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A Literature Review on the Evolution of Lean Manufacturing

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Abstract. Until today, the industrial world has been knowing four industrial revolutions; which impacted positively the global economy. Consequently, different industrial tools have been knowing many changes through the aforementioned industrial revolutions. Among them, the lean manufacturing tools. In this context, this paper presents a literature review of the different evolutions of the lean manufacturing during the different industrial revolutions. In fact, the lean manufacturing passed by four steps; beginning by the lean primitive when some tools were even used before the industrial age as well as during the first industrial revolution. The second step is marked by the development of the lean tools inside Toyota company, during the second industrial revolution. The third step concerns the automation and digitalization of many lean manufacturing tools. The concept of lean automation is then brought out. The fourth and the last step is about the lean 4.0 which is a combination of lean manufacturing and the industry 4.0.

Keywords: industrial revolution, industry 4.0, lean automation, lean manufacturing, lean production, lean 4.0, smart.

1. Introduction

The word « revolution » means a dramatic change (Ladenburg, 2007), which is not necessary a fast and sudden (Vries, 2008). The expression « industrial revolution » could be identified as implying a transition from the pre-industrial to the industrial society (Vries, 2008). To have an industrial revolution, the natural resources, the infrastructure and the money to invest, etc., should exist (Ladenburg, 2007). Until today, the industrial environment has known fourth major revolutions (Kamarul

Bahrin et al., 2016; El abbadi et al., 2018); that could be seen as a series of events (Min et al., 2018).

The first industrial revolution is considered as a big step advancement in humanity (Liaoa et al., 2018). It was marked by the transformation of the human and animal labor technology to the machinery (Mohajan, 2019); and is started by using water and stream-power (Liao et al., 2018). During 20th century, the second industrial revolution is marked by electricity and new concepts like labor division and mass production (Liaoa et al., 2018). With the manufacturing automation, the third industrial revolution started in the 1970s (Liaoa et al., 2018). Bringing changes in terms of power, knowledge and wealth, the fourth industrial revolution is building on the third industrial revolution regarding digital revolution, and blur the lines between the physical, digital, and biological spheres (Min et al., 2018).

During the different phases of the four industrial revolutions, a concept was being developing, called later, the lean manufacturing or lean production (El abbadi et al., 2018; Cumbo and Kline, 2006). Most of the authors refer the origin of the lean manufacturing to Toyota because they consider it as the fruit of Taiichi Ohno experience, an engineer at Toyota (Elrhanimi et al., 2019). Regardless of the tools created by Toyota as SMED (Elrhanimi et al., 2018); some others lean tools and concepts were known long before the toyotism as "the just time" calculation developed by Taylor (Lyonnet, 2010).

This paper exposes the different phases passed by the lean manufacturing through the different industrial revolutions while presenting the evolutions that have known some lean manufacturing tools.

2. Lean manufacturing till the first Industrial revolutions: lean primitive

Before the industrial era, the production was hand-crafted, based on well qualified and experimented labor (Ma, 2013), and its practices was inspired by the country culture, like in Japan (Elrhanimi et al., 2018). In fact, the Japanese culture requires, among others, the qualification of the staff (Meier and Liker, 2006) as well as the perfection in any activity (Gapp et al., 2008; Meier and Liker, 2006). Also, in this culture, a problem resolution begins first with its understanding where it exists (Ballé, 2005). It is the origin of "genchi genbutsu" (Ballé, 2005). The "hansei" (Meier and Liker, 2006) aiming to the identification of what is wrong and taking the steps to resolve the problem, it results from the Japanese philosophy (Meier and Liker, 2006). Likewise, "sensei" meaning a person who is there before me and who is a guarantor for the knowledge and for the know-how (Ballé, 2005). This principle inspired by the Japanese culture (Ballé, 2005), exists also in the Moroccan handicraft sector, where the craftsmen always ask the master craftsman assistance to solve any problem (Sefrioui, 1975).

