Lean Industry 4.0—Wastes Versus Technology Framework

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Abstract Both lean management and Industry 4.0 are obviously important in practices of modern manufacturing companies. Lean management a is well-known and deeply researched approach while Industry 4.0 is also well recognized, but still relatively new with a big part of the theory and practice to be developed, validated, verified and applied. However, Industry 4.0 gains more and more interest of both researchers and practitioners and is very important for manufacturing and other industries. The main goal of this paper is to analyze synergies, or deficits, of lean management and Industry 4.0. For this purpose, a lean framework for waste typology was combined with the Industry 4.0 potential to decrease those wastes. It was also analyzed if some properties of Industry 4.0 may lead to increase in some types of waste. Each type of waste was analyzed to consider its possible decrease and increase through the application of Industry 4.0 grounding of field practice and literature analysis.

Keywords Industry 4.0 · Lean management · Lean manufacturing · Waste

1 Introduction

Industry 4.0 refers to a series of changes in the way that products and services are manufactured. Grounding on the systematic use of the Internet of Things, Augmented Reality and other technologies, revolutionary change is observed in production relations between the employer and the employee. This is a significant challenge for managers.

Industry 4.0 enables fast collection, analysis, and communications of big sets of data between machines. This forms an enabler for faster and more flexible response to existing problems, as well as for more efficient processes to produce high quality products at a decreased cost. All these elements will consistently lead to the increase

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in production efficiency and then changes in the labor force profile and required skills.

The basis of lean management (LM) is the elimination of wastes, while taking into account the role of the employee in creating the value of products and services provided.

A global survey conducted by The Boston Consulting Group (Küpper et al. 2016) has shown that leading industrial companies recognize the importance of both lean management and digitization in their long-term planning. In a survey conducted among more than 750 production managers, 97% of respondents in the automotive industry stated that lean management would be of great importance in 2030, compared with 70% who said that it is important today. Of these respondents, 70% said that digitization of the factory would be very important in 2030, compared with 13% who claimed that it is important today.

Although the need to implement both Lean Management and Industry 4.0 is clear to many managers, they are not sure how to combine these two elements to achieve their convergence and avoid contradictions. BCG experts indicate that companies must think about Lean Industry 4.0 in terms of individual cases of practical use—the optimal combination of lean tools and digital technologies. Then, they must carefully choose from case to case, which individual practices should be applied for addressing key problems.

By using integrated Lean Industry 4.0 solutions to eliminate production problems, factories can achieve a number of benefits. The research problem formulated in this article is to examine the possibilities of Lean Management and Industry 4.0 integration in the context of elimination of wastes. The efforts were aimed at finding evidence from literature and systemizing knowledge on how Industry 4.0 technologies can support lean initiatives in the context of the set of wastes and selected lean methods, concepts, techniques. The proposed framework consists of Industry 4.0 support for the: (1) elimination of specific wastes and (2) application of selected lean tools.

2 Literature Review

The systematic literature review strategy proposed by Levy and Ellis (2006) i.e., choose, know, understand, apply, examine, combine and evaluate, was adopted. In this paper, studies related to lean management and lean manufacturing combined with Industry 4.0, as shown in Fig. 1, were reviewed.

The IEEE/IEE Electronic Library, Scopus, Web of Science Core Collection databases were chosen for the review. The initial searching query was 'Lean Industry 4.0'.

