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The synergy of Lean Manufacturing methodology in the context of Industry 4.0: An integrative review

Sinergia da metodologia Lean Manufacturing no contexto da Indústria 4.0: Uma revisão integrativa

Sinergia de la metodología Lean Manufacturing en el contexto de la Industria 4.0: Una revisión integradora

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Abstract
Lean Manufacturing methods are used by industries that seek to improve their competitiveness through flexibility, cost reduction, product quality improvements and customer satisfaction. Still, the level of complexity and demand in the manufacturing industry is rapidly expanding, intensifying organizational problems. Industry 4.0 systematically employs state-of-the-art technological solutions, unlike Lean Manufacturing, which is firmly based on the human factor. With a qualitative approach, this study aims to explore the synergistic aspects between Lean Manufacturing and Industry 4.0 in an integrative review. The searches were carried out in the following databases: Web of Science, Scopus, Science Direct and IEEE, totaling 552 articles, of which 19 were selected after applying the inclusion and exclusion criteria. The results show that the technologies that stood out the most in Industry 4.0 with Lean Manufacturing are the Internet of Things, Big Data and Cyber-Physical Systems, making processes faster and more efficient when integrated. A theme identified in two studies was the presence of the Lean leader, who has Lean management skills and is recognized as a critical factor for the implementation of Industry 4.0, as it requires a broad view of the organizational process and the application of Lean tools.
Keywords: Lean manufacturing; Industry 4.0; Synergy; Implantation.

Resumo
Os métodos Lean Manufacturing são utilizados por indústrias que buscam melhorar sua competitividade por meio de flexibilidade, redução de custos, melhorias na qualidade do produto e satisfação do cliente. Ainda assim, o nível de complexidade e demanda da indústria manufatureira está se expandindo rapidamente, intensificando os problemas organizacionais. A Indústria 4.0 emprega sistematicamente soluções tecnológicas de última geração, ao contrário do Lean Manufacturing, que se baseia firmemente no fator humano. Com uma abordagem qualitativa, este estudo tem por objetivo explorar os aspectos sinérgicos entre Lean Manufacturing e Indústria 4.0 em uma revisão integrativa. As buscas foram realizadas nas seguintes bases de dados: Web of Science, Scopus, Science Direct e IEEE, totalizando 552 artigos, dos quais 19 foram selecionados após aplicação dos critérios de inclusão e exclusão. Os resultados mostram que as tecnologias que mais se destacaram na Indústria 4.0 com Lean Manufacturing são a Internet das Coisas, Big Data e Sistemas Ciber-Físicos, tornando os processos mais rápidos e eficientes quando integrados. Um tema identificado em dois estudos foi a presença do líder Lean, que possui habilidades de gestão Lean e é reconhecido como fator crítico para a implantação da Indústria 4.0, pois requer uma visão ampla do processo organizacional e a aplicação de ferramentas Lean.
Palavras-chave: Lean manufacturing; Industry 4.0; Sinergia; Implantação.

Resumen
Los métodos de manufactura esbelta son utilizados por industrias que buscan mejorar su competitividad a través de la flexibilidad, la reducción de costos, la mejora de la calidad del producto y la satisfacción del cliente. Aún así, el nivel de complejidad y demanda en la industria manufacturera se está expandiendo rápidamente, intensificando los problemas organizacionales. La Industria 4.0 emplea sistemáticamente soluciones tecnológicas de última generación, a diferencia del Lean Manufacturing, que se basa firmemente en el factor humano. Con un enfoque cualitativo, este estudio tiene como objetivo explorar los aspectos sinérgicos entre Lean Manufacturing e Industria 4.0 en una revisión integradora. Las búsquedas se realizaron en las siguientes bases de datos: Web of Science, Scopus, Science Direct e IEEE, totalizando 552 artículos, de los cuales 19 fueron seleccionados tras aplicar los criterios de inclusión y exclusión. Los resultados muestran que las tecnologías que más se destacaron en la Industria 4.0 con Lean Manufacturing son Internet de las Cosas, Big Data y Cyber-Fysical Systems, haciendo que los procesos sean más rápidos y eficientes al integrarlos. Un tema identificado en dos estudios fue la presencia del líder Lean, que tiene habilidades de gestión Lean y es reconocido como un factor crítico para la implementación de la Industria 4.0, ya que requiere una visión amplia del proceso organizacional y la aplicación de herramientas Lean.
Palabras clave: Lean manufacturing; Industria 4.0; Sinergia; Implantación.