In the 19th century, the population was growing (Allen, 2006; Blinov, 2014) faster than food production (Blinov, 2014). The humankind reached a solution to the hunger problem (Blinov, 2014). For Britain, it was impossible to import food from countries around it because of the supreme hunger rules and the inexistence of nourishment surplus (Blinov, 2014). So, it chose to be supplied with the food produced by itself (Blinov, 2014). It focused first on improving productivity of agriculture and then the productivity of labor (no-foods goods) (Blinov, 2014) by using machinery and inventions (Allen, 2006). Indeed, this revolution stimulated labor productivity in the agriculture and suppressed the development of the industry in other countries (Blinov, 2014). Therefore, the economic environment passed from the craft production to the industrial production (Elrhanimi et al., 2018). It is about the first Industrial Revolution. Known also as the British industrial revolution (Crafts, 2005; Mohajan, 2019). It initiated the transition from human and animal labor technology into machinery, new chemical manufacturing and iron production processes, the development of machine tools (Mohajan, 2019), improved efficiency of water power (Deane, 1979; Mohajan, 2019; Schwab, 2016) as well as the increasing use of steam power (Deane, 1979; Mohajan, 2019; Lee et al., 2018; Min et al., 2018; Schwab, 2016).

Otherwise, this period was characterized by the mechanization (Mohajan, 2019), the specialization and the division of labor (Mohajan, 2019; Salavisa et al., 2009), the efficiently in market transactions (Mohajan, 2019), the increase of productivity (Mohajan, 2019; Salavisa et al., 2009), as well as the scientific and the technological advances (Salavisa et al., 2009).

The division of labor, developed by Adam Smith, is a source of productivity increasing and eliminating of the dead time (Aim, 2013). It is also among the basic items of the work standardization (Elrhanimi et al., 2018), which is among the fundamental of lean manufacturing (Lyonnet, 2010).

On the whole, some manufacturing tools/practices, known later as lean manufacturing tools, were then applied unconsciously by Japanese people in their everyday life (in their houses and in their daily works) before industrial revolution as well as during the first industrial revolution, it is about the lean primitive tools (Elrhanimi et al., 2018).

3. Lean manufacturing and the second Industrial revolutions: lean production

Three distinct trains of ideas were the origin of the beginning of the second industrial revolution (Jevons, 1931). The first one is that the accountancy became a science aiding in terms of business profitability (Jevons, 1931). The second one is that engineers began to use the results of the pure science in the construction of bridges and others (Jevons, 1931). The third train of ideas, was originated from the increasing of competition between manufacturers causing the multiplication of the produced products; and decreasing the prices (Jevons, 1931).

The Second Industrial revolution began in the USA in the middle of 19th century and later spread throughout many other parts of the world (Mokyr, 1990; Mohajan, 2020). This is why it is called the US industrial revolution (Mohajan, 2020). It was characterized by the invention of a large number of new technologies (Atkeson and Kehoe, 2001; Mohajan, 2020), such as electricity, internal combustion engine, chemical industries, alloys, petroleum and other chemicals, electrical communication technologies (telegraph, telephone and radio) and running water with indoor plumbing (Gordon, R. J., 2000; Mokyr, 1990). During this industrial revolution, the inventions and innovations were science-based that were centered on iron and steel, railroads, electricity and chemicals (Atkeson and Kehoe, 2001). They allow the increasement of productivity per hour (Atkeson and Kehoe, 2001; Mohajan, 2020) with a lowest cost (Jevons, 1931; Mohajan, 2020).

In the Second Industrial revolution the existing manufacturing and production methods of first industrial revolution were improved (Mohajan, 2020), like the replannification of the plants process and the adoption of Taylor's method (Jevons, 1931). However, the most important achievement in the second industrial revolution is the adoption of the continuous-flow production, allowing the control of the working speed and minimizing the wasted time (Mokyr, 1990). But the working conditions was inadequate with low wage and long working hours (Mohajan, 2020).