In the databases, after entering the indicated query, the following number of publications appears: IEEE/IEE—13, Scopus—144, WoS—93. Authors included documents that discussed relations between LM and Industry 4.0. Particular attention has been paid to publications regarding the issue of LM wastes and the possibilities

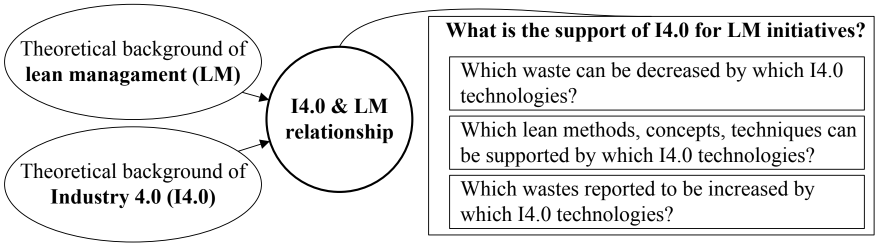

Fig. 1 Framework of the study

of their reduction using Industry 4.0 tools. LM techniques have also been identified in specified articles, which can be helpful in supporting Industry 4.0 applications. Authors excluded documents that were not in English, papers in abstracts which did not appear at the same time words 'Lean' and 'Industry 4.0' or authors have not identified any binding relation between them. Papers dated 2011–2019 were investigated. Authors also reviewed reference lists of found articles for important references missed in the database search. 74 relevant works (journals or proceedings) were selected after screening abstracts of found papers. Then, 9 articles were removed which did not have the full version in the searched databases (only abstracts). A full list of identified publications is available from the authors.

From the selected publications, 31 articles discuss LM wastes related to Industry 4.0. The majority of publications were dominated by a qualitative approach, which only described the potential possibilities of using Industry 4.0 to reduce the 8 main wastes of LM. Only in a few publications, quantitative LM wastes reduction values were identified because of the Industry 4.0 solutions. It is worth emphasizing that none of the publications describe a situation in which the Industry 4.0 application causes an increase in any of the 8 LM wastes.

In addition, 17 publications describe how selected LM techniques can support the application of Industry 4.0 tools. Usually it is a general qualitative description explaining how a given technique can contribute to a more effective functioning of the Industry 4.0. A few publications have been case studies which very precisely presented how the selected LM technique can support Industry 4.0.

2.1 8W-I4.0 (8 Wastes—Industry 4.0) Framework

2.1.1 8 Wastes and Industry 4.0 Technologies

In this section the set of lean wastes was confronted with the potential of I4.0 to decrease in specific waste. Papers found in the query were analyzed and the evidence of I4.0 support for LM in the literature was discussed.

In many publications, it was possible to reduce transport losses because of the Industry 4.0 concept. This kind of losses was considered mainly in terms of internal logistics. Examples of the reduction of losses related to transport using Industry 4.0 are autonomous transport robot including automated small parts storage and order picking and use of internal ICT in conjunction with AGV (Automatic Guided Vehicle) to transport spare parts in stock for production lines and transport objects within the material flow automatically. Despite many publications regarding transport losses related to Industry 4.0, only in one of them can be found a quantitative value concerning the reduction of this factor (Satoglu et al. 2018a, b). The use of tablets made it possible to interact with employees within the transport system. This allowed for more efficient delivery of materials and shortening of the paths (by about 25%), with the same level of supplier reliability.

In many publications, the issue of losses related to inventory in the context of the use of Industry 4.0 was described. Most often mentioned are the following solutions that can reduce inventory: CPS, 3D printing, IoT, Data Analytics, RFID, ICT, simulation, optical order system, iBin (advanced Kanban), autonomous robotic carrier, new data acquisition technology and Big Data analysis, Kanban 4.0, AGVs, Drones and 3D Printing Levers, Digital Warehouse Operations Lever, various sensors and smart bins/boxes, smart sensors. In one publication (Lugert et al. 2018), which was a comprehensive review of the literature on wastes in LM related to Industry 4.0, it was stated that inventory could be improved by 70.2% thanks to the use of appropriate Industry 4.0 tools.

