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Inter-dependencies Between Lean Manufacturing and Industry 4.0

A systematic state of the art literature review

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Abstract (English)

Lean Management as a concept has been available and applied in different business areas for the past 50 years and it is an already well-established and mature topic of discussion. With the introduction and development of ICTs, the symbiosis between Industry 4.0 and Lean Manufacturing is becoming more and more inevitable, eventually resulting in the concept of Lean 4.0. Given the fact that Lean Manufacturing focuses on reducing production wastes in the processes, the introduction and development of modern Industry 4.0 technologies, such as Cloud Computing, Big Data Analysis, Machine Learning, Augmented and Virtual Reality and Digitalization, support and aid the improvement of the overall Lean Manufacturing concept and implementation for the purposes of advancing business.

The purpose of this report is to analyze the existing and available research on the correlation and interdependencies between the concept of Lean Manufacturing and Industry 4.0, by exploring the points where the two concepts interact.

Abstract (Italiano)

Il concetto di Lean Management è stato applicato in diverse aree aziendali negli ultimi 50 anni ed è un argomento di discussione già maturo e consolidato.

Con l'introduzione e lo sviluppo delle TIC, la simbiosi tra Industry 4.0 e Lean Management sta diventando sempre più inevitabile, portando infine al concetto di Lean 4.0.

Tenendo conto del fatto che il Lean Manufacturing si concentra sulla riduzione di perdite di produzione; l'introduzione e lo sviluppo delle moderne tecnologie di Industry 4.0 come il Cloud Computing, Big Data Analysis, Machine Learning, realtà virtuale e aumentata e la digitalizzazione supportano e aiutano il miglioramento del concetto generale di Lean Manufacturing e l'implementazione ai fini dell'avanzamento dell'industria.

Lo scopo di questo report è di analizzare la ricerca esistente sulla correlazione e le interdipendenze tra il concetto di Lean Manufacturing e Industry 4.0, esplorando i punti in cui i due concetti interagiscono.

Keywords

Lean Manufacturing; Industry 4.0; Lean 4.0

1. Introduction

As a concept, Lean Manufacturing was developed in Japan in the early 50s' of the 20th century that was meant to be the survival strategy providing solutions to the challenges that the Japanese industry was facing after the World War II, such as damaged industrial facilities, post war reparation costs towards other countries, resource scarcity etc. Thus, the idea was to produce more Output by using less Inputs in the process. Nowadays, the companies are still aiming to improve their outputs on account of the inputs and following the original Lean Manufacturing ideas, however there are many more variables that affect the manufacturing processes on the inside and outside of its boundaries. Lean Manufacturing methods aim to reduce the wastes and as a result, improve their overall performance, in the processes defined by Sanders (2016) focusing on constantly providing an added value to the customer, however, the customer's perception of the value is changing with time. Compared to the early days of Lean Manufacturing when the concept did not include any traces of ICTs, not only do the customers of today's modern and fast-developing world expect to be able to purchase the product and have it delivered in reasonable time, but they also want to be part of the process itself and be able to define or tailor the product according to their needs. As these needs cannot be aggregated to all customers, it is in the company's best interest to create their products to satisfy the needs of as many customers as possible. Failing to do this, the companies could be doomed to collapse, caused by their own customers and are therefore at risk to being put on the margins of the market in which they operate.

The development of the ICTs has set a new ground for the development of new and more innovative solutions for the businesses which in addition, it plays a major role in the improvement and optimization of the already existing Lean concepts. As a result, in 2011 in Germany at the Hannover Fair, the concept of Industry 4.0 was conceived to address the need of a smarter, more efficient approach to production.

As stated in the work of Roblek and colleagues (2016), Industry 4.0 unifies its main features such as: **digitization**, **optimization**, **customization of production**, **automation and adaptation**, **human machine interaction (HMI)**, **value-added services and businesses** and **automatic data exchange and communication** under one platform that would systemize the way in which this topic is researched and implemented in the companies. Therefore, Industry 4.0 is a concept that enables transition from ***manual/analog*** processes into **a*utomated/digital*** processes thus creating an intelligent, self-learning system that would incorporate state of the art technologies and eventually result in a ***smart production system.***

In Bill Gates' words, *the first rule of any technology used in a business is that automation applied to an efficient operation will magnify the efficiency. The second is that automation applied to an inefficient operation will magnify the inefficiency.*

Moreover, in the paper *Integration of Industrie 4.0 in Lean Manufacturing Learning Factories* (2018), the authors Harald Bauer et al., state 90% of the highest grossing and most successful manufacturing companies enjoy their status because they have managed to successfully implement the Lean Manufacturing principles and methods within their organization. This further demonstrates that Bill Gates, a pioneer in his own right, has perfectly summarized and emphasized the reason why the interaction between Lean manufacturing methodologies and the concept of Industry 4.0 is of utter importance.

The focus of this review will be on presenting how Industry 4.0 tools enable the Lean Manufacturing processes by accepting the premise that the Lean Manufacturing and Industry 4.0 are already well-established as independent concepts and that their mutual integration could potentially result in improved production performance and lower waste rates.

2. Methodology

This literature review will follow a methodology proposed by the authors Jane Webster and Richard T. Watson, in their paper *Analyzing the past to prepare for the future. Writing a literature review* (2002). The paper will follow a two-stage approach in which during in the first stage, a manual research was conducted according to predefined keywords.

In the first stage, the research was conducted based on the databases of *Scopus*, *Google Scholar and ScienceDirect*. In the second stage, the results obtained in the first one were filtered according to certain criteria, including the language used to present the ideas and that the scope of the literature cover discussions about Lean manufacturing concepts and Industry 4.0 concepts. In addition to that, the publications that were considered for this review were evaluated according to the relevance of the topics covered.

To maintain the relevance of this review to the main topic of research and discussion, the publications that cover **both** Industry 4.0 and Lean Manufacturing were considered for further analysis. This report will follow ***an author-based*** logic, including a table where the analyzed literature will be classified in accordance with the topic that it covers and the authors that are elaborating those topics.

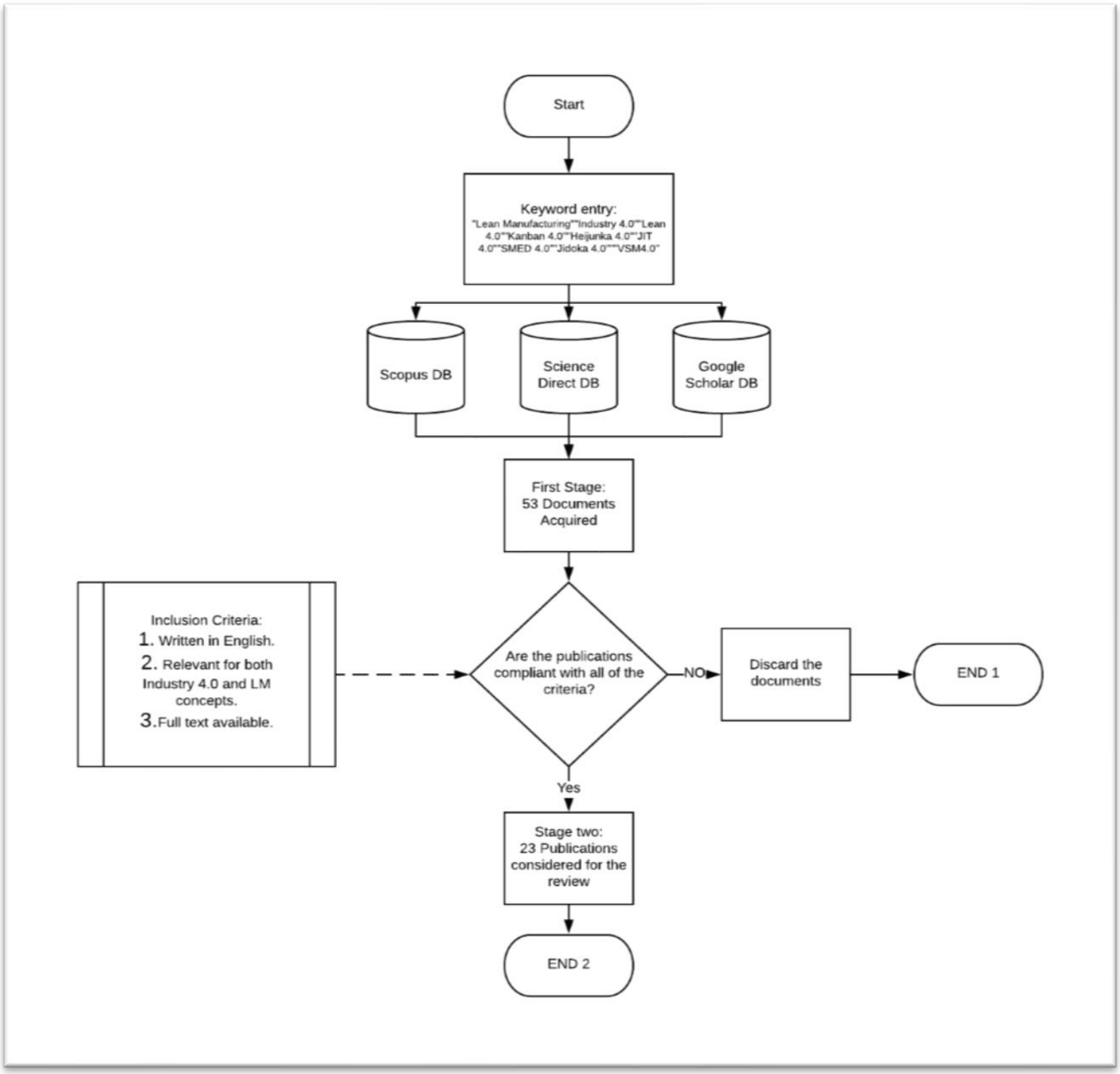


Figure 1:Visual representation of research methodology

Furthermore, the reviewed literature will be divided in three parts. Firstly, the concepts and frameworks found in the literature will be analyzed and compared, while suggestions on how to close the gaps between them will be provided, as well.