During this revolution, Henry Ford was developing in their automotive plants, a new model of mass production basing on work division, production lines, parts interchangeability as well as economy of scale by making huge plants to reduce costs (Mokyr, 1990; Lyonnet, 2010). In this time, Japanese producers experienced a shortage in terms of resources needed for the production (Abdulmalek and Rajgopal, 2007), which prompted Toyota to provide it with the minimum possible of resources (Meier and Liker, 2006; Taj and Berro, 2006). Toyota was only, partially, able to develop the Ford production system in its first car factory «Koromo» created in 1937 (Lyonnet, 2010). In fact, due to funding constraints, only paint, assembly and foundry shops were able to benefit from conveyor systems for production (Lyonnet, 2010). For the other production shops, Toyota preferred to simplify the production process and obtain new flexible machinery able to be adjustable to any model (Lyonnet, 2010). In 1949, Taiichi Ohno, reorganized the production system of Toyota by implementing the principles of just-in-time and autonomation (Jidoka in Japaneese) (Meier and Liker, 2006; Lyonnet, 2010). Consequently, a new model of production was developed, called TPS (Toyota Production System) (Meier and Liker, 2006); that has spread in the 1980s, following the IMVP "International Motor Vehicle Program" conducted by the Massachusetts Institute of Technology (MIT) (Duffie, 2003). The TPS, later named lean manufacturing or lean production, began to invade the industrial world (Wan and Chen, 2008). With the publication of the book "The

Machine That Changed The World" by James Womack and Daniel Jones (Duffie, 2003), western industry gradually began to converge towards the adoption of the lean manufacturing (Pettersen, 2009). This has encouraged the publication of a wide range of scientific articles dealing with the lean manufacturing and its relation to the firm performances (Arlbjørn and Freytag, 2013).

Lean manufacturing stems from the philosophy of achieving improvements by following the most economical ways while focusing especially on reducing waste (muda in Japanese) (Dahlgaard and Dahlgaard-Park, 2006). It requires "half of the human effort, half of the manufacturing space, half of the investment and half of the engineering hours for a new product in a half of the time" (Melton, 2005). Thereby, it aims at banishing all the types of waste (Elrhanimi et al., 2019). Taiichi Ohno, one of the pioneers of the lean manufacturing (Shah and Ward, 2007), was the first to identify seven types of waste; overproduction, unnecessary stock, unnecessary transport, unnecessary processing, unnecessary movements, waiting times and defective parts (Elrhanimi et al., 2015).

Lean manufacturing is based on two pillars: just-in-time and autonomation (Ballé, 2004). Each pillar of lean manufacturing requires a set of tools as well as a systematic approach to eliminate waste and increase production flexibility (Cumbo and Kline, 2006; Kadem et al., 2008). For example; Just in Time requires SMED, Takt time, Kanban and piece to piece flow (Lyonnet, 2010). As for Jidoka, this pillar requires many tools such as andon, poka-yoké (Ballé, 2004).

4. Lean manufacturing and the third Industrial revolutions: lean automation

As a result of the second industrial revolution, the industrial production systems were based on the mechanization (Mohajan, 2019). With the development of digital technologies, the manufacturing environment is changed (Schwab, 2016). We talk about the third industrial revolution, called also the digital revolution (Schwab, 2016). It is based on the use of electronics and information technology (IT) system to further digital automate production (Kamarul Bahrin et al., 2016; Schwab, 2016; Min et al., 2018).

Therefore, the automation is the key element of the third industrial revolution. It has been used first, in 1960’s, with ergonomics reasons (Zafarzadeh and Jackson, 2013). It includes the mechanization for the physical flow of goods, and the computerization for the flow of information (Granlund and Jackson, 2013). Afterward, it has been seen as a meaning to improve efficiency (Granlund, et al., 2014; Winroth et al., 2006), productivity, quality and safety as well as to reduce cost in operation (Granlund, et al., 2014). Despite all the automation benefits, it is not always the best solution and, in some cases, it is not even a feasible one (Spath et al., 2009). In fact, the wrong technology, or even the bad implementation of the right technology, can be disastrous (Baines, 2004).