1. Introduction

The Lean Manufacturing (LM) methodology is applied to manufacturing systems worldwide to reduce or even eliminate waste on the shop floor by creating efficient processes. Another newer and increasingly introduced concept also in manufacturing systems, called Industry 4.0 (I4.0), promotes a more technological approach. The connection of these two models in real time is expected to deal with future production problems, such as, for example, the high demand for customised products that require a high degree of flexibility (Langlotz & Aurich, 2021).

All non-value-added process activities must be eliminated to increase business productivity. Based on this, customer-oriented production processes can be further improved through technology. The interaction of LM and I4.0 production can allow for significant improvements, but they are complex for many companies. Therefore, knowing the synergy of both approaches is vital to supporting companies and implementing strategies (Dillinger, et al., 2021).

In recent years, the manufacturing industry's level of complexity and demand has increased significantly, which is a problem for organizations. In addition, factors such as increased international competitiveness, market volatility, and demand for highly customized products pose severe challenges for companies (Bianco, et al., 2021). The use of the LM methodology only to increase efficiency with minimal resources makes it clear that due to high competition, companies are forced to rethink and redo their processes and create new strategies (Marinelli, et al., 2021).

In addition, data collection needs to be better leveraged because the vast majority of the data collected is not used in decision-making processes (Singh & Jha, 2021). Information and communication technologies have become essential factors, conditions, and opportunities for business development, while the size and complexity of production lines require intelligent flow control methods (Marinelli, et al., 2021).

Although the concept of I4.0 has gained notoriety in recent years, many companies have failed in its implementation. This also occurs with the LM methodology because it is still challenging to implement within companies. After all, many try to use these techniques when it is not so simple to use (Cagnetti, et al., 2021).

In addition to methodological and technological issues, the industry also faces an era of significant transformations. Leaders need to develop a specific leadership style that will drive innovations and make them possible for businesses. Lean leadership literature only came after the Lean tool's literature. Similarly, leadership studies in Industry 4.0 are expected to take time to consolidate (Bianco, et al., 2021).

Existing approaches to value creation are inadequate to address the growing requirements related to efficiency, costs, flexibility, adaptability, stability, and sustainability (Bianco, et al., 2021). LM's low-tech approach focuses on simplicity that may conflict with I4.0's technology-based system.

LM is characterized by intense human integration focused on efficiency, which may be contrary to the higher levels of automation implied in I4.0. In addition, the high level of investment needed to implement I4.0 technologies and the lack of qualified professionals represent obstacles that undermine the adoption of I4.0 (Pagliosa, et al., 2021).

Research in other manufacturing organizations has previously proven that there are advantages to the cross-use of I4.0 technologies and LM manufacturing methodologies, which can reduce failure rates in implementing improvements in the production process (McKie, et al.,, 2021), (Tripathi, et al., 2022). Still, there are doubts about whether both approaches are symbiotic or competitive, how to connect them and how companies should approach them, and their relationship in the production process (Hurta & Noskievičová, 2021), (Marinelli, et al., 2021).

The theme addressed in this research is relevant because to maximize processes, organizations have been developing significant synergies with the systematic use of lean control with the support of Industry 4.0 technologies. As a result, sensors have become cheap and efficient enough for the first time in the modern era, clouds can send, receive and process large volumes of data fast enough, and software is smart enough to draw concrete conclusions from real-time data (Singh & Jha, 2021), (Pagliosa, et al., 2021).

Today companies face the effects of the fourth industrial revolution, a designation for manufacturing approach based on the use of cyber-physical systems, automation, and digitization (Hurta & Noskievičová, 2021).

In the 1980s, the process management approach and its central methodology, Lean Manufacturing (LM), were widely used in the business environment. LM is a widely used process management approach based on increased productivity and production effectiveness, reducing complexity and costs, eliminating waste such as defects, overproduction; wait; transport, inventory; movement; processing, and misuse of talents.

The problems influence the industries' revenue in the production system, making it difficult to manage operations according to economic conditions. In recent years, to find more profitable solutions, production management systems have used some methods of LM and industry I4.0 technologies (Tripathi, et al., 2022), (Cagnetti, et al., 2021).

Another essential factor in this context of methodological and technological advances in production processes is that leadership needs to evolve to direct organizations in the transition to the fourth industrial revolution (Bianco, et al., 2021).

