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Lean manufacturing and Industry 4.0 combinative application: Practices and perceived benefits

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Abstract: This paper investigates the industry practices regarding the combinative use of Industry 4.0 and lean tools in the manufacturing sector. Following review of the literature, a questionnaire survey was distributed among manufacturing professionals in organizations which have already adopted Industry 4.0 technology and lean manufacturing, with the aim to highlight the popular combinations of tools as seen in manufacturing practice and capture the perceived level of their contribution to operational performance. The survey results show that Real time data, IoT for data exchange, big data analytics, Cyber –Physical Systems (CPS), predictive algorithms and robots are among the most popular I4.0 applications used to support lean attributes like continuous flow, Kanban, standardised work, TPM and continuous improvement. It also emerges that although the beneficial impact of lean production across the respondents' organizations is widely accepted, the perceived impact of Industry 4.0 tools is not as clear.

Keywords: Lean production, Industry 4.0, production management, information technology, decision making

1. INTRODUCTION

Today's competitive marketplace requires designers to design reliable products that can be produced efficiently and quickly. In this quest to maximize value and product quality for the customer, as well as reduce lead times and costs, the philosophy of Lean Thinking is commonly adopted by manufacturers as a tool for continuous improvement. Specifically, with the employment of a variety of industrial practices directed towards waste elimination, the lean production model strives to identify value adding processes from the purview of customer and enable flow of these processes at the pull of the customer. When the concept of Lean Thinking was first introduced, it acquired global attention and gained popularity within the manufacturing sector striving to improve its efficiency performance. Coming to today, as companies continue to use Lean in a pursuit to increase efficiency with minimal resources, it is becoming clear that due to high dynamic competition, companies are forced to rethink and remake their processes and come up with new strategies. Information and communication technologies have become one of the most important factors, conditions and opportunities for company development (Relich, 2017), while the size and complexity of production lines requires intelligent flow control methods to be employed (Rudnik, 2018). Recently, a new set of advanced disruptive technologies, known as Industry 4.0 (I4.0) has emerged to offer a new outlook for dealing with the operational challenges of the company. Industry 4.0 stresses the need to seek solutions that allow information systems to create a virtual copy of the physical world (Bocewicz et al., 2019) and brings together new technologies such as Cyber Physical Systems (CPS), Big data and data analytics, Cloud computing, Industrial Internet of Things, Robotics and Augmented Reality. In other words, I4.0 combines embedded production system technologies with intelligent production processes to pave the way for a new technological age that will fundamentally transform industry value chains, production value chains, and business models (Zhong et al. 2017). Given that both lean manufacturing and I4.0 are promising to solve future challenges in manufacturing, the question arises if and how these developments can possibly support each other (Mayr et al., 2018). Thus, this paper aims to contribute to this research area by presenting the main features of the Lean and I4.0 paradigms, investigate the practical implementation of the respective tools and highlight how their combined use can create efficiency enhancing synergies.

2. BACKGROUND THEORY

2.1 Fundamental lean concepts and tools

The roots of the underlying lean theory and thinking lie in the post-World War II Japan and specifically in the car manufacturing company of Toyota.

Value-added activities / Waste

Toyota introduced a Just-in-Time production system – in contrast with the prevailing mass production approach- with the aim to deliver maximum value to the customer by eliminating all possible kinds of non-value adding activities (overproduction, waiting time, over-processing, defects,

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inventory, motion, transportation and non-utilized talent), as well as variation (Womack and Jones, 2003).

Kaizen

Kaizen is the underlying organisational philosophy, aiming to increase the amount of value-added work and eliminate waste through Continuous Improvement. The key to continuous improvement is small changes and endless efforts to change in the long-term. The most significant effects of kaizen application are productivity, quality, and efficiency improvement, lower costs, waste elimination, workplace safety etc (Janjic et al., 2020).

Kanban

Kanban is a tool for implementing customer pull production and promotes a continuous material flow with waste-free processes, while maintaining a pre-defined inventory level to ensure uninterrupted material supply (Mayr, 2018). Upon a particular customer demand, different Kanban cards are created to signal required manufacturing processes and to trigger the replenishment of necessary raw materials, inventory, dies, etc.

