrelationships. Finally, the waste and proposals for improvements is ordered as a priority; therefore, the construction of the future state map is one of the most important topics.
[18]	Theory	In this work, a model designated as *Variability Source Mapping* (VSMII) is proposed, with a focus on the identification and reduction in variability throughout the production system. The construction steps are similar to the classic VSM model, but it adds some details, such as the mean, standard deviation and coefficient of variation of the cycle time for each job. It also assesses the variability of the flow on arrival between jobs or phases, developing a system variability metric that is able to identify the most critical locations or jobs with variability levels. With the help of lean tools and control production policies, it is possible to build a future state map that allows for the reduction or elimination of the sources of variability, thus decreasing the variability level of the system
[105]	Theory	In this work, the authors provide a new approach capable of incorporating the PDCA (Plan–Do–Check–Act) methodology with environmental VSM (E-VSM). This is an alternative proposal capable of improving the environmental performance of operations using principles, techniques and lean tools. Reductions in energy consumption and waste production are some of the environmentally analyzed wastes with great focus on E-VSM. The PDCA approach allows for a systematic methodology in the elaboration of the current state map and future state map. According to the author, the main focus of this model is for industrialists who intend to achieve environmentally sustainable operations.
[106]	Theory	In this work, the author presents a new tool called Ergo-VSM, based on the VSM methodology and incorporating ergonomic indicators related to the physical and psychological factors of workers. The goal is to improve the ergonomic conditions of workers without compromising the classic productivity indicators. The inclusion of factors related to the physical environment of workers, such as noise, temperature and luminosity, can affect not only the health of workers but also their own performance. Therefore, this tool can also have a positive effect on productivity.
[107]	Construction	In this work, the authors propose a new model based on the integration of LCA (Life Cycle Assessment) and VSM, called LCA-VSM, a tool capable of prioritizing measures that improve economic and environmental performance, encouraging a continuous process improvement approach. The model was validated by a construction company that produces paint materials and tools, providing a reduction between 5% and 15% in environmental impact (across nine environmental categories), reducing lead time from 103.26 to 24.01 days and promoting a reduction in cycle time from 35.7 to 33.75 s.
[108]	Theory	In this work, the authors provide a model capable of modeling VSM from an economic and environmental perspective. The methodology is called E^2-VSM. It is a simulation model that considers the dynamic behavior of a multi-product production system and assesses its environmental impact, such as energy consumption. The model also evaluates the financial and environmental performance of each of the manufactured products. The goal is to optimize the machines, production orders and production parameters that lead to the best solution through energy efficiency and resources for a production system.
[109]	Multisector	This work shows the practicality of Sus-VSM. Three cases of studies demonstrating their applicability in different areas of industry are presented. It enables improvement in the ratio of activities with added value (such as the classic VSM model) as well as the improvement of environmental and social indicators. At the environmental level, for example, reductions in energy consumption, water consumption and raw materials consumption were achieved. At the social level, for example, workers' exposure to ergonomic hazards and risks in the workplace were also reduced.
[111]	Electronics	This paper presents a new methodology called Socio-VSM, the objective of which is to incorporate environmental and social indictors in order to accelerate the transition to sustainable manufacturing. For the validation of this methodology, a case study was carried out by an electronics company in Malaysia. Indicators such as noise level, ergonomic workstation conditions and classical productivity indicators were evaluated. On the basis of these indicators, changes were made to reduce the risk of injury or occupational disease by workers by reducing noise exposure and ergonomic changes in jobs. At the environmental and economic level, no changes were made to the production system.