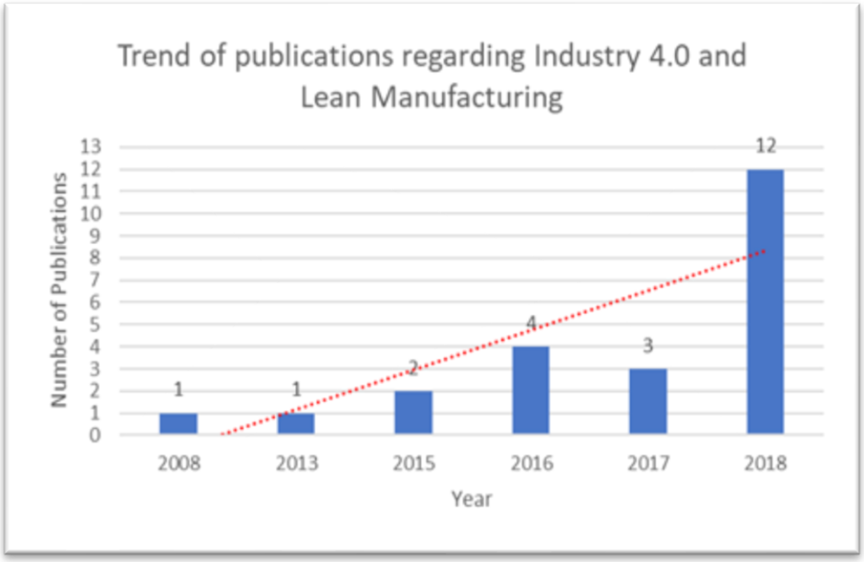
In the second part a review on the toolbox interdependencies classifications will be provided followed by the open research issues. The third part will be dedicated to complete review on the head to head tools and methods interdependencies of the two concepts and propositions for further research topics will be provided. Finally, a conclusion of the review will be provided, summarizing all the discussions present in the review.

3. Statistical overview on the performed research

In this section a statistical overview on the performed research will be provided. The aim of this section is to point out the trends in research activities concerning the topic of interdependencies between Lean Manufacturing and Industry 4.0.

	Publishers						
Year	Elsevier	Springer	OmniaScience	SciRp	Taylor&Francis	Informa UK	Conference Publication
2008	---	1	---	---	---	---	---
2013	---	---	---	---	---	---	1
2015	2	---	---	---	---	---	---
2016		1	1	1	1	---	---
2017	3	---	---	---	---	---	---
2018	9	2	---	---	---	1	---

Table 1: Number of publications arranged by year versus publishing house



Graph 1:Trend of number of publications in the last 10 years

The visualization in Graph 1 shows clear positive trend in the last years. This analysis shows that the interdependencies of the two concepts are becoming more and more interesting for the researchers. Additionally, from the Figure 2 can be seen that 78% of the published works are published by the two most famous publishing houses such as Elsevier and Springer which clearly shows that they are interested in publishing research topics regarding the interdependencies of the two concepts.

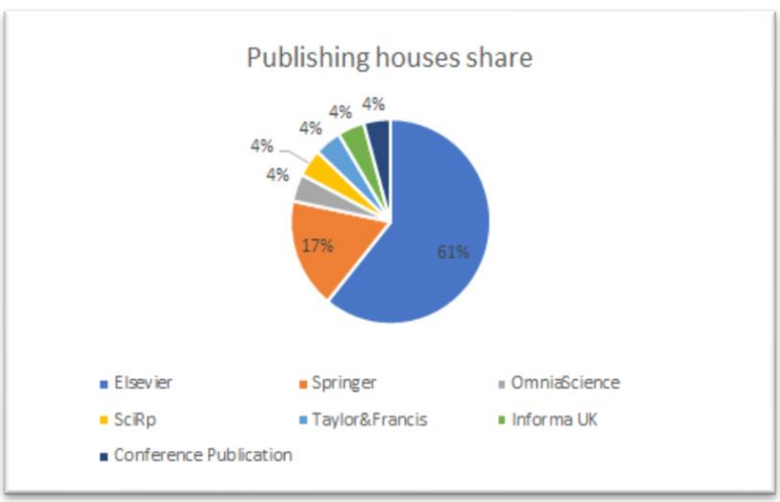


Figure 2:Publishing houses share

In the next table a complete representation of the classification of the publications kept for this review is shown.

Authors	Publications Title	Review Article	Book chapter	Case study
Azambuja, M., Schnitzer, T., Sahin, M., Lee, F.	ENABLING LEAN SUPPLY WITH A CLOUD COMPUTING PLATFORM – AN EXPLORATORY CASE STUDY			✔
Kolberg, D., Zühlke, D.	Lean Automation enabled by Industry 4.0 Technologies	✔		
Dave, B., Kubler, S., Framling, K., Koskela, L.	Opportunities for enhanced lean construction management using Internet of Things standards			✔
Thürer, M., Pan, Y.H, Qu, T., Luo, H., Li, C., Huang G.Q.	Internet of Things (IoT) driven kanban system for reverse logistics: solid waste collection			✔
Sanders, A., Elangeswaran, C. & Wulfsberg, J.	Industry 4.0 Implies Lean Manufacturing: Research Activities in Industry 4.0 Function as Enablers for Lean Manufacturing	✔		
Rüttimann, B.G., Stöckli, M.T.	Lean and Industry 4.0—Twins, Partners, or Contenders? A Due Clarification Regarding the Supposed Clash of Two Production Systems	✔		
Kolberg, D., Knobloch, J., Zühlke, D.	Towards a lean automation interface for workstations	✔		
Dombrowski, U., Richter, T., Krenkel, P.	Interdependencies of Industrie 4.0 & Lean Production Systems - a use cases analysis -			✔
Mrugalska, B., Wyrwicka, M.K.	Towards Lean Production in Industry 4.0	✔		
Wagner, T., Herman, C., Thiede, S.	Industry 4.0 impacts on Production systems	✔		
Krishnaiyer, K., Chen, F.F., Bouzary, H.	Cloud Kanban Framework for service operations management			✔
Dombrowski, U., Richter, T.	The Lean Production System 4.0 Framework – Enhancing Lean Methods by Industrie 4.0	✔		
Kumar, M., Vaishya, R.,	Real Time monitoring system to Lean Manufacturing			✔
Bauer, H., Brandl, F., Lock, C., Reinhart, G.	Integration of Industrie 4.0 in Lean Manufacturing Learning Factories			✔
Prinz, C., Kreggenfeld, N., Kuhlenkotter, N.	Lean Meets Industry 4.0 - a practical approach to interlink the method world and cyber - physical systems	✔		
Goienetxea, A.U., Nga, A.H.C., Moris, M.U.	Supporting the lean journey with simulation and optimization in the context of Industry 4.0	✔		
Kouri, I.A., Saalmimaa,T.J., Vilpola, I.H.	The Principles and Planning Process of an Electronic Kanban System		✔	
Mayr, A., Weigeit, M., Kuhl, A., Grimm, S., Erll, A., Potzel, M., Franke, J.	Lean 4.0 - A conceptual conjunction of lean management and Industry 4.0			✔
Sony, M.	Industry 4.0 and lean management: a proposed integration model and research propositions	✔		
Wagner, T., Herman, C., Thiede, S.	Identifying target oriented Industrie 4.0 potentials in lean automotive electronics value streams			✔
Buer S.V., Fragapane G.I., Strandhagen J.O.	The Data Driven Process Improvement Cycle:Using Digitalization for Continuous Improvement	✔		
Hartmann , L., Meudt, T., Cevikcan, E., Durmusoglu, M.B.	Value stream method 4.0: holistic method to analyse and design value analyze value streams in digital age			✔
Satoglu, S., Emre, A.U.	Lean Production Systems for Industry 4.0		✔	

Table 2: Classification of the publications kept for this review

4. Framework Interdependencies

In this section, a review of the available literature on the framework interdependencies of the two concepts will be provided. The publications are classified and will be reviewed in accordance to three main features:

1. ***Integration*** - The author has discussed the idea of an integrated Lean manufacturing and Industry 4.0 model.
2. ***Methodology*** - The author has discussed potential steps that would achieve integrated Lean manufacturing and Industry 4.0 model.
3. ***Performance*** - The author has discussed performance measurements.

	Kolberg, D. et al.(2015)	Rüttimann, B.G. et al.(2016)	Dombrowski U. et al (2017)(2018)	Sony, M (2018).
Integration	✔	✔	✔	✔
Methodology	---	---	---	✔
Performance	---	✔	✔	---

Table 3: Research broadness per author

As visually represented in Table 3, all authors whose work was considered for this portion of the literature review, have proposed an overview of the scope of integration between Lean Manufacturing and Industry 4.0. On the other hand, the methodological and performance features are not equally represented, as only one of the authors has offered their views on the methodologies that would result in a unified model, while two of them have offered their views on performance results.

A **full** overview on all topics has only been supplied by the author Bruno G. Rüttimann and colleagues' *Lean and Industry 4.0—Twins, Partners, or Contenders? A Due Clarification Regarding the Supposed Clash of Two Production Systems* (2016).

4.1 Integration

As previously stated, Industry 4.0 is a relatively new and still-developing concept, whereas Lean Manufacturing as a concept is already well established, analyzed and implemented by the majority of the manufacturing-oriented companies. Consequently, the authors and engineers that are researching the area of the interdependencies between the two concepts, would often say that a unified framework is yet to be introduced (Kolberg, et all. 2016).

In his work, Rüttimann and Stöckli (2016) propose that the individual frameworks of the two concepts are already well established and that the best way to integrate these concepts is to introduce them under the platform of CPPS (Cyber Physical Production System). This means that an organization should respect the already established Lean principles in the physical world and to follow the value stream by engaging the technologies that are currently available as part of the Industry 4.0 platform, focusing mainly on the production and logistics aspects of the organizations.

On the other, hand in *Lean Automation enabled by Industry 4.0 Technologies* (2016) Kolberg and team argue that Lean Manufacturing as a concept has already reached its limits and currently, does not provide solutions for the modern challenges in the market, such as the need of production of a single customized product. Furthermore, not only do the authors state that the concept of Lean Manufacturing cannot cope with the modern market trends, but it does not provide insights of how to integrate the modern ICTs into its principles either. It can therefore, be concluded that Kolberg and team's (2016) framework is loosely accepting the fundamentals of the Lean Manufacturing framework, and by adding the adjective "Smart" before every LM object, his ideas match the ones proposed by Rüttimann and Stöckli (2016), showing that Lean Manufacturing should not be present only in a physical system, but instead needs to be understood as Cyber Physical System.

