Lean 4.0: Smart Lean Based Manufacturing

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Abstract

Industries, one of the most important development indicators of countries, have begun to take shape with the use of steam power, and today they are turning into self-sufficient high technology bases by digitalizing. The lean production approach, which aims to produce in a short flow time with waste-free processes by centered on the concept of value defined from the perspective of the end user, remains insufficient in an environment of high competition and uncertainty. For this reason, with the fourth industrial revolution, which aims to digitize production and create a networked global value chain, a technology-intensive production approach is being adopted. However, there are points where this production system is insufficient. In order to overcome this, Industry 4.0 technologies can be applied to the infrastructure provided by lean production and Lean 4.0 production model can be created by combining the two production models. In this study, first of all, lean production approach was examined. Then, Industry 4.0, which is a technology-intensive production model, is discussed. In the light of this information, Lean 4.0, which is a lean-based smart production model formed by the integration of Industry 4.0 technologies into lean systems, has been explained. In this article, the advantages of lean manufacturing to digital transformation and the ways in which digital transformation supports lean production are discussed.

Keywords: Lean, Industry 4.0, Digital Transformation, Lean 4.0.

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1. Introduction

The industrial revolution, which began with the transition from an agrarian-based economy to an industrial-based production model in the 18th century, changed and transformed both production methods and people's lifestyles. The mechanization of production through the use of steam in machines in 1784 and industrial production led to competition in the market through mass production. The production concept where companies determine the characteristics of their products and guide the market in the face of high demand was replaced by an understanding in which cheap but high-quality products are produced to meet customer needs, with the history of economic crises and recessions. In order to survive in the tough market conditions where flexibility, quality, speed, and cost are the most important elements of competition, companies must understand the needs of the end user and offer products that are technologically competent and in the amount and time demanded by the market. To do this, products that can be personalized in small batches should be produced and delivered to the market quickly (Carnes and Hedin, 2005: 28). Lean production aims to eliminate waste from all processes with a value-oriented approach and reduce production costs. Lean operations help deliver low-cost, high-quality products to the market quickly. Thus, companies can grow both organizationally and culturally (Çanakçıoğlu, 2019). The operational and cultural changes brought by Lean production are not sufficient in the ever-changing high-uncertainty environment (VUCA World). One of the methods for sustainable competitive advantage is Industry 4.0 technologies, which aim to create a global value chain with systems that can be monitored, connected, and communicated throughout the product life cycle through cyber-physical systems. However, to bring digital transformation into play, long- and short-term strategies that can integrate change, employees open to change, and lean processes that can adapt to technological change are required. If both technology, employees, and processes can be digitized at the same time, the benefits of Industry 4.0 can be fully utilized (Angelopoulos et al., 2019). Lean 4.0, which is the combination of digital technology and the Lean philosophy, is an effective approach in the implementation of evolving technologies with the timeless but powerful foundation brought by the Lean philosophy (Deloitte, 2020). In this context, lean production approach, principles and tools used to realize these principles are explained. Finally, the focal points and basic technologies of the Industry 4.0 concept are discussed. Finally, these two production understandings were handled holistically and basically with the lean 4.0 concept. The meeting points of lean production and digital access, the boundaries between them and are discussed. It discusses how the concept of Lean 4.0 can be applied in businesses. Thus, road transitions of those who want to achieve digitalization to lean businesses.

