POLITECNICO DI MILANO

Dipartimento di Gestione

Laurea Magistrale in Scienze

Ingegneria Gestionale

The relation between lean management and industry 4.0

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July 2022

Contents

List of Figures

List of tables

Abstract

By using Industry 4.0, product quality will increase, and it will make manufacturing processes more efficient. However, the way these technologies are integrated into existing production systems and the processes they can support, are still under investigation. Thus, this thesis examines the relationship. between lean management (LM) and the industry 4.0 (I4.0), execute the research, 150 papers have been reviewed, for achieving that, we use data collecting by using Scopus to collect paper Our findings indicate that. LM are positively associated with Industry 4.0 technologies, and their implementation leads to more productive company.

Key words: industry 4.0, lean management

Sommario

Utilizzando Industry 4.0, la qualità dei prodotti aumenterà e renderà i processi di produzione più efficienti. Tuttavia, il modo in cui queste tecnologie sono integrate nei sistemi di produzione esistenti e i processi che possono supportare, sono ancora oggetto di studio. Pertanto, questa tesi esamina la relazione. tra la gestione snella (LM) e l'industria 4.0 (I4.0), eseguire la ricerca, sono stati esaminati 150 articoli, per ottenere ciò utilizziamo la raccolta di dati utilizzando Scopus per raccogliere la carta I nostri risultati lo indicano. I LM sono positivamente associati alle tecnologie Industry 4.0 e la loro implementazione porta a un'azienda più produttive.

Parloe chiave: industry 4.0, lean management

1. Introductions

The only method for producing cars before 1908 was craft production (James P Womack, Jones, &Roos,2007). (Vahid Taghavi, 2020)All car parts were assembled. There was no defined standard. Henry Ford introduced mass production i908 by model T, a revolutionized methodology that happened in the automobile industry. Ford increase demand the performing 800$ to 20$. MakiThey were makings. They were making for families. Ford had the largest share of the automotive industry for 45 years. Until Toyota company emerged its Toyota production systems. Taiichi Ohno and Eiji Toyoda traveled to ford company to learn about on. They determined mass production is unadoptable in Japan because Toyota couldn't afford the expensive mass production facilities link t and Toyota could not afford to maintain theme time, hiwhilehno and Toyoda found out that mass production is full of waste. Therefore, they used ford's idea focused on reducing waste and low-cost automation. Finally, they produce Toyota's products succeed increasing stability by removing waste in the production process from the order of customers and the supply chain to the final delivery. Toyota acted as a competitive advantage and market leader. Toyota called lean by John Krafcik in his article titled Triumph of the lean production system in 1988.

I4.0 is aimed primarily at automation, using cyber-physical stems (CPS) to reduce costs, and throughput time and increase quality (Prinz, 2018)

The term "industry .4.0" is used for the next industrial revolution .it has three kinds of revolutions' first was the introduction of mechanical production facilities, which started in the 18th century and intensified throughout the 19th century. From 1870 on, electrification and the divisions of labor led to the second industrial revolution, which was called "the digital revolution in 1, when advanced electronics and information production process. (Hermann Mario, 2015)

Industry 4.0 merged in 2011 for the first time at Hanover university with the German Government university and companies. The summary of the characteristic of the industrial revolutions is illustrated in Figure1. Thus industry 4.0 is based on honest communication to monitor and act on physical systems.IT takes Different Names Smart Factory, Smart Industry, Factory of Future, Industry of The Future and Digital Factory (Kaoutar Douaioui, 2018)

The term industrial 4.0 is not well known outside Germany. Thus, finding a similar idea from a global perspective is vital. General Electric promotes and is called "Industrial Internets".it is defined athletic migration of complex physical machinery and device with networked sensors software used to predict, control, and plan for better business and societal outcomes. The US government supports research and development activities in the Industrial Internet with a two-billion-dollar fund for Advanced Manufacturing (Hwang, 2017)Significant changes happened due to implementing 14.0 in the organization, which is more flexible in space and time.

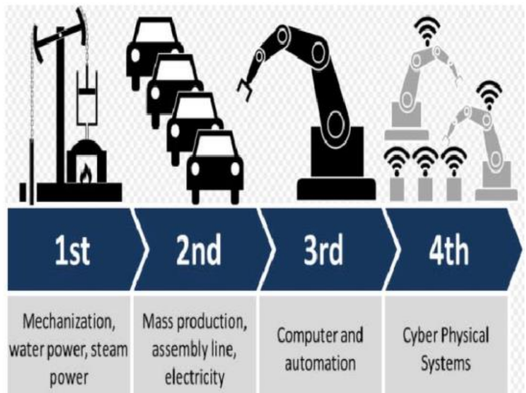

Figure 1 Summary of the characteristics of the industrial revolutions (Vahid Taghavi, 2020).

This thesis carried out a Literature review to identify the relationship between Industry 4.0 and Lean management on each other. Most companies using Industry 4.0 use lean management to reach high quality and reduce costs. This thesis considers the influences of this mixture in different sections when this method is a literature review.

2. Industry 4.0

2.1. Identification of industry 4.0

There is no set standard definition for I4.0, but there are some authors that define it in the following.

- (Ray Y. Zhong, 2017) defines it as the "next generation of the industry 4.0 that promise increased flexibility, better quality, and customization, improved productivity. It helps companies to cope with the challenges of producing increasingly individualized products with higher quality
- A short lead-time to market (Ray Y. Zhong, 2017)
- Another definition is coming from Saurabh "new level of organization and control over the entire value chain of the life cycle of products; t is geared toward increasingly individual customer requirement" (Saurabh Vaidaya, 2018)
- (syed Imran Shafiqa, 2015)defined different definitions for industry 4.0:
    1. industry 4.0 is the integration of complex physical machinery and devices with networked sensors and software used to predict, control, and plan for better business and societal outcome
    2. Industry 4.0 is a new level of value chain organization and management across the lifecycle of products.
    3. . Industry 4.0 is a term for technologies and concepts of value chain organization. Within the structured Smart Factories of Industry 4.0, CPS monitors physical processes, creates a virtual copy of the physical world, and makes easier decisions (syed Imran Shafiqa, 2015). The instrument for reaching automatic is CPS. EA smart factory is equipped with a microcontroller sensor and a communication interface. Regarding sources and decreasing their usage, in 2020 author claims that "the new perspectives on how manufacturing can conjoin with advances in digitization to produce maximum output by using minimum resources.
- (Sony M. A., 2020)Robert, in 202,0 claims that I4.,0 described in the following, (Sony M. , 2018) (Zhuang, 2018) (Robert Saxby, 2020)
    1. use of new technologies like 3D printing
    2. Cloud computing, where data and computing power shared

3. The use of Cyber physics systems (CPS) which link data collection and analysis to mechanical actuators
4. Highly integrated enterprises, both horizontally and vertically
5. The availability of large amounts of process/products data for analysis
6. Smart products which can sense and react to their conditions
7. Smart manufacturing process which can self-optimize.

The department of innovation factory system (IFS) for artificial intelligence identified four enablers for smart factories' innovative products. In this situation, employees take a central position and become an operator and supervise and control activities through ICT)

8-The internet of things (IoT), where physical assets share and act upon data.

2.2. Principal of industry4.0

- (syed Imran Shafiqa, 2015) in their article consider these six a principal

1. Interoperability: the ability of physical components, humans, and Smart Factories to connect and communicate with each other
2. Virtualization: virtual copy of physical objects
3. Decentralization: the ability of components to make decisions on their own
4. Real-Time Capability: the capability to gather and analyze data in real-time
5. Service Orientation: The services of companies, CPS, and humans are available over the IOS and can be utilized by other participants.
6. Modularity: flexible adaptation of Smart Factories to changing requirements by replacing or expanding individual modules

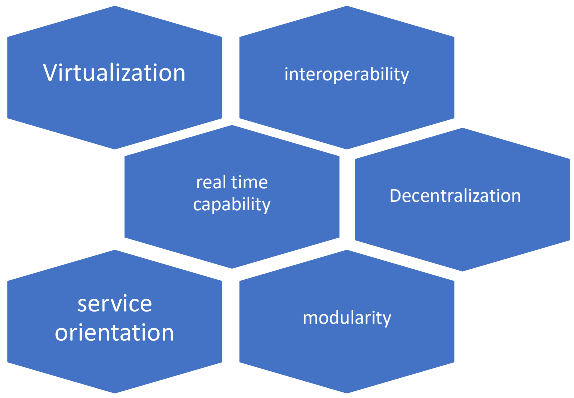

Figure 2 (principal of I4.0, (syed Imran Shafiqa, 2015)and (Fettermann G. L., 2017).

2.3. Technology (component, element)

The author has different ideas about the technology industry 4.0. they called in different methods like component elements that are vital for industry 4.0 in 2020 author considers these elements as technology cyber-physical systems (CPS), internet of thing(IOT) and cloud computing Radio Frequency Identification (RFID), Enterprise Resource Planning (ERP), and social product development (Sony M. A., 2020)In 2019 the author considered these technologies for I4.0 (IoT, Could Computing, Big Data, Augmented reality, Machine Learning) (Guilherme Tortorella))

In 2018 author considered four drivers of industry 4.0: IOT, industrial internet of things (IIOT), cloud-based manufacturing, and intelligent manufacturing. (Saurabh Vaidaya, 2018)

Another researcher in 2018 claims Industry 4.0 comprises many technologies, such as IoT,cloud-based manufacturing, Radio Frequency Identification (RFID), and Enterprise Resource Planning (RP) (sony, 2018)

Ray considers these critical technologies technique Industrial 4.0: IoT, CPSs, cloud computing, technologies are defined in the following:

- IoT.: offering advanced connectivity of physical objects, systems, and services, enabling object to-object communication and data sharing.
- CPS is a mechanism in which physical objects and software are closely intertwined, enabling different components to interact in a riad way to exchange.
- Cloud computing: delivering computational services through visualized and scalable resources over the internet.

- Big data typically stems from various channels, including sensors, devices, video/audio, networks, log files, transactional applications, the web, and social media feeds.
- ICT: It refers to an extended IT that highlights unified communications and the integration of telecommunications, as well as other technologies that can store, transmit, and manipulate data or information (Ray Y. Zhong, 2017)

In 2014 jay al et al. considered computing and CPS helps machines to be self-aware and actively perform. ((Jay Lee Hung-An Kao, 2014)).

2.4. Integration of industry 4

There are three kinds of integration in Industry 4.0. Horizontal, vertical end-to-end engineering integration (sony, 2018)vertical integration, the organization is connected in terms of hierarchy, guaranteeing a continuous data flow between the production systems like ERP (Enterprise Resource Planning). Vertical integration cyber-physical systems Horizontal integration is used for sharing formation between the supply chain, involving business partners. end-to-end integration manages all functions and data flow evolving from product lifecycle management.

Vertical integration is associated with cyber physics systems; a new concept emerged, the Digital Twin, creating a virtual model using physics entities for this goal. Therefore, offering the possibility of making decisions in n virtual environment). TD all representation at real-time production system another organization components (Juliana Salvadorinho l. T., 2020)

2.5. Industry 4.0 challenges

- Digitization of the shop floor is expensive and time-consuming
- digitalization needs specialized knowledge
- I4.0 lacks the definition of a digital strategy
- Digitization requires the intervention of all(people)
- Digitization can decrease problem management skills
- Digitization and automation require definition, mapping, and standardization of the process
- A priori need for the shop floor to have lean management
- Acquisitions of technological resources.
- Integration of human resources
- definition of digital strategy
- promoting a culture that fosters involvement

- guarantee the knowledge of all processes that can reproduce (Juliana Salvadorinho l. T., 2020)

2.6. Information system (ERP and MES)

An information system that includes people, software, and hardware. Data and process are essential elements in the I4.0 context, the function of planning material and resources.

Roles of MES are

- Allocation and control of recourse
- Dispatch of production
- Management of quality
- Management of process and monitoring of the production
- Analysis of the operational performances
- Scheduling of operation
- Document management
- management of maintenance and transport
- accounting and tracking of material

2.7. Value stream mapping in Industry 4.0

Principles and methods are essential to do a full investigation of the resources to reach the research goals. This thesis concentrates on articles dealing with Leans management and Industry 4.0 in terms of relationships and influences on each other when two methods are implemented completely. When a company implemented lean production practices might be more likely to adopt industry 4.0 technologies (Matteo Rossini, 2019)and ((Fettermann G. L., 2017)

1. Lean management (LM)

Lean Management (LM) is a quality method ideally applied worldwide since the latter half of the 20th century. It has been applied in several sectors and is associated with Toyota production systems (TPS (Robert Saxby, An initial assessment of Lean mangemnt for industry 4.0, 2020) The TPS integrates a method to eliminate the seven forms of waste (Muda) and produce profit through cost reduction. LM is technical management for the efficiency of system which can eliminate waste through the minimization or reduction of the sources of internal and external variability (Miguel Núñez-Merino, 2020).