In 2018, in the paper *The Lean Production System 4.0 Framework – Enhancing Lean Methods by Industrie 4.0* Dombrowski U. and colleagues represent the individual frameworks of Industry 4.0 and Lean Production Systems and offers a proposition of a unified Lean Production Systems 4.0 framework. In their work, the Lean Manufacturing organization would ideally be divided in 5 hierarchical levels, including: *Goals, Processes, Principles, Methods and Tools,* as the authors emphasise the importance of the Industry 4.0 concepts on the Processes, Methods and Tools levels (Dombrowski and colleagues 2018). Therefore, Dombrowski et al. cover a broader overview of the vertical integration of the Industry 4.0 concept into the Lean Manufacturing environment. In another article Dombrowski U. et al. (2017) propose a framework based on the processual influence versus the technical aspects based on the Industry 4.0 concept.

Finally, in his work Sony, M. (2018) attempts to propose a model enabled entirely by Lean Manufacturing principles as he argues that a clear distinction between the integration strategies has to be done. In fact, he suggests an integrative model for vertical, horizontal and end to end integration of the two concepts. Each of the integration models is described as an iterative cycle formed by the very basic principles of Lean Manufacturing concept, such as: *Identify value, value stream mapping, create flow, establish pull and seek perfection*.

4.2 Methodology

In the databases indicated in the *Methodology* portion of this paper, very few sources referring to the implementation methodologies and steps of a unified framework can be found. In fact, the only source on the implementation methodology of the integrated framework available is the work by Sony M. *Industry 4.0 and lean management: a proposed integration model and research propositions (*2018) in which, the author clearly describes the steps required for an organization that to be able to integrate both the concept of Lean Manufacturing and Industry 4.0, starting with a strategy, all the way to the operational level.

4.3 Performance

As mentioned in the beginning of this section, performance refers to the outcomes and results of implementation of a unified model of the two concepts. Leads to this notion can be found in Rüttimann and Stöckli's work, in which the author explores the performance change of some key Lean Manufacturing features after a unified framework is applied such as the flexibility, pull system, production flow etc.

4.5 What can be learned from the available literature?

Due to the recentness of the topic of the integration between Lean Manufacturing and Industry 4.0, not many information about integrative frameworks, concepts nor implementation steps are available in the literature. By analyzing and reviewing the publications regarding the frameworks suggested, it can be learnt that a conjunction between the two concepts in form of a framework is indeed possible. What we can conclude after analyzing the publications is that several different points of view are accepted depending of the specific case on which the authors refer to. In particular it is known that one can accept a more general or strategic point of view, as demonstrated by Dombrowski U. (2018) or to build up on a more specific operational related point of view described by Kolberg and Zühlke (2015), whereas Sony M. (2018) proposes a framework that emphasizes the importance of the vertical, horizontal and the end to end integration of such a concepts.

4.6 Open research issues on the topic

4.6.1 Conceptual frameworks integration research propositions

In terms of conceptual frameworks interdependencies between Lean Manufacturing and Industry 4.0 several open issues are present. In fact, all of the authors presented in this review are agreed upon the fact that a unified framework indeed is missing. The main differences between the research activities of the authors can be found in the broadness of the integrational framework proposed. Thus, the future research should be focused on a modular framework that will unify the different points of view of the authors. Which means that in one single framework the importance of strategic, business and operational roles as well as the role of different integrational levels such as vertical, horizontal and end-to-end integration should be emphasized. Finally, the appropriate technological opportunities offered by the two concepts should be plugged in the appropriate module of the framework.

Another interesting question for a future research topic could be If the framework should be limited to a single organization usage or with the latest technological advancements this framework can also integrate third parties outside the organization boundaries such as: customers, supplies, government etc.?

4.6.2 Methodology research propositions

With respect to the methodologies, a clear methodological reference is missing. It is still unclear where should one start with the implementation of the combined concept of Lean Manufacturing and Industry 4.0, whether the Lean principles should be the starting point or the Industry 4.0's, or it might be that parallel implementation should be the best. Thus, a research topic on this issue could clearly set a roadmap of implementation steps that could help the future implementers to better cope with the challenge of implementation.

4.6.3 Performance research propositions

In the presented literature, a performance evaluation of the integration of the two concepts is rarely present. Thus, future research proposition could be definition of performance indicators that could guide the implementers through the process of implementation. The performance indicators should be able to represent the effects of the integrated concept in terms of: *costs, quality and risk*. Furthermore, indicators are needed to point out the effects of such integration on the internal human relationship as well as the change in overall management performance. Of course, one of topics of future research should be whether such integration will affect the socio-economic and environmental conditions of the entire system.

5. Toolbox Interdependencies

The **Toolbox Interdependencies** section of this literature review will discuss and review the presence of the concept of a combined Industry 4.0 and Lean Manufacturing toolbox proposed in the literature considered for this paper.

Firstly, a short representation of the toolboxes of the two concepts will be provided. The definitions of each tools, methods and methodologies covered by this literature review will be provided in the next section in order to keep the consistency and the integrity of the study.

In Figure 3 the house of Toyota Production System is represented which is the basis of later defined Lean Manufacturing concept.

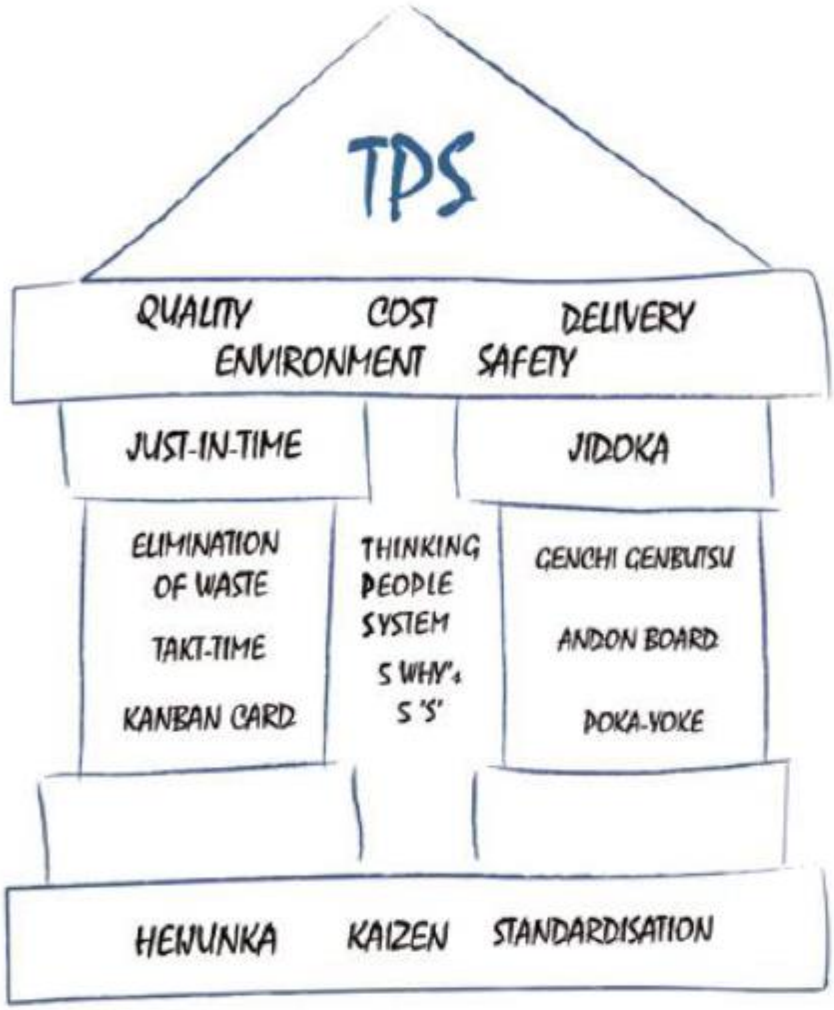


Figure 3:Visual Representation of the Toyota Production System (TPS)

Understanding the framework of Toyota Production System is crucial in order to set the pillars of a strategic integration of Lean Manufacturing and Industry 4.0 concepts. Furthermore, the general representation and definition of the Industry 4.0 technologies and tools will be illustrated. The aim of the representation of the two concept's toolboxes is to visualize the initial stage where there are two already defined concepts and to follow up integration propositions of a unified concept based on the Industry 4.0 and Lean Manufacturing Toolboxes.