Table 4. *Cont.*

Authors	Application Area	Description
[112]	Car industry	This paper presents a new methodology called scrap value stream mapping (S-VSM), a tool that allows for the mapping and identification of scrap and its costs throughout the process chain, from which it is possible to act with lean tools in order to attenuate the volume of scrap and generate potential savings. The validation of this tool was achieved with a case study by an automotive company, in which savings of €44,782 were possible in the following years if the volume of plastic waste remained at the same level in 2015.
[79]	Car industry	In this work, the focus was on minimizing the sources of waste resulting from the transport of raw materials in a manufacturing plant. With the spaghetti diagram, inefficiencies were identified with respect to layout and transport, allowing for optimizing the distances traveled from raw materials in the factory from 152 km to 117 km per year. With respect to time consumed in material transports, a decrease from 67 h to 30.1 h per year was achieved.
[80]	Health	In this work, the focus was on improving the satisfaction of patients in a hospital through the standardization of drug logistics processes. By applying the spaghetti diagram, it was possible to optimize the routes of the medicine cart and thus decrease the travel times through the hospital. About 92% of patients reported that, after the intervention in the cart routes, the medications were provided in less time. In addition, the application of the 5S in the cart allowed for reductions in the time spent in the search for drugs from 50.8 s to 30.2 s per unit.
[81]	Feed	In this work, the focus was on the application of lean philosophy in a food industry factory. A spaghetti diagram allowed for the tracking of worker movements and identifying unnecessary movements that could be eliminated, from which it was possible to redesign the layout, and there was a reduction from 6 m to 2 m of distance traveled by the workers for each cycle of time. Other tools such as VSM, OEE and Job Balancing were applied in the project. Overall, productivity increased by around 40%.
[82]	Health	In this work, the focus was on the application of lean six sigma in the medical records department of a hospital. Several tools were used, including a spaghetti diagram, from which it was possible to record the patterns of movement in the work area under study and to identify unnecessary movements between various points of the department. A new layout was designed to minimize movements and delays. The study resulted in a decrease in the processes, on average, from 19 to 8 min. Overall, the project allowed the hospital to save about 20,000 USD in human resources and fixed costs related to the hospital's bureaucratic processes.
[83]	Car industry	In this work, the objective was to improve the productivity of a seating factory in the automotive industry through the lean methodology. Several tools were used in the project. The spaghetti diagram allowed for the study of the layout, cycle times and movements of the workers. This work led to outlining a new layout proposal that allowed for reducing the number of workstations from 6 to 5, the cycle time from 807 to 697 s and the movements of the workers for each seat produced on the line from 15 to 9.6 m.
[84]	Health	In this work, the focus was on improving efficiency and quality in the provision of medical care in the urology department of a hospital with lean methodology. Data such as patient volume, waiting times, cycle times and the movements of physicians were collected with the help of a spaghetti diagram. As result of that work, it was possible to reduce the average cycle time per patient from 46 to 41 min in a period of 90 days. In addition, it allowed for reductions in waiting times and increases in the available contact time between the doctor and the patient from 7.5 to 10.6 min. The time of added value in the patient's visits to the hospital increased, in proportion, from 30.6% to 66.3% at the end of the 90-day period.
[91]	Car industry	Through the Yamazumi tool, it was possible to analyze three jobs and identify sources of waste. Improvements were made with respect to job design and the sequence of operator activities, allowing for the value of the takt time imposed on the assembly line to be fulfilled.
[94]	Manufacturing	In this work, the objective was to improve the efficiency of an assembly line of a refrigerator factory in Turkey. With Yamazumi's help, the situation presented was analyzed, resulting in improved productivity from 118 units to 155 units per shift. The number of operators was reduced from 32 to 28. The average idle time of the operators dropped from 155 s to 70 s.
[95]	Textile	In this work, the focus was on improving the efficiency of a production line of a textile factory. Yamazumi and 5S were the tools selected for process analysis. The improvement proposals were designed and implemented, resulting in a 34% decrease in production cycle time and a 32% decrease in time without added value. The application of the 5S was crucial for the increase in the line efficiency by 12.5%; therefore, human resources were well-used.

