‘Lean 4.0’:
How can digital technologies support lean practices?

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Abstract

The digitalisation of business offers great possibilities to create new products and processes, as well as improve existing ones. In this paper we seek to understand how digital technologies can support process improvement in a manufacturing context. Several studies have proposed synergies among digitalization and lean at a conceptual level, yet so far we lack any empirical proof. To this effect, we present exploratory quantitative research aimed at explaining how digital technologies can support lean practices, improving our understanding how to harness the potential of digitalisation in operational improvement. We conclude with areas for further research.

Keywords: Lean, process improvement, digitalization, manufacturing.

Introduction

Digital technologies are powerful innovations that have rightfully captured the imagination of manufacturing managers. It has been frequently stated that digital technologies can support or enhance lean practices. Here, technologies often associated with ‘Industry 4.0’ are cited, and we will refer to such digital enhancements of lean practices as ‘Lean 4.0’. For example, according to Wagner et al. (2017), digitalization will not only support lean practices, but it will also enlarge their scope. Even on the performance point of view, researchers reached the consensus on the operational improvements lean practices yield thanks to digitalization (i.e. Davies et al., 2017; Kolberg and Zühlke, 2015; Tortorella et al., 2018). However, beyond these early studies, to the best of authors' knowledge, conclusive proof of this claim is still outstanding.

It is easy to conceive areas where they directly support lean practices, yet so far much of this discourse is based on conjecture. With the underlying study we seek to provide a rigorous identification of the mechanisms explaining how digital technologies can support lean practices, and thus contribute to our theoretical understanding of the true impact of 'Industry 4.0' technologies, and to support managerial decision in making the business case for their adoption.

In this paper, we present a structured literature review of lean practices as well as digital technologies of relevance to operations management. We show findings of an initial survey that demonstrated the lack of maturity of digital technology adoption in practice and highlighted the needs for further qualitative research. We conclude with comments on preliminary results and presenting our next steps.

Theoretical background

Lean: wastes and practices

The concept of 'lean production' has been widely researched and discussed in the operations management literature (c.f. Holweg, 2007, Fujimoto, 1999, and many others). At the very heart of lean stands the concept of waste reduction, namely to improve a process by reducing non-value activities herein. Taiichi Ohno coined the original seven wastes (or 'muda') in manufacturing (often abbreviated as TIMWOOD – Transportation, (excess) Inventory, Motion, Waiting, Overproduction, Overprocessing and Defects), which later have been expanded to also include 'Skills', or wasted human talent and ideas. Muda, together with 'mura' (unevenness) and 'muri' (overburden), provides the original, and still the most succinct, way how to conceptualise lean (Bicheno and Holweg, 2016).

It is for that reason that we adopt the seven (eight) wastes for our study, coupled with the lean practices that have been built upon them to form an integrated management system (Shah and Ward, 2003; Womack, Jones and Roos, 1990). These practices work synergistically to achieve the main goals of lean production, which are related to the creation of a streamlined, high quality system that produces finished products at the pace of customer demand with little or no waste (Shah and Ward, 2003). For their nature, lean practices are applicable to the entire company (Ruiz-Benítez, López and Real, 2018). However, in the scientific community, there is no a unique classification of practices or consensus on which is the complete set of lean practices. Different authors, in fact, refers to them providing their own classification or list of practices. For this reason, and for the scope of this study, a systematic literature review has carried out, with the aim to define a comprehensive list of lean practices.

We adopted an ad-hoc keywords strategy to article title/abstract and keywords on Scopus database. Keywords selected are based on the term "lean" combined with the Boolean operator AND to terms referring to "practice" or "bundle". Moreover, we adopted five inclusion criteria. Firstly, we reviewed only contributions in English. Secondly, we considered only journal paper belonging to high-ranked journal (Q1 according to Scimago ranking), discarding conference contributions, books chapter or journal paper published in a medium-to-low ranked journal (according to Scimago ranking). Thirdly, we included only contributions with a proper and specified review/classification of practices. Fourthly, we restricted our focus to manufacturing industry, discarding then all contributions clearly referred to service industries. Eventually, we considered contributions from 2000 on.

