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Lean Thinking contributions for Industry 4.0: a Systematic Literature Review

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Abstract: Lean Thinking has successfully challenged mass production practices, providing greater flexibility in production systems and processes, resulting in "leaner" products and supply chains, i.e., with less waste. More recently, the term Industry 4.0 emerged. It was first used in Germany in 2011 to refer to the 4th industrial revolution. It aims to connect the physical and virtual worlds in industrial production and has become increasingly popular with the many opportunities and business models that can be consolidated through new technologies. With such automation associated with Industry 4.0, questions arise about the interoperability between the two approaches and the role of Lean in this ongoing industrial revolution. Therefore, a systematic literature review was carried out in order to answer the research questions, and to identify the role of Lean in this scenario. The review was conducted for the period from 2011 to 2018 and resulted in a total of 26 articles being analyzed. This paper´s focus is the effect of Lean Thinking as a facilitator, within the scope of Industry 4.0. It is also clear that this is an emerging research area, with most of the selected studies published between 2017 and 2018.

Keywords: Lean Production, Lean Thinking, Industry 4.0, Smart Factory, 4th Industrial Revolution.

1. INTRODUCTION

Toyota Production System coined by Krafcik (1988) as Lean Production (LP) and popularized by the best-seller book of Womack et al. (1990), became a widely recognized and widespread approach in companies due to its notoriety in obtaining greater efficiency in productive processes. Some of the key criteria related to its successful implementation are directly linked to the elimination of all steps that do not add value from a customer point of view, and by adopting a mindset for continuous improvement.

Continuous improvement is the ongoing search for waste reduction or ideally elimination, as defined in the last Lean Thinking (LT) principle by Womack and Jones (1996): the pursuit of perfection. The four principles that precede this are; the identification of value, value stream, flow, and pull production. These authors defined these principles to guide companies in the implementation of LP. In addition to LP tools, a "change-promoting work environment" is needed, meaning a willingness to adapt mentalities and approaches, and a forward-thinking attitude towards new technologies that can contribute to waste reduction.

With the emergence of Industry 4.0 (German term, originally used to frame the Fourth Industrial Revolution), a promising way of dealing with future challenges in the production environment emerges (Kagermann et al. 2013). Industry 4.0 (I4.0) introduces new ways of developing smart products, introducing technological tools to create a new concept of factory: the smart factory.

However, this new approach does not replace Lean, and both can and should be integrated (Nunes et al. 2017). This is because although it represents the most modern in technological terms, its implementation and validation is put at risk without the knowledge and wise use of productive practices. Furthermore, the Lean work environment nurtures a culture more receptive new technologies, mainly when these reduce waste, as already mentioned. Nevertheless, many doubts still exist about how Lean Thinking contributes to I4.0, whether I4.0 inhibits or enables Lean implementation, or even, and whether both could be successfully integrated.

Attending to these concerns, the authors of this paper developed a systematic literature review to answer three research questions:

- Does Lean Thinking have a facilitating effect on the implementation of Industry 4.0?
- Can Industry 4.0 technologies support Lean Production practices?
- What are the possible barriers or constraints related to the integration between Lean Production and Industry 4.0?

Because of the limitations of this paper, just the first question will be explored. The authors will present the partial results related to the Lean Thinking contributions to the implementation of I4.0. The complete study can be consulted in Bittencourt (2018) and Bittencourt et al. (2019).

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This paper is structured in six sections. Following the introduction, a brief literature review will be presented. In the third section, the research methodology is outlined. The fourth presents the results for the question explored in this paper that is followed by a discussion of key points in the fifth section. Finally, section six presents the main remarks.

2. BRIDGING THE GAP BETWEEN LEAN AND INDUSTRY 4.0

The definition of the term I4.0 was first proposed at the Hannover Fair in 2011. A report funded by the German government, with the participation of specialists and industries in 2013, defined the approach as a way of promoting competitive advantages through the application and integration of new technologies (Kagermann et al. 2013). This approach is characterized by the strong connection between processes, products and services, represented by the Internet of Things (IoT). Its concept has been widely discussed by academics and organizations, and its high level of integration forms a working network that links physical space and the virtual world through Cyber-Physical Systems (CPS) (Kagermann et al. 2013).

