

## Industry 4.0 Technologies and Lean Practices: a Systematic Literature Survey

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### Resumo:

Para a maioria das empresas inseridas em mercados competitivos é fundamental ter como um de seus objetivos estratégicos o constante aperfeiçoamento de seus processos, produtos e serviços através da implementação de ferramentas e tecnologias que visam elevar o nível de seu desempenho. Nesse sentido, muitas empresas adotaram a manufatura enxuta (ME) como uma forma eficiente de alcançar melhores resultados e se tornarem-se mais competitivas. Com o advento da Indústria 4.0 (I4.0), seus novos conceitos e tecnologias, novas possibilidades de se alcançar melhores resultados passaram a ser acessíveis o que pode mudar a forma como as empresas operam. No entanto, existem dúvidas importantes sobre como as tecnologias I4.0 podem melhorar ou modificar as relações entre as práticas do enxutas (PEs) já implementadas pela ME, bem como o resultado dessas associações. O objetivo deste trabalho é identificar as principais tecnologias da I4.0 e PEs existentes na literatura. Para isso, foi realizada uma revisão sistemática da literatura, na qual foram analisados 85 artigos que resultaram na identificação de nove tecnologias I4.0 e 14 práticas PEs. Posteriormente, as principais tecnologias da I4.0 foram analisadas em relação às suas aplicações nos diferentes níveis do fluxo de valor.

**Palavras chave:** Smart Manufacturing, Tecnologias da Indústria 4.0, Práticas Enxutas, Revisão da Literatura.

### Abstract:

For most companies inserted in competitive market is essential to have as one of their strategic objectives constantly improve their processes, products and services through implementing tools and technologies that aim to raise the level of their performance. In these sense, many companies have adopted lean manufacturing (LM) as an efficient way to achieve better results and become more competitive. With the advent of the Industry 4.0 (I4.0) their new concepts and technologies, new possibilities can be accessed in order to achieve better results and change the way companies operate. However, there are important doubts about how the I4.0 technologies can improve or modify the relationships between the lean's practices (LPs) already implemented as well the result of these associations. The objective of this paper is to identify in the literature body the main I4.0 technologies and LPs. For this, a systematic literature review was conducted which 85 papers were analyzed that resulted in the identification of nine I4.0 technologies and fourteen LM practices. Subsequently, the main I4.0 technologies LPs were analyze with regard to their applications in the different levels of the value stream.

**Key-words:** Smart manufacturing, Industry 4.0 Technologies, Lean Practices, Literature Survey

### 1. Introduction

As companies continue to evolve and seek new ways to improve their production systems there will always be an interest in incorporating new approaches and technologies that can

help such organizations to achieve better results. In order to ensure competitiveness and self-sustainability many companies have adopted LM as an efficient way to achieve better results and become more competitive. LM is described as a approach composed of organizational practices and principles, the main objective is to systematically eliminate wastes, improve productivity and quality by meeting the client's customer requirements (WOMACK et al., 2004; JASTI, KODALI, 2015 ).

However, LM considered as a socio-technical approach with principles and practices of management based on the human factor, characterized by the simplicity and low technology (SEPPÄLÄ; KLEMOLA, 2004; DICKMANN, 2008), may present contradictory points in relation to the modern technologies of I4.0.

According to Neugebauer et al., (2016), the term "Industry 4.0" was create to emphasize the enormous opportunities to digitize and integrate the different phases of the production system as well as to increase the value added to the products. With the advent of the I4.0 their new concepts and technologies, new possibilities can be accessed in order to achieve better results and change the way companies operate. I4.0 technologies offer greater flexibility and automation in manufacturing should support the creation of new forms of operation (ASHTON, 2009).

In this way, this research seeks to answer this question, aiming to identify the main technologies of I4.0 and LM existing in manufacturing companies as well as to present in which levels of the flow of value the main technologies are being used in the manufacturing companies to from a systematic literature review.