The review process identified 528 eligible studies from all the keywords. We filtered the studies by scanning their titles and abstracts, removing duplicates and selecting those consistent with the aforementioned inclusion criteria, resulting in 179 articles. Full-texts were assessed with the same criteria, to discard out-of-scope documents, resulting in 81 articles. 140 practices have been identified, with more than 75% of them cited less than 10 times, highlighting the lack of structured and comprehensive list of practices. Following the final selected sample of practises considered, having each a number of citations at least equal to 10.

Table 1 - Lean practices

Lean practice	Number of citations
JIT(Just in Time/ Continuous flow production)	66
Pull system (Kanban)	56
Quick changeover techniques and reduction of setup time (SMED)	53
TPM (Total productive maintenance)	47
Continuous improvement programs (Kaizen)	39
TQM (Total quality management/Zero defects)	37
Supplier involvement and developement (feedback and partnership)	34
Production smoothing (bottleneck removal, Heijunka)	31
Cross-functional work force	31
Cellular manufacturing	30
VSM (Value Stream Mapping)	28
5S	27
Work standardization (SOPs stand. operating procedures)	26
Error proofing (Poka-Yoke)	26
Lot size reductions	23
VLPM (Visual Performance Measures/Visual control)	23
Customer involvement and partnership (feedback)	22
Statistical Process Control (SPC)	17
Employees' involvement (suggestion schemes)	16
Autonomation (Jidoka)	16
Information sharing	15
Lean Management Training	15
Elimination of waste	14
Shop floor organization and safety	14
Small group problem solving	14
Preventive maintenance	13
Low inventory	13
HRM (Human Resources Management)	12
Top management leadership for quality	11
Reduced number of suppliers	10
Takt time definition	10

The resulted panel is made by 31 lean practices, with various degree of frequency. JIT and Pull systems are referred to most frequently, while Smaller number of suppliers and Takt time definition are of less interest in the reviewed literature.

As mentioned before, according to its definition, lean strives to minimize general understanding of waste (Womack, Jones and Roos, 1990). It is essential hence to understand the role played by lean practices on the 8 wastes. Here following a table summarizing which lean practice acts on specific waste. As result of reviewing literature, some practices result to have a more horizontal impact on wastes compared to others. As example, Kaizen events affect positively all 8 wastes, while the takt time definition results to impact only on waiting and inventories.

Table 2 - Lean practices and 8 wastes

Lean practice	Transportation	Inventories	Motion	Waiting	Overproduction	Overoprocessing	Defects	Skills
JIT(Just in Time/ Continuous flow production)	x	x		x	x			
Pull system (Kanban)	x	x			x			
Quick changeover techniques and reduction of setup time (SMED)				x	x		x	
TPM (Total productive maintenance)		x		x				
Continuous improvement programs (Kaizen)	x	x	x	x	x	x	x	x
TQM (Total quality management/Zero defects)		x				x	x	
Supplier involvement and developement (feedback and partnership)	x	x						
Production smoothing (bottleneck removal, Heijunka)		x		x				
Cross-functional work force			x					x
Cellular manufacturing		x	x					
VSM (Value Stream Mapping)	x	x			x			
5S			x				x	
Work standardization (SOPs stand. operating procedures)			x	x			x	
Error proofing (Poka-Yoke)			x				x	
Lot size reductions		x		x				
VLPM (Visual Performance Measures/Visual control)		x			x	x	x	
Customer involvement and partnership (feedback)					x	x	x	
Statistical Process Control (SPC)		x			x	x	x	
Employees' involvement (suggestion schemes)	x	x	x	x	x	x	x	x
Autonomation (Jidoka)			x	x			x	
Information sharing	x	x	x	x	x	x	x	x
Lean Management Training	x	x	x	x	x	x	x	x
Elimination of waste	x	x	x	x	x	x	x	x
Shop floor organization and safety		x	x					
Small group problem solving								x
Preventive maintenance		x		x				
Low inventory		x			x			
HRM (Human Resources Management)				x				x
Top management leadership for quality	x	x	x		x	x	x	x
Reduced number of suppliers	x	x						
Takt time definition		x		x				

Digital technologies

The availability of low-cost sensors, increases of computing power and high-speed internet connectivity are some of the enablers of massive advances in technologies for operations and supply chain management. Companies have always used new technologies to advance their process. The shipping container is probably the most successful example of a technical revolution that not only significantly improved supply chain processes but also shaped global trade flows in the long term (Cooper and Levinson, 2010).