Losses related to unnecessary motion were considered only in terms of the shop floor. The publications indicate how Industry 4.0 can help reduce this type of loss. The main activities in this area are: application of the Indoorway InSites 4.0 platform for multidimensional motion analysis (Wielki and Kozioł 2019), new HMIs & Wearable Computing Levers (Romero et al. 2018), Adaptive Robotics, Augmented Reality, Cloud Computing, IoT. Two publications provided quantitative values for reducing losses caused by unnecessary motion. The first publication (Powell et al. 2018) deals with the issue of "Smart Tool Management", and the authors are of the opinion that this concept will reduce the tool-inventory by at least 30% and will have a positive impact on the cost of tooling. In the second publication (Axelsson et al. 2018), it was found that with the use of Industry 4.0 tools it will be possible to reduce fuel consumption by 30% due to the elimination of unnecessary movements of the machine.

Losses caused by too long waiting times in the context of the use of Industry 4.0 were discussed in several publications. The main area of research was production, although in 2 publications medicine was considered (Camgoz-Akdağ et al. 2018; Ilangakoon et al. 2018). It was stated in them that the use of Industry 4.0 technologies would improve the performance of the healthcare system and decreased waiting times. In production area, there are also ways to reduce losses due to waiting: simulation and virtualization, adaptive robotics, Data Analytics, Cyber-Physical Systems Lever. Only in one publication (Wang et al. 2016) is the numerical value of the reduction of waiting time. Thanks to the use of VSM, it has become possible to reduce the manufacturing lead time from 108.14 to 9.94 days.

Several authors reported convergence of I4.0 technologies and eliminating overproduction. This was discussed showing that transparency of the processes is improved through data analytics enhancing forecasts quality and real time identification/location of objects enabled by I4.0 technologies such as e.g. RFID.

Data analytics along with simulation and virtualization were seen as enabler for decrease of overprocessing. However, overprocessing was directly addressed only in two papers. This seems to be awkward, as overprocessing might be treated as the waste leading to all the other types of wastes.

The possible decrease in the number of defects effecting from implementation of I4.0 technologies was widely discussed by several authors. However, there were no detailed case studies presented, nor concrete numbers reported, nor simulation models presented. It was reported that I4.0 technologies should lead to decrease in defects by better transparency, process and quality control.

Skills were mainly discussed in the context of the change and requirements to enable I4.0 implementation. However, six papers addressed directly elimination of incorrectly used skills of workers. It was assumed that using I4.0 technologies would lead to the better use of trained staff by moving them from sit-to-site problem to troubleshooting. It was indicated that automation of simple tasks enabled with I4.0 concept implies a decrease in skills waste.

Table 1 presents the 8 main wastes of LM along with publications that describe how the Industry 4.0 application can reduce them. Most publications present the possibility of reducing losses related to inventory (16) and transportation (15). The least number of publications concerned losses related to overprocessing (2), overproduction (5) and waiting (5). In the exemplary reference, mostly we can find publications which give only a very general description of how Industry 4.0 may be useful in the reduction of types of wastes. The articles are dominated by qualitative descriptions, that are mostly based on the belief in the opportunities and benefits of Industry 4.0 and not verified by empirical research or case studies.

2.1.2 Lean Tools (Methods, Concepts, Techniques) and Industry 4.0 Technologies

Table 2 presents LM techniques, methods and concepts that were identified in the analyzed publications. Papers that formed a basis for Table 2 are only those which were discussing lean wastes (see Table 1). They were combined with Industry 4.0 solutions, which may be support in their application. The greatest possibilities of using Industry 4.0 technologies (18) give them application in Kanban, pull signals, Just in Time and Just in Sequence techniques. However, there are LM techniques that can use only a few Industry 4.0 tools, e.g. 5S (1), Cellular Manufacturing (2), Continuous flow (2), Andon (3). It seems that the possibilities of using Industry 4.0 solutions in the support of LM techniques depend on the degree of their complexity and the possibility of using them in enterprises. The more areas of a company a particular LM technique covers, the more Industry 4.0 tools can support them. The most frequently mentioned solutions of Industry 4.0 that could support LM techniques were: Sensors and Actuators (7), Data Analytics (6) and Automated identification/location (5). However, many Industry 4.0 solutions were assigned to support only one LM