1.1. Literature Review

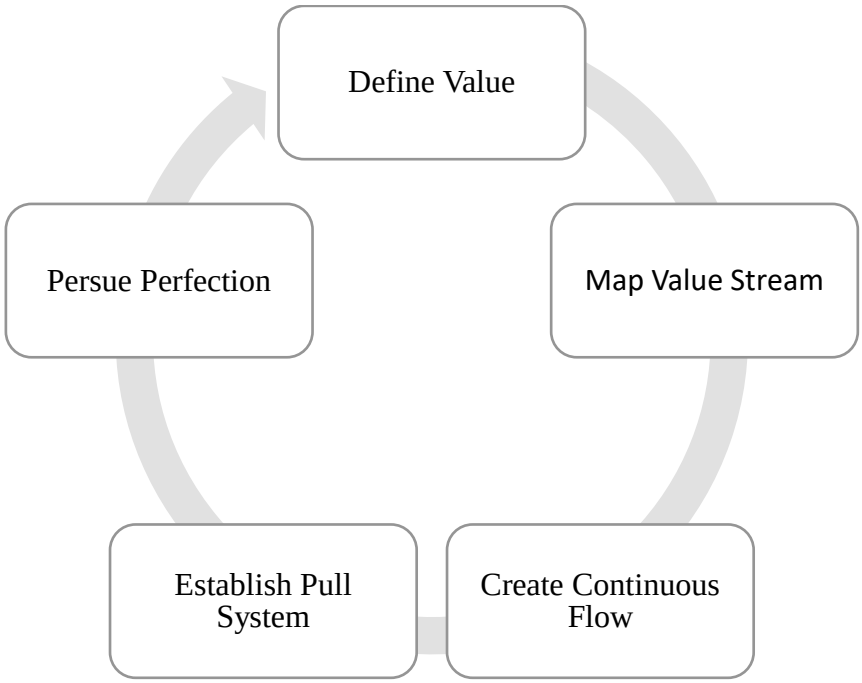
Table 1. Literature review.

AUTHOR/S	YEAR	TITLE	DESCRIPTION
BCG	2017	When Lean Meets Industry 4.0: The Next Level of Operational Excellence	They worked on improving the key performance indicators of lean production with Industry 4.0 technologies. They presented a roadmap on the realization of the lean 4.0 methodology required to achieve the highest level of operational excellence.
Deloitte	2020	Digital Lean Manufacturing: Industry 4.0 Technologies Transform Lean Processes to Advance The Enterprise	They worked on the digitalization of lean tools and the use of Industry 4.0 technologies in the minimization of waste. They presented a roadmap to digital lean businesses.
Valamede, L. S. and Akkari, A. C. S.	2020	Lean 4.0: A New Holistic Approach for the Integration of Lean Manufacturing Tools and Digital Technologies	In their study on the digitalization of lean tools, they followed a three-stage path: observation, categorization and association. They discussed Industry 4.0 technologies to be used in the digitalization of lean tools.
Wagner, T., Harrmann, C, Thiede, S.	2017	Industry 4.0 Impacts on Lean Production Systems	A study was conducted on the realization of just-in-time delivery with cyber physical systems. Matrices have been developed on the stabilization of material supply in just-in-time delivery.

Yavuz, O.	2021	Lean Manufacturing and Industry 4.0	The use of Industry 4.0 technologies in improving the key performance indicators of lean manufacturing has been investigated.

2. Lean Manufacturing

Lean manufacturing is a manufacturing system design in which all elements (operations, machines, employees) that do not add value and do not provide maximum output with minimum input are eliminated. Lean production aims to optimize the efficiency, productivity, and performance of the business by only producing the amount of products demanded by the customer, at the time they are requested, with only the necessary workforce. Production begins with the customer's order. Therefore, it reduces the use of physical space, energy, raw materials, machines, unnecessary information and documentation. By reducing unnecessary elements and increasing value-adding activities, costs are reduced and customer satisfaction is increased (Ohno, 2020: 109). The principles and tools of lean manufacturing, based on the understanding of achieving operational excellence by eliminating muda, muri and muras in administrative and operational processes, form the basis of lean production. (Rahor et al., 2012; Aktaran Çilhoroz ve Çakmak, 2020: 1332). Lean manufacturing aims to eliminate any activities that do not add value to the product by using lean tools, in accordance with the flawless working of five basic principles.



Shape 1. Lean manufacturing principles.