On the other hand, there are also technologies like Radio Frequency Identification (RFID) that have triggered high expectations for process improvement in retailing operations, but have so far only been able to partially fulfil (Gaukler and Seifert, 2007). Ultimately, new technologies can provide benefits in two fundamentally different ways, i.e. either by increasing efficiency or by increasing revenues – many technologies aim to achieve both. As we are interested in the technology benefits that aim at waste reduction, we carefully screened for relevant technologies in this context. Since new technology developments are currently observed every day, we focused our literature analysis on practitioner articles as well as white papers and reports issued by large technology firms and big consultancies. While the mentioned technologies differ slightly and the terminology is also varying a comprehensive picture emerged that put six technology clusters in the focus of our interests. Table 3 provides a summary of the technologies that we identified as potentially most relevant for process improvement.

Table 3 - Summary of technologies

Technology	Description	Examples
IoT solutions	Sensors, cameras and smart devices that process and share gathered data using internet connectivity.	Process control sensors, environmental monitoring, cameras, smart replenishment solutions.
Virtual and augmented reality	Interactive experience where real world objects are either represented completely "virtual" or "augmented" by computer-generated perceptual information.	Smart glass, holo-lens, virtual twins.
Advances analytics	Data science tools for improved decision making, e.g., by gaining deeper insights, making predictions, or generating recommendations.	Predictive Analytics, Machine Learning, Deep Learning, Support Vector Machines.
Autonomous vehicles	Solutions allowing semi- and fully autonomous transportation, ranging from long-distance to short-distance deliveries.	Platooning trucks, autonomous trucks, drones, self driving delivery vehicles.
Robotics	Physical robotic systems used across all supply chain processes within enclosed environments.	Robotic mobile fulfillment systems, picking robots, industrial robots, cobots.
Digital manufacturing	Integrated, computer-based system manufacturing comprised of simulation, 3D visualization, analytics and collaboration tools to create product and manufacturing process.	Digital printing, 3D printing, CNC milling, Stereolithography.

'Lean 4.0'

The integration between lean and Industry 4.0 (Lean 4.0) is currently highly discussed in literature (Buer, Strandhagen and Chan, 2018). Even if academia seems to agree on the potentials of the aforementioned integration, there are different points of view depending on the author explaining the subject. Two main perspectives can be drafted in the academia. Some authors describe lean as a basis for the implementation of Industry 4.0 (Hambach, Kümmel and Metternich, 2017). Indeed, since lean practices are aimed at wastes reduction along the process (Womack and Jones, 2003), having a streamlined and under control process represents the prerequisite for any process digitalization (Buer, Strandhagen and Chan, 2018). Other studies have significantly confirmed that companies with a higher associated level of lean implementation benefit the most in embracing Industry 4.0 and in grasping its potentials (Hoellthaler, Braunreuther and Reinhart, 2018).

Other researchers refer instead to Industry 4.0 as a completion of lean (Kolberg and Zühlke, 2015), that was declared as limited by some studies. Market requirements are nowadays more complex and customers demand for highly personalized products may hinder lean to be still effective. Lean could not only be able to keep up with the pace of personalization using the same tools used since the second half of the 20th century with no technological advancements supporting those tools (Sanders, Elangeswaran and Wulfsberg, 2016). In this sense, Industry 4.0 represents the mean lean can exploit to face new trends in the manufacturing world, preserving its process' robustness.

The strong interest for the topic from the academia is evident, however due to the infancy of the Industry 4.0 topic, it is still difficult to assess the effect of Lean 4.0. To the best of authors' knowledge, available scientific studies are mostly focused on theoretical research, and hence conclusive proof for Lean 4.0 potentials is still outstanding.

This research is an attempt to study the mechanisms explaining how digital technologies can enhance lean, and to assess the impact of 'Lean 4.0' on operational performance. The scope is limited to industrial operations management, including manufacturing, logistics and supply chain operations, since it is the traditional application space for lean.

Exploratory survey

In this section we will we will present our exploratory survey carried out in the European manufacturing sector aimed at deepen the relationship between Lean and digital technologies adoption, as well as the effects on operational performance. Firstly, we will describe the design of the survey and its instrument, as well as its implementation. Secondly, we will present first preliminary results of our quantitative study.

Design

A survey methodology has been selected as the most suitable one among quantitative methodologies.