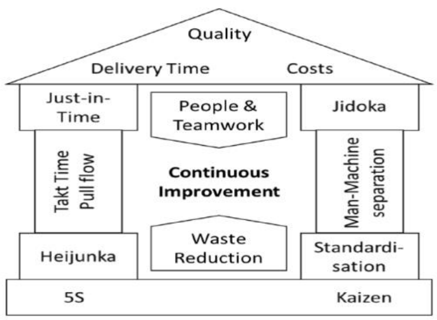

Figure 3 House of Toyota production.

The figure symbolizes the lean production principle. This approach is a continuous production event by integrating principle size, Just in time (JIT),Heijunka . Takt time, Pull flow machine separation on People and teamwork and waste reduction(wagner.2017)

Same as I4.0, there is not a standard definition for lean, but Saby 2020 published a definition to share common elements, including:

- Waste removal (Bicheno and Holweg 2016, Liker 2004, Ohno1988)
- Engagement of people and culture change (Liker2004, Mascarenhas,et al. al2019, Rand et al 1997,Vilaet al 2019)
- Continues improvement (Costa et al. 2019, Pearce and pons20149, Womack et al. 2007)

1.1. Lean philosophy

The lean philosophy goals to minimize sources of productive waste and increase the use of products and services, .in addition to establishing the practices to decrease variability of the process, minimize delivery time and customer satisfaction besides the lowering the cycle times ((Juliana Salvadorinho l. T., 2020)

1.2. Lean management principal

In 2017 author claims three central principles of lean management are Kaizen, Total Quality Management (TQM), and Business Process Reengineering (BPR) ((Leyh, 2017)

In 2018 Sony considered the following as a principle of lean management

- Specify the desire valued by customers
- Identify the value stream for each product
- Make product flow continues
- Introduce the pull when continuous flow is not possible
- Manage toward perfection (Sony M. , 2018)

1.3. Lean steps and principles

far the implementation of lean is concerned, there are discussed diverse frameworks .it is evident that improvement activities appear in the sequence in manufacture. Process. However, continuous improvement should be introduced late during the process to allow it to benefit from the earlier established other principles ((Mrugalska, 2017)change can be supported by job rotation, continuous improvement, and teamwork, which follows advantage at the beginning of the following. In addition, it should change the employee's attitude about changes or get material-only value-adding operations. Following Womack and Jones's lean there is a need to identify a change agent to create a new lean organization. Such a person should be the first to acquire knowledge and share it with the rest of the organization. After creating a lean function, business systems will fix. Lean thinking can be completed when applied to suppliers and customers strategy is a continuous improvement program that is transitioned from a top-down to a bottom-up. Furthermore, H ((Mrugalska, 2017)proposed a step-by-step implementation or lean, which hypothetically can reflect the five lean principles.

Table 1lean principle

Step	Lean principle
Establish strategic visions	
Identify and establish teams.	
Identify product Identify process	value
Review factory layout	flow
Select the appropriate pull strategy	Pull
Continues to improve	perfection

Therefore, Hines (P. 2016) claims that the pre-step can define the strategy for implementing the project and, in the second step, extend people in this project.

1.4. Lean tools

Value stream mapping :(the lean tool allows having a global perspective of the entire production process (materials and data flow). It allows organizations to develop a map of the current state of how the company works and a map of the future state.

Total productive maintenance (TPM): Total Productive Maintenance Management includes practices that help to anticipate or reduce the frequency of equipment stoppages, ensuring the smooth completion of activities related to production

Hoshin Kenari: Technique that intends to transform the corporate vision of a company into objectives and actions that are cascaded into the organization to achieve multilevel PDCA cycles (Plan-Do-Check-Act)

Poka-yoke: Mechanisms that help employees avoid production errors

Just in time: Method that guarantees the delivery of the right product, at the right time and place, with the appropriate quantity and quality, at the appropriate cost.

Total quality management: It includes the adoption of innovative quality practices, such as the commitment of top management and the strategic planning of all production processes

Kanban: It intends to maintain a minimum stock level with a view to the uninterrupted supply of material

Andon: it works as a real-time tool for communicating problems that may occur in the workplace to obtain an immediate solution (Juliana Salvadorinho l. T., 2020)

In 2020 considering these tolls are the same as Kanban (VSM, Poka Yoke, Andon, visual management, KPIs.) (Juliana Salvadorinho l. T., 2020)Information systems in Industry 4.0: Mechanisms to support the shift from data to knowledge in Lean environments.

Two other tools are FMEA(Failure Mode and Effect Analysis), which is promoted through lean tools such as five ways the design of risk management strategy.

Table 2 Lean tools description.

Value system mapping	Lean tool allows for having a global perspective of the entire production process (materials and data flow). It allows organizations to develop a map of the current state of how the company works and a map of the future state (Kale, 2019)
Total Productive Maintenance (TPM)	Productive Maintenance Management includes practices that help ensure the smooth completion of activities related to Production and reducer anticipate the frequency of equipment stoppages, (Yadav, 2020)
Hoshin Kanri	A technique that intends to transform the corporate vision of a company into objectives and actions that are cascaded into the organization to achieve multilevel PDCA cycles (Plan-Do-Check-Act (Romero, 2019))
Poka-Yoke	Mechanisms that help employees avoid production errors (A mayer, 2018)
Just-in-Time	The method that guarantees the delivery of the right product, at the right time and place, with the appropriate quantity and quality at the appropriate cost (A mayer, 2018)

Total Quality Management	It includes the adoption of innovative quality practices, such as the commitment of top management and the strategic planning of all production processes (Yadav, 2020)
Kanban	It intends to maintain a minimum stock level with a view to the uninterrupted supply of material. (A mayer, 2018)
Andon	It works as a real-time tool for communicating problems that may occur in the workplace to obtain an immediate solution (Bhuvaneshwari Alias Sunita Kulkarni, 2019)

1.5. Lean elements

- Team working and employing involvement.
- Operation of pull systems or Kanban (just on time) to support the zero-inventory principle.
- Elimination of waste over-production, waiting, transportation, over-processing, inventory, movement, and defective product
- continuous improvement or Kaizen
- Jidoka, stop fixing problems.

Andon's process has been stopped due to a problem. Attention can then be focused on fixing that Problem. Corporate culture, go and see it. can encourage managers to leave their offices and investigate

- Problems on the shop floor.
- Engaging the supply chain within Lean: with lean enterprises, suppliers are engaged as partners and work to reduce their costs through efficiencies.
- Customer value
- Standard work system
- Level workflow (continues process flow, level out workload)

1.6. Waste of lean

There are seven original wastes of lean: inventory, waiting, defects, overproductions, motions, transportation, and over-processing (Vahid Taghavi, 2020)

In (Leyh, 2017)considered management to avoid these eight causes of waste; these causes are the possibility of process, unnecessary movement, waiting times, and r production. Tight tolerance, defects, and new skills of employees. Kanban system sends a virtual kanban trigger replenishment. (Leyh, 2017)

1.7. Disadvantages of LM

In 2018 kan stated that LM organized production with high quality and decreased lead time. In addition, this concept of continuous improvement and reduction of waste. But, nowadays, it shows some limitations.

- substantial deviation in the Marco conflicts
- LM supports a higher Variety of production and is not suitable for the single-item product.
- LM was invented in the 1950s and thus does not consider the possibilities of ICT
- LM. changes in the production process buffer stock, or cycle time required to adjust Kanban cards or bins. (Dennis Kolberg, 2015)

1.8. Lean automation

The combination of LM and automation technology is called Lean automation. The term occurred in the mid-1990s,990s but in the last decade, it did not consider. Digitalization of the Kanban for several years. Physical card production is replaced by Virtual Kanban (Kolberg, 2015))

1.8.1. Augmented Operator

The Augmented Operator should reduce the time between failure occurrence and failure notification. Therefore, the Andon method can be applied, which is one of the principal elements of the Jidoka quality-control method recognized as a part of the Lean approach. It is realized by showing signal lights on an operator smartwatch in close to real-time. The information concerns both error messages and error locations. Such alerts may be recorded in a database and further studied as part of a continuous-improvement program. In addition, failures can be recognized with CPS equipped with proper sensors and automatically initiate fault-repair actions on other CPS.

1.8.2. Smart machine

A Smart Machine can contain a smart panel based on RFID UHF. Such a solution enables to detection of Kanban cards in real-time. It is assumed that the read-rate of cards placed on such a panel is typically 100%. Additionally, such panels can prevent detecting other tagged Kanban cards that are not placed on the panel but are at a close physical distance from the panel. Except for RFID, continuous improvement can also be assured due to production line data collected from machines with technologies such as actuators, sensors, and wireless video. These data are analyzed and proceeded in the cloud to give better operational intelligence but mainly to avoid mistakes which is the main idea of Poka-Yoke. Furthermore, the application of Plug''Produce makes it also possible to introduce the Single Minute Exchange of Die method into whole production lines. (Kale, 2019)

Therefore, starting from the challenges inherent to the fourth industrial revolution and relying on the integration of Lean principles and emerging technologies from I4.0, several benefits can be expected such as

- Increased productivity since integration enhances agile and intelligent processes (Doh, 2016) (Pagliosa, 2019)
- Increased quality, as it is possible to anticipate production errors and manage equipment malfunctions in a more controlled approach (Doh, 2016) (Pagliosa, 2019); (Stadnicka, 2019)
- Greater flexibility, since I4.0 allows flexible and modular production systems so that highly customized products can be mass-produced, with the possibility of demand adjustment (Ghobakhloo, 2020); (Pagliosa, 2019)
- Greater transparency in communication, as there is constant monitoring of production with real-time data, which promotes more accurate and decentralized decision-making in near-real-time (Gigova, 2019)
- Increased worker safety, since the heavier and more routine activities, which normally lead to workers 'injuries are likely to be automated (Stadnicka, 2019)
- Cost reduction, either by eliminating a substantial part of waste or by predictive maintenance enhanced by these environments lead to a reduction in maintenance costs (Ghobakhloo, 2020)

In this way, with the application of emerging I4.0 technologies integrated with Lean's principles, using for that. Information Systems, namely ERP and MES, it is possible to increase operational efficiency and, consequently, organizational efficiency

2. Review principles

Based on a literature review by Liao et al., To ensure that all papers could be assessed with less subjective opinion, two fundamental review principles were defined (Yongxin Liao, 2017)Explicit inclusion. The criteria and exclusion criteria. The criteria for including or excluding collected paper should be outlined. In Table 1, six inclusion and exclusion criteria, together with their subsets, have been outlined.

Data collection with evidence. For the collection of data that require subjective judgments, which potential area for action that an included paper puts its focus on, the original supporting text descriptions of the paper should also be gathered as notes into the database.

Table 3 Inclusion and exclusion criteria and their explanations

I/E	Criteria	Criteria explanation
Exclusions	Search engine reasons (SER) Not related (NR)	• A paper has only its titles, abstracts, and key words in English but not full text .NR-1: a paper is not an academic article, for example editorial material, conference review, content, or forward • NR-2: The definition about I4.0and LM is not related to this job
	Loosely related (LR)	• A paper doesn't focus on the review, survey, discussion, or problem-solving of industry 4.0 or lean management. • LR-1: Industry 4.0 and LM is only used as an example • LR-2: Industry 4.0 is only used as a part of its future research direction, future perspective, or future requirement LR-3: Industry 4.0 or lM is only used as a cited expression • LR-4: Industry 4.0 is only used in keywords and references
	without full text to be assessed (WF)	A paper without full text to be assessed
	Closely related (CR)	The research efforts of the paper are explicit dedicated to I4.0 and LM
inclusions	Partially related (PR)	• PR-1: A research about the fourth revolution without mentioning I4.0 or lean without considering LM • PR-2: I4.0 and LM only used to support the description of some challenges, issues, or trends that a paper intends to deal with • PR-3: I4.0 and LM is one of several objects to be reviewed or discussed • The research efforts of a paper are dedicated to I4.0 or LM

2.1. Systematic literature review

This research is conducted by applying the systematic Literature review of the rough mixed-method approach Furthermore, the thesis is structured by following the method in the preferred reporting item for systematic review and meta-analysis (PRPRISMA statement (Adrian Miqueo, Lean Manual Assembly 4.0: A Systematic Review, 2020)The chart that reports different phases of this systematic literature review is shown in the figure.