Total Productive Maintenance (TPM)

TPM is an approach to maintenance that optimizes equipment effectiveness, eliminates breakdowns and promotes autonomous maintenance by operators through day-to-day activities involving total workforce (Bhadury, 2000). TPM encompasses a powerful structured approach to change the mind-set of employees thereby making a visible change in the work culture of an organization (Ahuja and Khamba, 2008).

Value Stream Mapping (VSM)

VSM is an important technique used in lean manufacturing to enable the systematic identification of waste in consecutive production processes and detection of improvement potentials. Only few methods for optimising production offer a holistic mapping and design approach such as the VSM (Meudt et al. 2017).

Standardized work

Standard work is defined as a set of work procedures establishing the best methods and sequences for each process and each worker. It aims to minimize waste and maximize performance assuring that the pace of production is lined up with the flow of customer orders and in such a way that the operators can easily change positions within the process (Pereira et al., 2016). Standardized work, once established and displayed at workstations, is the object of continuous improvement through kaizen. The benefits of standardized work include documentation of the current process for all shifts, reductions in variability, easier training of new operators, reductions in injuries and strain, and a baseline for improvement activities. (Lean Enterprise Institute, 2008).

Poka-Yoke (Error-proofing)

Methods that help operators avoid mistakes in their work caused by choosing the wrong part, leaving out a part, installing a part backwards, etc. An example of error-proofing is a product design with physical shapes that make it impossible to install parts in any but the correct orientation (Lean Enterprise Institute, 2008).

2.2 I4.0 key features

The term Industry 4.0 was first used in 2011in Germany, to refer to the 4th industrial revolution which aims to connect the physical and virtual world in industrial production (Bittencourt et al, 2019).

Cyber Physical System (CPS)

CPS are systems of collaborating computational entities which are in intensive connection with the surrounding physical world and its on-going processes, providing and using, at the same time, data-accessing and data-processing services available on the Internet (Monostori et al., 2016). In other words, CPS can be generally characterized as physical and engineered systems whose operations are monitored, controlled, coordinated, and integrated by a computing and communicating core (Rajkumar, 2010).

Internet of Things (IoT) / Industrial IoT (IIoT)

The Internet of Things (IoT) represents the radical evolution of internet into a network of interconnected objects with built-in sensors and computing capability enabling them to collect, exchange, and act on data, usually without human intervention (Konanahalli et al., 2020). In 2012, GE introduced the concept of the Industrial Internet of Things (IIoT). The IIoT is a circulation of data, hardware, software, and intelligence that enables their interaction by storing, analyzing, and visualizing data acquired through intelligent machines and networks for final intelligent decision-making (Zhong et al., 2017).

Radio-Frequency Identification (RFID)

RFID is one of the cornerstones of IoT. Since the 1980s, RFID has been used to identify and track objects providing sufficient real-time information about things making use of wireless communication. In many cases, the automatic and continuous sensing capabilities of RFID can eliminate the need for human labour in the data collection process and enable more automated factories (Xu et al, 2018).

Big Data

The term “Big Data” represents a revolutionary step forward from the traditional data analysis and is used to describe vast amounts of data whose size is beyond the ability of typical database software tools to capture, store, manage, and analyze and has the potential to be collected, stored, retrieved, integrated, selected, preprocessed, transformed, analyzed, and interpreted for discovering new or extracting useful knowledge (Bibri, 2018).

Cloud computing and Cloud Manufacturing

A modern enterprise's operation involves numerous decision-making activities, requiring a large amount of information and intensive computation. Cloud is a technology which allows a large volume of data to be uploaded and stored to a computing centre, thus facilitating complex decision-making requiring multiple computing resources in manufacturing and production (Xu et al. 2018).

Robotics

Robots play an important role in modern manufacturing by enabling autonomous production methods. The integration of the robots in human workplaces increases efficiency and productivity as workers can be notified of errors and give fixing instructions to the robots; therefore production issues can be resolved even if the workers aren't in the production line (Bahrin, 2016). Nielsen et al. (2017) and Dang et al.