Table 4. *Cont.*

Authors	Application Area	Description
[96]	Graphic	In this work, two practical cases related to two departments of a printing press are presented. The first case was carried out on a line of the production department. Standardization of Work and Yamazumi were the tools chosen to increase productivity. Line balancing was achieved with a reduction in the variation of waste throughout the processes, allowing for decreases in the number of workers from 17 to 15. The bottleneck operation of the production line was optimized to increase production from 16.3 copies per hour to 21.3 copies per hour. The second practical case was carried out in the packaging department. Line balancing was achieved by reducing movement times and reducing material flow distances through changes in layout organization. The bottleneck of the production line was also optimized, and some manual operations were eliminated, resulting in increased productivity from 22 boxes per hour to 25 boxes per hour.
[64]	Polymer industry	In this work, the authors describe the adaptation of a *lean production* system for Industry 4.0. The practical case, which took place in a polymer industry organization, consisted in the development of a *Poka-Yoke* tool through a sensor system, which was able to manage the interactions between the physical components and the corresponding manufacturing processes, thus communicating instructions and corrections through block functions. Lean 4.0 tools can interact with the production database and can be updated depending on the scenario, making Lean 4.0 tools dynamic, intelligent and flexible, and ensuring compliance with lean principles, organization objectives, the elimination of waste and increased productivity and value creation for the customer.
[2]	Aerospace	In this work, the focus was on production in an aerospace company. First, the layout was identified, and the operations in the production lines were sequenced. Through observation, it was possible to reconfigure the layout to reduce transport times and to improve the production flow. With the 5S tool application, a more organized system was constituted, reducing movements and waits and also eliminating inventory and unnecessary materials in the production line. A worker was added at one of the stations to decrease wait times. Work standardization was also crucial to increase efficiency in addition to promoting a better work environment. These changes resulted in increased productivity and decreased cycle times of operations.
[65]	Multisector	In this work, the application of lean techniques in small and medium-sized enterprises in India is analyzed. Nine manufacturing units were subjected to the lean program, which lasted about 18 months. Depending on the diagnosis performed in each manufacturing unit, an improvement project was developed using tools such as VSM, 5S, Kaizen and SMED. Overall, these projects achieved savings in the order of 9 million Rupees (official currency of India) and a reduction in the setup time from 135 min to 45 min, and more than 300 *Kaizen* measures were implemented, resulting in material savings, time and improved working conditions. Manufacturing units have managed to create jobs and compete with more attractive prices and higher quality.
[120]	Logistics	In this work, the focus was on optimizing the time spent by the product in logistics processes. With the application of DMAIC and VSM methodologies, and with the perspective of lean thinking, it was possible to identify foci of waste in order to improve the processes. VSM allowed for the understanding of the logic of flow in logistics and for the optimization of the times of the various processes identified by changing the current map state. The development and application of the future state map allowed for the achievement of reductions in lead time and reductions in processing time.
[36]	Manufacturing	In this work, the DMAIC methodology was applied together with the *Sus-VSM* approach, seeking to achieve sustainable manufacturing. Thus, not only was it possible to make improvements in the set of classical metrics of production management, but improvements in a set of environmental and social metrics were also achieved. The significant reduction in energy consumption and chemicals in the practical case that is presented must be highlighted.

5.3. Tool Effects

Based on the publications analyzed, an impact matrix was constructed in order to evaluate the impact of the tools on the economic, social and environmental dimensions. The "+" sign indicates that the tool has a positive impact, whereas the "-" sign points out that the tool has a negative impact on a given dimension (economic, social and environmental). Regarding the number of repetitions of each signal ("+" or "-"), it represents the relevance of an effect that has been reported in the literature (Table 5).

Table 5. Matrix of tools' impact on economic, environmental and social pillars.