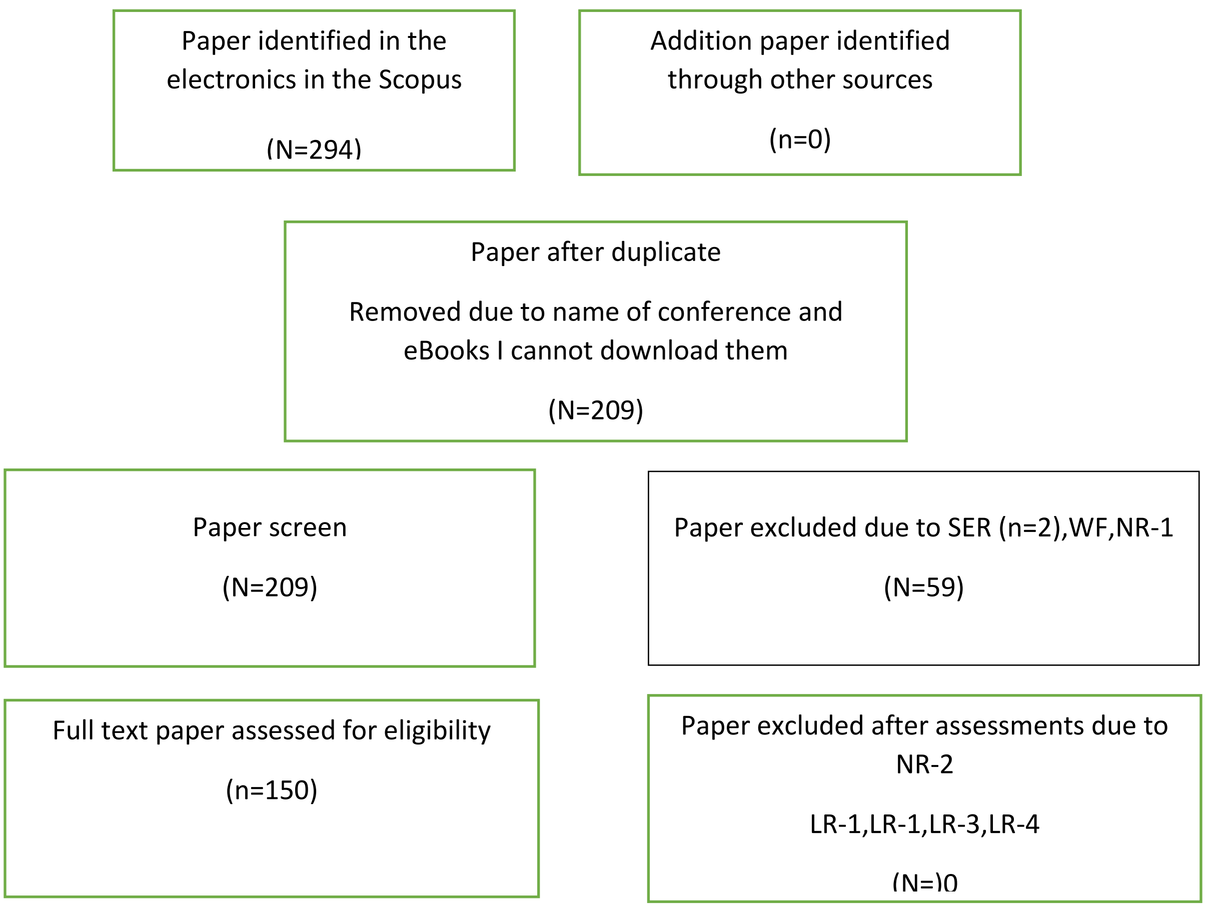

Figure 4 search process and results, adapted from PRISMA.

2.2. Paper collections

To obtain a comprehensive set of paper search strings was the industrial 4.0 and Lean management”. The Systematic search used for the electronic database Scopus that was published

- Contained at least one of the identified words in either the abstract, title and keyword
- were published in the journal, conference proceedings, or book series
- were written in the English language.
- Regarding the date, it does not have any limitations.

After removing duplicates, the first screening was carried out to exclude for whcih1.there were no access to their full text (WF); had only title abstract and keywords word in English (SER).3.were not academic articles(NR-1). Then a paper that passed the initial screening process was briefly reviewed by reading the titles and abstracts. or if more information was needed, inclusion or exclusion was needed, Full text. This second screening process was employed to exclude papers that (1) define 'the fourth industrial revolution' out of the scope of this work (NR-2); or (2) do not focus on Industry 4.0 research (LR-1)

- Finally, all eligible papers were studied in detail and classified into diverse sub-categories of the inclusion criteria (CR and PR-1 - PR-3).

According to Figure 4 in this thesis, the candidate searches the relationship between Industry 4.0 and lean management, and then 294 in the following chart, the results will show related to year, access, and subject area.

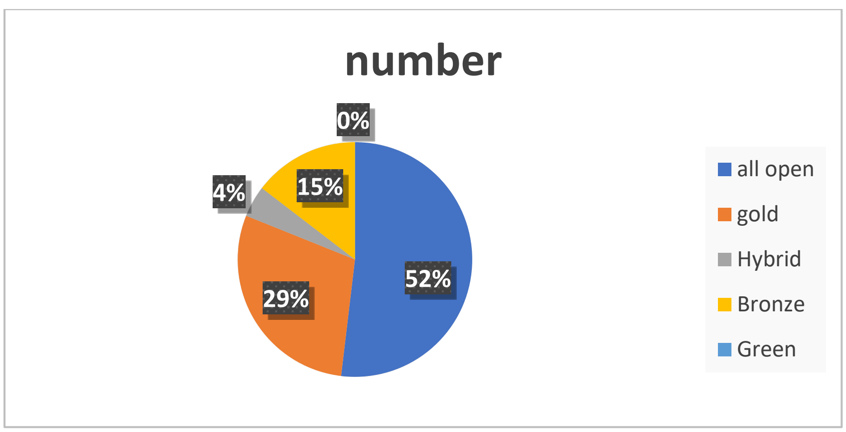

Figure 5 Articles availability.

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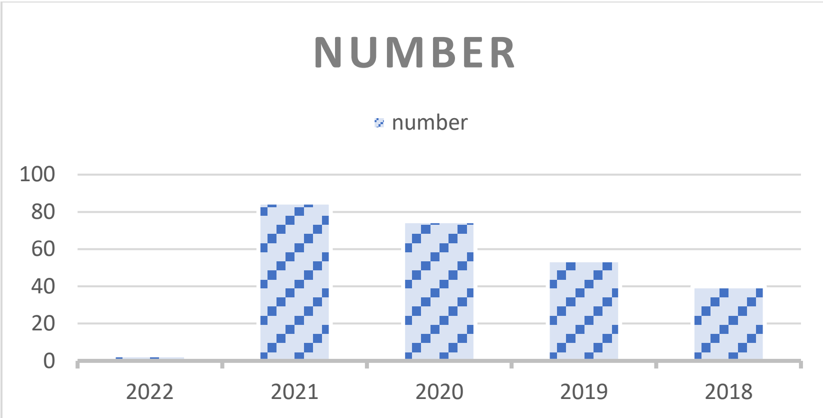

Figure 6 Article's publishing date.

Regarding date of publishing the articles, three articles are related to 2022,85 papers in 2021, and papers in 2020 and 54 papers in 2019, and 40papersr in 201 8. this search does not show any articles. before2018.

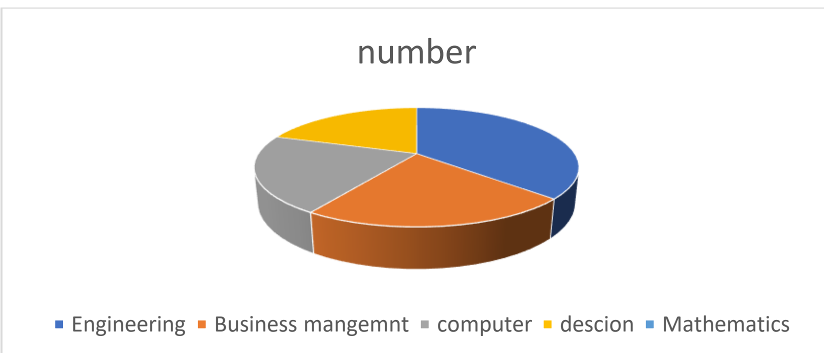

Figure 7 Publication field.

3. The bilateral effects between Industry 4.0 and Lean

It was mentioned earlier that one of the challenges of the industry 4.0 implementation would be the existence of a shop floor with Lean management practices. This idea is reinforced in several studies, not only because of the need to preserve current manufacturing systems and Lean has been a wave of the 90s (Teixeira, 2019) (Wagner, 2017),but also because the automation of inefficient processes will only further increase operational inefficiency and, therefore, industrial inefficiency (A mayer, 2018)Because the MES system works on shop floor operations, it can benefit from Lean procedures and tools already present in several organizations. Lean's core is mainly the specification of value and the discovery, identification, and eradication of waste (Juliana Salvadorinho L. T., Information systems in Industry 4.0: Mechanisms to support the shift from data to knowledge in Lean environments, 2020). It is a philosophy that is governed by objectives of time, quality, costs, safety, and workers' engagement. I4.0 also considers these objectives in its mission, adding the customization capacity fostered by information and communication technologies, thus empowering new models to operate, flexibility in operations, and systems connectivity (Enke, 2018)

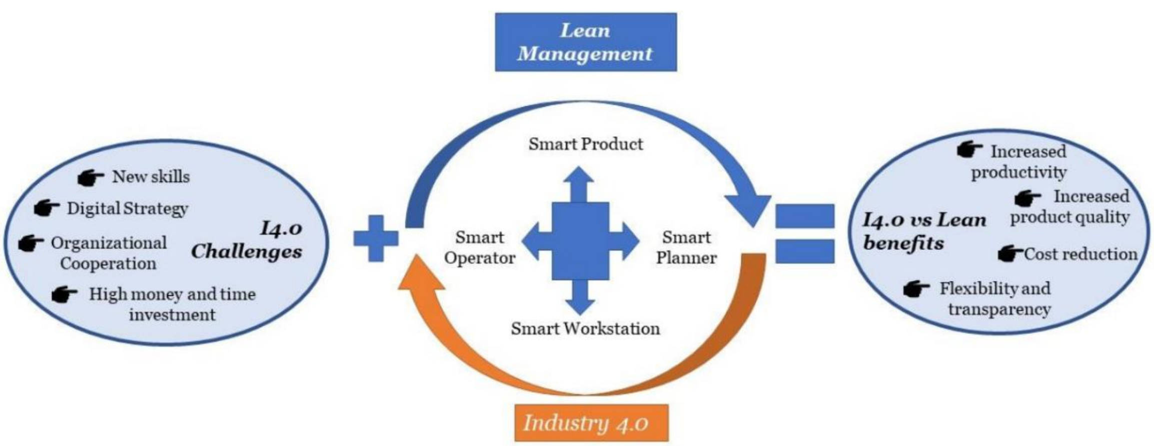

Figure 8 lean shop floor (Juliana Salvadorinho L. T., Information systems in Industry 4.0: Mechanisms to support the shift from data to knowledge in Lean environments, 2020).

With the main bilateral effects between Industry 4.0 and Lean, based on the challenges established by I4.0. Thus, the main challenges that emerge from I4.0 can find it answered in the integration of Lean philosophy, together with the emerging technologies of the fourth industrial revolution. According to (Kolberg, 2015)the integration of Lean philosophy with the principles inherent to the

I4.0 context gives rise to four new concepts on the shop floor, namely: Smart Operator, Smart Product, Smart Workstation, and Smart Planner. Since the MES is the information system connected to the shop floor, its essential elements are based on the components indicated, operator, product, planner, and workstation. It is important to realize that these four elements must be integrated with the MES information system and be part of it, thus giving "life" to those elements that were previously static

3.1. Smart Operator

this concept includes the introduction of IoT mechanisms, such as Smart Watches, which will facilitate the notification of employees, using Andon logic, about messages and error locations. Augmented reality can help establish JIT on cycle times, scheduled tasks, and even digital work instructions (Ghobakhloo, 2020)Simulation, in combination with augmented reality, on the other hand, will facilitate training when new functions or jobs are involved, as well as maintenance actions (Rossini, Costa, Tortorella, & Portioli-Staudacher, 2019)The establishment of knowledge management systems will make it possible to retain the right knowledge, at the right time and in the right place (JIT), in addition to the potential to foster brainstorming (creating new knowledge) and thus consolidate the skills of the teams (Ghobakhloo, 2020)

3.2. Smart Workstation

is meant the use of IoT technologies to assign the ability to react to processes through alerts based on events and decision-making by the job itself (e.g., stopping the process or even exchanging production products). Communication via RFID (Radio Frequency Identification) of products/materials in progress with equipment is also a reality, which allows for avoiding production errors (Jidoka (Rossini, Costa, Tortorella, & Portioli-Staudacher, 2019). As with the product, here, it is also possible to establish statistical process control systems. In the area of maintenance management, the entire action schedule becomes more agile, the control of equipment inactivity is performed, and predictive analysis is possible to be carried out, contributing to a Total Productive Maintenance Management (TPM) (Ghobakhloo, 2020) (Haddud, 2020)

3.3. Smart Planner

The introduction of autonomous robots (example of Automated Guided Vehicles - AGV) is a reality that allows the movement of products and materials between workstations, the information sharing about the destination and delivery times, as well as the readjustment of milk-run routes (logistics system for the collection or delivery of materials with several stops, in order to optimize the route) whenever necessary (Rossini, Costa, Tortorella, & Portioli-Staudacher, 2019).In this context, visual management benefits from real-time data, offering conditions for better risk management and identification of anomalies in the system (Haddud, 2020)Simulation techniques will also be essential in the context of testing different production parameters and the design of numerous flows, contributing to better planning of movements and identification of sources of waste (Kolberg, 2015)