Lean production begins with the definition of value from the customer's perspective. After value is defined in order to eliminate any activities that do not add value to the product, the value stream mapping technique can be used to ensure the flow of value. The value stream map is a lean production tool that enables the design of the value flow in accordance with the lean philosophy, by defining operations process-based, simplifying and tracing the value flow from raw materials to the end of production. Value stream mapping documents the product's path throughout production by visually displaying the product's production process and classifying and improving value-adding and non-value-adding tasks, centered around the customer. This production concept helps identify and eliminate waste sources (Rother and Shook, 1999). In a simplified and waste-free system, the aim is to produce just-in-time using kanban cards that communicate and facilitate the flow of information and parts between processes and indicate how much each process needs from the previous process. Just-in-time production, the core of lean production, can be defined as the delivery of parts to the assembly line in the required amount and at the required time, in order to eliminate the seventh of the seven basic wastes, stocks, and reduce inventories (Yazgan et al., 1998: 130-131; Yılmaz, 2012). In lean production, which aims to produce a high-quality product in just-in-time, machines equipped with devices that stop production to detect and prevent faulty products from passing to the next process are used. This system, referred to as automation, aims to prevent errors and defects. Jidoka, which ensures that quality control is performed in each process, progresses in collaboration with the worker (Yazgan, Sarı, Seri, 1998: 131; Ohno, 2020: 43). In addition to machine-based faults, poka yoke is used to detect and prevent errors and defects caused by human factors (Shingo, 1986: 7; Robincon, 1997: 134; Quoted Arslandere, 2017).

The goal is to shorten the production time of the product by reducing the mold change times to less than ten minutes and establishing systems that can perform flexible production at a level, (Bilgin-Sari, 2018: 595). Likewise, Total Productive Maintenance developed by Seiichi Nakajima is a method that optimizes quality, efficiency, and machine performance (Gonen, 2013; Ersöz et al., 2018: 448; allaboutlean.com/maintenance-history/seiichi-nakajima/, 2022-01-06). By using a combination of systematic practices, including the elimination of all unnecessary elements referred to as 5S in Lean production, ensuring order and organization, and making it easier to access materials and information, a clean and organized working environment is achieved, which increases the efficiency, effectiveness, and productivity of the operation (Karsiyaka and Sütcü, 2019: 89). Lean production draws its power from visual tools, one of which is andon, a visual management tool. Andon is a light, sound, and visual system that allows for real-time monitoring by visualizing the production flow and stopping the line and performing necessary checks when determined errors occur, and it can also be activated

by operators and provides information on the operation of production through different colors (Ohno, 2020: 191; Yazgan et al., 1998: 132; https://www.grupas.com.tr/gorsel-yonetim-ve-andon-sistemleri, 2022-08-01). Thus, traceable and transparent processes are designed. Although Lean increases the productivity and profit of the operation by using its existing resources, not every operation has been successful in Lean transformation. Some operations have been insufficient in the changing and globalizing market. The limitations of Lean production are presented in Table 2.

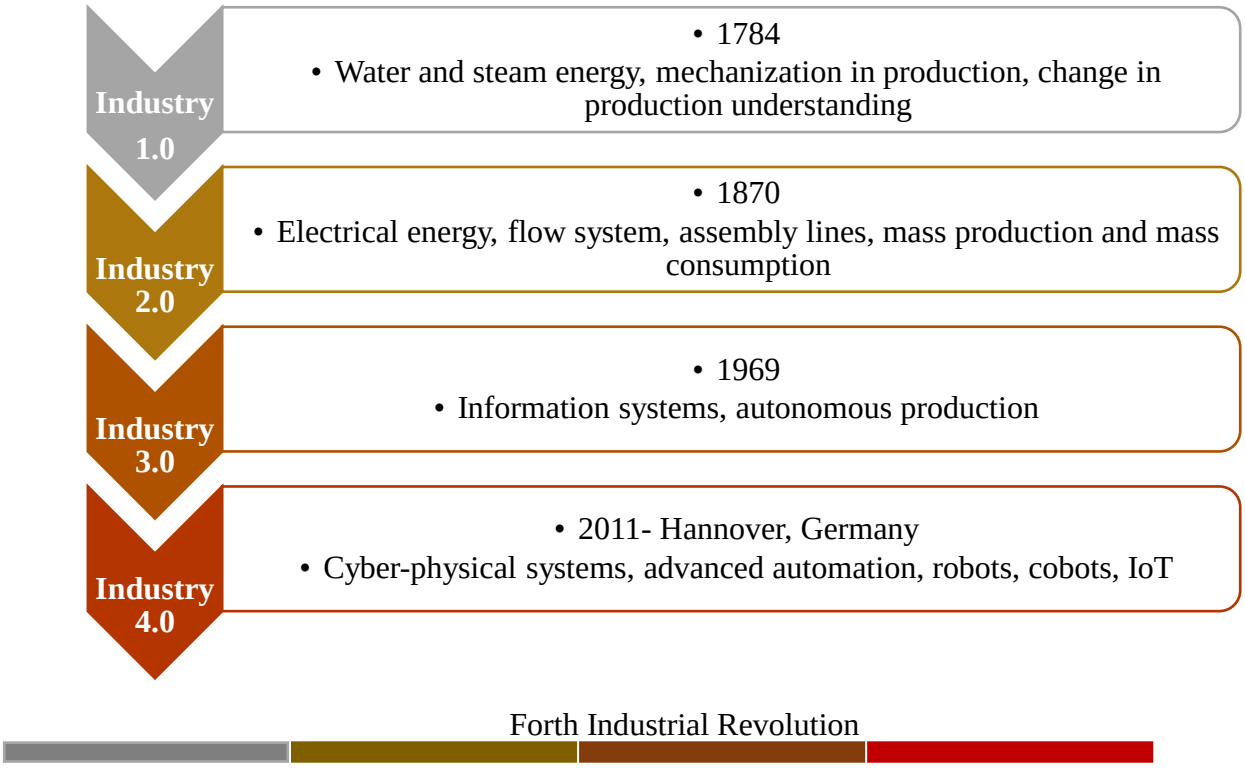
Table 2. Limitations of lean manufacturing (Nithia et al., 2015; Uriarte et al., 2018).