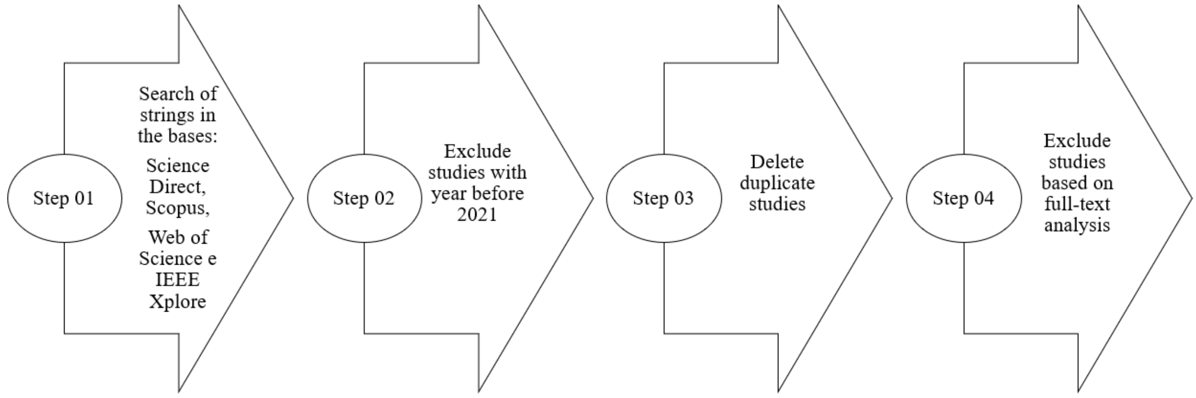
LM and I4.0 are two concepts that have been studied in recent years, focusing mainly on the relationship between them. These two concepts can strengthen themselves to develop business opportunities more efficiently (Cagnetti, et al., 2021). On the other hand, several authors claim that lean manufacturing cannot be efficient without implementing Industry 4.0 technologies and vice versa. For this reason, this article explores the synergistic factors between Lean Manufacturing and Industry 4.0.

2. Methodology

This section presents the methodological steps used in this study to achieve the desired results. First, a methodological structure was defined: approach, nature, research objective, and the search procedure, including definitions of terms to be searched. Mapping synergy factors between LM and I4.0, their classification, and finally, data analysis.

This applied research with a qualitative approach aims to build knowledge for practical and immediate application. An integrative review of the literature (Whittemore & Knafl, 2005), (Broome, 2000) was performed to identify the positive and negative synergy factors between LM and I4.0. The search for articles was divided into four steps so that only relevant studies of LM and I4.0 were selected, as seen in (Figure 1).

Figure 1 - Systematic search steps for selection of articles.



Source: Authors.

The first step as an inclusion criterion was the definition of search strings so that relevant and open access articles were found with the following keywords: "Lean Manufacturing" AND "Industry 4.0" conformable (Table 1).

Table 1 - Strings used to search electronic databases.

Strings
‘‘Lean Manufacturing’’ AND ‘‘Industry 4.0’’;

Source: Authors.

In addition, at this stage, the research bases: Science Direct, Scopus, Web of Science, and IEEE Xplore, were chosen for the credibility already known by the academic community and for their contents adept at the proposed theme (Strozzi, et al., 2017), (Powell & Peterson, 2017), (Ejsmont, et al., 2020).

Because it is a current theme, the second step as an exclusion criterion was to eliminate articles whose year of publication was before 2021. The beginning of using of information and communication technologies (ICT) in the processing industry occurred in the 1970s. The term "Industry 4.0" was first used in 2011 in Hannover, Germany, and the main ideas of Industry 4.0 were published in the same year (Kagermann, et al., 2011). Thus, the years 2021 and 2022 suggest bringing the most recent publications to the proposed theme. The third step was to eliminate the articles in duplicate, and the fourth and final step was to exclude the studies verifying the support of titles and abstracts related to the proposed theme. In (Table 2) you can view the inclusion and exclusion criteria.

Table 2 - Selection criteria for inclusion and exclusion of articles.