3.4. Smart product

In reference to Kaizen, which helps to pave the way on lean the journey, Smart Products can collect and use for analyzing the information about repeating actions from their sensor and properties such a: context-aware, adaptive, self-organized, and proactive and the ability to support the whole lifecycle which allows them for continuous improvement process. Moreover, their data allow Visualization of the manufacturing process and flow of information for a chosen group of products. On this basis, it is possible to create a Current State Map, which shows wastes in particular processes and assigns future strategic planning activities, the aim of Value Stream Mapping. Additionally, a Smart Product could contain Kanban information to control production processes which are presented by Smart Factory KL at Hannover Messe 2014 in Germany ((Beata Mrugalska, 2017)

4. Lean management and industry 4.0

Before now, companies have often used lean management to increase productivity in value-added processes by optimizing the organization. LM focuses on the implementation of the method by employees themselves. This approach can be applied to the value-added process, and employees should think about their actions .so. That should be called a continuous improvement process (CIP).On the contrary, I4.0 shows a technology-driven method and represents the networking of the natural and cyber worlds. The term digitization is commonly used as a synonym of I4.for Human beings in the production are not considered. But they have required a use they can process and process to make decisions; however, the number of employed employees increased due to automation (Prinz, 2018)And the difference between these two methods. Since they have different approaches, they have a goal: increasing value-added. Implementation of I4.0 will decrease the production system's complexity, leading to better management in the process. In addition, for better control of the process, it is vital to have transparency and standardization. LM implementation can exploit higher effectiveness in the I4.0, so it can be assumed that I4.0 and LM without each other cannot be productive. In the following

Graph that (Prinz, 2018)showed this possible productivity increase with provided LM and I4.0.

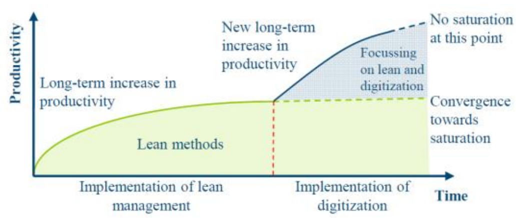

Figure 9 possible productivity LM and I4.0.

The contradiction between lean and industry 4, lean can exist without it((Kolberg, 2015)

- The contradiction between the people's focus on Lean and the machine focus on i4.0 is that they claim that the operator's role is more important than machines.
- The process is Industry 4.0 technologies' implementations are most beneficial for sectors in which the cost-saving and simple Lean methods cannot fulfill requirements.
- companies that had achieved higher levels of performance improvement were more likely to be those who either had or were implementing both i4.0 and Lean

4.1. Lean production tools in Industry 4.0

Lean production, or lean management, is recognized as the groundwork for Industry 4.0 (Prinz, 2018). Many researchers wanting to achieve a higher lean level have focused on how to use and improve existing lean production tools (Buer, 2018)ICTs can be incorporated into lean production tools in highly customized, dynamic, and complex manufacturing environments (Kolberg D, 2017); (Buer, 2018)((Prinz, 2018)Researchers also stated that the integration of these technologies with lean production tools could help manufacturing enterprises further improve production efficiency, reduce cost, and improve quality (Khanchanapong, 2014)(A. Sanders C. E., 2016 (Moeuf A, 2018) (A mayer, 2018)suggested the introduction of various lean tools in Industry 4.0 such as Kanban 4.0, Just-in-time (JIT) 4.0, total productive maintenance (TPM) 4.0.

They adopted a cloud-based, data-driven approach to improving the efficiency of implementing TPM. (Wagner, 2017)introduced a conceptual integration framework enabled by CPS and JIT and described the operational procedure. (Shahin, Bouzary, & Krishnaiyer, 2020)proposed the fundamental elements and an implementation framework for cloud Kanban (Kolberg D, 2017)described the combination of ICTs and Kanban in lean automation practice.

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4.2. Lean impact on I4.0

- Through just in time philosophy provides the necessary information at the right format and time, promoting the reuse of knowledge.
- Hoshin Kanri makes it possible to scale objective of company in the logic way that will facilitate the stakeholder involvement.
- Robot can make mistakes is the introduction of Poka-Yoke system
- Value stream mapping help to finding out where is the waste is for selecting better I4.0 technologies.
- By designing lean philosophy, the vertical hierarchical integration must happen
- Obeya room is tool for daily meeting to discuss improvement of digital technology
- Shop floor like Kanban preserve production system and boosting digital ecosystem

- The design of digital risk management can be promoted through lean tools such as FMEA
- DMAIC methodology can improve the process, monitor them and imposing standard work on the shop floor.

4.3. Industry4.0 impact on lean

I4.0 principles cannot replace with lean philosophy; those can help each other. leans environment promote a culture receptive to new technology, especially when the enhance the reduction of the waste and allows an accurate knowledge about the process that will create value.

- Static behavior tolls like value stream mapping can benefit from IOT technologies which allow the availability of data in real time and making more real to event presented.
- I4.0 responds to market dynamic behavior .so being capable to benefit from a levelling of production based on lean and fostering a make to order process.
- The digitization of some lean tools like Kanban can facilitate adoption of process.
- Information technologies can support total quality management by offering statistical process management tools through control chart
- IOT and connectivity enable more effective and efficient management in real time.
- Introduction of I4.0 make it possible to schedule operation
- Simulation can anticipate potential difficulties and mitigate process failure
- IOT allows tracking and sending progress state to flow managers and simulation help to test different scenarios in the just in time and continues flows
- Augment reality will help employees to obtain visual feedback(jidoka)

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- Information technologies can support total quality management by offering statistical process management tools through a control chart.
- IoT and connectivity enable more effective and efficient management in real-time.
- The introduction of I4.0 makes it possible to schedule operations.
- Simulation can anticipate potential difficulties and mitigate process failure.
- IoT allows tracking and sending progress state to flow managers, and simulation help to test different scenarios just in time and continues flows.
- Augment reality will help employees to obtain visual feedback (jidoka)

Integration of lean principle and emerging I4.0 technology can be expected to several benefit

- Increased quality
- Increased productivity
- Greater flexibility
- Greater transparency
- Cost reduction
- Increased work safety

The evolution of Lean management in the context of Industry 4.0 leads to risks and opportunities. According to (Rother & Baboli, 2019)the success factors of the coming transformation are three: management engagement, involvement, and interaction. Therefore, the proposed approach is to use the technological advances to free up manager time and use it to focus on human relationships: sharing knowledge, developing the workforce's skills, and managing progress (Rother & Baboli, 2019)Total Quality Management will need to evolve as quality planning, quality control, quality assurance, and quality improvement are different in a digital manufacturing framework compared to the previous human-capabilities-based era (Rother & Baboli, 2019)

management has a key role to play in the successful transition to Industry 4.0. From the Lean perspective, changes brought by Industry 4.0 could be used to free up manager time to be invested in focusing on human relationships

Table in the following presents the results obtained from categorizing the articles found by the search methodology. Some authors, specifically (Dombrowski U. T., 2017)and (Prinz, 2018), did not provide sufficient detail on the use of the proposed technologies to provide a conclusion regarding the level of capability used. They have therefore been excluded from the results. The articles are presented with the numbers used

The following subsections present references according to the categories of Lean principles from Liker's TPS house diagram (2004). A category has been added, Foundations, which includes the principles at the base of Liker's TPS house diagram (2004), as well as the principle of continuous improvement presented in the center of the house.

4.6.1. Just-in-time

Several authors have proposed work presenting applications of Industry 4.0 technologies to support the principle continuous flow. We have included in this principle the articles that concern, among other things, operation planning, and scheduling. In terms of monitoring capability, authors have suggested using the Internet of Things to track products in real-time and send production progress data back to managers e.g., (Mao, 2018) (Müller, 2018); (Wagner, 2017); (Yuan, 2016). Other authors have proposed cloud computing to make progress information available e.g., (Kumar, 2018); Sanders, (Ellgass, 2018). Simulation is also used to ensure a continuous flow, especially to detect bottlenecks e.g. (Frédéric Rosin, 2019)

Some authors have proposed integrating systems with partners to ensure that everyone has up-to-date information on production progress e.g. (A. Sanders C. E., 2016); (Sony M. , 2018)The optimization capability level is used by some authors, mainly in simulations e.g (Block, 2018); (Heger, 2017); (Ismail, 2015); (Kück, 2016); (Leitão, 2016); (Mousavi, 2017); (Rüßmann, 2015); (Saez, 2015) (Snyman S. a., 2017); (Zhuang, 2018)

Here, the simulation is used to test different response scenarios to production flow disruptions in real-time, but it is up to managers to apply the changes (Snyman S. a., 2017)us simulation to find optimal scheduling scenarios for production. Also, the Internet of Things e.g. (Mao, 2018); (Rüßmann, 2015); (A. Sanders C. E., 2016)), systems integration e.g. (Zhuang, 2018), cloud computing (Snyman S. a., 2017)and big data (Metan, 2010)are proposed. At the autonomy level, (Rüßmann, 2015)propose using the Internet of Things and autonomous robots to independently adjust production according to unfinished products. These robots can collaborate to respond in real time and ensure that production runs smoothly. Also, the authors discuss the concept of collaborative robots or robots, which assist employees in their work and benefit from a certain level of autonomy to react to the employee's actions e.g., (Fasth-Berglund, 2016); (Levratti, 2019)

(A mayer, 2018)) also propose the use of autonomous robots to adjust production planning in real-time. (T. Wagner, 2017)proposed system integration to ensure a continuous flow by allowing systems to adjust autonomously to production planning. The pull production system is studied in three of the four capability levels. The proposals are mainly related to the improvement of the kanban principle to synchronize work between working stations. First, at the monitoring level, the Internet of Things is suggested by some authors e.g. (Davies R. T., 2017); (A mayer, 2018); (Mrugalska, 2017); (A. Sanders C. E., 2016). In particular, (A. Sanders C. E., 2016)Propose the kanban, which allows each product to be tracked electronically and ensures that the right product arrives at the right destination at the right time. Similarly, (Mrugalska, 2017) propose the use of electronic kanban to ensure that the right products go to the right workstations. Simulation is proposed by Alves, (Rüßmann, 2015)to simulate changes in the kanbans used. (Frédéric Rosin, 2019)propose a real-time information exchange platform based on cloud computing to facilitate just-in-time supply between a producer and its supplier. At the optimization level, (A mayer, 2018) and (Kolberg, 2015)propose using simulation to test different parameters of kanbans. Similarly, (A mayer, 2018) propose the use of simulation to represent products and find optimal kanban parameters, such as batch size, minimum inventory, and delivery frequency. For the autonomy level, (Wagner, 2017)present a system using the Internet of Things, called Just-in-Time delivery, to automatically send orders. (Hofmann, 2017)also present a system using the Internet of Things to facilitate the use of electronic kanban and order automation. The principle of quick series change has also been studied from the point of view of Industry 4.0. At the Optimization level, (Rüßmann, 2015)suggest the use of simulation to optimize machine setups by testing various methods. The principle of integrated logistics requires that the logistics system be designed to operate as efficiently as possible with production. In terms of monitoring level, (Hofmann, 2017)use the Internet of Things to always get an overview of the movement of products. Through system integration, (Kolberg, 2015) but between suppliers and customers. At the autonomy level, many authors use the potential of autonomous robots to move products between workstations, including (Müller, 2018)and (Li, 2018)). Although the literature presented here is limited, the research work related to transport robots with autonomy capability is very extensive. These transport robots take advantage of the Internet of Things to exchange information about the destination and timing of delivery with the product, making transport possible. These auto-guided vehicles (AGVs) can react to disruptions and adapt to find alternative routes.