LIMITATIONS OF LEAN MANUFACTURING
Lean production, which was developed after the mass production system did not meet the needs of the day, was insufficient to achieve personalized mass production.
Inability to accurately predict the volatile market demand
Problems in optimization of capacity utilization
Insufficient use of the potential of information technologies
Businesses that have reached lean maturity benefit from the benefits of lean production
In the time it takes to reach lean maturity, some businesses abandon this production approach.
The tendency of businesses to return to their previous lean production order
When the expected success is not achieved, the motivation of the employees decreases.
Ignoring the transformation of the workforce when changing and transforming organizational systems
Failure to integrate lean transformation plans into operations
Failure to adopt a continuous improvement mentality
Not being a learning-to-learn organization
Low fault tolerance in lean manufacturing
Lean business stakeholders do not know this production model / lack of training

3. Industry 4.0

Every day, lifestyles, technologies, attitudes, and methods of making money are changing and transforming. This highly dynamic process takes place systematically beyond human control. Industries, which are indicators of the level of development of countries that started with the first industrial revolution, are also affected by this inevitable change. The fourth industrial revolution, which was first discussed in 2011, aims to change and transform production systems in a way that there will be no return to digital transformation. The goal of this revolution, which aims to digitize

industries and connect them, is to establish a global value chain. Digital transformation, based on cyber-physical systems, is carried out by integrating cyber technologies into traditional production systems and creating smart factories that can be managed centrally with advanced automation. Flexible production networks are created that can be monitored at all stages and improved data-focused without being dependent on a specific center. With the domination of robots, cobots, and data-collecting devices in the factories, low-cost, high-quality products can be produced in a short flow time, replacing human labor. This offers a cost advantage that will erode long-term production strategies based on cheap labor for advanced countries (https://www.plattform-i40.de/IP/Redaktion/EN/Downloads/Publikation/hannover-declaration.html, 2022-01-15; Özdoğan, 2019; Bilgin-Sarı, 2020).



Shape 2. Industrial Revolutions.

Industry 4.0, also known as digital transformation, is carried out on the basis of eleven key technologies. These technologies are big data and analysis, the internet of things, cloud computing, augmented reality, autonomous robots, additive manufacturing, simulation, system integration, artificial intelligence and smart systems, sensors, and cyber security (TUSIAD-BCG, 2017). Integrating smart technologies into traditional systems, digital transformation offers a manufacturing model that increases its power through modular systems that support human-machine interaction and allow for real-time monitoring and control of processes and systems. While digital transformation has

become a prerequisite for businesses to survive in a challenging competitive environment, it also comes with some limitations. The limitations of Industry 4.0 are presented in Table 3.