In this sense, the concept of I4.0 can be interpreted as a strategy to increase competitiveness in the future scenario. This focuses on optimizing the value chain due to dynamic and autonomously controlled production (Kagermann et al. 2013). As a result, it facilitates fundamental improvements in the industrial processes involved in manufacturing, material utilization, supply chain and life cycle management. Smart factories that are already beginning to emerge employ a new productive approach. Smart products are uniquely identified, can be located at any stage of the process and know their own history, current status, and alternative routes to achieve their goal (Kagermann et al. 2013).

Achieving the paradigm shift required for the delivery of I4.0 is a long-term project and requires a gradual process. Through this process, it will be essential to ensure that the values of the current manufacturing systems are preserved (Kagermann et al. 2013). Therefore, it is essential to know the current processes and how they add value to the products. These must be produced at the best quality, lowest cost and highest safety in an environment that respects both the customer (internal or external) and the environment.

Although this claim seems obvious and has always been present in the objective of production, it wasn't always the case in industry. Whether due to the rush motivated by the economic growth, or the lack of technology that allowed it, it is nevertheless an area of vital concern considering our current environmental situation. I4.0 offers new technologies, which in the context of LT will also promote a different mind-set (Spear 2004; Womack & Jones 1994; Yamamoto & Bellgran 2010).

The brief review carried out allowed the authors to reflect on these two concepts that, although with different origins and moments of appearance, seek the same: to reduce costs and to increase productivity for companies. LT prefers to focus on waste reduction, while I4.0 focuses on the use of new technologies powered by IoT. Although with different approaches, they can and should be complementary, since the implementation of Lean will encourage a company to promote thinkers (Alves et al. 2012) who will be fundamental in implementing the changes required by I4.0, as represented in Figure 1.

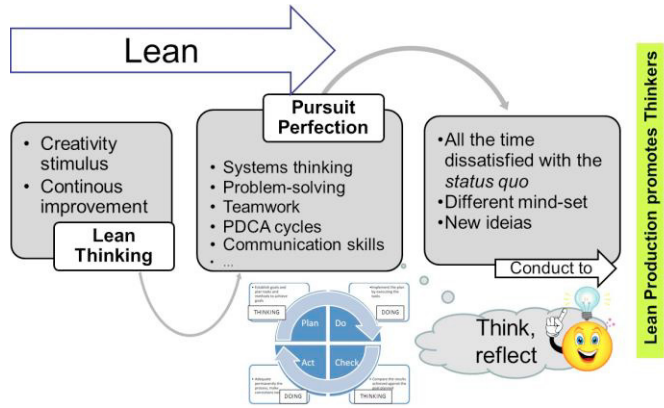

Figure 1. Lean Thinking promotes thinkers (Alves et al. 2014)

For this training, it will be necessary that employees acquire the skills referred to in the May 2018 publication of Mechanical Engineering. The magazine published by ASME (Brown 2018), focuses on critical-thinking and problem-solving, to name a few; which have been discussed in other publications (UNESCO 2016). It is hoped however, that new technologies can also help with this training as well as better-informed decision-making, through collaborative work platforms, teaching platforms and learning factories (Meissner et al. 2018; Blöchl & Schneider 2016; Prinz et al. 2018).

Researchers have already done some work in this area, although the literature available is still scarce and requires much more depth. These researchers also appear to view Lean and I4.0 as concepts that present possible limitations as to their compatibility (Kolberg, Knobloch and Zühlke, 2017; Ma, Wang and Zhao, 2017; Yin, Stecke and Li, 2018). Thus, in the context of the systematic review carried out, it is sought to evaluate the facilitating effect of Lean in the implementation of I4.0.

3. RESEARCH METHODOLOGY

A systematic literature review (SLR) was the research methodology used to explore the literature (conference papers and journal articles) relating I4.0 and LP, and the interaction between both systems. A SLR is an important research process that uses a pre-planned research strategy and not simply a review of previous research. This type of review aims to respond to specific research questions, build on existing studies, select and evaluate contributions, analyze and synthesize data, and report the evidence in such a way that allows the researcher to draw their own conclusions about what is known and unknown (Denyer & Tranfield 2009; Thomé et al. 2016). By bringing together the results of different studies on a specific topic, a greater understanding of the topic is also achieved, as well as a more in-depth level of conceptual or theoretical development than by any individual study (Campbell et al. 2003; Thomé et al. 2016).

A SLR covers all or most of the following steps (Denyer & Tranfield 2009; Thomé et al. 2016): (1) planning and formulating the research question; (2) localization and searching the literature; (3) data gathering and quality evaluation; (4) data analysis and synthesis; and (5) interpretation and presenting results. The research question formulated to guide the SLR was as follows: Does LT have a facilitating effect on the implementation of I4.0?