## 2. Industry 4.0

"Industry 4.0" became publicly known in 2011 when an initiative called "Industrie 4.0" an association of business, political and academic representatives promoted the idea as an approach aiming to strengthening the competitiveness of the German manufacturing industry (KAGERMAN et al., 2013). According to Neugebauer et al., (2016), the term "Industry 4.0" was created to emphasize the enormous opportunities to digitize and integrate the different phases of the production system as well as generate more added value to the products.

I4.0 has as objective an autonomous and dynamic production, through the use of a set of technologies that are capable of mass production of highly customized products. (SCHMIDT et al., 2015). In this sense, the I4.0 is becoming more present in the strategies of the organizations, due to the benefits that it can offer.

Companies intent combining some I4.0's technologies such as automation, connected capability, cloud computing, sensors, 3D printing, intelligent algorithms and 'internet of things' (IoT) services to improve their performance and results (PWC, 2016). According to Kagermann et al. (2013), the implementation of automation equipment improves the quality of the product, while making manufacturing processes more efficient.

Despite the theme growing notoriety, many companies still have difficulties about how I4.0's high-tech practices should be implemented into their operations (EROL et al., 2016; SANDERS et al., 2017). The feasibility of integrating I4.0 technologies into existing production systems as LM is still understudied and need to be checked.

## 3.0 Lean Manufacturing

The LM can be described as a production system that has among its objectives the increase in productivity, quality, reduction process variation and the elimination of waste existing along

the value chain (SHAH; WARD, 2003). LM is a socio-technical production system that considers the human being as the fundamental factor to sustain continuous improvement (SCHEIN, 2004; LEONARD; PAKDIL, 2016).

The implementation of the LM implies a systematic and low technology approach composed of several principles and practices that consider the human being as the main element to sustain continuous improvement (SEPPÄLÄ; KLEMOLA, 2004; SCHEIN, 2004; LEONARD; PAKDIL, 2016). According to Hines et al. (2004), the understanding about LM has evolved in organizations as they seek to obtain better results. The use of the LM can offer improvements in performance by reducing costs, reducing defects and producing with a focus on demand customers (OHNO, 1988; WOMACK et al., 2004; DENNIS, 2008).

In this sense, due to the simplicity of its application and its results obtained using its principles and practices, LM has become widely used in the different organization of several segments that seek to become more competitive (SIMPSON; POWER, 2005).

#### 4. Systematic Literature Survey about I4.0 and LM

In this work, the identification of I4.0 technologies and LPs was carried out from a systematic literature review. The Systematic Search Flow method (SSF) proposed by Ferenhof and Fernandes (2016), was used, due to its consistency and reliability. The method is composed of four phases divided into eight activities, as shown in Table 1.

| Phase                     | Activity                                         |
|---------------------------|--------------------------------------------------|
| 1– Research Protocol<br>↓ | Search strategy (1.1)                            |
|                           | Query the data base (1.2)                        |
|                           | Management of documents (1.3)                    |
|                           | Standardization and selection of documents (1.4) |
| 2 – Analysis<br>↓         | Data consolidation (2.1)                         |
| 3 – Synthesis<br>↓        | Build reports (3.1)                              |
| 4 – Writing<br>↓          | Writing (4.1)                                    |

Source: Adapted from Ferenhof and Fernandes (2016)

Table 1–. Phases and activities of the SSF method

#### 4.1 Protocol of research for selecting the literature about the I4.0 technologies and LPs

The first phase of the SSF methodology seeks to define the research protocol, and is divided into 4 activities: (a) search strategy; (b) database query; (c) document management; (d) standardization and selection of documents; and arrangement of the document portfolio.