Inclusion Criteria	• studies related to Synergy between Lean and I4.0; • open access studies;
Exclusion Criterion	• duplicate studies; • publication prior to 2021; • with titles and abstracts not adhering to the proposed theme;

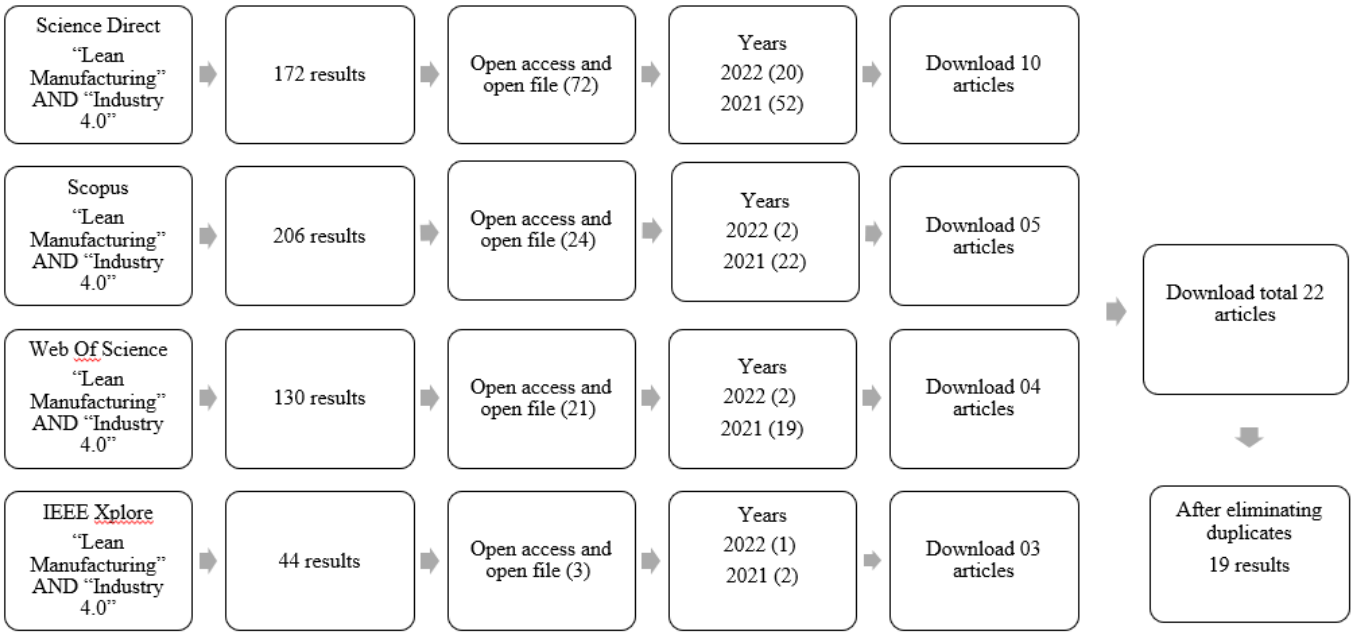
Source: Authors.

As a result, 172 articles were found in the Science Direct database, and ten were selected according to the exclusion criteria. In the Scopus database, 206 articles were found, and five were selected. Initially, 130 articles were found in the Web of

Science database, and four were selected. Finally, 44 articles were found in the IEEE Xplore search database, and three were selected according to the exclusion criteria.

Thus, 22 publications were eligible according to the inclusion and exclusion criteria; however, three articles were eliminated by duplicity, totaling 19 remaining to incorporate this research. All the steps mentioned in the study selection process can be seen in (Figure 2).

Figure 2 - Study selection flowchart.



Source: Authors.

It is noted that the databases with the highest number of publications are concentrated in Scopus and Science Direct, with 172 and 206 publications, respectively, of a total of 552 publications, representing 68%, and this suggests that the proposed theme can be better explored in these databases. On the other hand, the IEEE Xplore contributed with a smaller number of 44 publications. Unfortunately, the authors did not have access to 432 publications because they did not have open access. That is, 78% of the publications initially selected were not examined in this research, which may indicate additional content.

3. Results and Discussion

Based on the literature review of the articles, the advantages of combining the concepts LM and I4.0 were identified. Most benefits are associated with using technologies to support LM principles and tools (Hurta & Noskievičová, 2021), (Ghaithan, et al., 2021), (Mofolasayo, et al., 2022) emphasize the use of I4.0 technologies to develop and enhance Lean tools and methodologies, the use of CPS (Cyber-Physical System) devices that allow connecting and managing all plant systems generating e-Kanban’s (means “signaling” and proposes the use of cards to indicate and monitor the progress of production within the industry) that assist in decision making efficiently and in real-time (Marinelli, et al., 2021).