Tool	Effect(s)	Impact Dimension		
		Economic	Environmental	Social
Standardized Work	Reduction in the workforce; Improvement in process productivity; Reduction in non-productive times; Reduction in workers' movements;	++		++
SMED	Improvement in process efficiency; Increased energy consumption;	+	-	
5S	Improved organization and safety; Reduction in material consumption, movements, energy and waste;	++++	+++	++
Visual Management	Improvement in process efficiency; Process control;	++		
TPM	Improvement in process management; Reduction in non-productive times, rework and energy consumption; Prevention of mechanical problems;	+++++	+	
VSM	Improvement in process efficiency; Identification and reduction in waste such as: the excessive use of raw materials, energy, waste, non-productive times, stocks and a reduction in th workforce;	+++++	+++	+
Sus-VSM	Reduction in the environmental and social impact of processes; Reduction in consumption of chemicals, water, energy and noise; Evaluation of ergonomic conditions;	+++	++++	+++
Socio-VSM	Assessment of risk factors for workers' health and safety;	+		+
S-VSM	Identification of and reduction in waste and scrap throughout the process chain;	++	++	
Spaghetti Diagram	Reduction in movements, transport and work;	+++		++
Yamazumi	Balancing jobs; Compliance of takt time; Improvement in process productivity; Reduction in the workforce;	++++		
Poka-Yoke	Reduction in process inefficiencies; Reduction in energy consumption;	+	+	
Kaizen	Reduction in energy, waste and material consumption;	+++	+++	
Kanban	Improvement in the operational efficiency of the processes; Reduction in material consumption;	++	+	
LESSVSM	Reduction in waste related to energy consumption;	+	+	
VSM II	Identification and reduction in the variability of the production system;	+	+	
E-VSM	Identification and reduction in energy waste sources;	+	+	
Ergo-VSM	Evaluation of ergonomic conditions related to physical and psychological factors of workers;			++

5.4. Conceptual Model

Based on the analyzed studies, through a bibliometric analysis, a conceptual model (Figure 11) is proposed. This model is able to relate the different tools analyzed with the different pillars (economic, social and environmental); therefore, organizations can choose the best tools for each scope, serving DMAIC as a structural basis for the construction of the projects, with the ultimate goal of achieving operational excellence. The tools in the economic pillar are the ones that best suit economic growth. The tools that are in the social pillar are the ones that best suit the achievement of social responsibility, i.e., the widespread improvement of working conditions. The tools that are in the environmental pillar are the ones that best suit the achievement of the sustainability of operations and environmental goals. This model aims to help the industry clarify which tools are most relevant for meeting different objectives (economic, social and environmental) [135]. It should be noted that this model was not subjected to practical validation, although it was based on empirical studies.

Figure 11. Conceptual Model.

6. Discussion

6.1. Evolution of Publications

The bibliometric analysis developed in this work, based on the Web of Science, allowed for the distribution of publications per year and average annual citations for the period between 2010 and 2021. Through these fields, it was possible to conclude that these terms are receiving increased attention. With respect to publications, the peak was reached in 2019, with about 19 publications. In relation to the average annual number of citations, the peak was reached in 2021, with about 527 citations. The analysis also involved the design of a cluster map based on the link between keywords, illustrating an intellectual structure that allows for the detection of trends and flaws in research on lean, six sigma, lean six sigma and the Shingo model. This map clarifies that the research based on these four topics considered the following: (1) the strong link of lean tools in combating different sources of the waste of organizations; (2) the strong connection of DMAIC to projects to improve organizations; (3) the strong link between operational excellence and improvement philosophies such as lean, lean six sigma, green lean and PDCA, which allow for the construction of a competitive advantage; (4) the weak link between the environmental concept and lean philosophy; (5) the strong link between organizational culture and sustainability and the overall performance of organizations; (6) the strong link between innovation and factors related to the environmental pillar; (7) the weak link between the tools related to the social pillar and the industry area; and (8) the strong connection of the concepts of responsibility and leadership capacity in achieving a level of business excellence.

6.2. Relationship between Lean, Six Sigma, Lean Six Sigma and the Shingo Model

The bibliometric analysis involved the categorization of the selected publications based on the four research topics (lean, six sigma, lean six sigma and the Shingo model), from which a temporal distribution and application area were made. With respect to research topics, lean was the topic that was most addressed, whereas the Shingo model topic was the least addressed. The results obtained show that:

- For the lean topic, the automotive industry is the most debated area, also being compatible with six sigma through lean six sigma;
- For the lean six sigma topic, the theoretical area is the most debated area, despite the growing importance in the automotive and metallurgical industry that relates lean and six sigma concepts;
- For the six sigma topic, the metallurgical area is the most debated, which relates lean concepts through lean six sigma;
- For the Shingo's model topic, the theoretical area is the most debated, demonstrating a weak relationship of this topic with practical areas, with only one publication with this topic in a practical area (health);
- In the "Other" area, the presence of Lean is highlighted in several areas of which there is a tendency for the adoption of these concepts [135], involving areas such as logistics, aerospace, agriculture and pharmaceuticals, among others.