The second step is associated with the source's location (Web of Science, Scopus, Taylor & Francis, and Science Direct) and searching the literature. The search terms used, Table 1, were broad enough not to restrict the search and aimed at addressing the different objectives established by this work. As part of this step the choice of articles was also limited to the abstract, title and keywords, these being determinant factors in the selection process.

Table 1. List of search terms

Search terms
TITLE-ABS-KEY ("industry 4.0" OR "fourth industrial revolution" OR "smart factory") AND ("Lean production" OR "Lean manufacturing" OR "Lean thinking" OR "Lean management" OR "5S" OR "one piece flow" OR "andon" OR "kanban" OR "heijunka" OR "just in time" OR "poka-yoke" OR "SMED" OR "VSM" OR "TPM" OR "SPC")

The third step, data gathering and quality evaluation, is related to the search phase of the literature itself. It is in this step that the procedure used is defined, including the time period, the exclusion criteria and the classification criteria applied.

The time frame considered was from 2011 to July 2018. This period was considered since it was at the end of 2011 that the term I4.0 was used for the first time (Schwab 2016). The exclusion criteria were chosen based on the key concepts and approaches of I4.0. Sources with a superficial or partial approach to I4.0, and possible lack of consideration for different aspects, were therefore excluded. The classification criteria support further selection process. For this reason, the articles to be analyzed in detail would have to have elements regarding the relationship between Lean and I4.0, and whether Lean principles and tools had an approach focused on the integration of I4.0. Finally, only articles in English were considered to address this study's questions.

The data analysis and synthesis (fourth step) was carried out through the categorization of the selected papers by title, author, year of publication, type of publication, type of research and topic approached. All steps are summarized in Figure 2.

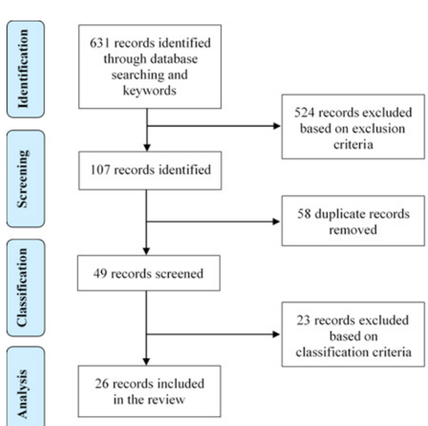

Figure 2. PRISMA flowchart

The results were categorized in order to give a better understanding of the studies already carried out in this area of research. The data gathered and considered most relevant were discussed individually (step five).

4. FACILITATING EFFECT OF LEAN THINKING ON THE IMPLEMENTATION OF INDUSTRY 4.0

In this paper, as noted previously, the results related to the LT contributions to the implementation of I4.0 will be presented and discussed. As a result of the SLR conducted, an important point was observed on the interaction between I4.0 and Lean: Lean can be used as a basis to build an implementation of I4.0, thus becoming a facilitator in this implementation process. In the articles selected this interaction is visible, as nine out of the 26 articles discuss the positive synergy potentiated by this interaction (Table 2).

Table 2. List of authors that discuss positive synergy of Lean Thinking with Industry 4.0

Perspective	Author
Lean Thinking facilitates the Implementation of Industry 4.0	Kolberg & Zühlke (2015); Tortorella & Fetterman (2017); Leyh et al. (2017); Davies et al. (2017); Mrugalska & Wyrwicka (2017); Buer et al.(2018); Prinz et al. (2018); Lugert et al. (2018); Uriarte et al. (2018)

Kolberg and Zühlke (2015) highlighted Lean's role in the implementation process of Industry 4.0. Lean concepts such as work standardization, organization and transparency are highlighted as support for implementation of solutions linked to I4.0. At the same time, through the analysis of implementation cases in the industry, Lean processes' improvement capacity is highlighted from its integration with I4.0. By comparing technologies from I4.0 with Lean methods, the authors proposed an overview of possible connections and presented two cases from two German companies: Würth and Wittenstein.

The Würth Company has introduced an order replenishment system based on Kanban baskets. A sensor detects the number of items in the basket and the data is automatically transmitted to the control system. In addition, the new system can send orders automatically to suppliers, causing the stock to be reduced, space clearance on the shop floor occurs, and orders are made according to the demand.