Contrary to popular belief, lean Production does not exclude automation (Kolberg et al., 2016). This later does not bring more complexity and even in contradiction with lean principals (Zafarzadeh and Jackson, 2013). However, it was recommended by its founder Ono to automate repeating and value-adding tasks (Ōno, 1988). Consequently, in a manufacturing environment, the lean production system can use both manual and automated processes (Singh, 2017). In addition, an effective implementation of automation depends on the determination of the appropriate level and type of automation that can serve lean requirements (Zafarzadeh and Jackson, 2013).

The integration of automation technology to lean principals bring out the concept of lean automation (Kolberg and Zühlke, 2015). This new concept was appeared in the first time in 1990s (Kolberg and Zühlke, 2015; Sanders et al., 2017;), after the peak of Computer Integrated Manufacturing (CIM) (Kolberg and Zühlke, 2015), in order to support and expand the approaches and the concepts of lean manufacturing (Leyh et al. 2017) without changing their goals (Leyh et al. 2017). While human-operator remain at the heart of the new lean automation system (Zühlke, 2009).

According to Dulchlnos and Massaro (2005), the lean automation can be defined as, "a technique which applies the right amount of automation to a given task. It stresses robust, reliable components and minimizes overly complicated solutions" (Dulchlnos and Massaro, 2005).

In the last decade, the scientific community did not pay much attention to lean automation (Coffey and Thornley, 2006; Kolberg and Zühlke, 2015; Kolberg et al., 2016). However, the lean and automation are already combined in the Jidoka pillar (Kolberg et al., 2016), since its development. The jidoka, called also Autonomation, means that the process is automatized and supervised by employees (Kolberg et al., 2016; Ohno, 1988).

5. Lean manufacturing and the fourth Industrial revolutions: lean 4.0

Today, the socio-cultural and economic environment are metamorphosing using new generation of technologies (Lee et al., 2018) that blur the lines between the physical, digital, and biological spheres (Min et al., 2018). It is the fourth industrial revolution (Schwab, 2016).

Consequently, the industrial environment is being transformed to the fourth stage with the rise of autonomous robots, contemporary automation, cyber-physical systems, the internet of things, the internet of services, and so on (Kamarul Bahrin et al., 2016). In other way, it is moving from a physical process with IT support to an integrated cyber-physical production system (Kagermann et al., 2013) with radical changes in the execution of operations as well as a real-time planification of production, associated with dynamic self-optimization (Sanders et al., 2016). It is the industry 4.0 that has been presented at the Hannover Fair in 2011 (Dombrowski et al., 2017; Sung, 2017) in Germany. It applies the principles of cyber-physical systems, internet, future oriented technologies and smart systems with enhanced human-machine interaction paradigms (Sanders et al., 2016). It is based on machines using self-optimization, self-configuration and even artificial intelligence to complete complex tasks in order to deliver vastly superior cost efficiencies and better quality of goods or services spheres (Min et al., 2018).

Indeed, the industry 4.0 technologies enabler to improve production and reduce machine downtime, scrap and rework, increased quality and efficient maintenance activities (Mayr et al., 2018). It enables human beings, machines, products and resources to exchange information with each other using internet of things (IOT) (Wagner, et al., 2017) and a huge network integration between machines and its components (Karamveer, 2017). In other words, it allows the sharing of information across the company departments locally and internationally.

In the context of industry 4.0, the lean manufacturing is transforming to lean 4.0, this new concept, is considered as the combination of lean manufacturing and Industry 4.0 (Mayr et al., 2018). These approaches are positively correlated (Sanders, et al., 2016) and can support each other (Mrugalska and Wyrwicka, 2017). In fact, the industry 4.0 can be integrated in lean production and beyond that changed lean manufacturing by increasing the integration of ICT (Kolberg and Zühlke, 2015) as well as promoting the lean tools (Dombrowski, 2017). That means that the application of modern ICT can improve the performance of lean manufacturing system by gaining more efficient production and logistics processes (Dombrowski, 2017) and make lean manufacturing system more flexible (Ruttimann and Stochli, 2016).