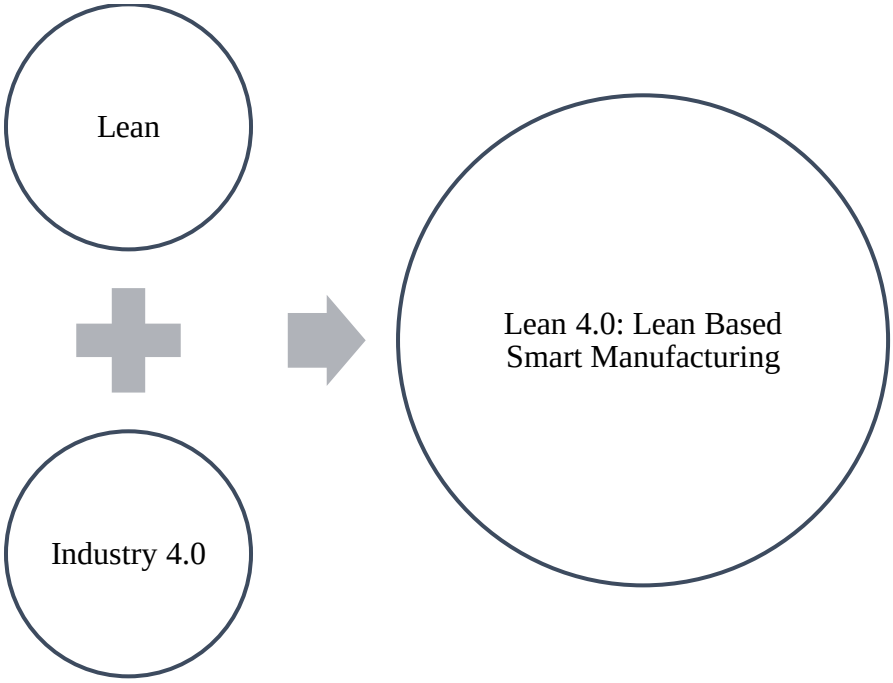
Table 3. Limitations of Industry 4.0 (Uriarte et al., 2018; Sony, 2020).

LIMITATIONS OF INDUSTRY 4.0
Insufficient understanding of both the conceptual phase and the implementation phase
Inability of businesses to move to the application phase in the digital transformation process
Failure of companies that invest in technology without determining a digital transformation strategy
Inability to collect real-time flowing data in data-driven processes
Problems in storing and securing the collected data
Failure to recognize the importance of cyber security
Interruptions in human, machine and process communication provided by the Internet of Things and the inability to establish fully connected operations
Only large enterprises or technology startups are willing to use Industry 4.0 technologies
Small and medium-sized companies are resistant and unwilling to change due to their inability to grasp digital transformation and its advantages.
Inability to provide cyber security of devices connected to the network with IoT technology
Employees who do not have cyber awareness fall into cyber traps.
Businesses are open to cyber-attacks due to their ignorance of cyber security vulnerabilities.
Employees not having the skill set brought by the fourth industrial revolution
Failure to provide necessary training to employees in processes that are changing and transforming with digitalization
Employees resisting change for fear of losing their jobs
Failure of technology investment without system stabilization and stability
Low tolerance for delays in the system
Failure to realize that digital transformation should be handled holistically
High technology investment costs (High initial cost)
In some cases, data sharing negatively impacts competitive advantage.

4. Lean 4.0

Lean production is a value-driven and method-based production mode that aims to achieve its principles through the use of lean tools (Wagner et al., 2017). In lean production, non-value-adding activities in production systems are minimized and the system is streamlined to reduce waste and