Table 1 Lean waste decrease supported by Industry 4.0 solutions

Waste	References	No. of papers
Transportation	Blöchl and Schneider (2016), Doh et al. (2016), Dombrowski et al. (2017), Duarte and Cruz-Machado (2018), Edirisuriya et al. (2018), Jayaram (2016), Kolberg and Zühlke (2015), Lugert et al. (2018), Mayr et al. (2018), Romero et al. (2018), Ruiz Zúñiga et al. (2017), Ruppert et al. (2018), Sanders et al. (2016), Satoglu et al. (2018a, b), Wielki and Kozioł (2019)	15
Inventory	Blöchl and Schneider (2016), Blöchl et al. (2017), Buer et al. (2018), Doh et al. (2016), Edirisuriya et al. (2018), Kolberg and Zühlke (2015), Kolberg et al. (2017), Lugert et al. (2018), Mayr et al. (2018), Romero et al. (2018), Ruiz Zúñiga et al. (2017), Ruppert et al. (2018), Sanders et al. (2016), Satoglu et al. (2018a, b), Wang et al. (2016), Yin et al. (2018)	16
Motion	Ahmad et al. (2018), Axelsson et al. (2018), Powell et al. (2018), Romero et al. (2018), Satoglu et al. (2018a, b), Wielki and Kozioł (2019)	6
Waiting	Camgoz-Akdağ et al. (2018), Ilangakoon et al. (2018), Romero et al. (2018), Sanders et al. (2016), Satoglu et al. (2018a, b)	5
Overproduction	Ilangakoon et al. (2018), Mayr et al. (2018), Powell et al. (2018), Romero et al. (2018), Satoglu et al. (2018a, b)	5
Overprocessing	Ilangakoon et al. (2018), Satoglu et al. (2018a, b)	2
Defects	Brusa (2018), Buer et al. (2018), Ma et al. (2017), Mayr et al. (2018), Powell et al. (2018), Romero et al. (2018), Sanders et al. (2016), (Satoglu et al. (2018a, b), Slim et al. (2018)	9
Skills	Buer et al. (2018), Edirisuriya et al. (2018), Ilangakoon et al. (2018), Mora et al. (2017), Powell et al. (2018), Romero et al. (2018)	6

technique. The total number of identified Industry 4.0 solutions that may support LM techniques, methods and concepts was 38.

3 Discussion and Conclusion

After analyzing the available literature on the issue of Lean Industry 4.0, we can see that there is an increasing interest of scientists in this subject. In recent years, the number of publications in this area has been systematically increasing. Despite the growing interest of scientists in the subject considered in the article, there is a research gap regarding the use of Industry 4.0 solutions in the context of the support for wastes elimination. The article structures issues related to this area and indicates

Table 2 Industry 4.0 potential support for LM

Techniques, methods, concepts	Industry 4.0 potential support	References
5S	Virtual and Augmented Reality (V&AR)	Wagner et al. (2017)
Kanban/pull signals/Just in Time/Just in Sequence	Sensors/Actuators (S&A), Automated identification/locating/inventory of WIP/goods/assets etc. (RFID, RTLS, etc.), Smart reallocation of order, Material replenishment monitoring, 3D Printing, Real-time data, Digitalization, Product controls environment, Cloud Computing, Big Data, Data Analytics, M2M Communication, V&AR, SOA, Subcontracting, Decentralized decision making	Ahmad et al. (2018), Davies et al. (2017), Enke et al. (2018), Kolberg et al. (2017), Lugert et al. (2018), Mayr et al. (2018), Mrugalska and Wyrwicka (2017), Romero et al. (2018), Sanders et al. (2016), Satoglu et al. (2018a, b), Wagner et al. (2017), Wang et al. (2016)
TPM	S&A, Data Analytics, V&AR, Machine-worker communication, Condition-based maintenance, Self-maintenance assessment, Predictive maintenance, Digitalization	Davies et al. (2017), Enke et al. (2018), Sanders et al. (2016), Satoglu et al. (2018a, b)
Andon	S&A, CPS, Wearables	Mayr et al. (2018), Mrugalska and Wyrwicka (2017)
VSM	IoT, Digitalization, V&AR, 3D Printing, Automated identification/location, Semantic Technologies, Pint-sized automation equipment, S&A	Ahmad et al. (2018), Camgoz-Akdağ et al. (2018), Davies et al. (2017), Enke et al. (2018), Lugert et al. (2018), Mayr et al. (2018), Mrugalska and Wyrwicka (2017), Wang et al. (2016)
Jidoka	IoT, S&A, CPS, Cloud Computing, SOA, Agent, Semantic Technologies, Big Data, Data Analytics, M2M Communication	Buer et al. (2018), Lugert et al. (2018), Ma et al. (2017), Satoglu et al. (2018a, b), Slim et al. (2018), Wagner et al. (2017)