(2012) also propose optimization algorithms for the use of robots in material handling.

Simulation

Simulation modelling is the method of using models of a system or a process to better understand or predict its behaviour. Simulation-based decision making tools allow solution development, validation and testing for systems and individual elements. The Industry 4.0 paradigm involves the virtual factory concept and the use of advanced artificial intelligence (cognitive) for process control, which is best represented by the concept of 'Digital Twin' (Rodič, 2017, Uriarte et al., 2018).

3. COMBINING INDUSTRY 4.0 TECHNOLOGIES WITH LEAN MANUFACTURING

The interaction of Lean and I4.0 paradigms has attracted significant research interest in the recent year with lean methods being generally considered as enablers for I4.0 implementation, and conversely, I4.0 as a means to realize the extended lean enterprise. Mayr et al (2018) argue that the generally supported compatibility between Lean and I4.0 can be attributed to conceptual similarities concerning targets (e.g. the reduction of complexity), the holistic approach and the pivotal role of employees, among others. Regarding the joint employment of tools, the literature also includes numerous research papers suggesting the combined use of I4.0 and lean tools with the aim to improve operational efficiency in the context of manufacturing. For example, Davies et al (2017) refer to the use of CPS supported real time data for the generation of e-Kanbans which enable automatic orders and inventory level control. Furthermore, a CPS based production system with the help of RFID technology, can collect information about inventory, location, networking, man-machine interface and enable digitized information sharing between shop floors and business departments (Müller, 2017). This results in a transparent leaner process, since the efficient communication of changes in components and technical drawings reduces errors, increases capacity and enhances customer satisfaction. Additionally, CPS-based smart devices e.g. smart watches allow operators to receive error messages in real-time and act on repair actions required with no delay. In addition, CPS equipped with proper sensors can recognize failures and automatically trigger fault-repair actions on other CPS (Kolberg and Zühlke, 2015). Moreover, Ma et al (2017) proposed an integrated standardized approach to design and implement a CPS-based smart System which uses Cloud and IoT technology, ensuring flexible configuration, deployment and performance of the System. Furthermore, a CPS supported framework where intelligent agents make autonomous decisions about their routes has been presented by Blunck et al, (2018), demonstrating its value towards reducing throughput time and providing flexibility and optimal allocation of production capacity.

In the field of IoT and Cloud, an IoT/IIoT based logistics model incorporating Lean Six Sigma elements proposed by Jayaram et al. (2016) allows a fully autonomous global supply chain, with an optimized flow and overall efficiency. This IIoT-supported model enables the communication between production and supply chain with real time data used to optimize processes, reduce costs and resource consumption. Furthermore, Ferrera (2017) proposed an IoT framework achieving easy integration and data exchange between machines, sensors and end users of software tools at industrial sites. Similarly, a cloud -based application able to process real time inputs from computational systems within the company with the aim to automatically create electronic work instructions and standard work has been developed by Silva et al. (2018). Another study by Ogu et al. (2018) presents the integration of cognizant computing and lean practices in order to ensure business success. Cognizant computing provides real-time databases supported by cloud computing and powered by IoT technology. The benefits reported include tremendous savings and returns, reduction in lead times, inventory volumes, process wastes and minimal rework. Furthermore Rauch et al. (2016) note that in the context of the product development process, the implementation of cloud makes substantial contribution towards the elimination of wastes associated with disconnected users or sending wrong information. Additionally, Mayr et al. (2018) highlight how cloud computing and machine learning-based condition monitoring enhance product quality and TPM by reducing the machine downtime, rework and scrapping. Furthermore, the cloud can be used to provide maintenance data to the workers and enable the dynamic scheduling of maintenance activities. Further to the above, the use of Big data to facilitate lean applications has also been widely reported in the literature. The combination of data analytics and cloud technologies towards real time KPI generation has been suggested by Rauch (2016) as an improved data processing approach which, based on current information can promote the project team motivation and efficiency. Furthermore, Meudt et al. (2017) discuss the Value Stream Mapping (VSM) 4.0 as a new VSM approach focused on data collection, storage, handling and utilization for KPI generation, with the aim to achieve maximum waste reduction and appreciation of how information flows within the logistic processes. Similarly, Lugert et al (2018) supported the potential use of Big Data technology for improving the VSM. Their main focus was to optimize the value stream with the use of data analytics, simulation and an RFID-supported user interface that enables real-time results' visualization and employee engagement.