During this phase several filters were executed to select only the articles that are aligned with

the research theme. The articles selected come from four different databases. In addition to search filters related to keywords, other types of filters were used, such as: (i) document type, (journal article and conference article) and language; (ii) non duplicate articles; (iii) titles, keywords and abstract in line with the theme; (iv) available documents, and finally, (v) full reading of the document. At the end of this process the total of 85 articles that formed the bibliographic portfolio (PB) of this research were obtained as shown in Table 2.

|                | Keywords                                                                                                                                   | Total Databases papers | Process of analyzing papers   |                |                           |           |                  |                 |
|----------------|--------------------------------------------------------------------------------------------------------------------------------------------|------------------------|-------------------------------|----------------|---------------------------|-----------|------------------|-----------------|
|                |                                                                                                                                            |                        | Type of document and language | Not duplicated | Title, keywords, abstract | Available | Complete reading | Final portfolio |
| Scopus         | "INDUSTRY 4.0" OR "CYBER PHYSICAL SYSTEM" OR "CPS" OR "SMART FACTORY" OR "SMART MANUFACTURING" OR "INTERNET OF THINGS" OR "IOT" AND "LEAN" | 1,464                  | 1,058                         | 907            | 109                       | 94        | 85               | 85              |
| ProQuest       |                                                                                                                                            |                        |                               |                |                           |           |                  |                 |
| Web of Science |                                                                                                                                            |                        |                               |                |                           |           |                  |                 |

Table 2 – Search procedure used in the systematic literature review

## 4.2 Data Analysis

The objective of this phase is to consolidate the data. In this phase the researcher performs the analysis and interpretation of bibliometric data that help to establish relations of significance and to evidence factors relevant to the research (FERENHOF; FERNANDES, 2016). The analysis of the variables were: (a) number of papers per journal; (b) evolution of research over the years; (c) type of study, being classified as theoretical or practical, (d) what are the main I4.0 technologies used in manufacturing; (e) which are the main LPs used in manufacturing and (f) in which level the value stream mapping (VSM) are the main I4.0 technologies are been applied.

## 4.3 Synthesis

At this activity the deductions on the topic are built, and later grouped and condensed into reports, tables and graphs that will be presented in more detail in the following sections. It is important to note that at this stage the existing knowledge gaps are raised to suggest themes for future works.

## 4.4 Writing

Finally, the objective of the last phase is to consolidate and record the results of the research with the scientific writing. During this activity it is necessary to recover the objective of the literature review, as well as the results obtained in the previous phases.

## 5. Result of the Bibliometric Analysis

The 85 publications used, are distributed in 37 journals and 48 conferences. Regarding the journals, it is worth mentioning the Advances in Manufacturing and the International Journal of Production Research, with four publications each. Regarding to the events, the highlight are conferences Changeable, Agile, Reconfigurable & Virtual Production Conference, and International Federation of Automatic Control has four publications each. Table 3 shows the number of papers per journal and events contained in the BP.

| Events     | Description                                                                        | Total number of publications |
|------------|------------------------------------------------------------------------------------|------------------------------|
| Journal    | Advances in Manufacturing                                                          | 4                            |
|            | International Journal of Production Research                                       | 4                            |
|            | International Federation for Information Processing                                | 2                            |
|            | International Journal of Innovation Management                                     | 2                            |
|            | Other 25 journals                                                                  | 25                           |
| Conference | Changeable, Agile, Reconfigurable & Virtual Production Conference                  | 4                            |
|            | International Federation of Automatic Control                                      | 4                            |
|            | 50th Conference on Manufacturing Systems                                           | 3                            |
|            | 9th International Conference on Digital Enterprise Technology                      | 2                            |
|            | 6th Conference on Learning Factories                                               | 2                            |
|            | 27th International Conference on Flexible Automation and Intelligent Manufacturing | 2                            |
|            | 49th Conference on Manufacturing Systems                                           | 2                            |
|            | International Symposium on Intelligent Manufacturing and Automation                | 2                            |
|            | Other 27 Conferences                                                               | 27                           |

Table 3 – Number of papers published in journals and conferences, from the selected papers

After the analysis of the journals, the change in the number of publications during the years was verified. Although there was no time limit in the selection stage of the BP documents, it is observed in Figure 1 that all publications are concentrated in the period between 2010 and 2017. This behavior takes place because I4.0 is a relatively recent topic, and also because the search is contemplating only works that correlate Lean and I4.0. It was identified that 72.7% of the BP publications correspond to the last two years. In addition, the publications present a peak of 33 papers in the year 2016, and there is a similar amount in 2017 (Figure 1).