Sensors and software allow physical objects on the shop floor to be connected to the Internet and thus exchange data. This technology, known as IoT, for example, allows companies’ continuous improvement departments to operate faster and more assertively compared to manual LM methods (Marinelli, et al., 2021), (Silvestri, et al., 2022), (Naciri, et al., 2022). Still,

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on the theme of continuous improvement, also known as Kaizen (means “change for the better”) in the LM, the use of Big Data analysis (a strategic tool used for the collection, organization, analysis, and interpretation of a large volume of data) was highlighted by the authors (Marinelli, et al., 2021) because they assist managers in strategic business decisions.

Value stream mapping (VSM) is a popular LM tool with a high penetration level into the production process. It presents managers with a static map of the need for improvement in the production flow. Combining Cyber-Physical Systems (CPS) with VSM provides managers with more accurate real-time information to better manage improvement projects in more realistic scenarios. (Pagliosa, et al., 2021), (Schumacher, et al., 2021), (Naciri, et al., 2022).

The works presented by the authors (Pagliosa, et al., 2021), (Schumacher, et al., 2021), (Ghobakhloo, 2021), (Ghaithan, et al., 2021), (Silvestri, et al., 2022), (Reyes, et al., 2021) reiterate that IoT and CPS technologies, very present in I4.0, are fundamental to connect factories to the Internet. On the other hand, LM is all about identifying and eliminating waste in the production process using tools like Kaizen, et al., (“fail-safe” in Japanese). The authors say combining these I4.0 technologies with these LM tools can reduce waste, making processes more efficient.

In addition to having a more detailed view of the findings of this research, a form was prepared and presented in (Table 1) classified as the authors propose (Shah & Ward, 2007), who conducted a comprehensive, multi-step study to identify a multidimensional lean structure. First, they quantified the conceptual definition and proposed measuring the ten factors, which were divided into four categories (Table 3).

Table 3 - Multi-step factors to identify a multidimensional lean structure.

Categories	Factors
Supplier	Supplier feedback; delivery of JIT (Just in time, meaning “at the right time”) by suppliers; supplier development;
Customer	Customer engagement;
Processes	Pulled production; continuous flow; reduced setup time;
People	Total Productive Maintenance (TPM); statistical control of processes; employee involvement;

Source: Adapted from (Shah & Ward, 2007).

According to the publications, the research identified a series of Positive Synergies (Table 4). Furthermore, the articles present a series of methodological processes, tools, and technologies of LM and I4.0 that, when combined, promote satisfactory results in the production process and, for this reason, will be called Positive Synergy. On the other hand, when this combination does not present favorable or conflicting results, it will be called Negative Synergy.

Synergy is when two or more people, organizations, and processes, among others, interact and cooperate to produce a combined effect more significant than the sum of their separate parts. It occurs successfully when each group can discuss their different perspectives. When more than one group works on an initiative, it is essential to know how they feel about the answers to the questions and how confident they are in the decisions made. The result may be harmful if someone has information failures or is less competent or overconfident.

In mathematical terms, a synergy is when 2 + 2 = 5. Negative synergies also exist. In mathematical terms, a negative synergy occurs when 2 + 2 = 3 (Ansoff, 1965). If there is a negative synergy, the whole is less than the sum of its parts. In other words, people can do more by working alone than working together.

Table 4 - Positive Synergy between LM and I4.0.