In the other case analyzed, from the Wittenstein Company, a flexible system of supply chain is in operation. Instead of fixed transport intervals, an integrated system with production and automated guided vehicles (AGVs) determine the milk-run system-based transport interval through real-time demand. According to the study, the interaction between employees and the transport system is via portable screens, which reinforces the verticalization provided by man-machine interaction, one of the principles of I4.0. As reported, the system registered gains of 25% with the new implementation.

In Tortorella and Fettermann (2017) the relationship between Lean and I4.0 was analyzed, as well as its influence on operational performance in companies. According to the same authors, the literature that correlates Lean and I4.0 is scarce, nevertheless suggesting a positive association between these approaches. Based on the data of 110 companies, these authors evaluated the results of the questionnaires that were validated through mathematical methods. It indicated that companies with a low degree of maturity in the framework of a Lean Production (less than two years) presented a low level of interaction with I4.0. According to the same authors, the degree of maturity of a Lean production system is associated with a higher level of awareness, which provides a better understanding of its underlying practices and principles. This leads to the conclusion that the level of maturity of the Lean system within a company is an important variable in a process of association with I4.0.

Davies et al. (2017) presented I4.0 and Lean as mutually supportive, where Lean methods are seen as facilitators of I4.0, and where I4.0 is analyzed as a factor that strengthens Lean. Interoperability is treated from both an operational point of view and a socio-technical one. From an operational point of view, it is possible to observe the vertical and horizontal integration of the productive process by the integration of tools and principles already known by Lean and I4.0. As an example, it is possible to mention the use of the electronic Kanban system and the Total Productive Maintenance (TPM) system due to the connectivity between machines/maintenance team. An important point addressed by the authors, which was not mentioned in other studies, is the restriction of the exchange of information due to security factors and access protocols. This is mainly as a result of the continuous sharing of information occurring through the Internet in Cyber-physical systems. These same authors considered socio-technical factors from an interaction between Lean and I4.0. Systems that involve a complex interaction between people, machines, and the environmental aspects of organizational systems, are understood as socio-technical systems. The complexities that arise with increased socio-technical interaction will be managed through the change in the way people at each organizational level interact.

According to this publication, the conventional relationship of a management system that predominantly controls workers will lead to an active participation, where there will be a mutual transfer of knowledge across the managerial and operational levels. Management decisions will be optimized based on shared knowledge, and workers at the operational level will no longer be passive agents who carry out their tasks without any reference. Instead, they will be elevated to the status of "knowledge worker" in view of the verticalization of processes generated by increased interaction between workers and the process.

Mrugalska and Wyrwicka (2017) supported the claim that Lean and I4.0 can coexist and are mutually supportive. This is supported by other authors (Uriarte et al. 2018) who even claim that barriers in implementing both can be overcome from a combination of different approaches.

Uriarte et al. (2018) suggests that in the future, Lean, far from disappearing, will be still a fundamental philosophy to support companies to become more efficient. I4.0 solutions will support their implementation in companies, overcoming even some of the existing hurdles for Lean´s implementation today. Moreover, according to the authors, changes in technologies alone will not help in any productivity gain, an organizational change will be required to support the use of new technologies included by I4.0.

An investment to adapt the skills of workers will be necessary to embrace the new advances that this industrial revolution will bring. This was also observed in the publication of Mrugalska and Wyrwicka (2017). This is in accordance with the principle of respect for people, a key point of Lean, where human aspect has to be developed with the aim of maximizing individual and team performance (Ohno 1988; Sugimori et al. 1977).

Buer et al. (2018) showed how the simplified, waste-free process achieved through a Lean transformation simplifies additional efforts to automate and digitalize the manufacturing process, thus promoting the implementation of I4.0.

Prinz et al. (2018) investigated a learning factory whose main objective is to prepare workers for the new reality of the I4.0. In this learning factory several operations of a production line were simulated at different stages and with different requirements. Lean tools associated with pull production and the milk-run system were also tested in this line, followed by failure simulations that forced employees to find answers.

According to these authors, employees were then encouraged to use technologies associated with I4.0 to solve such problems and improve the current system, using the digitalization of resources in order to obtain real-time information and assistance, which are considered elementary in the concept of I4.0, being associated with CPS and IoT. According to the publication, the purpose of the training is to make clear the benefits of both Lean and I4.0; but for the successful implementation of new scanning technologies, the production process must be optimized and organized by Lean principles.

Still, according to Prinz et al. (2018), the implementation of technologies related to I4.0 in a production system compromises the optimized use of such resources without first of all having a framework of the organization. This framework will use tools such as process standardization and production flow, inherent to Lean, which will guarantee transparency of the process and gain of productivity. These authors also evidenced that companies benefit from the technological implementation of I4.0 through an increase in operational performance with a solid Lean system.