4. METHODOLOGY

Extensive literature search in the field of Lean manufacturing and I4.0 was carried out in three stages. The first stage concerned the theoretical concepts of Lean and its tools while the second concerned I4.0, its technologies and their capabilities. In the third stage, combined keywords were used to enable the search for studies which provide a bridge between the two different areas. After reviewing the literature, it became clear that only selected methodologies of lean can be combined with a few chosen technologies of I4.0. These potential combinations were used to find sources supporting the combination. Based on the literature, a questionnaire was developed and comprised of four parts.

The first section was focused on participants' demographics like age, experience, gender, role and country of activity. Second section was focused on understanding the Lean practices being implemented within the company and the perceived level of resulting benefits and similarly the third section concerned the implementation of I4.0 technologies in the company. Specific options to choose from were given to the respondents in both cases. The concluding section of the questionnaire was prepared based on literature suggestions for combinations of Lean and I4.0 applications which bring together the principles and capabilities of both.

The questionnaire was distributed online among 200 industrial professionals of different manufacturing companies having experience and relevant knowledge regarding Lean manufacturing and Industry 4.0. 44 responses were received i.e. the rate of response was 22%. It was observed that the highest rate of industries of the respondents were Automobile/Auto components 16% and Iron and Steel/Metal industries representing the 15% of responses each. Other frequent industries included Industrial products and Heavy machinery (10%), Aerospace (7%), Textile/ Garments/ Accessories (6%) and Chemical/ Petrochemical/ Plastic/ Rubber (6%). Regarding the geographical distribution of respondents, the most represented countries were the United Kingdom, India and Indonesia with 11% of the participants each, while another 9% of the participants was based either in Germany, Netherlands or Vietnam.

5. RESULTS

5.1 Lean adoption

Table 1 presents the lean tools that were listed in the questionnaire for the respondents to indicate whether they are applicable or non-applicable in the context of their current professional practice. The percentage reflects the total frequency of application observed for each of the entries. It can be noted that Kaizen has an almost universal acceptance and applicability, with 5S, Root cause analysis and Kanban also demonstrating very high popularity.

Table 1. Lean tools/ concepts and implementation frequency

Tool / concept	Frequency
Continuous Improvement (Kaizen)	97%
5S	80%
Kanban	70%
Poka Yoke (Error Proofing)	59%
PDCA (Plan Do Check Act)	56%
Value Stream Mapping	53%
Standardized Work	50%
Total Productive Maintenance	47%

Following this, respondents were asked to reflect on the benefits brought to the organisation as a result of the implementation of the lean tools. Their perceptions on the improvement of a number of operational and customer related aspects were captured through a number of statements which they had to agree or disagree with, using a 1-5 Likert scale (1- strongly disagree, 2- disagree, 3- neutral, 4- agree, 5- strongly agree) while an overarching question regarding the achievement of expected benefits was also included to capture the overall satisfaction of the respondents with the lean tools applied in their company. The average level of agreement of the respondents with the presented statements is given in Table 2.

Table 2. Perceived benefits from lean adoption

As a result of lean implementation in your company, the following were observed:	Average level of agreement
Quality Improvement	4.09
Meeting Customer Demand	4.00
Reduction in Inventory level	3.73
Wastage Reduction	4.03
Productivity Improvement	4.24
Lead time reduction	3.85
Machine downtime reduction	3.76
Setup time reduction	3.70
Customer Satisfaction increase	4.09
Increase in Value creation	3.88
Increase in Productivity	4.12
The implementation of lean techniques in your organization has brought the expected benefits	4.12

5.2 I4.0 Implementation

Table 3 presents the I4.0 tools that were presented to the respondents for them to indicate whether they are applicable or non-applicable in the context of their current professional practice. The percentage reflects the total frequency of application observed for each of the entries. It is clear that the technologies of IoT, Big Data and RFID are the most popular ones, with high levels of applicability (>35%) also being observed for RFID, 3D Printing, Simulation and Cloud computing.