4.6.2. Jidoka

The andon principle is addressed by (Kolberg, 2015)and (Mrugalska, 2017) at the monitoring level. In both cases, the Internet of Things allows products to communicate with equipment and send a warning when the wrong product is being produced. For the control level, (Kolberg, 2015)propose extending the possibility of using the Internet of Things, but this time by allowing the equipment to react to this error warning by stopping the work or by changing products. The principle of human-machine separation suggests that work should be carried out by the equipment and that employees should supervise the machines. For the Autonomy level, (Porter M. E., 2014) (Kermorgant, 2018)propose the use of autonomous robots to produce without direct employee intervention. In fact, although the selection of articles here is limited, the literature on the use of autonomous robots for production work is extensive. The anti-error principle is addressed at the monitoring level by (Kolberg, 2015)and (A mayer, 2018)by using the Internet of Things in a similar way as the Andon principle, which was described above. In addition, augmented reality is proposed by (Kolberg, 2015)and (A mayer, 2018)to allow employees to obtain visual feedback if errors occur. At the control level (Mrugalska, 2017)propose the use of the Internet of Things to ensure that the right products go to the right workstations and automatically redirect products in the event of referral errors. At the autonomy level, (Krueger, 2019)and (Nikolakis, 2019)use autonomous robots that detect and correct detected production errors themselves. In-station quality control is associated with several articles. At the monitoring level. (Boersch, 2018), (Carvajal Soto, 2019) (Cochran, 2016)and (Peres, 2018) suggest using Big data analysis to identify defect trends. In particular, (Peres, 2018)propose the IDARTS system, which uses massive data analysis and the Internet of Things to perform real-time quality control. At the optimization level, (Frédéric Rosin, 2019)use the Internet of Things to feed an agent-based optimization model, the GRACE project (Integration of Process and Quality Control using multi-agent technology), and detect manufacturing defects, particularly by analyzing equipment vibrations. At the autonomy level, Ma, (Wang, 2017)) propose the SLAE-CPS system, which combines the Internet of Things, autonomous robots and cloud computing, allowing anomalies to be detected and corrections to be made autonomously on the product. (Chiarini, Belvedere, & Grando, 2020)also in the GRACE project, provide that quality agents can communicate and modify production parameters to improve quality in the event of a problem. (Eleftheriadis R. J., 2016)present the IFaCOM (Intelligent Fault Correction and self-Optimizing Manufacturing Systems) project, which takes advantage of the Internet of Things to achieve zero defects. This system can be associated with the Control level and the Autonomy level, depending on the level of intelligence associated with defect correction. The main concept is based on the use of the Internet of Things to monitor quality parameters to suggest corrections to the production system in real-time and to adapt parameters, also in real-time

4.6.3. Waste reduction

In the waste reduction category, the principle of eyes for waste at the monitoring capability level can be improved by using the Internet of Things e.g. (Frédéric Rosin, 2019); (Buer, 2018); (A mayer, 2018); (Mrugalska, 2017); (Uhlemann, 2017)The idea shared by the authors is to take advantage of real-time product tracking to see product expectations and unnecessary transportation. This information can then be used to reduce waste (Sony M. , 2018)offers horizontal integration of systems between different departments within an organization to make information more accessible and to identify waste. (Stojanovic, 2018)proposes using Big data to identify, in real-time, unusual conditions in the production system and the identification of root causes. Simulation is also proposed to identify sources of waste e.g. (Ellgass, 2018); (Kitazawa, 2018) ; (Zhuang, 2018)These authors use the concept of the digital twin, which is a simulated copy of a production system. Among them, (Zhuang, 2018)use a digital twin to simulate scenarios for solving production problems on a virtual copy of a production system. This enables ideas to be tested and allows managers to choose the most promising ones.

4.6.4. *People and Teamwork*

Linked to the People and Teamwork category, only the Cross-Training principle appears to be improved by Industry 4.0. To facilitate employee training, at the monitoring level, various authors propose the use of visual augmented reality interfaces to provide additional information to the employee on the tasks to be performed and to provide real-time feedback on errors made in a training context e.g. (Al-Ahmari, 2016); Longo, Nicoletti, and Padovano 2017; Segovia et al. 2015). For their part, (Lu, 2016) suggest the use of simulation to facilitate employee training, allowing employees to train in a simulated environment. At the optimization level, (Al-Ahmari, 2016)propose the use of augmented reality to optimize the training process itself.Foundations

Other principles included here in the Foundations category are improved by Industry 4.0. First, at the monitoring level, the continuous Improvement principle can take advantage of augmente reality. (Davies R. T., Review of Socio-Technical Considerations to Ensure Successful Implementation of Industry, 2017) and (Davies R. T., "Review of Socio-Technical Considerations to Ensure Successful Implementation of Industry, 2017)suggests using this technology to visualize Value Stream Mapping (VSM) and value chain mapping. (Sony M. , 2018)proposes using system integration to facilitate information sharing and value mapping creation. At the optimization level, (Stojanovic, 2018)integrate Big data analysis and numerical twin simulation into a continuous improvement process aimed at finding an optimal solution. (Kamar, 2018)on the other hand, use real-time simulation in the context of continuous improvement to optimize the production system in terms of stocks, movements, overproduction, and waiting. With regards to the leveled production principle, at the optimization level, (A mayer, 2018)mention the use of Anaprox software, which takes advantage of Big data to smooth production, thus optimizing production planning. At the monitoring level, augmented reality is proposed by (Longo)to make processes stable and standardized. More specifically, they present the concept of a 'smart operator,' in which the operator is assisted by different technological means, including an augmented reality visual device, to help him/her perform the standardized tasks to be performed for each product. The aim here is to achieve a level of surveillance. With regards to the autonomy level, (Boudella, 2018)and (T. Wagner, 2017)offer autonomous robot applications, namely a picking robot((Boudella, 2018)and a robot that works in conjunction with an operator (Wang, 2017)which Helps standardize work procedures Visual management can take advantage of several Industry 4.0 technologies. Various authors use the Internet of Thing to obtain information on the status of the production system and to make it available to employees, corresponding to the monitoring level e.g., (Alexopoulos, 2018); (Bonci, 2016) (Cao, 2017); (Davies R. T., 2017); (Hwang, 2017); (A mayer, 2018) (Mousavi, 2017); (Saez, 2015); (Zühlke, 2015); (Zhuang, 2018) (Tao, 2017)and (Zhuang, 2018)) suggest using cloud computing to make information related to the production system available. Also, (Zhuang, 2018)use Big data to extract relevant information from the large amount of data collected by the sensors distributed in the production system. (Saez, 2015), on the other hand, propose the use of simulation to provide visual data to managers, while (Kolberg, 2015)proposes the use of augmented reality to present this data. To support the Toyota philosophy, at the monitoring level, (Sony M. , 2018)and (A. Sanders C. E., 2016) suggest a vertical integration of systems between suppliers and customers to facilitate the identification and sharing of customer value.

4.7. Can Lean and Industry 4.0 coexist and support each other?

There are four main lines of thought when answering this question:

- Lean techniques and Industry 4.0 technologies interact in a positive way, and there are many cases to illustrate this [(Wagner, 2017) (A mayer, 2018)), (Shahin, Bouzary, & Krishnaiyer, 2020)((Tortorella, et al., 2020)
- Lean facilitates the change towards Industry 4.0 (Bittencourt, Alves, & Leão, 2019)
- , Industry 4.0 supports Lean, i.e., makes the factory Lean [((Romero, 2019) (Dombrowski & Richter, 2018)
- Lean and Industry 4.0 aim for the same goals, but their approach is essentially different regarding digital technology.

Dombrowski et al. analyzed 260 industrial companies in Germany and found Lean an enabler of Industry 4.0 (Dombrowski & Richter, 2018).Tortorella et al. investigated 110 user cases in Brazil and found a positive Lean-Industry 4.0 correlation, as well as increased benefits of new digital technologies where Lean was also present (Tortorella & Fettermann, 2018)Rossini et al. analyzed 108 cases of European manufacturers, concluding that Lean allows for achieving higher levels of Industry 4.0 while lacking Lean production techniques makes it more challenging to change towards Industry 4.0 (Rossini, Costa, (Tortorella & Fettermann, 2018). (Chiarini, Belvedere, & Grando, 2020). that most strategic, operational areas benefit from implementing Industry 4.0, such as design-to-cost, supply chain integration, or machinery–electronics–database integration ((Chiarini, Belvedere, & Grando, 2020),

Lorenz et al. analyzed user cases in Switzerland and found that Lean maturity allows for more significant performance improvements from implementing Industry 4.0. there is a wealth of evidence showing that Lean manufacturing goods is a valid improvement to improve assembly operation in the context of mass customization and that Lean, and Industry 4.0 can benefit from synergies because each one enhances the other. However, according to some authors (Lorenz, Buess, Macuvele, Friedli, & Netland, 2019)

Industry 4.0 and Lean have essentially different approaches regarding the role digital technologies should have. While some authors deem that TPS considers robots, machines, and computers on the opposing side of *jidoka* it should be noted that the lack of enthusiasm of TPS towards digital technologies could have been influenced by the current digital technologies of that era (the 1950s–1980s). Since the rate of change in digital technology has been particularly remarkable in the past four decades, it seems bold to assume that TPS's views on computers in the second half of the 20th century still apply.

Research on Lean tools for assembly operations is still an open topic. Firstly, it should be noted that since internal logistics are tightly associated with assembly, both should be analyzed together because changes to one will affect the other as well. Lean production systems typically employ assembly lines or cell layouts to establish pull and create material flow. For certain contexts involving high-cost, high-variability, and short product development cycles, assembly systems are particularly competitive because they are focused on adaptability. KPIs and performance assessment frameworks are used to measure the effects of changes in Lean production systems. Establishing a set of KPIs needs to consider multiple stakeholders and align the strategic and operational goals of the organization. Simulations and case studies show the beneficial effects of Lean methods and allow us to estimate the economic return of investment of Lean management decisions.

The Toyota Production System (TPS), on the opposing side of *jidok* automation with a human touch, considers robots, machines, and computers, but it should be noted that their lack of enthusiasm toward digital technologies is influenced by the current digital technologies of that (1950–the 80s). The changes in digital technology have been particularly significant and TPS's views on computers in the s the 20th century still apply in the past four decades. Currently, there is a wealth of evidence showing that Lean manufacturing is a valid approach to improving assembly operation in the context of mass customization and that Lean, and Industry 4.0 can benefit from synergies because each one enhances the other. Some classic Lean tools—e.g., Value Stream Map—may need to change to remain useful for analyzing digital processes. In general terms, Industry 4.0 technologies are expected to support the ability of people to make Leanoriented decisions. in the successful transition to Industry 4.0 Management has a vital role to play. From the Lean perspective, changes brought by Industry 4.0 could be used to free up managers' time to be invested in focusing on human relationships. Learning Factories could be a great tool to share the vision of Lean 4.0 assembly, but they need to mimic real-life scenarios to become useful for non-academic learners with industrial backgrounds, such as assembly operators. Industry 4.0 technologies could also be used to enhance the training environment of Learning Factories. Since both. Lean and Industry 4.0 stress the importance of people; it seems only natural that supporting human capabilities becomes a priority in Lean 4.0 assembly.

(Buer, 2018). examined the relationship between lean manufacturing and industry 4.0 based on the results of current research mapping, the result is that most of the current research argues technologies in Industry 4.0 supports lean manufacturing practices, and some research argues lean manufacturing supports Industry 4.0. According to (Buer, 2018)companies that have already implemented lean manufacturing require rules about the best way to respond to Industry 4.0 effects (M. Tischa, 2017)). These companies need to incorporate the new advancements from Industry 4.0into their current lean manufacturing systems (Wagner, 2017), but the knowledge of how this should be done is still undeveloped (Kolberg, 2015) (Wagner, 2017)Integration between lean manufacturing and Industry 4.0 is still not clear which tool practices could be integrated; this research must be able to define which one makes up each other and which tools contradict each other.

4.8. Industry 4.0 impact on lean tools

Over the last years, organizations have been adopting Lean Production Systems to align their processes with the customer’s perspective, which means that almost processes and procedures are designed based on the lean principle. Lean aims at eliminating waste, focusing on the value-added from customer vision, and honoring demands in the least time, at high quality, and at the lowest cost. In addition, the lean concept aims at conserving the idea of continuous improvement in all enterprise's direction. Thus, it becomes a factor of competitiveness between companies in the market. The market demands are changing and becoming more specific. The demands are changing to one lot size. The thing that does not match with lean architecture is defined for mass production. However, this change coincides with the emergence of the fourth industrial revolution. This revolution brings sophisticated technologies that promise to cooperate with future market requirements. Many authors confirm that I4.0 technologies will not remove lean principles and tools, contrary; they will enhance their use to become more efficient and flexible (A mayer, 2018),

4.9. Lean is a basis for industry 4.0

Lean acts as a basis for the I4.0 .in 2017, researchers showed that mixed two methods increase profitability. In addition, companies with less than two years have no extensive association between lean production and i4.0; the author also has found that companies poorly associate lean production.

authors (Tortorella & Fettermann, 2018) and (Rossini, Costa, Tortorella, & Portioli-Staudacher, 2019)concluded that implementing 14.0 is higher in the companies adopting lean production, also (Leyh, 2017). Classified thirty-one I4.0 models and claimed that lean management and lean production are the basis for the I4.0. also (Rossini, Costa, Tortorella, & Portioli-Staudacher, 2019) stated the vital role of lean production and continuous improvement in adopting new tools like I4.0.in In (Dombrowski & Richter, 2018)mentioned that lean acts as a basis for I4.0.

In addition, other researchers claim that lean is an essential foundation for industry 4.0 (Kolberg, 2015) (A mayer, 2018) (Prinz, 2018)

Another researcher (A mayer, 2018)argues that the principles that exist in lean such a standardization of processes, reducing waste, and focusing on customer value, are the basis for Industry 4.0 implementation.