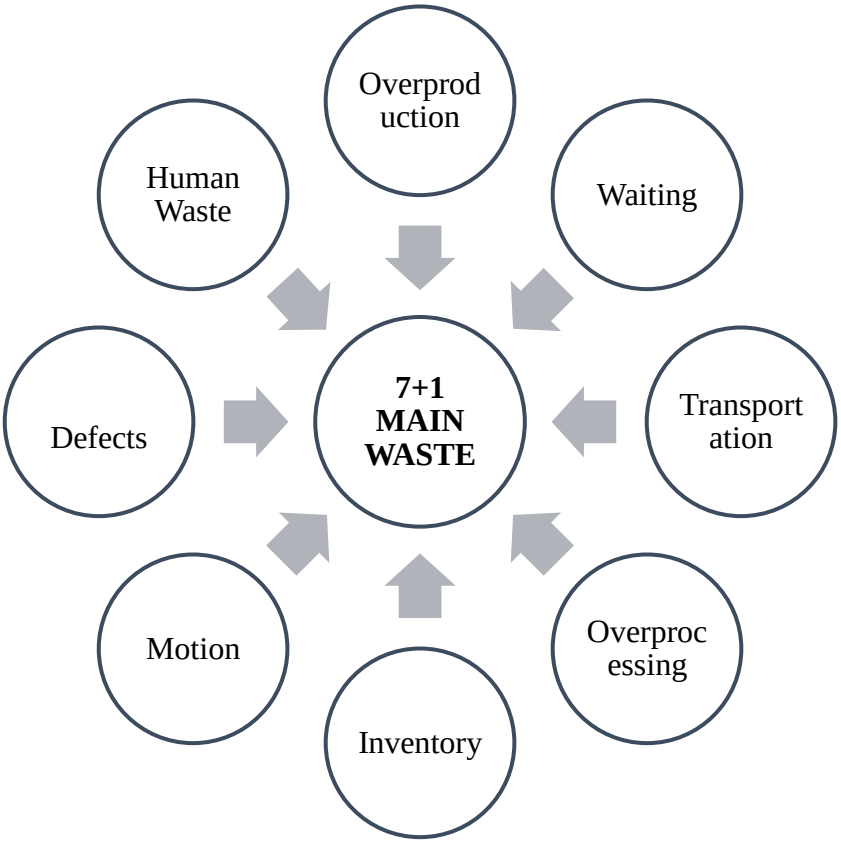
achieve more output with less resources. Lean production can reach maturity in organizations that adopt the mentality of standardization and always striving for improvement (BCG, 2017). On the other hand, Industry 4.0 is a data-driven, high-tech, and automation-based production model based on a structure-based structure that collects data from cyber-physical systems to the Internet of Things (Wagner et al., 2017). Modular systems that can communicate with each other can perceive their environment and make necessary optimizations. The integration of two different production models that aim to achieve operational excellence with different methods and tools can take this goal to the next level (BCG, 2017).



Shape 3. Lean 4.0: Lean Based Smart Manufacturing.

4.1. Reduction of Waste in Lean Production with Digital Transformation

After defining value, every action that does not add value is considered waste. Seven basic wastes have been defined in lean production. Human waste has been defined as the eighth waste item due to changing conditions (Novis, 2008).



Shape 4. Eight main waste model.

With the support of Industry 4.0 technologies for the lean tools used in determining the root causes of waste sources and eliminating them, more stable and robust systems can be designed. The lean tools used in eliminating non-value-adding processes and activities in the system and the Industry 4.0 technologies that support them are given in Table 4.

Table 4. Root Causes of Waste, Lean Tools and Industry 4.0 Technologies That Can Be Used to Prevent Them (Canakcioglu, 2019; Deloitte, 2020).

WASTE	**ROOT CAUSE**	**LEAN TOOLS**	**INDUSTRY 4.0 TECHNOLOGIES**
Overproduction	Failure to establish a supply-demand balance	Kanban, takt manufacturing by takt time, heijunka	Instant traceability, simulation, IoT, cloud computing
Waiting	Unbalanced and unleveled production, failures in production planning, problems in supply, unplanned machine downtime,	One piece flow, continuous flow, kanban, SMED, standards, jidoka, poka yoke,	Bottleneck detection with data analysis, simulation, AGVs, instant action, cloud computing, production planning