(continued)

Table 2 (continued)

Techniques, methods, concepts	Industry 4.0 potential support	References
Supplier Feedback/Development	IoT, Data Analytics, Collaborative manufacturing, Better communication mechanisms, Synchronization of data, Standardized interfaces, Virtual organizations—synergetic cooperation	Sanders et al. (2016), Satoglu et al. (2018a, b)
Quality Control and Process Control	S&A, Data Analytics, Pattern Recognition, Workpiece-machine communication, Improved man–machine interface, Automated identification/location, Integration & management, Digitalization, Digital business models, Product controls environment	Enke et al. (2018), Mayr et al. (2018), Sanders et al. (2016), Satoglu et al. (2018a, b)
Setup Reduction	S&A, Automated identification/location, Self-optimization and machine learning, Workpiece-machine communication	Sanders et al. (2016), Satoglu et al. (2018a, b)
Cellular Manufacturing	Adaptive robotics, Data Analytics	Satoglu et al. (2018a, b)
Continuous flow	Automated identification/location, M2M communication	Mayr et al. (2018), Powell et al. (2018), Sanders et al. (2016)

which I4.0 solutions can be useful to the support LM tools. The article can also serve as a kind of a signpost for researchers and practitioners dealing with the reduction of LM wastes using I4.0 solutions. Thanks to the publication, it will be very easy to get to the papers related to particular types of LM wastes and support to select the LM techniques in the context of using I4.0. It should be emphasized that in the literature there is no comprehensive study regarding the subject of wastes reduction and LM support by Industry 4.0. Most publications in this area are proceedings, not journals.

There are also some limitations in the available articles. Most papers address only initial considerations regarding the possibility of reducing LM wastes with the help of Industry 4.0 or LM techniques that are supported by Industry 4.0 solutions. The descriptive approach dominates, and the presented possibilities of LM and Industry 4.0 integration in the areas of wastes reduction or support for their cooperation are at a very general level. There is a lack of empirical researches and case studies, confirming the statements presented in analyzed papers. There were not found simulation models, which might be of a great value for practitioners planning and implementing the concept of Industry 4.0. There was only one paper that approaches the set of wastes systematically (Satoglu et al. 2018a, b). However, it is limited and is based on a descriptive approach with no details. It also lacks the eight waste, which is skills. This is a strong limitation, because skills are very important for Industry 4.0 and human factor was included in the set of lean wastes long ago. The article also indicates which wastes have not been described in detail and verified by the I4.0 solutions. The publication also allows us to see which LM techniques can be supported by I4.0 solutions and which techniques the use of I4.0 has not yet been widely considered.

Further research should aim at practical verification of the possibilities of LM and Industry 4.0 integration in order to reduce wastes. It will be very important to present the research results in a quantitative (measurable) form, so that their interpretation is objective and it can be unambiguously determined whether LM and Industry 4.0 are complementary or not.

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