From this set of studies, the description of positive effects on the economic pillar is highlighted with greater emphasis. With less intensity, there were also positive effects on the social and environmental pillars, demonstrating that the environmental and social pillars suffer detriment to the economic pillar. The literature, in general, corroborates this disproportion of positive effects on the different pillars [9]. Lean interventions may result in green benefits, but not all Lean practices are in line with green strategies [136]. Lean tools and interventions tend not to impact the different pillars of sustainability in an integrated way [7].

However, in order to achieve operational excellence, organizations need to gradually redirect their efforts to these issues; therefore, sustainability is effectively achieved. According to Teixeira et al. [137], although the economic and environmental pillars have a stronger positive relationship with the organizational performance of companies, the social pillar remains relevant for achieving a superior competitive advantage, highlighting the need for organizations to improve the performance of sustainability pillars in an integrated way to maximize competitive advantage.

In the impact matrix, it is possible to observe that only 3 tools in 18 of those reported had a positive impact on all sustainability pillars (5S, VSM and Sus-VSM). This analysis allowed for the construction of a conceptual model that incorporates different tools in the three pillars of sustainability in order to help organizations achieve better results and achieve operational excellence.

7. Conclusions

This work presents a bibliometric analysis on lean philosophy, six sigma, lean six sigma and the Shingo model. It involves an evaluation of the selected literature based on the temporal distribution of publications and annual average citations. This analysis allows for the design of a new model, through which it is possible to select the best lean tools to improve the operational performance of a company. In fact, companies can present asymmetries with respect to performance regarding each operational pillar. The categorization achieved through the developed model allows for selecting, firstly, the pillar where the DMAIC needs to be focused on, and, after that, for selecting the best tools that are able to fit this goal. Indeed, the different lean tools are categorized considering each pillar of the DMAIC methodology, helping readers and researchers to easily identify the best tools they need to improve each one of the pillars that is usually considered to obtain operational excellence using the DMAIC methodology. This topic represents the main novelty of this paper, contributing to an easier selection of the tools that can lead a company to the operational excellence in each pillar, since companies can be differently prepared to be sustainable in each of the three pillars that are widely and usually considered in the literature. It can be highlighted that this categorization is only possible based on an extensive literature review, which points out each tool that is used and the main purposes behind its use. The contributions, limitations and recommendations for future research are as follows.

7.1. Contributions

This study contributes to the topic under discussion through the following points:

- The identification of the most and least discussed items related to lean, six sigma, lean six sigma and the Shingo's model;
- The categorization of the literature according to the four topics (lean, six sigma, lean six sigma and the Shingo's model), including its distribution by area of application and reporting its main conclusions;
- Highlighting the main effects of the tools identified in the literature and their relationship with the objectives of sustainable development;
- Proposing a conceptual model based on sustainability in order to achieve operational excellence.

7.2. Limitations

This study has the following limitations:

- Research was restricted to peer-reviewed publications;
- Publications came from scientific journals, discarding other sources of information such as dissertations, reports and theses;
- The Web of Science was the only data collection platform in this research, thus rejecting publications from this field of study that are on other platforms and that may have had a significant impact on data representation;
- The conceptual model was not subjected to empirical validation in a real case study.

7.3. Recommendations for Future Research

In future research, some additional efforts are recommended in the identification of tools and their effects in the social and environmental area because they are the pillars presenting the less volume of tools in the conceptual model, determining a methodology for quantifying the effects of these tools through key performance indicators in order to direct them to more specific objectives. To do so, it is necessary to validate the conceptual model in real case studies, preferably in different sectors of activity, to be able to evaluate the adaptability of the model in different contexts. Moreover, as main future work, researchers can use this model to apply the selected tools in specific sectors and to validate its suitability in achieving the desired results with respect to each pillar.

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