Table 3. I4.0 tools and implementation frequency

Tool / Concept	Frequency
IoT/ IIoT	53%
Big Data Analytics	47%
RFID	44%
3D Printing / Additive manufacturing	38%
Simulation	38%
Cloud Computing	35%
Real time location system	29%
Robotics	29%
Virtual Reality / Augmented reality	26%
Cyber Physical Systems	18%

5.3 Combined use of Lean and I4.0 applications

Table 4 presents a representative sample of Lean and I4.0 combinations included in the questionnaire for the respondents to indicate whether they are applicable or non-applicable in the context of their current professional practice. The percentage reflects the frequency of adoption observed for each of the entries.

Table 4. Combined I4.0 and Lean tools and implementation frequency

Lean and I4.0 combination	Frequency
Real time data are used to facilitate continuous flow	65%
IoT infrastructure supports easy integration and data exchange among shop-floor and other departments.	53%
CPS based smart devices allow operators to receive error messages in real time.	44%
Big data analytics empower human workers through mobile information for continuous improvement.	44%
Predictive algorithms improve autonomous maintenance.	44%
CPS collect maintenance data and automatically sends signals to maintenance staff for TPM.	38%
Big Data technology for improving VSM procedures.	32%
Workers performing Standardized work are assisted by robots.	32%
The CPS supported real time data allows automatic orders processing and inventory level control through e-kanbans.	32%
Algorithms improve the management of standard work procedures.	27%

As presented in Table 4, the 65% of the respondents confirmed the utilization of real time data to facilitate continuous flow, which is one of the fundamental principles of Lean, while another 44% confirmed the use of CPS-based smart devices for the generation of real-time error messages. Real time data exploitation for the generation of e-Kanbans which enable automatic orders' processing and inventory level control was also reported by the 32% of the respondents. Furthermore, the results verify the use of CPS and predictive algorithms in the optimal scheduling of maintenance tasks in the context of TPM by the 38% and 44% respectively.

Moreover, the IoT-enabled data exchange among shop floor and other departments for continuous improvement and decision making is also among the popular options with 53% of the respondents reporting its applicability. Similarly, the use of Big Data analytics was highlighted for a number of purposes also present in the literature, including the empowerment of workforce towards continuous improvement objectives (44%) and the enhancement of VSM procedures (32%). Finally, the use of robotic elements for the facilitation of workers in the execution of standardized tasks as well as the employment of algorithms for the efficient management of standardized work procedures were also confirmed by 32% and 27% of the respondents respectively.

Respondents were also asked to evaluate the perceived contribution of I4.0 applications to the operational performance of the company. Their responses reveal that the perceived impact on aspects of efficiency and profitability is not as clear as with the application of lean tools. The average level of agreement for all the aspects included in the survey was between 3.10 and 3.50, which shows that the advanced technological tools' potential benefits for business performance have not yet been fully appreciated / evaluated. This could possibly be associated with the intensity of the I4.0 adoption i.e. the number of different combinations of tools simultaneously used or the kind of the industry. Furthermore, it could also be attributed to the fact that the I4.0 applications are still evolving and emerging, in contrast with lean, which represents a well-established and tested production philosophy.

6. CONCLUSIONS

The lean manufacturing and I4.0 production paradigms are promising developments for the future of manufacturing especially if the organisations are able to combine them with the aim to create efficiency enhancing synergies. A relevant questionnaire survey reveals that Real time data, IoT for data exchange, big data analytics, Cyber –Physical Systems (CPS), predictive algorithms and robots are among the most popular I4.0 applications used to support lean attributes like continuous flow, Kanban, standardised work, TPM and continuous improvement. It also emerges that although 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 business profitability benefits not being fully appreciated yet.

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