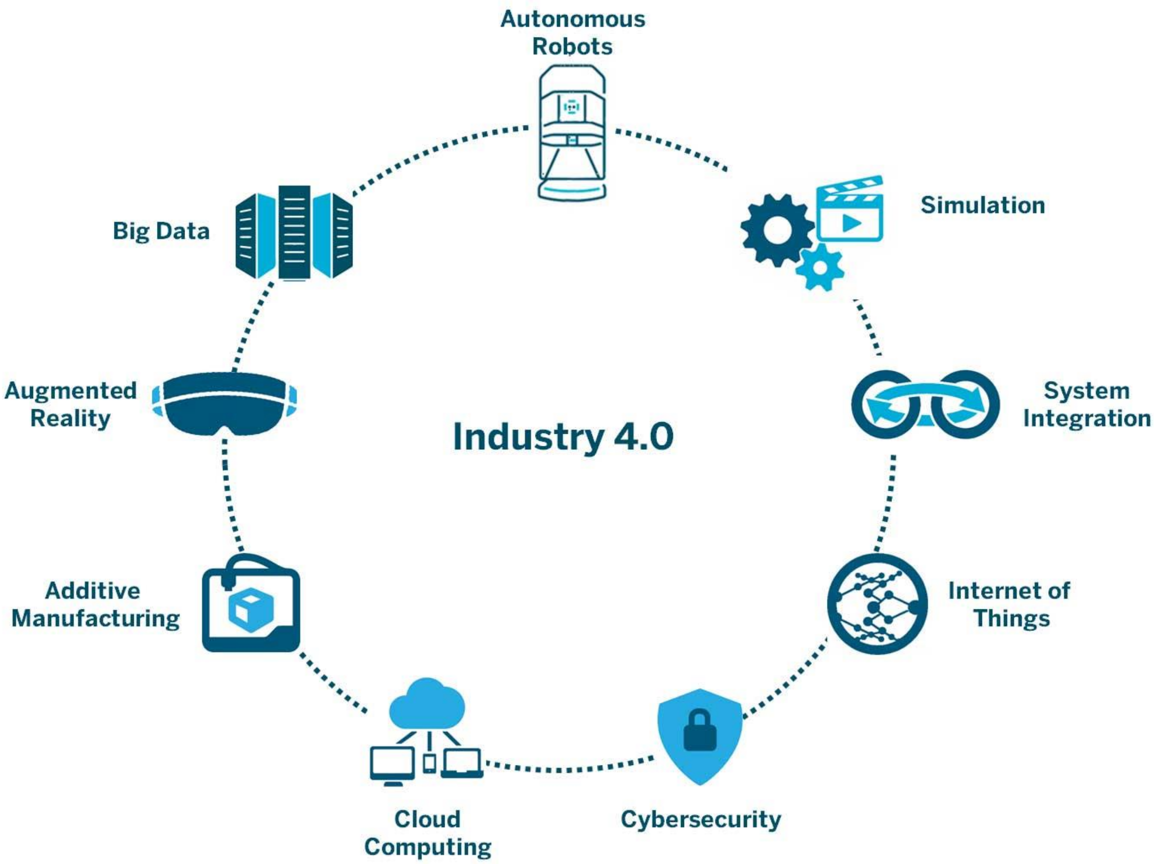


Figure 4:Representation of the Industry 4.0 tools and technologies

This section differs from the empirical (head-to-head) section because the idea of an integrated Industry 4.0 and Lean Manufacturing model is still in early development. Consequently, it is can be said that there are numerous sources that elaborate the topic of conceptual interdependence of the tools of the two concepts, rather than jumping straight into a detailed head-to-head research on specific interdependence of the tools. However, this type of head-to-head research is preparing the ground for developing a clear toolbox framework on which future research can be built.

In Figure 4 a classification of the authors elaborating specific Lean Manufacturing tools enabled by Industry 4.0 tools is provided. Each of the tools has keep their original Lean Manufacturing titles, however the extension “4.0” has been added. The reason for this is because all the authors are exploring the topic of how the Lean Manufacturing tools can further be improved and optimized by means of enabling the Industry 4.0 tools.

Lean Industry 4.0 Tools	Sanders A. et al. (2016)	Dombrowski U. et al. (2018)	Mrugalska B. et al. (2017)	Wagner T. et al. (2017)	Prinz, C. et al. (2018)	Mayr, A. et al. (2018)	Satoglu, S. et al. (2018)
JIT 4.0	✔	✔	---	✔	---	✔	---
Kanban 4.0	✔	✔	✔	✔	✔	✔	✔
Jidoka 4.0	✔	✔	✔	✔	✔	✔	✔
Andon 4.0	---	✔	---	---	---	✔	---
Kaizen 4.0	---	✔	---	✔	---	✔	✔
VSM 4.0	---	---	---	✔	---	✔	---
Poka Yoke 4.0	---	✔	✔	✔	✔	✔	---
Heijunka 4.0	---	✔	---	✔	✔	✔	---
SMED 4.0	✔	✔	✔	---	---	✔	✔

Table 4:Lean tools researched by authors

5.1 Tool-based approach

From the classification showed in the Figure above, it is easy to notice that the broadness of the tools and techniques researched is not the same for all the authors. Some of the authors provide a more focused research on specific Lean Manufacturing tools while others aim to explore all possible interaction points between the toolboxes of the two concepts.

In the work of Wagner T. et al. *Industry 4.0 impacts on Production systems* (2017) and Mayr A. et al. *Lean 4.0 - A conceptual conjunction of lean management and Industry 4.0* (2018), cross-matrices of the interdependencies of the tools are introduced, however both authors take different approaches.

On the one hand, by defining the tools for each concept, Wagner proposes a matrix that only includes the possible interaction between the tools, in addition to providing a one directional evaluation of the impact of Industry 4.0 tools on Lean Manufacturing tools. On the other hand, Mayr and colleagues' matrix shows the interaction opportunities and possibilities among the tool sets.

Nevertheless, fundamental differences between the two matrices can clearly be seen even though both of the authors are elaborating the same topic, mostly because neither of the authors has provided a individual evaluations on each available method.

5.2 Resource-based approach

Mrugalska and Wyrwicka (2017) offer a different point of view on the subject. In *Towards Lean Production in Industry 4.0* (2017), the author considers a more "resource-based" approach. Instead of plainly showing the points of interaction among the toolboxes, the author exploits the resources included in the whole production process by showing how the combination and merging of the different tools can result in what they refer to as a *Smart Product, Smart Machine and Augmented Operator.*

5.3 Reduction of wastes-based approach

Satoglu, S. (2018) shows the interaction of the tools of the two concepts by establishing an approach that aims to reduce the wastes in the production system. Although it is a fact that every Lean Manufacturing tool mainly aims to reduce the wastes in the production, Sule's point of view clearly gives more freedom of tool combination for the purpose of achieving the operational goals of the organizations, all in the spirit of Lean Manufacturing, by introducing and adding the tools of Industry 4.0. What is more, a technology ladder of the combination of the tools of both of the concepts is provided.

Prinz C. and colleagues (2018) propose an approach similar to the one by Satoglu (2018), the difference being that instead of the well-known production wastes defined by Ohnno T. (1978), Prinz and colleagues focus on the challenges that commonly occur in the production system, such as overproduction, machine failure etc. To support their ideas, the authors of *Lean Meets Industry 4.0 - a practical approach to interlink the method world and cyber - physical systems* (2018), provide a table of the possible solutions offered by Lean Manufacturing and Industry 4.0, independently one from the other.

5.4 What can be learned from the available literature?

From the available literature, different points of view in terms of conceptual toolbox interdependencies classification can be acquired. In fact, the authors tend to classify the toolbox interaction according to the problem that the toolbox combination is supposed to resolve. Consequently, classifications are present according to the needs to minimize some specific wastes in the production, then, classifications according to the object of interest and classifications based on what the authors consider as relevant tools for the possible interaction. In any case, a broad vision of possible interaction can be found in the literature that could be a perfect starting point for future research on the topic.

5.5 Open research issues on the topic of conceptual toolbox interdependencies

Unfortunately, in the literature available and reviewed in this paper, the authors seem to have different perspective on the same toolboxes, which is why their research lacks consistency and does not result in the much-needed unified toolbox matrix.

For researchers and engineers to be able to provide a unified matrix of toolbox interdependencies, all available methods need to be indexed, clearly defined and correctly classified.

6. Head-to-head research on the interdependencies of the tools and methods

In this section of the literature review, the author will provide a cross-matrix of the Industry 4.0 and Lean Manufacturing tools. The classification was conducted by taking into consideration the publications based around the idea of a specific cross tools empirical and theoretical research and the authors that covered their findings in research papers.

Several the publications in this area are based on case studies in which the solutions of the integrated toolbox of the two concepts have been applied. The aim of this section is to present what has been researched so far, what are the effects of the implementation of the integrated toolbox, the gaps of the known and unknown, and to give propositions for future research in this area.

The review of this section of the literature has been completed Lean-wise, which means that emphasis is put on the findings of implementation of the Industry 4.0 tools towards Lean Manufacturing tools. For this reason, in the first part, general definitions of the Industry 4.0 tools, methods and technologies will be provided, whereas regarding to the Lean Manufacturing methods, the definitions will be provided in the part where the actual head to head interdependencies will be elaborated.

- ***Internet of things*** - According to Patel K. K. and Patel M.S. (2016), Internet of things (IOT) can be defined as a network of physical objects. The authors suggest that the internet is not only a network of computers, but it has evolved into a network of device of all type and sizes , vehicles, smart phones, home appliances, toys, cameras, medical instruments and industrial systems, animals, people, buildings, all connected ,all communicating & sharing information based on stipulated protocols in order to achieve smart reorganizations, positioning, tracing, safe & control & even personal real time online monitoring , online upgrade, process control & administration. Furthermore, Patel K. K. and Patel M.S. define IOT into three categories as below: Internet of things is an internet of three things: (1). People to people, (2) People to machine /things, (3) Things /machine to things /machine, Interacting through internet.

- ***Cloud Computing*** – The National Institute of Standards and Technologies (NIST) (2011) of the U.S.A. defines Cloud Computing as a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction.
- ***Simulations*** – As defined by Banks J. and colleagues (2001), simulation is an approximate imitation of the operation of a process or system. The act of simulating first requires a model is developed. This model is a well-defined description of the simulated subject, and represents its key characteristics, such as its behavior, functions and abstract or physical properties. The model represents the system itself, whereas the simulation represents its operation over time.
- ***Big Data and Data Analytics*** – According to Breur T. (2016), Big data is a field that treats ways to analyze, systematically extract information from, or otherwise deal with data sets that are too large or complex to be dealt with by traditional data-processing application software. Data with many cases (rows) offer greater statistical power, while data with higher complexity (more attributes or columns) may lead to a higher false discovery rate.
- ***Augmented and Virtual Reality*** - Patrick, S. (2017) and the famous Huffington Post (2016) define Augmented Reality as an interactive experience of a real-world environment where the objects that reside in the real-world are “augmented” by

computer generated perceptual information, sometimes across multiple sensory modalities. Whereas, a definition of Virtual Reality can be found in Chavan S. R. (2016) and it states that Virtual Reality is an artificial environment that is created with software and presented to the user in such a way that the user belief and accepts it as a real environment. Virtual realities artificially create sensory experience, such as sight, touch, hearing, and smell.

- ***Additive Manufacturing*** – According to Tofail S.A.M and colleagues (2018), Additive manufacturing makes 'objects' from a digital 'model' by depositing the constituent material/s in a layer-by-layer manner using digitally controlled and operated material laying tools. Furthermore, they highlight fore main components of Additive Manufacturing: (1). A digital model of the object, which can vary from a pizza slice to an aero plane wing. (2). Material/s that are consolidated from the smallest possible form for example liquid droplets, wire, powder to make the object. (3). A tool for laying materials and (4). a digital control system for the tool to lay the material/s layer-by layer to build the shape of the object.

A representation of the literature classification is shown in Table 5.