6. Evolution of some lean tools during industrial revolutions

As stated above, the lean manufacturing is taking advantage of new technologies bring out by industrial revolutions. Consequently, lean tools are changing. To illustrate what has been changed in lean tools during the industrial revolutions that flowed lean development (the third and fourth industrial revolutions), we will present the evolution of three lean tools, as example: Kanban, andon and visual management.

6.1. Kanban

Kanban system is a lean tool for pull production system (Hines et al., 2004). It manages the flow of materials between workstations (Ramnath et al., 2009; Sugimori et al., 1977). Also, it is used to communicate effectively with internal and external operations on issues such as production schedules, delivery time and stock information (Apreutesei et al., 2010).

The functioning of the kanban system was based first on the circulation of material cards (el abbadi et al., 2018). These cards present a manufacturing order for specific product when they are used in a manufacturing context (Kumar and Panneerselvam, 2007; Mayilsamy and Pawan, 2014). With the arrival of third industrial revolution, the original Kanban system is replaced by the electronic Kanban system, known also as e-kanban, using new information technologies (Surendra et al., 1999). The electronic Kanban signal is then transferred trough an ERP system based on RFID technology (El abbadi et al., 2018). After that, it becomes the Kanban 4.0 system or smart Kanban system, using the industry 4.0 technologies, and basing on smart product or smart bin/ container (El abbadi et al., 2018).

6.2. Andon

Andon is a lean manufacturing tool deployed as part of visual management for propelling up communication in the industry (Effendi et al., 2019). It is applied for visualizing status and disruptions in production and thus supports the lean principle jidoka (Mayr et al., 2018). It allows the operator to stop producing immediately, when a defect is detected whilst to alert management to the situation (Everett and Sohal, 1991).

Traditionally, to achieve andon system, the operator pushes a button or pulls a cord that produces a signal by siren and/or illuminating signs (Everett and Sohal, 1991; Li and Blumenfeld, 2006) as a call for help and stopping the line when a defect is discovered (Li and Blumenfeld, 2006).

The development of science and technology has seen many new technologies being implemented (Subramaniam et al., 2009). Consequently, the andon system is advanced into electronic devices with audio and color-coded visual display (Subramaniam et al., 2009).

In the industry 4.0 environment, employees receive error messages and error locations close to real time (kolberg and Zühlke, 2015) using lamps HCI devices like tablets, smartphones, head-mounted displays and smart watches that enable a targeted notification for users in real-time regardless of the distance between operator and machine (Mayr et al., 2018). In addition, the cyber physical systems (CPS) are equipped with proper sensors that recognize failures and automatically trigger fault-repair actions on other CPS (kolberg and Zühlke, 2015; Mrugalska and Wyrwicka, 2017). The andon system became then smart (Lopez-Leyva, 2020).

6.3. Visual management

Visual Management, known as the visible management, refers to using intuitive method to reveal the station of management and operation, in order to make staffs to see working progress with the eyes clearly and quickly find out proper methods and countermeasures (Zhang, 2013). Consequently, it enhances transparency in the company (Mayr et al., 2018).

Firstly, the visual management tools were posted manually on physical boards. So, they could be changed by anyone (Parry and Turner, 2006). A current example of the manual visual management is the standardized operating procedures posted at manufacturing workstations as both pictures and text (Jaca et al., 2013). With the emergence of digitalization, the electronic data are projected or displayed on plasma screens (Parry and Turner, 2006). The Visual displays is then serving as reminders and functioning as knowledge transferred or integrated into the manufacturing environment (Norman, 1998). Recently, we are moving into an ever-increasing digital age where the information collection comes from multiple and heterogeneous sources (Chen et al., 2014). Consequently, the visual management system can gather information from multiple sources and use intelligent processing techniques, based on historical operations and future projects, to generate smart resource management scheduling (Steenkamp et al., 2017). This information can be presented more effectively on digital visual management tools with millisecond refresh rates (Steenkamp et al., 2017). It is a dynamic visual management.
The fig. 1 summarizes the evolution of kanban, andon and visual management through industrial revolutions.