Lugert et al. (2018) investigated the correlation between Lean and I4.0, focusing on the evolution of the VSM tool in the face of increasing digitalization in the manufacturing environment. After analyzing data provided by 170 Lean management experts, they concluded that I4.0 and Lean methods do not contradict each other; rather, there is a great potential to be gained from combining the two approaches.

According to this author, the main identified disadvantage of VSM is its static behavior, which can be overcome by the implementation of I4.0 solutions. If the real-time data from the manufacturing execution system is put together with the geographic data collected by an RFID system, the current value stream can be permanently displayed; and bottlenecks, as well as improvements, can be continuously verified. In this way, VSM would change from a static tool to a dynamic one

(Dombrowski et al. 2017; Enke et al. 2018; Lugert et al. 2018; Meudt et al. 2017; Wagner et al. 2018).

5. DISCUSSION

When analyzing the researched literature, the high investment necessary to digitalize a productive process in the context of I4.0, is of no use if the process is out of control and full of waste. The result according to Nicoletti (2013), will be the reproduction of some type of waste because, the automation of an inefficient process does not make it efficient. Similar to what Bortolotti and Romano (2012) point out: "Lean first, then automate". Therefore, Lean concepts, like work standardization, organization and transparency, are highlighted in the literature (Leyh et al. 2017; Tortorella & Fettermann 2017; Prinz et al. 2018) as the pillars for the implementation of solutions related to I4.0, that is, Lean is an important way to consolidate I4.0. Moreover, a positive relationship between LP .companies' degree of maturity and level of interaction with I4.0 can be identified.

Thus, through the SLR it is possible to systematize how Lean Thinking facilitates the implementation of I4.0: It simplifies processes and eliminates waste in a way that it is not repeated, reduces the possibility of compromising scarce resources, and increases the transparency of work processes/organization.

Although the current sample of studies provides some indications of possible performance impacts, the studies are clearly insufficient in breadth and depth, given that in most of the analyzed sources interoperability has not been approached in a holistic way, but in a punctual way. However, it is possible to observe that according to the authors, the focus of research is on how the technologies of I4.0 can be used to support existing Lean practices and tools. This emphasizes the idea that by increasing flexibility of production, the use of technologies to reduce human effort, and the enhancement of man-machine communication systems will be the main benefits. This research gap is addressed, for example, in Powell et al. (2018), where a case study of an Italian company operating within the automotive sector has been discussed, in order to present some evidence of real implementation of I4.0 projects and its relationship with different Lean aspects.

6. FINAL REMARKS

The main purpose of this work was to study the relationship and contribution of Lean Thinking in the context of I4.0. Despite the growing popularity of I4.0, the literature on its relationship with the popular field of Lean Production is still scarce. Considering the importance of analyzing such symbiosis, a systematic literature review was carried out in order to investigate the role of Lean as a facilitator agent within the I4.0. The review was conducted for the period of 2011 to July 2018, which resulted in a total of 26 articles being analyzed, after applying the exclusion criteria inherent to the SLR. This is an emerging research area, with most of the sources being published between 2017 and 2018, first article published in 2015, representing 85% of the studies evaluated in this research. From these 26 papers, ten discussed the facilitating role of Lean Thinking in the implementation of I4.0.

With the results presented, it was identified that Lean is seen as an important agent in the implementation and consolidation of I4.0, and Lean concepts such as work standardization, organization and transparency are fundamental in supporting the implementation and consolidation of the I4.0. Also, most studies identify a complex interaction between people, machines and the environmental aspects of organizational systems. Being each interaction handled in different ways according to each organization needs.

It was also possible to observe that technological factors represent a barrier to the present moment, with the absence of a standard architecture generating difficulties in the integration process between CPS and Lean tools.

Finally, it should be stressed that the human factor must be better integrated with existing models, since employees will continue to be an essential part of the processes. Therefore, more research is needed in order to understand the impact of certain key Lean aspects within I4.0, which have not yet been addressed in depth. Certainly, the main change will occur on the shop-floor where more highly-skilled operators will be required.

To conclude, it is important to discuss the limitations of this study. The sources, time-frame and the exclusion criteria used may have excluded relevant papers from the analysis, which could be an initial starting point for other researchers. As a continuous process, this SLR study could be an initial point for more studies by including different scientific and technologic sources and in languages other than English.

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