Table 4 Lean basis for industry 4.0.

contribution	factor	Results	Reference
The influence of implementing I4.0 on lean production according to operational performance improvement and the size of the company	• Time of implementing lean • production • Frequency • Adjusted residual	High-level lean production companies have more chance of implementing I4.0 in emerging economies. -Combining lean production with I4.0 elevates the profit. -Company background is vital in adopting lean production	(Tortorella & Fettermann, 2018)
The relationship between lean production and I4.0 classified models	Communication between Man-Man, Machine-Man Machine-Machine	-Information and communication technology are vital factors in the integration of lean production and industry 4.0 environments. -Lean management and lean production principles are the basis for I4.0.	(Leyh, 2017)
-Investigation of the relationship between I4.0 and lean production in 108 lean European companies that start to adopt I4.0	-Augment reality -Cloud computing -Integrated engineering system	-Adopting emergent methodologies are lower in companies in which lean production and continuous improvement are not established and are designed weakly. -I4.0 and lean production are correlated strongly.	(Rossini, Costa, Tortorella, & Portioli-Staudacher, 2019)
Combining I4.0 and LPS in consequence, creates LPS 4.0	-LPS 4.0 -Data management provision of information/data	-Lean build the biases for the adoption of I4.0. -I4.0 should be integrated with LPS to enhance LPS. -LPS is a prerequisite for I4.0	(Dombrowski & Richter, 2018)

4.10. Interaction industry 4.0 and lean

In 2017 Sandra et al. claimed that interaction between I4.0 and lean causes synergy. Also, Mayra et al. claimed that I4.0 supports the lean method.

In 2019 Valera et al. claimed that there is a relation between I4.0 and sustainability. In addition, they stated that lean manufacturing does not have any influence on sustainability.

In 2018 authors showed that I4.0 can solve the problem that exists in adopting lean manufacturing. In addition, they believed that for better quality and reliability in the product, the relation between I4.0 and lean is vital. (Satoglu, 2018) (Dombrowski U. T., 2017)that it is highly dependent between cloud computing and zero defect and big data.

Table 5 Interaction industry 4.0 and lean.

Contribution	factor	Result	Reference
-Different type of industry 4.0 elementshave been organized to technologies, systems, and process-related characteristics	-Cloud computing and -Big data -Horizontal and vertical Integration	-Higher dependencies between: 1. cloud computing and avoidance of waste and LPS principles. 2. Zero defect and big data.	(Dombrowski U. T., 2017)
How I4.0 can support lean methods	-Just in sequence 4.0 -Heijunka 4.0, - Kanban 4.0, VSM4.0, and JIT 4.0	-LM and I4.0 support each other. -I4.0 tools can support the analyzed lean methods in a condensed way.	(A mayer, 2018)
-The influence of I4.0 and lean manufacturing on sustainability have been measured qualitatively biased on 252 valid answer to the survey	-Environmental, Social and Economic sustainability	-Correlation between I4.0 and environmental, social, and economic sustainability. -There is no relation between lean manufacturing and sustainability	(Varela, 2019)
-How I4.0 and automation innovative technology support implementation of LM	-Additive manufacturing -Augmented reality -Simulation and virtualization -Overproduction and Inventory	LM and I4.0 are not mutually exclusive and should be integrated. -The I4.0 tools can provide solution to difficulties related to lean manufacturing like mismanagement and weakly-organized manufacturing systems. -Implementing lean manufacturing and I4.0 results in saving data correctly	(Satoglu, 2018)
-Exploring the interaction between lean management and I4.0.	-TPM -Takt time -SMED -VSM standardization	-The most support to the lean tools has been received from real time, decentralized and interoperability. -Numerous synergies between lean management tools and I4.0 principles. -Lean management tools are the prerequisite for I4.0.	(Sanders A. S., 2017)

4.11. Industry 4.0 completes lean

The influence of smart products and machines on continuous improvement was stated in 2017 by (Mrugalska, 2017) and in 2015 by (Kolberg, 2015)

. In addition, they stated that it could decrease the time between failure occurrence and failure notification through the smart operation. (Ruttimann, 2016)believed that lean transformation has better smoother and more accurate in the manufacturing company.

(Beifert, 2017)asserted that lean principles are not sufficient for shipbuilding because of the high transaction cost, and I4.0 provided the solution. In 2018 Cavalieri stated that i4.0 could coordinate supply chain and support just in time. In addition, Heijunka has become more reliable and optimized through big data and real-time remote activity.

(Susanna Loeb, 2017)focused on I4.0; improving the supply chain makes it smarter and more flexible by Improving the high level of date sharing for green supply chain and lean.

2017 some authors claimed that a combination of CPS and just in time has a positive affection on transparency and minimizing working space. Also, it showed that the I4.0 application could stabilize and support lean principles. I4.0 impact matrix on lean production systems gives a framework to start designing and developing I4.0 integrated applications (Wagner, 2017)Implantation of I4.0 helps companies to overcome Lean challenges and improve communication and coordination. (A. Sanders C. E., 2016) (Alexopoulos, 2018).

(Anthony, 2017)claimed I4.0 increased the ability of operators that help to reduce the number of employees on the shop floor

(Butollo, 2019)showed that I4.0 provide a solution for increasing demand for changing schedule and decreasing the bargaining power of the worker.

In 2019 Saxby et al. stated that Lean is partly but by no means wholly supportive. It was found the supportive elements of Lean in the world of Industry 4.0 would include Continual Improvement, Engaging the Supply Chain, Pull Systems, and having a Customer Focus. In 2019 (Varela, 2019)al. Considered the deep learning characteristic of lean management problem-solving behavior pattern is expected to help industry 4.0 leaders in some challenges like just-in-time production, total quality management, and service quality level increase.

(Vahid Taghavi, 2020)et al. focused on Three different main points of view: firstly, I4.0 completes lean, making it more efficient and stronger. Secondly, the integration of lean and I4.0 impact the value product. Customer satisfaction and competitiveness. Thirdly, they are unanimous about the way that these two influence each other.

Table 6 Industry 4.0 completes lean.

Contribution	Factors	Results	Reference
-Smart products and machines impact on Kaizen. -Augmented operator impact on Jidoka through recognizing the fault automatically	-Kaizen -Kanban -Jidoka	-Pave the way of lean in terms of Kaizen. -Give better operational intelligence -Drop the time between failure notification and failure occurrence.	(Mrugalska, 2017)
-Impact CPS on JIT (Cyber physical just in time) material process	-CPS -Big data analytic -Kanban card	-Increase transparency and stability of lean production. -Eliminate the shop floor. -Minimize the warehouse space	(T. Wagner, 2017)
-The gap between realms of lean and I4.0 -Analysis of the barriers for lean implementation due to the lack of resources	-Smart factory -Non-value added -Challenge to implement lean -Dimension of lean	-I4.0 makes factory lean beside being smart. -The positive correlation between lean and I4.0. -Companies could overcome challenges for lean implementation through adopting I4.0.	(Sanders A. E., 2016)
Globalizing the supply chain through communication between components of an industry.	-global supply chain-Production monitoring -Industrial IoT	-Lean six sigma eliminates unnecessary process and defects. -I4.0 and IIoT make systematic management of the supply chain more efficient and faster	(Jayaram, 2016)

-Outlined system of systems concept for improving productivity in road construction via lean and I4.0.	-Reference Architecture Model for Industry 4.0 (RAMI 4.0) -Hierarchical decomposition	-Improve the coordination of working machines. -Improve quality through reducing wastes and improve communication and coordination.	(Axelsson, 2018)
-Analyzing the autonomy in the work process in organizations that apply lean and I4.0.	-Autonomy - Interdependencies -Task rotation -Employee-oriented	-Close linked value chain and industry structures are prerequisites for higher quality -I4.0 and lean have a positive impact on greater task rotation. -New methods decrease the bargaining power of the workers.	(Butollo, 2019)
-How I4.0 is combined with lean and green supply chain -The influence of I4.0 on lean and green supply chain.	-IoT -Smart data -Smart supplier -Smart logistics	-I4.0 makes the supply chain more flexible with more visibility. -I4.0 evolves lean and supply chain. -The supply chain has been improved by IoT -I4.0 develops close cooperation with suppliers	(Duarte, 2017)
Investigation influence of I4.0 principles in lean automation.	-Kaizen -Smart operator, production machines, and planer	-I4.0 completes and supports lean. -I4.0 improves lean production. -Lean helps I4.0 to accelerate. -Smart products make Kaizen less labor-intensive.	(Kolberg, 2015)
-How lean be considered in the context of I4.0 initiative.	-Smart factory -Big data and IoT -Virtual reality	-I4.0 makes lean more stable and accurate also makes it faster and smother. -I4.0 should integrate into lean but I4.0 won’t be occurred as a revolution.	(Ruttimann, 2016)

-The influence of I4.0 in non-utilized employee's talents that is caused by the separation between the management and the process operations in lean organizations	-Operator 4.0 -Human CPS -Intelligent personal assistants Social networks	-Reduces the number of employees in shopfloor. -Transfers shift of human job towards the non-routine task. -Increases the ability of the operator through physical and cognitive interaction with machines	(D'antonio, 2018)
-A conceptual model that combines I4.0 in lean and green supply chain.	-Smart logistics -Smart products -Smart supplier -Smart operator -Smart manufacturing	-I4.0 improves lean. -I4.0 makes all concept of lean and supply chain smart. -Lean supports the installation of I4.0. -The green supply chain supports the implementation of the I4.0	(Duarte, 2017)
The way that I4.0 can deal with shortcoming sin lean manufacturing of the shipbuilding sector.	-Lean modeling and lean optimization tools -Potential cybercrime	-I4.0 solves the problems related to inadequate adoption lean and accelerate engagement of shipbuilding supplier. -I4.0 is a competitive advantage for SMEs and develops them in a smart approach	(Beifert, 2017)
-Investigation the potential of I4.0 to support key lean manufacturing constructs in an Italian company related to the automotive section.	-Just-in-time -Heijunka -Real time -Big data	- presents an approach to coordinate supply chain and supports just-in-time. -real time remote visibility optimizes elimination of wastes from overproduction	(Powell D. R.)

4.12. Integration of industy4.0 and lean

(Wagner, 2017)stated that the integration of I4.0 in the lean production value stream offers various improvement potentials for the manufacturing process. A value stream is a combination of value-adding and non-value-adding and supporting activity. in an international development project for a standardized shop floor, KPI reporting was shown to be a benefit in finding an I4.0 solution for problem-solving in the lean production system. Industry 4.0 is classified based on the principles of integration into vertical, horizontal, and end-to-end integration. The five principles for LM implementation is the overarching guideline for implementing LM Waste must be eliminated before implementing three mechanisms of integration; else, one will be automating the waste. With this principle, the model proposes LM principles in all three forms of integration in Industry 4.0 (sony, 2018)

4.13. Lean as a requirement for I4.0

IN 2018 Prinz demonstrated the necessity of lean management as a requirement for I4.0 (Prinz, 2018)

Table 7 Lean as a requirement for I4.0.

date	author	objective	Lean practices	ICT	result
2006	Coffey and Thornl	To present an alternative way of interpreting unfolding events as these pertain to the organization of manufacturing practices in the assembly plants of the leading Japanese car assembler, Toyota			tomation certainly played a much larger role in accounting for high labor productivity in the late 1980s than has generally been understood; but in the subsequent year's priority has been given to managing the manual component in car assembly, and aggressive automation as a preferred strategy has been put on ice
2008	Badak et al	To evaluate how LP should be supported and enhanced by a complementary Information Technology infrastructure	Production levelling and control	Enterprise Resource Planning	Improvement initiatives around LP and integrated Information Technology systems to address company requirements have so far been running in a disjointed manner and the literature has been unfairly dismissing any collaboration initiative.
2008	Hedeli and Jackson	to investigate whether industrial robot automation has a place in a manufacturing company pursuing the lean	Andon chart Visualization of production flow Operator maintenance Preventive maintenance Measurements in the cell Single minute	Interfaces between cell and surrounding IT-structure	Results show the need to align company's present robotic equipment and machinery towards lean principles. For that, it is needed the development of robotized working cells with increased availability, reduced set-up times by improving the ability for easily reconfiguration, and improved information design to clearly present visual information and options to the operator

			exchange of d, i.e. Jidoka		
2017	(Ma, 2017)	To provide an integrated and standardized approach to design and implement a CPS-based smart Jidoka system	joidoka	Service-oriented architecture Function block Cloud computing internet of things	The proposed CPS-based system can serve as an important reference value for combining the benefits of innovative technology and proper methodology
2017	(Wagner, 2017)	To present a conceptual framework to find LP supporting I4.0	5S Kaizen Just in time Jidoka Heijunka Standardization Takt time Pull flow Man-machine separation People and teamwork	Sensors/actuatorsCloud computing Big Data Analytics Virtual reality, Augmented reality Horizontal integration. Vertical integration	I4.0 can help stabilize and support LP principles. I4.0 impact matrix on LP systems gives a framework to start designing and developing I4.0 integrated application
2018	(Sony M. , 2018)	To propose an integration theoretical model of I4.0 and Lean management			The proposed model raises the important issue of vertical, horizontal and end-to-end integration of LP with I4
2019	(Guilherme Tortorella)	identifying the pairwise relationships between Lean Production (LP)			Findings indicate that I4.0 technologies are positively correlated with LP practices, providing evidence to bear the proposition of a LA framework that

		practices and Industry 4.0 (I4.0) technologies.			can potentially overcome traditional barriers and challenges of a LP implementation

4.14. Lean and Industry 4.0

Table 8 Lean and Industry 4.0.