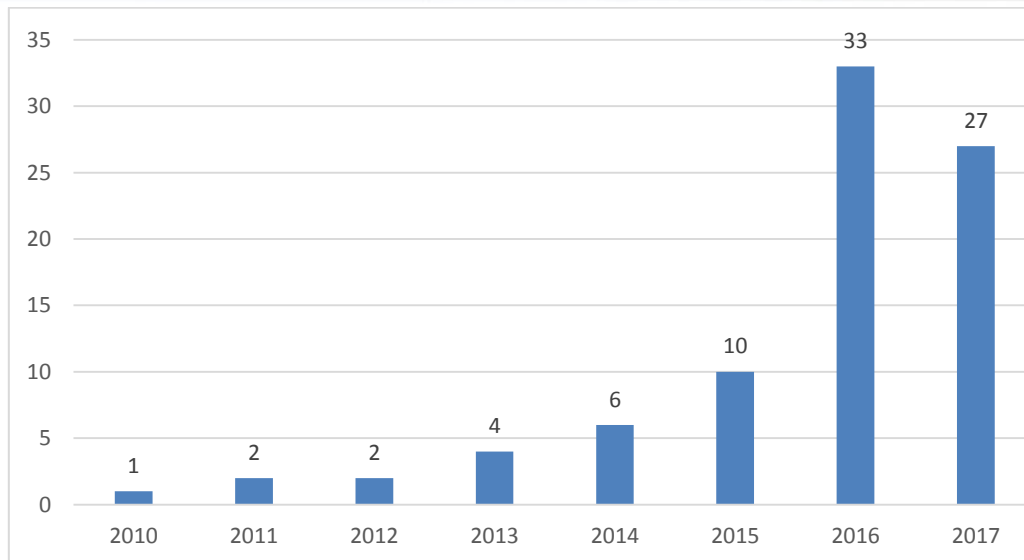


Figure 1 – Amount of publications that correlate Lean and I4.0

Another aspect analyzed relates to the type of study carried out, being classified into the following categories: theoretical studies or practical studies. It was identified that the largest amount of studies was theoretical (80% of the publications), and only 20% were practical.

### 5.1. Main Technologies of I4.0

As mentioned previously, the analysis of the advanced variables of this search addresses the identification of the main technologies of I4.0 and LPs existing in manufacturing companies. In this context, Table 4 presents the main I4.0 technologies identified in the literature according to their citation frequency.

Among the nine technologies identified, it can be noticed that the citation frequency varies significantly. This fact can be explained because they have different characteristics, applications and objectives. The most frequently cited technology was IoT (47 citations). This high citation frequency can be explained due to its great versatility, being able to be applied in many ways and in different environments (ISLAM et al., 2015; ALMADA-LOBO, 2016; SANTOS et al., 2016; SHARIATZADEH et al., 2016). The technological advances achieved, the ease of access and the reduction in the cost to acquire the Internet are some of the factors that have contributed positively to IoT being widely disseminated. In addition, because it is a technology that often serves as a basis for other I4.0 technologies (e.g. CPS, cloud computing, and simulation), IoT is seen as a gateway to I4.0 (CNI, 2016; TAMÁS et al., 2016; XU; CHEN, 2016).

Among the technologies with the lowest number of citations identified in the search is Additive Manufacturing (with 9 citations). Additive manufacturing (AM) comprises technologies such as 3D printing (RUBMANN et al., 2015) In addition, it refers to processes controlled by a computer system in which material is bonded and solidified layer by layer forming objects of various forms based on a digital model (TAUFIK; JAIN, 2013). AM presents a good application potential for producing in small batches of customized complex and light products. AM is already applied in industries such as aerospace (aircraft turbines), in which there are gains with reduction of raw materials, and decrease in the weight of the components and the manufacturing time (MIT TECHNOLOGY REVIEW, 2018).