The questionnaire is made by 19 questions, grouped into six main clusters: (i) companies' profile; (ii) contextual factors; (iii) lean practice implementation; (iv) digital technology implementation; (v) the effect of 'Lean 4.0'; (vi) operational performance.

The constructs related to lean practices and digital technologies used in the questionnaire are based on the reviewed literature both on lean practices and on technologies. For what regards operational performance, both questions and response interval come from the study of Shah and Ward (2003). Moreover, set-up time and inventories have been included as additional items due to their relevance for the lean approach. The response interval for these items is built following the same structure suggested by Shah and Ward (2003).

The sample selected for this exploratory survey is limited to the European manufacturing sector, with plants as unit of analysis. Respondents are required to be experienced in lean, therefore green belt and black belt experts have been targeted. These criteria led to a non-random choice of companies for the survey, a strategy used also in the study of Shah and Ward (2003). In order to define the size of the sample, it was considered that 15% is the average rate in management surveys and 100 is the minimum threshold of responses to perform a significant statistical analysis (Hair *et al.*, 2007). On the base of these numbers, sample considered valid consisted in about 1200 experts.

Implementation

The questionnaire instrument has been tested with a sample of 56 lean experts to verify and to validate the constructs and the questions. Testing phase started in May 2018 and lasted 5 months. The final and improved online survey, through Google Module, has been submitted from November 2018 to February 2019 to more than 1200 lean experts. Questionnaire submission exploited three different waves: first wave addressed 700 people, second wave 300 people, and third wave about 200 people. Non-response bias has been managed through two actions: first, while sending the survey it was specified that the questionnaire lasts at least 10 minutes; secondly, the questionnaire was sent three times with a time window of about one week.

The final number of completed surveys was 162 corresponding to a response rate of approximately 13,32%. The validity of answers was verified excluding answers coming from experts involved in service sector (56 answers) and cleaning the dataset from clearly random responses (1 answer). The final dataset is composed by 105 responses, referring to 88 different companies. In addition to all the answers provided, final dataset comprehends two additional values for each expert/plant: lean level (LL) and digital level (DL). According to the model developed by Soriano-Meier and Forrester (2002), LL can be defined starting from a self-evaluation on the implementation of several lean practices. The final LL comes from the computation of the average value of self-evaluation values. The same reasoning of LL has been used for computing DL, exploiting the six digital tools considered in the survey.

Results

In terms of production technology, responses are equally distributed among process and discrete manufacturing. Moreover, several industrial sectors are represented in the sample. Most of the respondents report their plant age as higher than 20 years while only about 7% of the plants have been built in the last decade (Figure 1 - A). About the plant size, according to the European classification, the sample is representative of medium-large plants (Figure 1 - B). Only about the 6,7% of the respondents is indeed in small plants (i.e. less than 50 employees).

Eventually, it is interesting to understand how respondents are spread out on different departments. It is indeed necessary to stress that all the respondents are lean experts, endowed with green or black belt certification, and are working in different departments within companies. 31,4% of the respondents are involved in the Production and Maintenance departments. A remarkable percentage of experts, 27,6%, belongs instead to the so-called Kaizen Promotion Office, that is usually a support-function in charge of continuous improvement activities of the company. Quality and Supply chain functions are also represented in the sample.

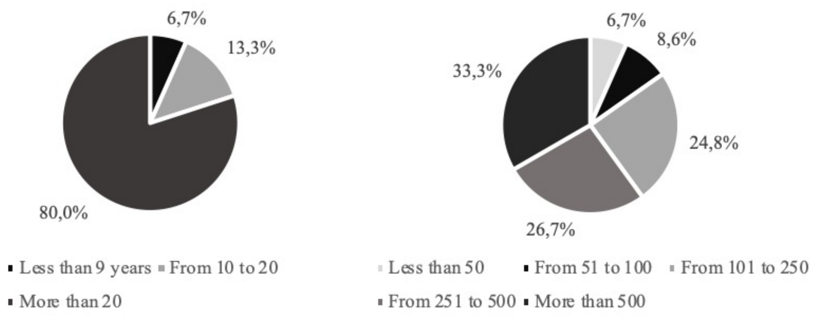

Figure 1 - Age plants (A) and Size plants (B)

Data gathered from the online survey have been using SPSS, a software of data mining and data statistical analysis.