Perspective	author
LM as enabler towards I4.0	(Huber, 2016) (B. Wang, 2016)
4.0 advances LM	(T. Wagner, 2017) (Stöckli, 2016) (Zühlke, 2015)
Positive correlation between LM & I4.0	(A. Sanders C. E., 2016) (Wyrwicka, 2017)

Lean offers an array of tools and techniques to deal with the increasing demand and complexity and variability and which could benefit assembly operation demand and complexity and variability, and which could benefit assembly operation in a context of mass customization, SMED, kaizen events, standardized simulation work, value stream management. At the same time, most authors consider lean as a valid approach for increased complexity of mass customization, other claims that lean cannot be applied straightforwardly in the industry 4.0 era.

Lean has positive synergy with industry 4.0, which can relate with new technologies can enhance lean assembly, and lean maturity supports the implementation of new technology; however, lean might not be necessarily the best possible starting ground for smart assembly in every situation, and it is not a perquisite for implementing industry 4.0.industry 4.0 increase the effectiveness of lean (A. Sanders C. E., 2016) (Anthony, 2017) (Eleftheriadis R. J., 2016) (Khanchanapong, 2014) (Leyh, 2017)) (A mayer, 2018) (Netland, 2015) (obias Wagner) (Dombrowski & Richter, 2018)Both industry 4.0 and lean consider making a vital role to the people in assembly operations. Lean is a main characteristic of the third industrial revolution production systems. While other aspects have evolved (e.g., technology, from computers to smart digital devices) or changed (e.g., market focus from the variety and lead time to customization and personalization), Lean is still an important part of I4.0.

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5. Conclusions

lean could finish the dominance of mass production in the automotive section, and it's being spread to other industries quickly. Lean considers any activity which does not add value to the product as waste and removes them from the manufacturing process to reduce costs. I4.0 optimizes the computerization of the fourth industrial revolution, and it makes the manufacturing process smarter, more effective, and more productive. Most authors confirm that relation of lean and I4.0 has positive impacts on companies, though there is no similar opinion about the way that the two approaches influence each other

References

A mayer, M. w. (2018). Lean 4.0 - A conceptual conjunction of lean management and Industry 4.0. 622-628.

A. Sanders, C. E. (2016). Industry 4.0 implies lean manufacturing: Research activities in industry 4.0 function as enablers for lean manufacturing. 811-833.

A. Sanders, C. E. (2016). Industry 4.0 implies lean manufacturing: Research activities in industry 4.0 function asenablers for lean manufacturing,. *Journal of Industrial Engineering and mangemnt* , 811.

Adrian Miqueo, M. T.-F. (2020). Lean Manual Assembly 4.0: A Systematic Review.

Adrian Miqueo, M. T.-F. (2020). Lean Manual Assembly 4.0: A Systematic Review.

Al-Ahmari, A. M. (2016). Development of a Virtual Manufacturing Assembly Simulation System. *Advances in Mechanical Engineering*.

Alexopoulos, K. K. (2018). An Industrial Internet of Things Based Platform for Context-Aware Information Services in Manufacturing.". *International Journal of Computer Integrated Manufacturing* .

Anthony, P. (2017). ean Manufacturing and Industry 4.0.

arcos Pagliosa, G. T. (2019). Industry 4.0 and lean manufacturing Joao Carlos Espindola Ferreira.

Axelsson, J. F. (2018). Towards a system-of-systems for improved road construction efficiency using lean and Industry 4.0. *Paper presented at the 2018 13th Annual Conference on System of Systems Engineerin.*

B. Wang, J. Z. (2016). Lean Intelligent Production System and Value Stream Practice.

Beata Mrugalska, M. K. (2017). Towards Lean Production in Industry 4.0. *Project, and Production Managemen*, 466-473.

Beifert, A. G. (2017). Industry 4.0–For sustainable development of lean manufacturing companies in the shipbuilding sector.

Bhuvaneshwari Alias Sunita Kulkarni, M. &. (2019). lean practicers in SMES towards improvement in production performance. *International Journal of Recent Technology and tewchnology*, 959–965.

Bittencourt, V., Alves, A., & Leão, C. (2019). Lean Thinking contributions for Industry 4.0: A systematic literature review. 904–909.

Block, C. D. (2018). Approach for a Simulation-Based and Event-Driven Production Planning and Control in Decentralized Manufacturing Execution Systems. 1351–1356.

Boersch, I. U. (2018). Data Mining in Resistance Spot Welding: A Non Destructive Method to Predict the Welding Spot Diameter by Monitoring Process Parameters. *international Journal of Advanced Manufacturing Technology* , 1085–1099.

Bonci, A. M. (2016). “A Database-Centric Approach for the Modeling, Simulation and Control of Cyber-physical.

Boudella, M. E. (2018). Kitting Optimisation in Just-in-Time Mixed-Model Assembly Lines: Assigning Parts to Pickers in a Hybrid Robot–Operator Kitting System. *." International Journal of Production Research* .

Brintrup, A. D. (n.d.). International Journal of Production Research 4. 2745–2764.

Buer, S.-V. S. (2018). The link between Industry 4.0 and lean manufacturing: Mapping current research and stablishing a research agenda. *production researach* , 2924–2940.

Butollo, F. J. (2019). *From Lean Production to Industrie 4.0: More Autonomy for Employees? In Digitalization in Industry* , 61-80.

Cao, W. P. (2017). “Real-time Data-Driven Monitoring in job-Shop Floor Based on Radio Frequency Identification.”92 (5-8): 2099–2120. *International Journal of Advanced Manufacturing Technology* , 2099–2120.

Carvajal Soto, J. A. (2019). An Online Machine Learning Framework for Early Detection of Product Failures in an Industry 4.0 Context. *" International Journal of Computer Integrated Manufacturing*.

Chiarini, A., Belvedere, V., & Grando, A. (2020). Industry 4.0 strategies and technological developments An exploratory research from Italian manufacturing companies. *production ,plan and control*, 1385-1398.

Christian Leyh, S. M. (2017). Industry 4.0 and Lean Production – A Matching Relationship? An analysis of selected Industry 4.0 models. *Proceedings of the Federated Conference on computer science and information systems*, (pp. 898-993).

Cochran, D. S. (2016). Manufacturing System Design Meets Big Data Analytics for Continuous Improvement. 647–652.

D’antonio, G. &. (2018). How to Manage People Underutilization in an Industry 4.0 Environment? *Paper presented at the IFIP International Conference on Product Lifecycle.*

Davies, R. T. (2017). “Review of Socio-Technical Considerations to Ensure Successful Implementation of Industry. *Procedia Manufacturing*.

Davies, R. T. (2017). Review of Socio-Technical Considerations to Ensure Successful Implementation of Industry. *Procedia Manufacturing* , 1288–1295.

Davies, R. T. (2017). Review of Socio-Technical Considerations to Ensure Successful Implementation of Industry 4.0. *Procedia Manufacturing*, 1288–1295.

Doh, S. W. (2016). Systems integration in the lean manufacturing systems value chain to meet industry 4.0 requirements.

Dombrowski, U. T. (2017). Inter-dependencies of Industrie 4.0 & Lean Production Systems - a Use Cases Analysis.

Dombrowski, U., & Richter, T. (2018). The Lean Production System 4.0 Framework—Enhancing Lean Methods by Industrie 4.0. In Proceedings of the Advances in Production Management Systems: Smart Manufacturing for Industry 4.0. 26-30.

Duarte, S. &.-M. (2017). Exploring linkages between lean and green supply chain and the industry 4.0. *Paper presented at the International conference on management science and engineering management.*

Eleftheriadis, R. J. (2016). A Guideline of Quality Steps towards Zero Defect Manufacturing in Industry." . *Proceedings of the International Conference on Industrial Engineering and Operations Management,*, 332–340.

Eleftheriadis, R. J. (332-340). A Guideline of Quality Steps towards Zero Defect Manufacturing in Industry. 2016.

Ellgass, W. N.-L.-B. (2018). A digital twin concept for manufacturing systems.

Enke, J. G. (2018). ndustrie 4.0 - Competencies for a modern production system: A curriculum for Learning Factories.

Fasth-Berglund, Å. F. (2016). Evaluating Cobots for Final Assembly in Procedia CIRP. 175–180.

Fettermann, G. L. (2017). Implementation of Industry 4.0 and lean production in Brazilian manufacturing companies. *international Journal of Production Research*.

Fettermann, G. L. (2017). Implementation of Industry 4.0 and lean production in Brazilian manufacturing companies. *International Journal of Production Research, 2018*, 2975-2987.

Frédéric Rosin, P. F. (2019). Impacts of Industry 4.0 technologies on Lean principle. *International Journal of Production Research*, 1644-1661.

Ghobakhloo, M. &. (2020). Corporate survival in Industry 4.0 era: the enabling role of lean-digitized manufacturing. *Journal of Manufacturing Technology Management*, 1-30.

Gigova, T. V.-A. (2019). Digital transformation-opportunity for industrial growth. 1-4.

Guilherme Luz Tortorella, M. R. (2019). A comparison on Industry 4.0 and Lean Production between manufacturers from emerging and developed economies. *Total Quality Management & Business Excellence*.

Guilherme Tortorella, R. S. (n.d.). Integrating Industry 4.0 into Lean Production. *proposition of a Lean Automation framework*, 2019.

Haddud, A. &. (2020). Digitalizing supply chains potential benefits and impact on lean operations. *International Journal of Lean Six Sigma.*

Heger, J. S. (2017). Online-scheduling Using Past and Real-Time Data: An Assessment by Discrete Event Simulation Using Exponential Smoothing. 158–163.

Hermann Mario, P. T. (2015). Design Principles for Industrie 4.0 Scenarios: A Literature Review.

Hofmann, E. a. (2017). Industry 4.0 and the Current Status as Well as Future Prospects on Logistics. 23–34.

Hu, S. (n.d.). Evolving paradigms of manufacturing: From mass production to mass customization and. *2013*, 3-8.

Huber, w. (2016). Industrie 4.0 in der Automobil production.

Hwang, G. J.-W. (2017). Developing Performance Measurement System for Internet of Things and Smart Factory Environment. *International Journal of Production Research 55 (9): 2590–2602*, 2590–2602.

Ismail, H. S. (2015). A Simulation Based System for Manufacturing Process Optimisation.

J. Metternich, M. M. (2017). lean for zwischen Widerspruch und Vision. 346-348.

Jay Lee Hung-An Kao, S. Y. (2014). Service innovation and smart analytics for Industry 4.0 and big data. *Product Services Systems and Value Creation. Proceedings of the 6th CIRP Conference on Industrial*, (pp. 3-8).

Jayaram, A. (2016). Lean six sigma approach for global supply chain management using industry 4.0 and. *Paper presented at the 2016 2nd international conference on contemporary computing.*

Juliana Salvadorinho, L. T. (2020). Information systems in Industry 4.0: Mechanisms to support the shift from data to knowledge in Lean environments. *Proceedings of the 5th NA International Conference on Industrial Engineering and Operations Management.*

Juliana Salvadorinho, L. T. (2020). Information systems in Industry 4.0: Mechanisms to support the shift from data to knowledge in Lean environments. *Proceedings of the 5th NA International Conference on Industrial Engineering and Operations Management*, (pp. 10-14). michigan.

Juliana Salvadorinho, L. T. (2020). The Bilateral Effects Between Industry 4.0 and Lean:. *Proceedings of the 5th NA International Conference on Industrial Engineering and Operations Management.* Michegan ,USA.

Juliana Salvadorinho, l. T. (2020). The Bilateral Effects Between Industry 4.0 and Lean: Proposal of a Framework.

Kale, S. V. (2019). Lean implementation in a manufacturing industry through value stream mapping. *Journal of Engineering and Advanced Technology*, 908-913.

Kamar, A. N. (2018). Using Discrete Event Simulation to Evaluate the Performance of Lean Manufacturing Implementation: A Case Study of an Electronic Manufacturer Company." Proceedings of the International Conference on Industrial. *Proceedings of the International Conference on Industrial.*

Kaoutar Douaioui, M. F. (2018). The interaction between industry 4.0 and smart Logestics: Concepts and perceptives.

Keonn. (2016). Smart Kanban Pannels. Advan Panel.