The low citation frequency of this technology can be explained due to the fact that its still not fully developed in the context of I4.0. Thus, only a limited number of companies have adopted their use to date and their applications are still restricted to more specific contexts when compared to other I4.0 technologies. In addition, the level of process virtualization in which additive manufacturing is embedded depends on the size of the company, since small and medium-sized enterprises often do not have resources intended for these purposes (BRETTEL et al., 2014).

| Code | I4.0 Technologies               | Theoretical Study | Practical Study | Frequency |
|------|---------------------------------|-------------------|-----------------|-----------|
| T1   | Internet of Things (IOT)        | 39                | 8               | 47        |
| T2   | Cyber Physical System (Cps)     | 33                | 7               | 40        |
| T3   | Big Data                        | 18                | 3               | 21        |
| T4   | Horizontal/Vertical Integration | 17                | 3               | 20        |
| T5   | Cloud Computing                 | 23                | 4               | 27        |
| T6   | Advanced Robots                 | 14                | 1               | 15        |
| T7   | Augmented Reality               | 9                 | 2               | 11        |
| T8   | Additive Manufacturing          | 9                 | 1               | 10        |
| T9   | Simulation                      | 12                | 2               | 14        |

Table 4 – Main technologies of Industry 4.0 identified in the literature

## 5.2. Main Lean Practices (LPs)

In relation to the identification of the main LPs in manufacturing companies, Table 5 presents the fourteen LPs identified in the BP according to their citation frequency.

The LP that had the highest citation frequency was kanban (10 citations). According to Kumar and Panneerselvam (2007), kanban is basically a card that contains the information needed to manufacture a product at all stages of its production. The high citation frequency of kanban is justified by its great importance within manufacturing systems. In addition, it indicates that it is an LP highly associated with the context of the smart factory proposed by I4.0 (KOURI, 2008; LAGE JUNIOR; GODINHO FILHO, 2010; KOLBERG; ZUHLKE, 2015; SANDERS et al., 2016). These works suggest the application of kanban with new technologies to increase its benefits.

With respect to LPs with the lowest number of citations, Total Productive Maintenance (TPM) had only three citations, which is an unexpected result. I4.0 is capable of providing a large amount of data and information that can be used for help to improve equipment performance, converging towards the desired objectives of the TPM implementation. The low amount of researches about this topic, such as Yoon et al. (2012), and Geng et al. (2014) suggest the application of I4.0 technologies to help to improve predictive maintenance. Zhu et al. (2012), and Zhang et al. (2015), propose the use of I4.0 technologies to assist in the maintenance, repair and operation of complex equipment.

Although TPM practice present a potential association with I4.0 technologies according to the evidences provided, to date there is a reduced amount of work relating these aspects and their possible synergies. In this perspective, it is worth mentioning that the low citation frequency

may not be related to the lack of association between them, but rather, due to other factors. TPM, for example, is characterized by being a set of connected activities that seek to meet a common goal. However, to date, I4.0 applications have focused on specific solutions where technologies are being applied without necessarily being related to the implementation of TPM support processes.

| Code | Lean Practices (LPs)               | Theoretical Study | Practical Study | Frequency |
|------|------------------------------------|-------------------|-----------------|-----------|
| P1   | Kanban                             | 11                |                 | 11        |
| P2   | Value stream mapping (VSM)         | 7                 | 1               | 8         |
| P3   | Kaizen                             | 7                 |                 | 7         |
| P4   | Poka yoke                          | 6                 | 1               | 7         |
| P5   | Andon                              | 6                 |                 | 6         |
| P6   | Pull production                    | 6                 |                 | 6         |
| P7   | SMED                               | 6                 |                 | 6         |
| P8   | Heijunka                           | 4                 |                 | 4         |
| P9   | Standardization                    | 4                 |                 | 4         |
| P10  | Total quality management (TQM)     | 4                 |                 | 4         |
| P11  | Takt time                          | 3                 | 1               | 4         |
| P12  | 5S                                 | 4                 |                 | 4         |
| P13  | Jidoka                             | 3                 |                 | 3         |
| P14  | Total productive maintenance (TPM) | 3                 |                 | 3         |

Table 5 – Main Lean Practices

### 5.3 Analysis of the Theoretical Viewpoints - Relation of I4.0 Technologies with Value Stream Levels

In this part of the research, the main industry 4.0 technologies are analyzed aiming to classify them from the theoretical point of view in the different forms of value stream according to their applications found in the PB. According to Womack; Jones (1997), value stream can be defined as the set of actions existent in production process of a product, from the receipt of the information until the delivery of the final product to the final customer. Value flow levels can be separated in different ways.