Author	Category	Theme	Main results
(Tripathi, et al., 2022)	Process	Storage Management	Lean integration with radio frequency identification technology improved results and reduced the total operating time by 87%.
(Cagnetti, Gallo, Silvestri, & Ruggieri, 2021), (Silvestri, Gallo, & Silvestri, 2022), (Dossou, Torregrossa, & Martinez, 2022), (Mofolasayo, Young, Martinez, & Ahmad, 2022)	Process	Technologies in the process	It is very likely that the company that decides to adopt the LM technique also applies I4.0 technologies, as both use standardized control and can increase productivity and flexibility
(McKie, Jones, Miles, & Jones, 2021)	People	Kaizen Improvement Projects	With the support of I4.0 communication, using the SharePoint® website and gathering all the information in one place not only improved access to critical systems, tools and data but also improved communication between the Integrated Production Systems (IPS) team and the Operations Team with a result 3.5 times better than the previous scenario.
(Bianco, Godinho Filho, Osiro, & Ganga, 2021), (Silvestri, Gallo, & Silvestri, 2022)	People	People Management	Research finds that the Lean leader has the skills to guide the organization to the fourth industrial revolution.
(Singh & Jha, 2021)	Customer	Customer Focus	It is lean's fundamental approach to production, and when combined with I4.0 technology, it enables industries to get a clearer view of their customer's needs and values.
(Singh & Jha, 2021)	Process	Simulation systems	Robust simulation and scanning tools allow manufacturers to test their ideas in a virtual environment before they are strained or introduced into the physical environment. These industry innovations 4.0 drive lean improvement in quality and productivity in the Lean environment
(Singh & Jha, 2021)	People	Maintenance Fee	Lean Industry 4.0 would be a very efficient method to achieve the subsequent level of manufacturing innovation. Industries with Lean 4.0 effectively adopted can reduce maintenance rates by almost 40% in 5 to 10 years and is much better compared to the reductions achieved by industry 4.0 alone.
(Singh & Jha, 2021), (Ghobakhloo, 2021)	Process	Performance of the production process	Lean and I4.0 systems must be fully integrated to unlock the maximum possible value of Industry 4.0, or only 40 to 60% of the potential value could be captured.
(Hurta & Noskievičová, 2021), (Silvestri, Gallo, & Silvestri, 2022)	Process	LM or I4.0 implementation projects	From the practical point of view of its integration, Industry 4.0 can be perceived as a support for Lean Manufacturing, or, on the other hand, the LM can be seen as a supporting role for Industry 4.0 systems.
(Hurta & Noskievičová, 2021)	Process	I4.0 as support for Lean implementation	Qualitative analysis showed that the largest group of authors sees Industry 4.0 as support for the new level of Lean Manufacturing (103 selected sources correspond to this research group).
(Hurta & Noskievičová, 2021), (Ghobakhloo, 2021)	Process	Lean as support for I4.0 implementation	On the other hand, 65 results are related to the opposite point of view. Authors of these sources perceive Lean Manufacturing as support for Industry 4.0.
(Hurta & Noskievičová, 2021), (Ghaithan, Khan, Mohammed, & Hadidi, 2021), (Mofolasayo, Young, Martinez, & Ahmad, 2022)	Process	Lean Tools with I4.0 Tools	The relationship between Lean and Industry 4.0 can be perceived as the use of Industry 4.0 tools and technologies to develop Lean, and Industry 4.0 implementation should be based on this finding.
(Hurta & Noskievičová, 2021)	Process	Maturity	There is a relationship between Lean's maturity and readiness for implementing Industry 4.0. The penetration of both approaches is so significant that they must be integrated to achieve a company's operational excellence.

(Marinelli, Ali Deshmukh, Janardhanan, & Nielsen, 2021)	Process	Lean and I4.0 Tools	A study published by the authors found that 65% of respondents use real-time data to drive a continuous flow of LM. In addition, 44% of respondents confirmed using CPS devices to control process failures. Automated Kanban by I4.0, also known as E-Kanban, was cited by 32% of respondents. The use of predictive algorithms in conjunction with TPM (a tool used by the industry to optimize process efficiency) was also indicated by 44% of respondents.
(Marinelli, Ali Deshmukh, Janardhanan, & Nielsen, 2021), (Silvestri, Gallo, & Silvestri, 2022), (Naciri, et al., 2022)	Process	Systems Integration	The Internet of Things (IoT) enabled data exchange describes the network of physical objects incorporated into sensors, software, and other technologies to connect and exchange data with other devices and systems over the Internet) between the shop floor and other departments for continuous improvement and decision-making is among the popular options, with 53% of respondents reporting their applicability.
(Marinelli, Ali Deshmukh, Janardhanan, & Nielsen, 2021)	Process	Systems Integration	The use of Big Data analysis (it is a strategic tool used for the collection, organization, analysis, and interpretation of a large volume of valid data for the generation of valuable insights that assist business managers) was highlighted for many purposes also present in the literature, including the empowerment of the workforce for continuous improvement objectives cited in 44% and the improvement of the VSM procedures cited in 32%.
(Pagliosa, Tortorella, & Ferreira, 2021), (Schumacher, Schmid, Bildstein, & Bauernhansl, 2021), (Naciri, et al., 2022)	Process	Systems Integration	Both CPS and VSM (value stream mapping is a tool that maps material, information, and runtime flows) have high penetration across the entire value stream, being used as a support technology and practice on which others can build or expand. Because a proper VSM application requires a large amount of information that is almost always outdated, incorporating of CPS can provide more accurate data for management decisions to prioritize continuous improvement and initiatives based on more realistic scenarios.
(Pagliosa, Tortorella, & Ferreira, 2021), (Schumacher, Schmid, Bildstein, & Bauernhansl, 2021), (Ghobakhloo, 2021), (Ghaithan, Khan, Mohammed, & Hadidi, 2021), (Silvestri, Gallo, & Silvestri, 2022), (Reyes, Mula, & Diaz-Madronero, 2021)	Process	Systems Integration	IoT and CPS play a crucial role in exchanging and transmitting data needed to connect the plant, aligned with certain proposed LM principles, such as fostering a culture that establishes continuous flow to raise and identify problems. In addition, LM extensively operationalizes Poka Yoke and Kanban, which have all been indicated as highly synergistic with both technologies.
(Marinelli, Ali Deshmukh, Janardhanan, & Nielsen, 2021), (Ghaithan, Khan, Mohammed, & Hadidi, 2021), (Dossou, Torregrossa, & Martinez, 2022)	People	Standardised work	The use of robotic elements facilitates the execution of standardized tasks of workers, as well as the use of algorithms for efficiently managing of standardized procedures.