Industry 4.0 Tools & Methods

Lean Manufacturing tools & methods	*IOT*	*Cloud Computing*	*Simulations*	*Big Data and Data Analytics*	*AR and VR*	*Additive Manufacturing*
Kanban	***[18][16]***	***[18][19] [20][21]***	---	---	---	---
JIT	***[10]***	***[10]***	***[23]***	***[10]***	---	---
VSM	---	---	***[23][11]***	***[25]***	---	---
Jidoka	***[20]***	***[20][26]***		***[20]***	***[11]***	---
Heijunka	---	---	---	***[11]***	---	---
TPM	---	***[11]***	---	***[11]***	---	---
CI	---	---	---	***[27]***	---	---
SMED	---	---	---	---	---	***[11]***

Table 5: Cross tools vs. authors matrix of the researched area

From Table 5, it is easy to conclude that some of the areas are of strong interest to the researches while others are not. The table is organized in such a way, that the most researched areas are pointed out in the top left portion of the table. It is worth mentioning that for some tools of the two concepts, the points of interaction are unfeasible, or the effect of combining of some tools does not improve the overall performance in any significant way.

Nonetheless, a detailed review will be provided, and all matters will be discussed more precisely in further text.

6.1 Kanban and Industry 4.0

Kanban has been one of the most interesting topics of research as it is the hearth of the Pull System strategy introduced by the Toyota Motor Company. After it was first implemented, Kanban has found a broad usage in many industrial companies in dealing with the wastes such as overproduction, transportation, waiting and unnecessary inventories (Ohno 1978). Literally translated from Japanese, Kanban means a signal card that authorizes the start of the production processes or movement of the materials through the production chain.

By combining Kanban with the tools of Industry 4.0, the method becomes the engine of not only the internal production and logistics processes, but also of the the entire horizontal and vertical supply chain in the companies that utilizes it. The effects that Industry 4.0 have on Kanban-based systems, especially as part of the digitization of the processes, are the cause why this method of Lean Manufacturing is one of the most popular for the researchers.

6.2. Kanban and Internet of Things (IOT)

	Author	
Kanban & IOT	*Kouri, I.A., Saalmimaa,T.J., Vilpola, I.H.*	*Thürer, M., Pan, Y.H, Qu, T., Luo, H., Li, C., Huang G.Q.*
Concept/Framework	✔	✔
Methodology	✔	✔
Performance	✔	

Table 6: Kanban and IOT research broadness vs. authors

The journey of combining advanced telecommunication technology with the Kanban systems starts in the late 80s' of the last centuries, however the first literature sources on the topic date back to the end of the first decade of the 2000s' when the advantages of the latest technologies are becoming more and more interesting for implementation not only in the advanced technical processes but in more management-oriented areas as well. The author of *The Principles and Planning Process of an Electronic Kanban System,* (2008), Kouri I.A. et al. represent the ideas of a, what is referred to as, an E-Kanban system, years before the actual Industry 4.0 platform was established or even introduced. An entire manufacturing and assembly process is represented through a case study in order to support the design of the Electronic Kanban System. Through the case study, *a user-centered design* methodology of the system is provided as well as training practices for the users of the system. The main communication technology used is *RFID (Radio Frequency Identification)*. Based on simulation of a real manufacturing and assembly activities, Kouri I. A and colleagues (2008) define the main advantages of the Electronic Kanban System over the traditional system such as*: Removing the problem of lost cards, On time delivery, minimal time and effort for card handling, minimal material shortage, improved supply chain transparency and improved analysis of the supplier efficienc*y.

Thürer and team (2016) provides a case study for solid waste collection by utilizing a Kanban System powered by IOT technology. In his work, *Internet of Things (IoT) driven Kanban system for reverse logistics: solid waste collection* (2016) similarly to what is proposed by Kouri I.A. the system is based on *RFID* tags. The main difference from the traditional Kanban systems is that in Thürer M. and colleagues' work, the topic is based on "reverse logistics" which means that in this case, the Kanban bins are not emptied by the customers but instead they are filled. The case study of solid waste collection provides useful knowledge of how the architecture of such a combination of tools should look like. The architecture is based on RFID tags that are communicated via wireless technology to the Cloud Computing unit and the "Smart Trucks" which in turn, are tracked via GPRS technology. By means of cloud computing, a larger amount of data can be calculated and transformed into useful information for the time of collection of the filled bins. Moreover, Thürer states that IOT, Kanban combination overcomes the main wastes of the traditional systems for solid wastes collection such as the waste of unnecessary motion. In his example, the calculation of the level of waste in the bins is performed in real time and, through cloud computing, the optimal route of the smart trucks is calculated and communicated through wireless communication. Finally, the leveling is done by Heijunka that gets updated in real time depending on the level of wastes in the bins.

The work of Thürer M. and colleagues (2016) is an excellent example of how the interaction of the two tools can significantly improve the process of solid wastes collection. The detailed architecture of the system provided is a useful knowledge for future researchers in this area. Even though a methodology is present, in the case study does not include information of the ways in which the implementation of this system affects the quality, costs and the performance of the service provided.

6.3 Kanban and Cloud Computing

Kanban & Cloud Computing	Author: Krishnan Krishnaiyer, F. Frank Chen, Hamed Bouzary	Kolberg, D., Knobloch, J., Zühlke, D.	Dave, B., Kubler, S., Framling, K., Koskela, L.	Azambuja, M., Schnitzer, T., Sahin, M., Lee, F.
Concept/Framework	✔	✔	✔	✔
Methodology	✔		✔	
Performance				✔

Table 7: Kanban and Cloud Computing research broadness vs. authors

According to Oktadini, N.R. and Surendro K. (2014), Cloud computing is one of the most famous tools of Industry 4.0 and it deals with computation, software, data access and storage services that may not require end-user knowledge of the physical location and the configuration of the system that delivers the services (SLA cloud Irrelevant literature). This type of computing allows the organizations to utilize enormous amount of data as well as data storage space for significantly lower costs with respect to the traditional server networks. The combination of the two methods results with faster gathering and transforming of the data into useful information. Additionally, by utilizing the Kanban system supported by Cloud Computing, the industries can broaden the area effects of the Kanban system not only in their local production environment but also spread these effects through a broader supply chain activity.

In the literature, the interaction of Kanban is closely tied to both Cloud Computing and Internet of Things, at the same time. This is understandable if we consider the fact that in the entire system, Kanban is the main information carrier whose data is stored and analyzed on Cloud servers so that finally, these information and data are emitted to the users via Internet communication and vice versa. However, in this review a division is applied in order to keep the consistency in terms of tools and techniques and to point out easily the gaps and future research options.

In the literature several case studies are available on the integration of the Cloud Computing tools into a Kanban system.

Azambuja et al. (2013) provide an example of Kanban System through a simple supply chain powered by Cloud Computing. In their work, *Enabling Lean Supply with a Cloud Computing platform – An exploratory case study* (2013) the information and material flow through the production and supply of Pipe spools is supported by Kanban system powered by **Google Fusion Table** cloud – based platform. The supply chain is described as a process formed by: *Engineering Design of the spools, Fabrication of the spools, delivery and on-site installation of the spools*. By applying the GFT platform, a real time integration and update of the information from every process in the supply chain was achieved that lead to a significant reduction of the Lead Time from design to installation as well as smoothing the flow of the operations inside the organization.

In *Towards a lean automation interface for workstations* (2016), Kolberg and colleagues. propose an interface framework for automated workstations supported by CPS (Cyber Physical Systems). An architecture is proposed, and the basic requirements of the Kanban system are listed as well. Moreover, a clear framework of the technology needed for an automated workstation is described. From a performance point of view, Kolberg et al. (2016) stress the main advantages of using digital Kanban System powered and governed by Cloud Computing platform such as: overcoming the problem of lost card, real time information of the movement of the materials and the fact that this type of integration neglects the time needed for changing the Kanban cards when a different type of product is introduced in the workstation.

Another example of the industry is the one provided by Dave and team from the construction industry. The author in *Opportunities for enhanced lean construction management using Internet of Things standards* (2015), described the main problems that the construction industry faces in project execution. Furthermore, the author identifies that there is lack of communication between the management, on-site workers and the internal production of the materials. As a possible solution, Dave B. at al. (2015) propose a rather interesting model where the Kanban cards are not digitized at all. Instead a camera and computer vision are used to capture and identify the tasks level of accomplishment, the level of the raw materials needed and consequently, this data through a cloud platform are transformed into useful information that trigger the movement of the material from the company's warehouse and consequently the order or production of new materials.

The approach of the Dave and colleagues (2015) can be justified by the fact that the construction industry is followed by many constraints in terms of resources, location and time. Thus, the utilization of such an approach enables the opportunity to exploit the advantages of a Kanban system, governed by Cloud platform which not many years ago was considered as impossible task in the construction industry.

For the purpose of research, the authors utilize the **VisiLean** cloud platform where all the involved parties are connected to the cloud server and can have a real time information update on the ongoing projects. Even though the article lacks information for the reader regarding the performance improvement or deterioration before and after the implementation, it still represents a clear and detailed methodology of the ways in which Kanban and Cloud Computing can be integrated.

Even though, the birth of Kanban is strongly connected to the manufacturing industry, it is also widely utilized in other sectors, such as the services. Although there are not many authors that elaborate the integration of Kanban and Cloud Computing in a service-oriented environment, Krishnaiyer K. et al. (2018) elaborate a Cloud Kanban framework for service Operations Management as well. In the field of service operations management, Kanban is mostly used to cope with the execution of the tasks that form the service provided. For this purpose, in his work *Cloud Kanban Framework for service operations management* (2018), Krishnaiyer and colleagues show how a Cloud Kanban system can improve the planning and execution of the tasks in the service-oriented companies. The research of these authors is a short and clear overview of the possibility to use **Microsoft Azure Web Service** as an application service, **SQL** as a database and the **Ant Colony System Algorithm** as a computing tool. The outcome of the research is obtaining the optimal planning and scheduling of the tasks. Although Krishnaiyer and team (2018) point out that this type of integration of Cloud computing and Kanban shows better performance with respect to the traditional systems, a further analysis is needed to support this claim.