	high lead time, transportation	manufacturing by takt time, heijunka	programs, horizontal and vertical integration, IoT, additive manufacturing, cloud computing
Transportation	Incorrect layout of the factory, not storing materials in a certain area, irregularity	One piece flow, value stream mapping, 5S	Big data and data analytics, simulation, digital twin, vertical integration, IoT, cloud computing
Overprocessing	Not understanding the customer's request and the conditions in the technical specification	Kaizen, jidoka, poka yoke	Digital twin, horizontal and vertical integration, data analytics, AR
Inventory	Failure to provide value stream, failure in demand forecasting	Kanban, manufacturing by takt time, heijunka, one piece flow, continuous flow	Instant traceability, RFID, data analytics, e-kanban, IoT, cloud computing
Motion	Inability to establish cellular production, lack of standard business plan, wrong design of work flow, lack of organization	Value stream mapping, 5S, cellular manufacturing	AR, simulation, data analytics, cloud computing
Defects	Incorrect product design, lack of quality control in every process, lack of standards	Jidoka, poka yoke, 5S, kanban, standards	AR, data analytics, image processing, e-kanban, RFID, simulation
Human Waste	Repetitive work, not using the employee's ideas and creativity	Employee rotation, cellular	Automated processes, robots and cobots, artificial intelligence

		manufacturing, root cause analysis	and data science, AR-VR

In digitalized processes, big data and data analytics are used to better understand the needs and requirements of customers and design and produce products accordingly. In lean-based digital production, unlike in lean production, waste can be monitored in real-time and preventive measures can be developed. Using factory data, the current status of the production system and the different actions that can be taken can be tested in a virtual environment using value flow maps modeled with assembly lines modeled in a virtual environment. This way, performance can be monitored at all stages, and optimized systems can be designed without the seven basic wastes. (Deloitte, 2020; Yavuz, 2021)

Continuity of the flow is required after the value is defined and flow is established. However, disruptions in logistics processes or failure to deliver the necessary raw materials in the required quantity, quality, and time cause the continuous flow to be disrupted (Valamede and Akkari, 2020). With the implementation of Industry 4.0 technologies, relationships with all organizations in the value chain can be improved and more flexible, high-quality production processes can be achieved with traceable systems. Wireless monitoring technologies such as RFID can be used in horizontal value chain integration to obtain raw materials of standard quality that can be monitored along the way. This way, value can be created by moving synchronously in a digital value chain ecosystem based on collaboration. (Valamede and Akkari, 2020; Yavuz, 2021). Products are produced in the required quantity and at the required time using electronic kanbans (Yavuz, 2021).

4. Results

In this study, which examines the relationship between Industry 4.0 technologies and the philosophy of Lean production, a literature review was conducted in which studies by different researchers were analysed. It was found that there was limited literature on Lean 4.0 and that this area was open to development. In the studies conducted, researchers presented studies on the relationship between the two manufacturing concepts, how Lean tools can be digitized, digitized Lean principles, reducing waste through digital transformation, and areas where Industry 4.0 technologies support Lean production in the face of its limitations. At the end of this comprehensive process, it was seen that Lean production creates the necessary infrastructure for digital transformation, while Industry 4.0 supports the Lean manufacturing approach. Both production models have limitations. Lean manufacturing is not sufficient for today's rapidly changing high-uncertainty production environment, while technology-focused Industry 4.0 lacks soft skills that are unique to humans. Therefore, when

the two production models are combined, a much stronger and more successful production model can be created. The key performance indicators desired in both production methods are the same, but the methods, tools, and technologies used differ. With the integration of Lean manufacturing and digital transformation, the Lean 4.0 model that emerges will result in factories with learning minds becoming smarter, able to adapt to any uncertainty and easily adopt new developments, becoming powerful businesses.

References:

Periodical Publication:

Arslandere, M. (2017). Poka Yoke System as A Defect Prevention Tool In Production And An Application Example. The Journal of Kesit Academy, 3(11), 339-350.

Bilgin-Sari, E. (2018). Lean Manufacturing Applications and Benefits. Uiiid-Ijeas, (17. Special Issue of Iik), 585-600.

Carnes, K., Hedin, S. (2005). Accounting For Lean Manufacturing: Another Missed Opportunity? Management Accounting Quarterly, 7 (1), 28-35.

Canakcioglu, M. (2019). Tcanakcioglu, M. (2019). Tools For Combating Waste In Lean Thinking Philosophy. Social Sciences Research Journal, 8 (3), 270-282.

Çilhoroz, Y., Çakmak, C. (2020). Lean Leadership from Lean Management Perspective. Journal Of Social Sciences Of Mus Alparslan University, 8(4), 1331-1339.