The levels of the value stream can be classified into three different categories (DUGGAN, 2012). (a) Intracellular: it comprises the activities performed within the cells of production. In general, they are activities of a more operational nature, carried out by the productive areas; (b) macro-processes this level corresponds to the management of the company and its processes between the different areas. It has activities related to the interface between processes, information flows and materials internal to the company and (c) supply chain; finally, this level refers to processes and flows that go beyond the limits of the company, are activities that involve suppliers and customers (KOZLENKOVA et al., 2015).

Table 6 shows at what levels of the value stream the I4.0 technologies are being applied. It can be observed that five technologies presented evidence of application at all levels of the value stream: 'T1 - IoT', 'T2 - CPS', 'T3 - Big data', 'T4 - Horizontal and vertical Integration' and 'T9 - Simulation'. In view of such a result, it can be said that such technologies are more

versatile and can be used in different ways and for different intents . Another characteristic is that they are related to activities of transmission and exchange of data between the three different levels. However, Technologies 'T5 - Cloud Computing', 'T7 - Augmented Reality' and 'T8 - Additive Manufacturing' have had applications mentioned at two levels of the value stream. This fact indicates that these technologies have the flexibility to be applied in different contexts, but in a degree of flexibility less than the technologies of the first group.

Finally, the study showed that the 'T6 - Advanced Robotization' technology was the only one mentioned in just one level of value stream. This result indicates that this technology has a tendency towards more specific applications. The use of advanced robotization is often related to applications in more operational contexts and is often used to replace human labor (FREY; OSBORNE, 2017). According to Rubmann et al. (2015), robotization has been used in operational activities, and in operations that require a high degree of complexity and increasingly specific, thus being naturally more restricted to the intracellular context.

| Code | I4.0 Technology          | Intracellular Level | Macro Processes Level | Supply Chain Level |
|------|--------------------------|---------------------|-----------------------|--------------------|
| T1   | Internet of Things (IoT) | ●                   | ●                     | ●                  |
| T2   | Cyber Physical Systems   | ●                   | ●                     | ●                  |
| T3   | Big data                 | ●                   | ●                     | ●                  |
| T4   | Horizontal/ Vertical     | ●                   | ●                     | ●                  |
| T5   | Cloud Computing          |                     | ●                     | ●                  |
| T6   | Advanced Robotics        | ●                   |                       |                    |
| T7   | Augmented Reality        | ●                   | ●                     |                    |
| T8   | Additive Manufacturing   | ●                   | ●                     |                    |
| T9   | Simulation               | ●                   | ●                     | ●                  |

Table 6 – Application of I4.0 Technologies in Different Levels of the Value Stream

## 6. Conclusions

I4.0 will enable better understanding of the structure of customer demand and accelerate the process of exchange and data in the entire value chain. However, despite the importance of the theme, there is a lack of researches related to it. In this sense, the present paper brings important contributions and helps to contribute with the enrichment of the same as it emphasizes the nine main technologies of I4.0 and fourteen main LPs and presents the characteristics of applications of I4.0 technologies at different levels in the value stream that are listed in the literature through a systematic literature review based on the PB of 85 articles related with this theme.

Regarding to the research gaps identified by the research, it was observed that to date the association of the I4.0 technologies with PE are focused on the solution of specific manufacturing problems. Thus, there are few studies addressing applications of I4.0 and PE technologies in a more complete way, where several technologies and LPs could be applied together. This model of approach can offer better benefits and results to productive systems. In addition, a more holistic view tends to be more consistent since the application of certain technologies supports new applications. In this sense, it is proposed the development of works

directed to this type of approach aiming to analyze the impact of technologies and LPs applied together in the manufacture.

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