6.4 Just-in-time and Industry 4.0

	Author	
Just-in-time & Industry 4.0	*Wagner, T., Herman, C., Thiede, S. (2017)*	*Goienetxea, A., Nga, A.H.C., Moris, M.U. (2018)*
Concept/Framework	✔	✔
Methodology	✔	
Performance		

Table 8: Just-in-time and Industry 4.0 research broadness vs. authors

As defined by Ohno (1978), "*Just-in-time is the act of having the right part at the right time in right amount*". As a methodology of Lean Manufacturing in the literature, Just-in-time often coincides with other methods that are mainly concerning with optimizing the flow of material and information especially with Kanban. However, Just-in-time should be understood as a methodology that is on a higher level than the other methods like Kanban. Often the general opinion about Just-in-time is that it is a utopia that it is very hard to achieve. This opinion arises from the fact that often the organizations that claim having a sustainable level of Just-in-time practices and that have significantly minimized the wastes in their processes, are indirectly transferring its wastes to the suppliers. Moreover, having in mind that the strong deviations in market demands conflict with required levelled capacity utilization by Just-in-time as noted by Kolberg and Zühlke (2015), it becomes very clear that improvements on the existing methods of Just-in-time are necessary and Industry 4.0 is the right way to achieve this.

At the core of Industry 4.0 are the tools needed to successfully cope with mass customization market needs, thus the combination of these two methods should help the organizations to meet these needs.

Empirical study of the Just-in-time interaction with the industry 4.0 methods can be found in *Industry 4.0 impacts on Production systems* (Wagner et al., 2017), a use case regarding Just-in-time delivery of electrical parts assembly. Wagner and team propose a model where the Just-in-time system is governed by a server on which all the parties of the vertical and horizontal supply chain are interconnected and can have real time access to the data. The traditional Kanban cards are removed and instead, an IOT machine-to-machine communication is introduced. In this way, the production orders, as well as the delivery orders from the vendors and the warehouse are done in real time by issuing RFID tags. The scheduling of the orders for the suppliers is done by collecting Big Data of the machines and the overall production. Consequently, this Big Data is transformed in useful information and transferred to the suppliers. In this case study (Wagner et al., 2017), a methodology for implementing a CPPS into Lean Manufacturing oriented company is available. However, not much knowledge on the performance change, both before and after the implementation, can be acquired and therefore, the success of the project is evaluated only from the point of view of Industry 4.0.

Regarding the utilization of simulations in support of Just-in-time systems, in the literature that is currently available, there are not many sources present. In *Supporting the lean journey with simulation and optimization in the context of Industry 4.0* (2018), Goienetxea et al. propose basic suggestions on how the simulations and data analytics can facilitate the use of Just-in-time system. Furthermore, a framework for combinations of the tools is provided, combined with knowledge regarding methodology and performance comparison cannot be acquired.

6.5 VSM and Industry 4.0

	Author		
VSM & Industry 4.0	*Hartmann , L., Meudt, T., Cevikcan, E., Durmusoglu, M.B. (2018)*	*Goienetxea, A., Nga, A.H.C., Moris, M.U. (2018)*	*Mayr, A., Weigeit, M., Kuhl, A., Grimm, S., Erll, A., Potzel, M., Franke, J. (2018)*
Concept/Framework	✔	✔	✔
Methodology	✔	✔	
Performance	✔		

Table 9: VSM and Industry 4.0 research broadness vs. authors

According to James P. Womack (1996) a value stream "map" identifies every action to design, order, and make a specific product. Each step is then sorted into three categories: those that add value, those that add no value but are currently necessary, and those that add no value and can be eliminated. As a result, Value Stream Mapping aims at eliminating the wastes in form of non-adding value activities and focusing and optimizing of the adding value activities. VSM is a visual representation of the flow of value in the specific processes of an organization and seems that it is difficult to combine with the Industry 4.0 toolbox. It depends on several factors outside and inside the boundaries of the organization such as: customer needs, suppliers delivery sequence, production times etc. (Womack, J.P., 1996). Thus, generating a Value Stream Map by itself might not be a very big challenge in the era of Industry 4.0, however, the digitalization of some of the aforementioned factors could significantly improve the use of the Value Stream Mapping in the modern Mass Customization markets.

In the literature, not many sources on this topic are available. In fact, in the research conducted for the needs of this review only one specific article for the interactions between the tools was acquired. In *Value stream method 4.0: holistic method to analyze and design value streams in digital age* (2018), Hartmann and team propose a holistic method of designing a value stream map with focus on the data acquisition and management from the side of Industry 4.0. In a practical example, the designing steps are presented, as well as the gaps between the traditional value stream mapping and value stream mapping in the era of Industry 4.0 with regards to the technology opportunities. The authors point out the main advantages of the VSM 4.0 method and set key performance indicators that support the claim of performance improvement with respect to the traditional VSM with regards to the information captured. Furthermore, Hartmann and team (2018) claim that this approach does not only facilitate the internal data management towards designing of optimal real time Value Streams, but also helps the customers to plan their own processes by having real time access to the status of the value added to their products.

Goienetxea and team (2018), as well as and Mayr and team (2018), suggest that simulations as a tool can vastly enhance the performance of the Value Stream Mapping. In their respective pieces, *lean 4.0 - A conceptual conjunction of lean management and Industry 4.0* (Goienetxea et al., 2018) and *Supporting the lean journey with simulation and optimization in the context of Industry 4.0* (Mayr et al., 2018) fundamental suggestions for the developing of this combination are proposed. Mayr et al. (2018) propose that Siemens Plant Simulation software can be utilized due to the availability of VSM modules, however the authors argue that a clear framework is still missing and that even the currently available technologies are still dependent on the traditional analog data acquisition and processing. Goienetxea and team (2018), on the other hand, propose a methodological approach for conjunction of the two methods in the era of Industry 4.0.

6.6 Jidoka and Industry 4.0

	Author		
Jidoka & Industry 4.0	*Kolberg, D., Knobloch, J., Zühlke, D., (2016)*	*Kumar, M., Vaishya, R., (2018)*	*Mayr, A., Weigeit, M., Kuhl, A., Grimm, S., Erll, A., Potzel, M., Franke, J. (2018)*
Concept/Framework	✔	✔	✔
Methodology			
Performance	✔	✔	

Table 10: Jidoka and Industry 4.0 research broadness vs. authors

Jidoka or “Human Automation” is a Japanese concept introduced by Toyota and elaborated by Taiichi Ohno (1978). The idea of the method is that the automated processes should act as much more intelligent possible in order to prevent human and machine errors in the production.

The main tools utilized in this method are Andon and Poka Yoke. The traditional approaches focus on visual signals that should trigger stopping of the production in order to detect and solve the problems in the production early. With the advancement of the technology, especially in telecommunications and automation, this method is becoming more and more independent from the human based decisions, and instead, it facilitates the human involvement in resolving the errors in production.

In the literature several, but certainly not many traits on the interaction between Jidoka and Industry 4.0 can be found. This is due to the fact that Jidoka itself from its very beginning continuously deals with certain automation that is often emphasized in the literature, while the human role in the process is neglected, which means that topics on automation of the error-proofing might be found, however, they are not relevant to the general idea that Jidoka represents: a symbiosis of human and machine interaction. Thus, in this section, the publications covering both the human and machines factor, will be considered.

Kolberg D. and colleagues (2016) Include Andon as a fundamental building block of creating a Lean Cyber physical workplace in the era of Industry 4.0. In the research, a utilization of Andon is represented, and an example of a smartwatch is provided. This smartwatch is connected to the production server and receives real time data on the key quality indicators both for process and product quality. Furthermore, the authors explain that, by utilization of the advanced Industry 4.0 data acquisition and management techniques, the operator can have real time overview on the process variation and as such allows the operator to remove the errors even without stopping the process, if possible. On the other hand, in *Real Time monitoring system to Lean Manufacturing* (2018) Kumar M. and colleagues represent an empirical research on Industry 4.0 tools implementation towards Poka Yoke method for error prevention. The research is performed on a simple production process for manufacturing of pinion gears in which after the initial analysis, the researchers found that the process does not actually satisfy the daily planned requirements of pinion gears. To cope with this situation, the researchers exploited the opportunities of a cloud Poka Yoke approach. Several laser displacement sensors were installed on the machine supported by PLC AND interface, furthermore, a LED display was attached to the machine so that the operator would have the opportunity to monitor the data coming from the sensors in real time. The findings from this research, presented in the form of a performance evaluation of the *before* and *after* of the project implementation are provided. Additionally, the authors supply a framework of the way this single project can be extended in order to integrate more processes through the horizontal and vertical supply chain powered by cloud computing. However, a more detailed methodology about the interaction of these methods cannot be found.

Mayr A. and colleagues (2018) argue that Poka Yoke method can be successfully combined with Machine Learning and Augmented Reality. Furthermore, the authors state that by combining RFID tags and Augmented Reality, the organizations can prevent adding value to defective parts acquired by the suppliers.

6.7 Heijunka and Industry 4.0

Heijunka & Industry 4.0	*Mayr, A., Weigeit, M., Kuhl, A., Grimm, S., Erll, A., Potzel, M., Franke, J. (2018)*
Concept/Framework	✔
Methodology	
Performance	

Table 11: Heijunka and Industry 4.0 research broadness vs. authors

Heijunka is the Japanese word for levelling and it was introduced and widely used by Toyota as a part of their Toyota Production System (Ohno 1978). Heijunka boxes are used in order to overcome the unevenness of the production, elegantly and without haste. In the literature not many sources are available on the interdependencies between Heijunka methods and the Industry 4.0.

Mayr and team in *Lean 4.0 - A conceptual conjunction of lean management and Industry 4.0* (2018) suggests that Heijunka method for levelling could be combined mainly with Cloud computing and Data acquisition and management tools such as Big Data, Machine Learning etc. furthermore the author states that with the advancement of some 4.0 tools contribute to improving Heijunka, for instance, Data analytics, could enhance the forecast quality. Planning is stabilized by using data history in combination with a better understanding of customer needs through an in-depth analysis of the market. Nevertheless, the current developments are not explained enough in the currently available literature in terms of methodologies, performance change, quality and costs etc.

6.8 Total Productive Maintenance and Industry 4.0

TPM & Industry 4.0	*Mayr, A., Weigeit, M., Kuhl, A., Grimm, S., Erll, A., Potzel, M., Franke, J. (2018)*
Concept/Framework	✔
Methodology	
Performance	

Table 12: TPM and Industry 4.0 research broadness vs. authors

TPM (Total Productive Maintenance) is one of the building blocks of the Lean Manufacturing and it was defined by Nakajima (1988) as a maintenance process that involves total participation of all employees through a small-group activity, in addition to maximizing equipment effectiveness and establishing a thorough system of a comprehensive planned maintenance system. In the literature, the topic of maintenance combined with the advanced technology is very popular. In fact, many articles are available on the topic of predictive maintenance by utilizing the methods of Industry 4.0 such as: Machine Learning, IOT, Big Data etc. However, Total Productive Maintenance is not based only on monitoring the status and availability of the machines, but instead in its focus has also the training and education of the operators, health and safety etc. Thus, it can be concluded that for having a sustainable TPM platform, a strong interaction between human and machine factors should be present.