Ersöz, T., Öztürk, E., Gürel, E. (2018). Total Efficient Maintanence Application In Iron And Steel Sector. Uiiid-Ijeas, (18. Eyi Special Issue), 447-458.

Karşiyaka, O., Sütçü, A. (2019). Improving Efficiency for Furniture Manufacturing Processes By Using 5s Applications: Case Study. Bilge International Journal of Science And Technology Research, 3(2), 87-101.

Mayr, A., Weigelt, M., Kühl, A., Grimm, S., Erll, A., Potzel, M., & Franke, J. (2018). Lean 4.0: A Conceptual Conjunction of Lean Management And Industry 4.0. Procedia Cirp, 72 (1), 622-628.

Nithia, K. K., Noordin, M. Y., Saman, M. Z. M. (2015). Lean Production Weaknesses in Manufacturing Industry: A Review. Applied Mechanics and Materials, 735, 344-348.

Novis, D.A. (2008). Reducing Errors in The Clinical Laboratory: A Lean Production System Approach. Labmedicine, 39(9), 521-529.

Sony, M. (2020). Pros And Cons of Implementing Industry 4.0 For The Organizations: A Review And Synthesis Of Evidence. Production & Manufacturing Research, 8(1), 244-272.

Valamede, L. S. Ve Akkari, A. C. S. (2020). Lean 4.0: A New Holistic Approach for The Integration Of Lean Manufacturing Tools And Digital Technologies. International Journal of Mathematical, Engineering And Management Sciences, 5(5), 851-868.

Wagner, T., Harrmann, C, Thiede, S. (2017). Industry 4.0 Impacts on Lean Production Systems. Procedia Cirp, 63, 125-131.

Yazgan, H. R., Sari, Ö., Seri, V. (1998). Features Of the Toyota Production System. Sakarya University Journal of Science, (2), 129-134.

Books:

Bilgin-Sari, E. (2020). Industry 4.0: Technology and Manufacturing Management. Ankara: Nobel Academic Publisher, 149.

Ohno, T. (1988) Toyota Production System: Beyond Large Scale Production. Productivity Press, New York.

Rother, M., Shook, J. (1999). Learning To See: Value Stream Mapping to Add Value And Eliminate Muda. USA: Lean Enterprise Institute, Inc.

Yavuz, O. (2021). Lean Manufacturing And Industry 4.0., E. Gelmez and N. Yilmaz. (Editors). Manufacturing Management with An Industry 4.0 Perspective: Featured Articles. Istanbul. Çizgi Kitabevi Publications, P. 53-85.

Thesis:

Gönen, K. (2013). Lean Production and Value Stream Mapping With Concurrent Engineering Approach In The Automotive Industry, Master Degree, Uludag University Graduate School Of Natural And Applied Sciences, Bursa.

Yilmaz, E. (2012). Lean Production Implementation In Make-To-Order Production Systems, Master Degree, İstanbul Technical University Institute Of Science And Technology, Istanbul.

Other References:

Küpper, D., Heidemann, A., Ströhle, J., Knizek, C., And Spindelndreier, D. (2017). When Lean Meets Industry 4.0: The Next Level Of Operational Excellence. Bcg: Bostan, Usa.

Laaper, S. And Kiefer, B. (2020). Digital Lean Manufacturing: Industry 4.0 Technologies Transform Lean Processes To Advance The Enterprise. Deloitte: Basel, Switzerland.

Tusiad Ve Bcg (2017). Turkey's Digital Transformation Competence In Industry (Türkiye'nin Sanayide Dijital Dönüşüm Yetkinliği). Publication Number: Tusiad-T/2017, 12-589, Istanbul.

Url-1: Https://Www.Plattform-I40.De/Ip/Redaktion/En/Downloads/Publikation/Hannover-Declaration.Html, (Last Access: 2022-01-15).

Url-2: Https://Www.Grupas.Com.Tr/Gorsel-Yonetim-Ve-Andon-Sistemleri, (Last Access: 2022-01-08).

Url-3: Https://Www.Allaboutlean.Com/Maintenance-History/Seiichi-Nakajima/, (Last Access: 2022-01-06).