In order to study the dependence of DL on LL, a box plot analysis was carried out to better understand how the data are distributed. As displayed in Figure 2 - A, not only data are not normally distributed but also DL shows a lower variability than LL. It is interesting to note that there are three outliners at the top of the graph: these three plants are classified as “old” and “large” and are associated with a very high LL. Same data of DL and LL are plotted in a scatter plot to have a graphical representation of the relation between the two variables (Figure 2 - B).

The second quadrant of the matrix presents a high concentration of observation, meaning that most of the plants having a low DL report a high LL. Moreover, not only the fourth quadrant is empty - there are no plants with high DL and low LL, but also DL is never higher than LL. This may confirm what is stated in the literature: highly digitalized plants are also strongly implementing lean, making lean the prerequisite for digital transformation (e.g. Buer, Strandhagen and Chan, 2018).

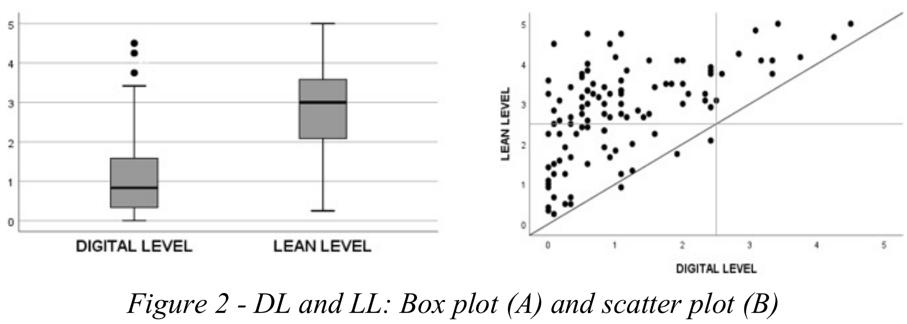

Figure 2 - DL and LL: Box plot (A) and scatter plot (B)

Despite this, too few plants registered an above average DL. Only about 10% of plants are belonging to the first quadrant, registering high DL and high LL. This prevented us to make meaningful statements on the possible digital mechanisms that affect lean.

Moreover, looking at operational performance results, the majority of plants is not at the moment affected by any significant operational performance increase. A cluster analysis of plants on operational performance highlights an interesting fact. Applying K-means methods, we ended with 3 different clusters (k=3 defined by Ward distance criterion) with plants not equally distributed among them. About 60% of plants indeed belongs to cluster 3. If cluster 1 and cluster 2 registered remarkable improvement in one or more operational performance, cluster 3 includes companies where Lean 4.0 did not affect operational performance. As shown in Figure 3, it is interesting to note that plants associated with high LL and high DL register a positive impact on operational performance. This represents an initial preliminary result on the performance improvement yielded by Lean 4.0. Unfortunately, further considerations cannot be draft due to the low numbers of observations available with high LL and high DL.

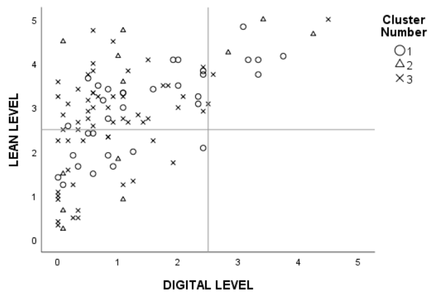

Figure 3 - Clustering analysis on operational performance

Conclusion and next steps

Preliminary results coming from our exploratory survey showed a positive relationship between the combined lean and digital adoption on operational performance. Low digital maturity levels however prevent us from fully disentangling the effects as the majority of plants still feature a low digital level. Thus, we will expand our research design to include qualitative research to identify the potential mechanisms how digital can support lean that practitioners foresee. Using a focus group-based study design (currently underway) we seek to identify both potential variation of impact, as well as level of importance, of the main digital technologies, as well as clustered mechanisms that vary across supply chain activities. In other words, we want to understand which digital technologies have the greatest impact on lean process improvement, and secondly, what the general mechanisms are how digital technologies support lean. Based on our combined survey and focus group findings we will provide a discourse on the how mechanisms identified link to the wide theoretical landscape of lean improvements, and how this can inform managerial practice to harness the potential that digital technologies offer to operations management more generally.

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