In the literature selected for this review, a practical example of combination between TPM and Industry 4.0 methods can be found in Mayr et al. (2018) where the author represents the interactions between TPM and Cloud Computing. An application of a Cloud Computing supported Total Productive Maintenance is provided on a stamping machine. As a Cloud platform, the **Siemens Industrial Cloud** is used. The use case represents the possibility of gathering data from multiple smart sensors that are monitoring the state of the RPM of the main drive, the cutting pressure, the used tools and the number of stamped sheets. The data is gathered on the Siemens Industrial Cloud where the computing is done and consequently visualizations of the state of the stamp are sent to the mobile devices of the operator and all concerned departments. The authors have presented a framework for the implementation mainly from data acquisition, management and visualization point of view. Although the authors stress out the performance improvement in terms of maintenance procedures, more exact numerical results on the improvements are not present.

6.9 Continuous Improvement and Industry 4.0

Continuous Improvement & Industry 4.0	*Buer S.V., Fragapane G.I., Strandhagen J.O. (2018)*
Concept/Framework	✔
Methodology	✔
Performance	✔

Table 13: Continuous Improvement and Industry 4.0 research broadness vs. authors

The Japanese word for Continuous Improvement is *Kaizen* and it is a philosophy that encourages people to continuously improve themselves and their environment. The most famous tool supporting the process of Continuous Improvement is the PDCA (Plan-Do-Check-Act) cycle defined by Edwards (1986).

In the literature presented in this review, an elaboration of the interaction between Continuous Improvement as a method and Data acquisition and management can be found in the work of Buer and colleagues (The Data Driven Process Improvement Cycle: Using Digitalization for Continuous Improvement 2018). Buer et al. (2018) propose a 5-step iterative method for Continuous Improvement in the digital era consisting of: *Data Collection, Sharing, Analysis, Optimization* and *Feedback*. In the article, a clear transition from the traditional approach is presented in form of a matrix of requirements. Each step of the cycle is supported by propositions of technologies that can be used such as: Smart sensors, Cloud Computing and Advanced Data analytics such as Big Data and Machine Learning. The article also gives insights of the economic, financial and structural implications on such projects. Moreover, an example of Kanban system transition from traditional Kanban to an Industry 4.0 Kanban system through data driven Continuous Improvement is presented.

6.10 SMED (Single Digit Minute Exchange of Die) and Industry 4.0

SMED & Industry 4.0	*Mayr, A., Weigeit, M., Kuhl, A., Grimm, S., Erll, A., Potzel, M., Franke, J. (2018)*
Concept/Framework	✔
Methodology	
Performance	

Table 14: SMED and Industry 4.0 research broadness vs. authors

SMED is a method of Lean Manufacturing that aims at reducing the changeover time from one type of product to another by dividing the activities of change into two categories: internal and external. The aim of the method is to eliminate the internal activities that must be performed while the machine is stopped, or at least to transform them into external ones that can be done while the machine is running (Shingo, 1985). SMED is very important method in the current market trends where the customization of the products is one of the crucial customer needs and

SMED is the right to tool to minimize the changeover time between two or more different products.

Mayr and colleagues (2018) agree that SMED is the tool that should be focused on in cases when the goal is to increase the products variety. Furthermore, the authors suggest that by improving the changeover procedures by implementing SMED small lot sizes can be achieved thus minimizing the lead time and maintaining a low level of stocks. In terms of interactions with the tools of Industry 4.0, Mayr and team (2018) suggests that best fit could be combination with Additive Manufacturing and Augmented Reality. The authors support these claims by explaining that Additive Manufacturing processes are not product-specific and varying work-pieces can be produced with minimum setup times. Additionally, times for selection, search and adjustment of tools and workpieces are omitted. However, small adjustments of the temperature, adjustments and cleaning operations have to be performed. Except for the suggestion of combining SMED and Augmented reality, in the article not much further knowledge about this interaction can be acquired.

6.11. What can be learned from the available literature?

From the reviewed literature, it can be concluded that for some areas of the interactions a substantial knowledge regarding the concepts, methodologies and the effects on the system performance after implementation of the tools combinations can be acquired. A significant share of the reviewed articles belongs to the elaboration of the topic of interdependencies between the **Kanban system** and some of the tools of Industry 4.0, such as Internet of things and Cloud Computing. Even though the focus of the authors in terms of the broadness of the research is not evenly distributed, by analyzing the listed publications a general knowledge of the concepts, methodologies and the advantages of the combinations can be acquired.

With regards to the interaction between the **Just-in-time** method and the methods of Industry 4.0, the knowledge that can be gathered is rather scarce. This could be due to the fact that often different methods of Lean Manufacturing coincide with the Just-in-time method which further amplifies the need of clear and indexed toolbox classification. However, a basic conceptual knowledge and methodologies that can be the base of future research can be acquired.

Value Stream Mapping in the literature has been elaborated mainly in correspondence with Data acquisition and management tools of Industry 4.0 as well as in combination with Simulation. Even though not many of the authors deal with elaboration of this topic, from the available literature, one can learn many useful practices on how to design and run a VSM project in Industry 4.0 era, and what are the main implications on the performance change with respect to the traditional approach of VSM.

The reviewed literature gives the very basics of the conceptual interdependencies between the **Jidoka** method with the Industry 4.0 methods mainly focusing on the interactions with Internet of Things, Cloud Computing, Data acquisition and management and Augmented Reality.

Insights on the performance change can be obtained but only in form of suggestions and propositions.

Heijunka, Total Productive Maintenance and SMED have been elaborated only in the area of conceptual interdependencies with the Industry 4.0 tools, without the possibility to better understand the opportunities and the obstacles of their implementation as well as the effect on the performance of the system.

Continuous Improvement, on the other hand, even though as a topic of discussion, was present only in the work of one source, after reviewing that source a rather complete perception of the concept, methodology and the performance change can be acquired.

7. Open research issues on the direct head to head methods interdependencies

Lean Manufacturing tools & methods	Industry 4.0 Tools & Methods: IOT	Cloud Computing	Simulations	Data acquisiton and Management	AR and VR	Additive Manufacturing
Kanban	[18][16]	[18][19] [20][21]	★	★	★	⊘
JIT	[10]	[10]	[23]	[10]	✚	✚
VSM	✚	★	[23][11]	[25]	✚	⊘
Jidoka	[20]	[20][26]	⊘	[20]	[11]	★
Heijunka	⊘	★	★	[11]	✚	⊘
TPM	✚	[11]	✚	[11]	★	★
CI	✚	✚	⊘	[27]	★	✚
SMED	⊘	⊘	⊘	⊘	★	[11]

Legend:
★ High potential of relevant research outcome
✚ Medium potential of relevant research outcome
⊘ Low potential of relevant research outcome

Table 15: Visual evaluation on the attractiveness of the future research topics regarding to direct head to head methods interdependencies

Table 15 shows a visual representation of the already-researched topics and the topics that are still not part of the literature. The idea of the visualization is to gradually point out the "attractiveness" of the topics based the personal understanding of the author of this review. Yellow star symbols mark the fields that can bring immediate value to the research topic as the methods can have many potential interaction points that can contribute to better understand the effects on the combination on the system.

Blue cross symbols denote the fields that could be interesting for future research, however they are considered to have lower level on contribution to significant research outcomes. This is due to the fact that even if there is available technology as part of Industry 4.0, it might not be expanded enough under the current development to significantly improve the performance of the combination with the Lean Manufacturing tools.

Finally, a red circle symbol marks the fields that are not considered attractive enough for immediate research. This can be explained by the fact there are significant touching points between the tools that can be enhanced, or because they are mutually exclusive due to fundamental differences in the ideas and the concepts of the methods. The propositions for future research will be presented Lean-wise and in accordance to the table presented above.

7.1 Kanban and Industry 4.0

With respect to the interaction between Kanban and the methods of Industry 4.0, such as IOT and Cloud Computing, a future research should:

- Provide better insights on the effect on the performance in terms of costs of implementation.
- Elaborate the effects on the human resources in the process. *Is the combination going to enhance the process awareness or it will contribute to the opposite?*
- Define the skills needed by the human resources to operate and maintain such a system.

A combination of Data Acquisition and Management with simulation techniques can have a strong effect on the Kanban system, a future research proposition could answer the question:

- Is there a possibility to achieve a more dynamic Kanban sizing according to the customers' needs by utilization of Big data analytics, simulations and advanced data analytics?

With respect to Augmented Reality and Virtual Reality, new perceptions are arising in terms of who authorizes the start of the production processes or the movement of the materials. Thus, a proposition for a future research could be:

- How can augmented reality devices enhance the utilization of the Kanban based systems and If the Augmented Reality technology can help the industries such as the construction industry case presented earlier by Dave, B and the colleagues (2015).

Additive Manufacturing cannot be considered a relevant enabler towards Kanban systems due to the fact that Kanban is dealing with information flow and additive manufacturing is a technology for physical production of parts.

7.2 Just-in-time and Industry 4.0

In terms of Just-in-time method and the Industry 4.0 methods interactions, the main gap in the current research is in the area of performance evaluation. The future research should focus on how the performance of the traditional approach to JIT can be improved by the tools of Industry 4.0.

Another proposition for future research should be if the Just-in-time method could be expanded with the help of Industry 4.0 techniques such as IOT and Cloud Computing to the suppliers outside the boundaries of the organization in order to support them in their efforts to achieve JIT and at the same time to reduce the wastes in their processes. With respect to the Augmented and Virtual Reality as well as the Additive Manufacturing methods, a broader research on the concepts of interactions should be performed.

7.3 Value Stream Mapping and Industry 4.0

The main gap in the research literature regarding VSM is in the field of interaction with Cloud Computing. In fact, cloud servers allow interconnection between several value streams in real time at a low cost. Thus, a future research in terms of conceptual, methodological and performance interdependencies should be performed. Furthermore, a understanding better of what are the benefits of IOT machine-to-machine communication, could contribute to a real time monitoring of the value streams and consequently, fast resolution of possible wastes in the value stream.