Kermorgant, O. (2018). A Magnetic Climbing Robot to Perform Autonomous Welding in the Shipbuilding Industry. *Robotics and Computer-Integrated Manufacturing*, 178-186.

Khanchanapong, T. D. (2014). The Unique and Complementary Effects of Manufacturing Technologies and Lean Practices on Manufacturing Operational Performance. 191-203.

Kitazawa, M. S. (2018). combining Workers' Behavior Data and Real Time Simulator for a Cellular Manufacturing System." . *World Automation Congress Proceedings*.

Kolberg D, K. J. (2017). Toward a lean automation interface for workstations. *International Journal of Production Research*, 2845-2856.

Kolberg, D. a. (2015). "Lean Automation Enabled by. 1870-1875.

Krueger, V. F. (2019). Testing the Vertical and Cyber-Physical Integration of Cognitive Robots in Manufacturing. *Robotics and Computer Integrated manufacture*, 213-229.

Kück, M. J. (2016). A Data-Driven Simulation-Based Optimisation Approach for Adaptive Scheduling and Control of Dynamic Manufacturing Systems. 449–456.

Kumar, M. R. (2018). Real-Time Monitoring System to Lean Manufacturing. 135-140.

Leitão, P. A. (2016). Industrial Automation Based on Cyber-Physical Systems Technologies: Prototype Implementations and Challenges. *Computers in Industry* , (pp. 11-25).

Levratti, A. G. (2019). TIREBOT: A Collaborative Robot for the Tire Workshop. *Robotics and Computer-Integrated Manufacturing*, 129-137.

Leyh, C. M. (2017). Industry 4.0 and lean production—A matching relationship? An analysis of selected Industry 4.0 models. 989-993.

Li, H. a. (2018). An Algorithm for Safe Navigation of Mobile Robots by a Sensor Network in Dynamic Cluttered Industria. *obotics and Computer-Integrated Manufacturing*, 65-82.

Longo, F. L. (n.d.). Smart Operators in Industry 4.0: A Human-Centered Approach to Enhance Operators Capabilities and Competencies Within the New Smart Factory Context.". *Computers and Industrial Engineering* , 144–159.

Lorenz, R., Buess, P., Macuvele, J., Friedli, T., & Netland, T. (2019). Lean and Digitalization-Contradictions or Complements? In Proceedings of the Advances in Production Management Systems: Production Management for the Factory of the Future, . 77-84.

Lu, Y. K. (2016). Current Standards Landscape for Smart Manufacturing Systems. . *National Institute of Standards and Technology*.

M. Tischa, J. M. (2017). Potentials and Limits of Learning Factories in Research, Innovation Transfer, Education, and Training.

Ma, J. W.-C. (2017). smart lean automation engine enabled by cyber-physical systems technologies.

Mao, J. H. (2018). Design of Intelligent Warehouse Management System. 1355–1367.

Mario Hermann, T. P. (2016). Design Principles for Industrie 4.0 Scenarios. *2016 49th Hawaii International Conference on System Sciences.*

Matteo Rossini, F. C. (2019). Industry 4.0 and lean production : an imperical study. *The international journal of advanced manufacturing technology*, 42-47.

Metan, G. I. (2010). Real Time Selection of Scheduling Rules and Knowledge Extraction Via Dynamically Controlled Data Mining. *International Journal of Production Research*, 6909–6938.

Michael Sony, S. N. (2020). Industry 4.0 integration with socio-technical systems theory: A systematic review and proposed theoretical model. *Technology in Society*.

Miguel Núñez-Merino, J. M.-M.-F. (2020). Information and digital technologies of Industry 4.0 and Lean supply chain management: a systematic literature review. *International Journal of Production Research*.

Moeuf A, P. R. (2018). The industrial management of SMEs in the era of industry 4.0. . *ournal of Production Research*, 1118-1136.

Mousavi, A. a. (2017). Automatic Translation of Plant Data Into Management Performance Metrics: A Case for Real-Time and Predictive Production Control. *nternational Journal of Production Research 55*, 4862–4877.

Mrugalska, B. a. (2017). Towards Lean Production in Industry 4.0. *7th International Conference on Engineering,*, (pp. 466–473).

Müller, R. M.-S. (2018). Development of an Intelligent Material Shuttle to Digitize and Connect Production Areas with the Production Process Planning Department. 967–972.

Netland, T. J. (2015). implementing Lean: The Effect of Takt Time.

Nikolakis, N. V. (2019). A Cyber Physical System (CPS) Approach for Safe Human-Robot Collaboration in a Shared Workplace. *Robotics and Computer-Integrated Manufacturing* , 233–243.

obias Wagner, C. H. (n.d.). industry 4.04.0 impacts on lean production systems. 125-131.

P, Å. (1998). Sequences in the implementation of lean production. 327-334.

P., H. (2016). The principles of the lean business system. .

Pagliosa, M. T. (2019). Industry 4.0 and Lean Manufacturing: A systematic literature review and future research directions. *Journal of Manufacturing Technology Management*.

Peres, R. S. (2018). "IDARTS – Towards Intelligent Data Analysis and Real-Time Supervision for Industry 4.0. *" Computers in Industry*, 138–146.

Porter, M. E. (2014). "How Smart, Connected productes are transforming competitions. 64-88.

Porter, M. E. (2014). How Smart, Connected Products Are Transforming Competition. *arvard Business Review*, 64-88.

Powell, D. R. (n.d.). Towards digital lean cyber physical production systems: industry 4.0 technologies as enablers of leaner production. . *Paper presented at the IFIP International Conference on Advances in Production Management system.* 2018.

Powell, D., Romero, D., Gaiardelli, P., Cimini, C., & Cavalieri, S. (2018). Towards Digital Lean Cyber-Physical Production Systems: Industry 4.0 Technologies as Enablers of Leaner Production. In Proceedings of the Advances in Production Management Systems: Smart Manufacturing for Industry 4.0. 26-30.

Prinz, C. N. (2018). lean meet Industrie 4.0 – a Practical Approach to Interlink the Method World and cyber physics world. *th Conference on Learning Factories 2018*, (pp. 21-26).

Ray Y. Zhong, X. X. (2017). Intelligent Manufacturing in the Context of Industry 4.0: A Review. *Engineering*, 616-630.

Robert Saxby, M. C.-K. (2020). An initial assessment of Lean Management methods for Industry 4.0.

Robert Saxby, M. C.-K. (2020). An initial assessment of Lean mangemnt for industry 4.0.

Romero, D. F. (2019). Five Management Pillars for Digital Transformation Integrating the Lean Thinking Philosophy. .

Rossini, M., Costa, F., Tortorella, G., & Portioli-Staudacher, A. (2019). The interrelation between Industry 4.0 and ean production: An empirical study on European manufacturers. *manufacture and technology*, 3963-3967.

Rother, E., & Baboli. (2019). A. Lean Manager in the Factory of the Future Case study in automotive industry. *n Proceedings of the 2019 IEEE 6th International Conference on Industrial Engineering and Applications*, (pp. 218-224).

Rüßmann, M. M. (2015). Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries. *Boston Consulting Group.*

Ruttimann, B. a. (2016). “Lean and industry 4.0 – twins, partners, or contenders? A due clarification regarding the supposed clash of two production systems”, . *Journal of Service Science and Management,.* , 485-500.

Saez, M. F. (2015). Real-time hybrid simulation of manufacturing systems for performance analysis and control. *EEE International Conference on Automation Science and Engineering,*, (pp. 526–531).

Sanders, A. E. (2016). Industry 4.0 implies lean manufacturing: Research activities in industry 4.0 function as enablers for lean manufacturing. *Journal of Industrial Engineering and Management*.

Sanders, A. S. (2017). Industry 4.0 and lean management–synergy or contradiction? *aper presented at the IFIP International Conference on Advances in Production Management Systems.*

Satoglu, S. U. (2018). “Lean transformation integrated with Industry 4.0 implementation methodology”, I. *ndustrial Engineering in the Industry 4.0* .

Saurabh Vaidaya, P. A. (2018). Industry 4.0 – A Glimpse. *2nd International Conference on Materials Manufacturing and Design Engineering*, (pp. 233-238).

Shahin, M. a., Bouzary, a., & Krishnaiyer, K. (2020). Integration of Lean practices and Industry 4.0 technologies: Smart manufacturing for next-generation enterprises. *manufacture technology*, 2927-2936.

Siham Tissir, S. E. (2020). Industry 4.0 impact on Lean Manufacturing: Literature Review.

Snyman, S. a. (2017). Real-time Scheduling in a Sensorised Factory Using Cloud-Based Simulation with Mobile Device Access. *South African Journal of Industrial Engineering*, 161-169.

Snyman, S. a. (2017). Real-time Scheduling in a Sensorised Factory Using Cloud-Based Simulation with Mobile Device Access. *" South African Journal of Industrial Engineering*, 161-169.

sony, M. (2018). Industry 4.0 and lean management: a proposed integration model and research propositions. *Production & Manufacturing Research*, 416-432.

Sony, M. (2018). Industry 4.0 and lean management: a proposed integration model and reserch perpositions. *Production & Manufacturing Research*.

Sony, M. A. (2020). Essential ingredients for the implementation of Quality. *technology quality and mangemnt*.

Stadnicka, D. &. (2019). Human-robot collaborative work cell implementation through lean thinking. *International Journal of Computer Integrated Manufacturing,*, 580-595.

Stöckli, B. G. (2016). Lean and Industry 4.0—Twins,partner or contender ? A due clarification regarding the supoosed cash of tw production system. *" Journal of Service Science and mangemnt*, 485-500.

Stojanovic, N. a. (2018). . "Data-driven Digital Twin Approach for Process Optimization: An Industry Use Case. *2018 IEEE International Conference on Big Data*, (pp. 4202–4211).

Susanna Loeb, P. M. (2017). *Descriptive analysis in education:.*

syed Imran Shafiqa, C. S. (2015). Virtual Engineering Object / Virtual Engineering Process: A specialized form of cyber physical system for industry 4.0. *19th International Conference on Knowledge Based and Intelligent Information and Engineering systems*, (pp. 1146-1155).

T. Wagner, C. H. (2017). Industry 4.0 Impacts on Lean productions system. 125-131.

Tao, F. J. (2017). A Manufacturing Service Supply Demand Matching Simulation tor Under Cloud Environment. *Robotics and Computer-Integrated Manufacturing 45:* , 34–46.

Teixeira, L. F. (2019). An Information Management Framework to Industry 4.0: A Lean thinking approach. *International Conference on Human Systems Engineering and Design* .

Tobis Wagner, C. H. (2017). INdustry 4.0 impact on lean production system. *The 50th* (pp. 125-131 CIRP conference on manufacturing systems). Science Direct.

Tortorella, G., & Fettermann, D. (2018). Implementation of industry 4.0 and lean production in brazilian manufacturing companies. *production and resourses*, 2975-2987.

Tortorella, G., Sawhney, R., Jurburg, D., de Paula, I., Tlapa, D., & Thurer, M. (2020). Towards the proposition of a Lean Automation framework Integrating Industry 4.0 into Lean Production. *manufacture,technology and mangement*.

U. Dombrowski, T. R. (2017). "Interdependencies of Industrie 4.0 & Lean Production Systems: A Use Cases Analysis. 1061-1068.

Uhlemann, T. H.-J. (2017). The Digital Twin: Realizing the Cyber-Physical Production System for Industry 4.0. *." Procedia CIRP*, 335–340.

Vahid Taghavi, Y. B. (2020). The Relationship between Lean and Industry 4.0:. *5th North American Conference on Industrial Engineering and Operations Management in Detroit michegan*, (pp. 10-14). michigan.USA.

Varela, L. A. (2019). Evaluation of the Relation between Lean Manufacturing, Industry 4.0, and Sustainability. *Sustainability,*.

Wagner, C. H. (2017). industry 4 imapct lean production system.

Wang, X. V. (2017). Human-robot Collaborative Assembly in Cyber-Physical Production:Classification Framework and Implementation.". *CIRP Annals-Manufacturing Technology*.

Wyrwicka, B. M. (2017). Towards Lean Production in. *Procedia Engineering*, 466-473.

Yadav, G. L. (2020). developing of the lean manufacturing framework to enhance its adoption within manufacturing companies in developing economies. *cleaner productin*.

Yaser Ali Husen, S. J. (2020). Integration of Lean Manufacturing and Industry 4.0: A Conceptual Framework.

Yongxin Liao, F. D. (2017). Past, present and future of Industry 4.0 - a systematic literature review and research agenda proposal. *International Journal of Production Research*.

Yuan, L. Y. (2016). Radio Frequency Identification-Enabled Monitoring and Evaluating in the Discrete Manufacturing Process. 2184–2196.

Zhuang, C. J. (2018). Digital Twin-Based Smart Production Management and Control Framework for the Complex Product Assembly Shop-Floor. *international Journal of Advanced Manufacturing Technology* , 1149–1163.

Zühlke, D. K. (2015). Lean Automation enabled by Industry 4.0. *IFAC-PapersOnLine*, 1870-1875.