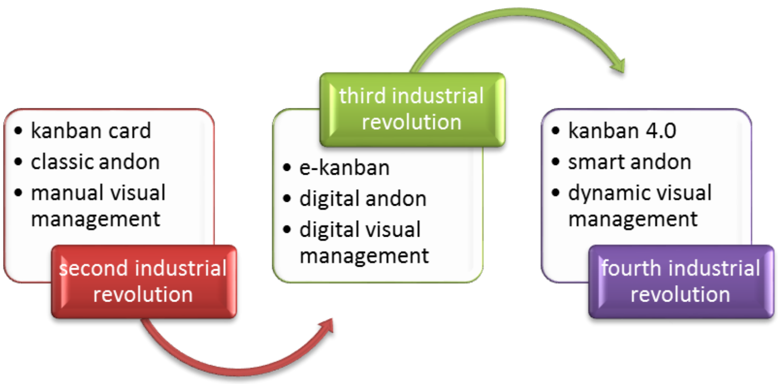

Fig. 1: the evolution of kanban, andon and visual management during industrial revolutions

7. Conclusion

During many years, the industrial world has been changing and the four industrial revolutions remain enigmatic. Many industrial concepts and tools have been developed, among them, the lean manufacturing and its tools.
The lean manufacturing passed through four stages; the first one initiated the development of some lean tools, it is about lean primitive tools used even before and out of Toyota production system, like "just in time" and genchi genbutsu. The second one, characterized the development of lean tools inside Toyota company and the invasion of the industrial world. The lean production is known and used during the last years of second industrial revolution. The third one coincides with the third

industrial revolution in which some lean tools have been digitalized and/or automized using technologies bring out during this industrial revolution, like e-kanban, digital andon and digital visual management. Nowadays, some lean tools are taking advantage of the technologies of the fourth industrial revolution and moving then to the fourth stage, like Kanban 4.0, smart andon and dynamic visual management. The fig. 2 summarizes the evolution of lean through industrial revolutions.

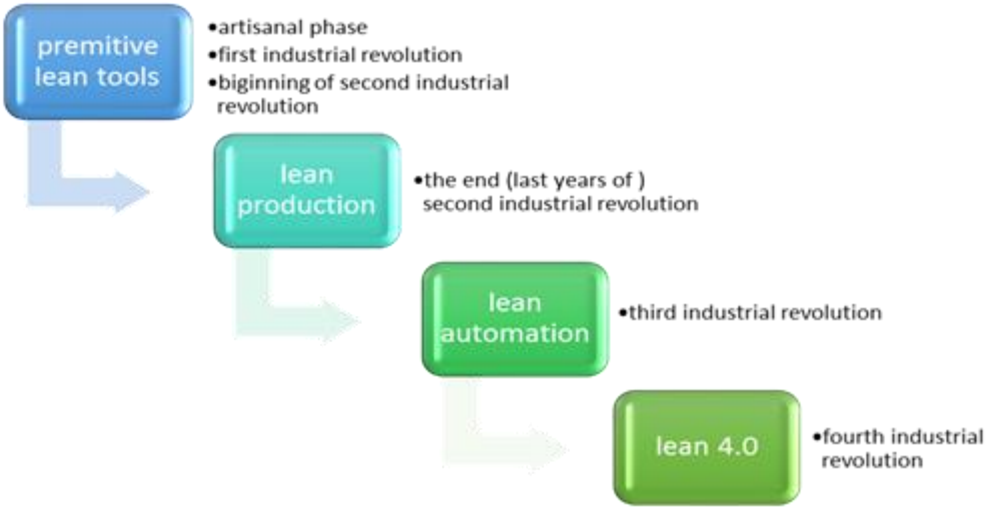

Fig. 2: the evolution of lean through industrial revolutions

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