7.4 Jidoka and Industry 4.0

Besides the fact that clear methodologies with regards to the implementation of the Industry 4.0 methods towards the Jidoka method should be in the focus of the future researches, an attention should also be paid to the interdependencies between Jidoka and the means of Additive Manufacturing. The main discussion could be how the Additive Manufacturing method could minimize the errors in the processes as well as how it contributes to the shortening of the response time to those stops and errors.

7.5 Heijunka and Industry 4.0

Heijunka as a method, is rarely present in the publications focused on the interdependencies between Lean Manufacturing and Industry 4.0. The future research on this topic should enhance the foundation of the combination with the Industry 4.0 methods with respect to implementable methodologies and performance evaluation. Furthermore, the interaction with Cloud Computing and Simulations remains undiscovered. In future research on this topic should be examine if the simulation of different customer demand scenario, supported by real time Cloud Computing, can significantly improve the production levelling in the companies.

7.6 Total Productive Maintenance and Industry 4.0

In the literature, besides the conceptual knowledge if the interactions between TPM and Cloud Computing that can be acquired, future research focusing on the topics of implementation methodologies, as well as performance evaluation should be performed. Moreover, TPM has high potential of points of interaction with methods of Industry 4.0 such as Data Acquisition and Management, Augmented and Virtual Reality and Additive Manufacturing that remain undiscovered. Augmented and Virtual Reality could possibly enhance the 5S and Autonomous Maintenance methods that are under the TPM umbrella. Additive manufacturing could additionally reduce the response time to dealing with the defects on the machines and in the processes.

7.7 Continuous Improvement and Industry 4.0

Continuous Improvement remains well explained in terms of interaction with Data acquisition and management tools of the Industry 4.0 toolbox. However, the other points of interaction remain undiscovered. The main focus of the future research could be the interaction between Continuous Improvement and Augmented reality. The motivation for this statement lies in the fact that continuous improvement is tightly connected with the human factor. Augmented reality being the method that creates computer generated vision, could enhance the senses of the human resources thus contributing to easier notice the abnormalities and variations in the processes.

7.8 Single Minute Exchange of Die and Industry 4.0

Being the tool that is one of the most important with coping with mass customization customer needs of today's market SMED should be kept in the focus of the researchers in terms of methodologies and performance evaluation. Furthermore, pushing for further discoveries in the field of interaction between SMED and Augmented reality. The opportunity lies within the fact that SMED procedures are often performed in order to shorten the time of small adjustments even without doing complete changeover. For shortening the time needed to perform these adjustments, the well-practiced skills of the performers of such adjustments are crucial. Augmented reality could enhance the process of faster learning and following such procedures of small adjustments.

8. Limitations and conclusion

8.1 Limitations

The idea of merging the concept and methodologies of Lean Manufacturing with the ones of Industry 4.0 is certainly a topic that has sparked the interest of many engineers and researches, however there were certain limitations without which more sources and authors might have been considered in this review. Since the concept of Industry 4.0 was introduced and is mostly researched in Germany, many articles that would have been interesting for this review were discarded due to the lack of language skills of the author. Furthermore, even though Scopus is one of the biggest scientific research databases, the browsing through the content of the database requires special programming skills or a sort of a subscription that were not available to the author. Thus, some interesting papers could have been overlooked or missed. Finally, the very small number of publications that research the two concepts hinders the aim of potentially drawing more valuable conclusions.

8.2 Conclusions

The combination of Lean Manufacturing and Industry 4.0 is a potential promise of a smarter and more intelligent future of production systems. While the concept is relatively new, some research has already been conducted, however, based on the findings presented in this literature review, we can conclude with certainty that in order for engineers to be able to provide a much needed unified Lean Manufacturing and Industry 4.0 framework, further research needs to be done. By defining clear classification of the tools and methods, clear implementation steps and performance evaluation, the research will move another step in the right direction in order to establish a state-of-the-art concept- Lean 4.0.

This literature review could represent a starting point for future research of the interdependencies of the two concepts on different levels, from the general strategic frameworks up to the specific operational and methodological level. Furthermore, the structure of the review itself, represents a roadmap that could lead to a final closure of the gap between what is known and what is about to be learned.

References

1. Sanders, A., Elangeswaran, C. & Wulfsberg, J. (2016). *Industry 4.0 Implies Lean Manufacturing: Research Activities in Industry 4.0 Function as Enablers for Lean Manufacturing*
2. Roblek, V., Meško, M., Krapež, A. (2016). *A Complex View of Industry 4.0*
3. Gates, B.
4. Bauer, H., Brandl, F., Lock, C., Reinhart, G. (2018). *Integration of Industrie 4.0 in Lean Manufacturing Learning Factories*
5. Webster, J., Watson, R.T. (2002) *Analysing the past to prepare for the future. Writing a literature review*
6. Rüttimann, B.G., Stöckli, M.T. (2016). *Lean and Industry 4.0—Twins, Partners, or Contenders? A Due Clarification Regarding the Supposed Clash of Two Production Systems*
7. Kolberg, D., Zühlke, D. (2015). *Lean Automation enabled by Industry 4.0 Technologies*
8. Dombrowski, U., Richter, T., Krenkel, P. (2017). *Interdependencies of Industrie 4.0 & Lean Production Systems - a use cases analysis*
9. Sony, M. (2018). *Industry 4.0 and lean management: a proposed integration model and research propositions.*
10. Wagner, T., Herman, C., Thiede, S. (2017). *Industry 4.0 impacts on Production systems*
11. Mayr, A., Weigeit, M., Kuhl, A., Grimm, S., Erll, A., Potzel, M., Franke, J. (2018). *Lean 4.0 - A conceptual conjunction of lean management and Industry 4.0*
12. Mrugalska, B., Wyrwicka, M.K. (2017). *Towards Lean Production in Industry 4.0*
13. Satoglu, S., Emre, A.U. (2018). *Lean Production Systems for Industry 4.0*
14. Prinz, C., Kreggenfeld, N., Kuhlenkotter, N. (2018). *Lean Meets Industry 4.0 - a practical approach to interlink the method world and cyber - physical systems*
15. Ohno, T. (1978). *Toyota Production System: Beyond Large Scale Production:* CRC Press
16. Kouri, I.A., Saalmimaa,T.J., Vilpola, I.H. (2008). *The Principles and Planning Process of an Electronic Kanban System*

17. Thürer, M., Pan, Y.H, Qu, T., Luo, H., Li, C., Huang G.Q. (2016). *Internet of Things (IoT) driven kanban system for reverse logistics: solid waste collection*

18. Azambuja, M., Schnitzer, T., Sahin, M., Lee, F. (2013). *ENABLING LEAN SUPPLY WITH A CLOUD COMPUTING PLATFORM – AN EXPLORATORY CASE STUDY*

19. Dave, B., Kubler, S., Framling, K., Koskela, L. (2015). *Opportunities for enhanced lean construction management using Internet of Things standards*

20. Kolberg, D., Knobloch, J., Zühlke, D., (2016). *Towards a lean automation interface for workstations*

21. Krishnaiyer, K., Chen, F.F., Bouzary, H., (2018). *Cloud Kanban Framework for service operations management*

22. Wagner, T., Herman, C., Thiede, S.(2018). *Identifying target oriented Industrie 4.0 potentials in lean automotive electronics value streams*

23. Goienetxea, A.U., Nga, A.H.C., Moris, M.U. (2018). *Supporting the lean journey with simulation and optimization in the context of Industry 4.0*

24. Womack, J. , Jones, D.T. (1996). *Lean Thinking: Banish Waste and Create Wealth in Your Corporation, Revised and Updated:* Free Press

25. Hartmann, L., Meudt, T., Cevikcan, E., Durmusoglu, M.B. (2018). *Lean Production Systems for Industry 4.0*

26. Kumar, M., Vaishya, R., (2018). *Real-Time Monitoring System to Lean Manufacturing*

27. Buer S.V., Fragapane G.I., Strandhagen J.O. (2018). *The Data Driven Process Improvement Cycle:Using Digitalization for Continuous Improvement*

28. Nakajima, S. (1988). *Introduction to TPM In:* Productivity Press, Inc.

29. Edwards, D.W (1986). *Out of the crisis*: Cambridge, MA: Massachusetts Institute of Technology, Center for Advanced Engineering Study. p. 88.

30. Shingo, S. (1985). *A revolution in manufacturing: The SMED system*: Productivity Press, pp. 113

31. Dombrowski, U., Richter, T. (2018). *The Lean Production System 4.0 Framework –Enhancing Lean Methods by Industrie 4.0*

32. Keyur, K. Patel, Sunil, M. Patel (2016). *Internet of Things-IOT: Definition, Characteristics, Architecture, Enabling Technologies, Application & Future Challenges*

33. National Institute of Standards and Technology (NIST) of U.S.A (2011). *The NIST Definition of Cloud Computing*
34. Banks, J., Carson, J., Nelson, B., Nicol, D. (2001). *Discrete-Event System Simulation*.
35. Breur, T. (2016). *Statistical Power Analysis and the contemporary "crisis" in social sciences.*
36. Patrick, S. (2017). *The Concise Fintech Compendium.*
37. Huffington Post (2016). *The Lengthy History of Augmented Reality.*
38. Chavan, S.R. (2016). *Augmented Reality vs. Virtual Reality: Differences and Similarities.*
39. Tofail, S.A.M., Koumoulos, E.P., Bandyopadhyay, A., Bose, S., O'Donoghue, L., Charitidis, C. (2018). *Additive Manufacturing: scientific and technological challenges, market uptake and opportunities*
40. Oktadini, N.R., Surendro, K. (2014). *SLA in Cloud computing: Improving SLA's Life Cycle Applying Six Sigma*
41. *Figure 3:* Visual Representation of the Toyota Production System (TPS), adopted from Toyota Forklifts website: *http://www.toyota-forklifts.eu/en/company/Toyota/Production/System/Pages/default.aspx*
42. *Figure 4:* Representation of the Industry 4.0 tools and technologies, adopted from Boston Scientific Group Website *https://www.bcg.com/publications/2015/engineered_products_project_business_industry_4_future_productivity_growth_manufacturing_industries.aspx*