Source: Authors (2022).

The results presented in (Table 4) indicate that the category "Process" listed in (Table 3) is the category where synergies between LM and I4.0 were further identified. Use of radiofrequency, standardized control, access to systems, simulation and scanning technologies, real-time data, CPS devices to control process failures, automated Kanban, predictive algorithms in conjunction with TPM, Internet of Things (IoT), Big Data analysis, CPS devices associated with VSM and Poka Yoke, use of robotic elements that facilitate the execution of standardized work, make up a series of positive combinations (synergies) applied to the production process, providing a highly effective environment.

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Among the I4.0 technologies presented, IoT, Big Data, and CPS stand out; combined with LM tools such as VSM, TPM, and Kanban, standardized work and continuous improvement deliver excellent results in the production process. On the other hand, not all synergies are positive. It is a wake-up call for companies looking to combine these two approaches in manufacturing. In (Table 5), the Negative Synergies between LM and I4.0 are related.

Table 5 - Negative Synergy between LM and I4.0.

Author	Category	Theme	Main results
(Singh & Jha, 2021)	Supplier	Business Strategy	The JIT concept (which means right time aims to produce the exact amount of a product, according to demand, quickly and without the need for stock formation, making the product reach its destination within the agreed timeframe) conflicts with I4.0's concept of customization. The main disadvantages are related to the lack of flexibility in the production system. The company that follows this model may have difficulties working with various products. The variation in demand for products in the short term can become a problem as well.
(Singh & Jha, 2021)	People	I4.0 hardware failure or workforce	It can lead to significant Lean inconsistencies, which can cause projects to delay deadlines. In not-so-automated processes, workers can move from one process to another, depending on inventory and production needs.
(Hurta & Noskievičová, 2021)	People	Barriers in implementation	The risks of barriers and differences between Industry 4.0 and Lean Manufacturing are not sufficiently mapped to avoid the failure rate of integration in some areas.
(Marinelli, Ali Deshmukh, Janardhanan, & Nielsen, 2021)	Process	Profitability	While there is consensus on the beneficial impact of Lean, the perceived impact of industry 4.0 tools is not equally clear, with the potential efficiency and profitability benefits of the business not yet being fully appreciated.
(Pagliosa, Tortorella, & Ferreira, 2021)	Process	Quality Systems	The relationship between Simulation and Poka Yoke (error-proof system) depends significantly on the context of the application. Although simulation can anticipate possible difficulties and mitigate failures in the production process, it does not avoid errors, which is the essence of Poka Yoke. A certain complementarity between Simulation and Poka Yoke is identified, although studies that have reported its concomitant application are still scarce.
(Pagliosa, Tortorella, & Ferreira, 2021)	Process	Automated Production	The relationship between advanced robotics and SMED (a tool used in the industry to accelerate setup processes, such as preparing machines, equipment, and production lines) can, if not well planned, lead to conflicting efforts between Lean and I4.0. Advanced robotics can require complex work typically found in machine setups. High levels of robotization and automation can reduce the flexibility of a production line, limit the range of product families that can be processed on that line, and impact setup times.
(Pagliosa, Tortorella, & Ferreira, 2021)	Process	Robotisation	Kanban and Heijunka are tools applied throughout the production chain and reach higher levels in the value stream, enabling more efficient processes. However, a high degree of robotization in the context of inefficient production processes is reflected in the limited applicability of this technology to companies. In this context, there is a risk that advanced robotization will hardly support LM, as they operate at a higher level of the production process.
(Pagliosa, Tortorella, & Ferreira, 2021)	Process	Production pace	Takt Time (the pace at which the company needs to produce a product to meet consumer demand) aims to precisely adjust the pace of the production system according to market demand. In addition, Takt Time is based on predictable demand and has difficulty absorbing demand fluctuations. The I4.0, in turn, allows the production system to be modular and flexible, allowing it to mass produce highly customized products. Thus, it can be emphasiszed that Takt Time somewhat contradicts to the principles of decentralization and autonomy implicit in adopting I4.0 technologies.

Source: Authors (2022).

In (Table 5), it is perceived that the process category also presents a more significant number of negative synergies between the LM and I4.0 approaches. Companies with a lower degree of maturity end up automating inefficient processes. For example, advanced robotics (Pagliosa, et al., 2021) can conflict with Kanban, and Heijunka (production leveling that supports demand and helps maximize capacity utilization), can pose a risk to the production process. In addition, in this context of advanced robotization, the relationship with the SMED (Single Minute Exchange of Dies) methodology widely used in LM, if poorly planned, can generate conflicting efforts, make production lines less flexible, and can decrease and affect changeover times of products (Pagliosa, et al., 2021).

Another example, simulation is another technology widely used in the context of I4.0. However, when connected to the LM's Poka-Yoke (error prevention system), the results highly depend on the application context. Simulation can anticipate potential problems and reduce errors in the production process, but it cannot avoid the errors that are the essence of Poka-Yoke. This fact suggests that companies strategically rethink whether it is worth investing in this technology when the objective is to avoid errors in the process (Pagliosa, et al., 2021).

4. Final Considerations

LM's production paradigms and I4.0 are promising developments for the future of manufacturing, especially if organizations combine them to create synergies that increase efficiency. This research identifies that real-time data, IoT for data exchange, Big Data analysis, and Cyber-Physical Systems are among the most popular I4.0 technologies used to support lean LM tools such as VSM, Kanban, Standardized Work, TPM, and Continuous Improvement (Marinelli, et al., 2021).

Companies have applied the concepts of I4.0 and LM as competitive strategies (Cagnetti, et al., 2021) to increase operational excellence and financial profitability within restricted resources. Studies strongly recommend that industry managers improve their shop floor's productivity and operational excellence using this new lean, intelligent hybrid manufacturing structure (Tripathi, et al., 2022).

However, a larger group of authors claim that I4.0 supports the new level of LM. This finding affects the path of its practical integration and implementation of I4.0 technologies. It suggests to companies that process automation should occur in conjunction with the improvements provided by the LM, which can be a decisive success factor in the implementation processes (Hurta & Noskievičová, 2021). On the other hand, LM has some limitations, such as demand volatility and poor product customization. Applying I4.0 technologies to the production process, companies can make lean production a more effective system, remove its limitations and make it technically more efficient. The combination of LM and I4.0 techniques allows companies to succeed because technology and man will work together (Cagnetti, et al., 2021).

Despite all the benefits, the implementation of IoT, Big Data, and Cyber-Physical Systems requires protection with information security systems that must protect data from unauthorized access, misuse, modification or destruction of data, accidents (Franke & Wernberg, 2020), or even cyber-attacks. Therefore, security must involve network infrastructure, hardware, and, control policies to protect data, often in the cloud with encryption data (Mbiriki, et al., 2018).

The study also identifies that lean leaders' competencies can sustain the skills that can be developed in I4.0 leaders. Therefore, it is another essential element that will enable companies to achieve significant results (Gallo, et al., 2021). In addition, there is a strong synergy between the competencies of both approaches (Gallo, et al., 2021).

As the main limitation of this research, the number of 19 articles surveyed may limit the number of Positive and Negative Synergies identified and not explain broader conclusions. However, the authors still believe that this study can guide future research to a deeper empirical understanding of the actual performance that must be performed understand better the potential benefits of an integrated LM and I4.0 solution.

As a suggestion for future work, focus on issues that have not yet been exhaustively researched, for example, a practical check of the possibilities of Lean and Industry 4.0 integration to reduce the eight types of waste (Unnecessary processing; Excessive production; Inventories; Transportation; Unnecessary movement of people; Defects and Reworks; Waiting and losing Talents) that that the LM widely fights.

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