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Compatibility, opportunities and challenges in the combination of Industry 4.0 and Lean Production

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ABSTRACT

The continuous increase in technology associated with the Fourth Industrial Revolution and advancing digitalization are influencing today's production processes and the competitiveness of factories. Integrating Industry 4.0 into Lean Production can generate more efficient, leaner production and logistics with the help of intelligent networking systems. However, combining the two concepts also poses some challenges, such as the complex integration of technology into the Lean Production tools, and a resistance from employees to accept new technological ways. Furthermore, there is a lack of practical studies that guide companies on which variant of the different Industry 4.0 technologies should and could be integrated into their Lean Production processes. This paper analyzes the compatibility of Industry 4.0 and Lean Production and presents practical solutions by highlighting the opportunities and challenges of combining the two.

This research is based on a systematic literature analysis and evaluating expert interviews which leads to the findings and hypotheses. The results explain how Lean Production and Industry 4.0 can be successfully combined, and which aspects need to be and should be considered on a management level.

KEYWORDS: Lean Production · Lean Management · Industry 4.0 · Digitalization · Automation · Compatibility

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1. INTRODUCTION

Lean Production approaches are increasingly reaching their limits in today's market and production environment due to intensified competition, volatile markets and rising product complexity [1]. In addition, the COVID 19 pandemic is resulting in increasing cost pressure and increasing fluctuations in demand [2]. All these factors make it difficult to manage volatile demand volumes and the broader diversity of variants with classic Lean Production concepts.

The combination of Lean Production and Industry 4.0 (I4.0) could help to overcome the described challenges. This is achieved by the interaction of machines, systems and operating equipment in a factory, which are able to communicate and control each other independently using specific technologies [3]. On the one hand, this independent network enables production to increase the range of variants, and on the other hand, it allows faster reaction to changes and a higher productivity [4]. At the same time, I4.0 can improve operational lean processes through speed and flexibility, as well as operational decision-making by enhancing the visibility and a better prevention [5].

Nevertheless, many companies are still cautious to integrate I4.0, mainly because of the feared high costs and potential IT and data protection problems [4]. Furthermore, there is a lack of clarity in practice about how to combine the methodological Lean Production approach with the technologically driven I4.0 approach [6]. This raises the question for many companies of whether Lean Production and I4.0 are compatible and how I4.0 technologies should be integrated within Lean Production in order to achieve efficiency benefits.

Some research approaches in the literature already explore the compatibility of Lean Production and I4.0. However, these mostly represent only general non-specific considerations about the compatibility of both approaches (e.g. [7]) or are limited to individual I4.0 technologies and solutions (e.g. [5]) and draw general findings for the compatibility of Lean Production and I4.0 (e.g. [8]). A comprehensive detailed investigation of the compatibility of Lean Production and I4.0 has not been conducted so far. Kolberg & Zühlke address the need for such an analysis [1]. Furthermore, according to Ejsmont et al. [9] challenges and contradictions of merging both concepts and practical I4.0 solutions represent a minority in the literature and thus form a research gap.

In addition, due to the existence of countless works with different approaches and focuses, there is confusion among companies that want to integrate I4.0 technologies into their existing Lean Production concepts. Consequently, this paper deals with the analysis of the compatibility of Lean Production with I4.0 with regard to practical technological solutions.

The paper focuses on two central questions:

– To what extent is Lean Production compatible with I4.0?
– What opportunities and challenges arise when integrating I4.0 technologies into existing Lean Production concepts?

The paper unfolds into five chapters. Following this first chapter, the second chapter introduces the concepts of Lean Production and I4.0 in more detail. The aim of the third chapter is to work out the compatibility between Lean Production tools and I4.0 principles on the basis of the current status quo of the literature. In the next step, a compatibility matrix and hypotheses are derived from the status quo of the literature, which are then verified or falsified through qualitative research in the context of the expert interviews. The results of the interviews also reveal the main success factors and challenges in the implementation of I4.0 as well as some practical technological solutions. Finally, in chapter four, the results are evaluated and discussed in order to assess the compatibility and the merging of the two approaches and the usability of the paper's results. The concluding chapter five gives an outlook for expected further developments in this field.

2. THEORETICAL BACKGROUND

2.1. Lean Production

Lean Production has its origins in the Toyota Production System (TPS), which was developed by Taiichi Ohno in 1950. In the literature, the TPS is often described as a "house" for reasons of simplification. Consequently, the TPS consists of a roof, two core pillars, a central room, and a foundation [10]. The roof represents the central goals of the TPS. The prerequisites for achieving the goals are the two supporting pillars: Just-in-time (JIT) and Jidoka [11]. Individual methods and tools are assigned to these two pillars, which should enable the realization of the established goals. For the pillar JIT, these are for instance Kanban, Single Minute Exchange of Die (SMED) and One-Piece-Flow. The pillar Jidoka consists amongst others of Andon, Poka Yoke and Total Productive Maintenance (TPM). Table 1 explains these tools in more detail.

In the central room of the TPS house are the employees or the teams, who work consistently in a disciplined manner, avoid waste and actively reflect their work, so that they can continuously optimize their own workplaces [10]. According to Ohno, the success of a production is dependent on the harmony and cooperation of the team [12]. A few talented employees

Table 1: Explanation of relevant elements of Lean Production

LP Elements	Explanation
JIT-Production	The material is delivered at the exact time and in the quantity required at the delivery location [12].
Kanban	Kanban is the prerequisite for implementing JIT production and represents the demand-driven production [10].
One-Piece-Flow	The One-Piece-Flow describes production with batch size 1 and forms the basis for the flow principle in JIT-Production [10].
SMED	The Single Minute Exchange of Die (SMED) enables the duration of the tool change to be reduced to a single-digit minute [13].
Jidoka	Jidoka describes the automation of human activities. The assessment ability of humans is transferred to a machine through simple methods. [10].
Andon	Andon is responsible for visualising the problems and deviations within production with the help of signalling systems[11].
Poka Yoke	Poka Yoke describes the avoidance of unintentional mistakes of employees [10].
TPM	Total Productive Maintenance (TPM) is a concept that aims to optimize the use of equipment through preventive maintenance and continuous improvement of equipment availability [14].
Kaizen	Kaizen describes the end-to-end process of continuous improvement in all areas of the company [15].

cannot replace a capable team, since it is not decisive how many parts an employee processes, but how many products are produced in total in the end [12]. Teamwork is therefore significant for the successful implementation of the two pillars JIT and Jidoka.

The foundation of the TPS house consists of the Kaizen approach, standardization and Heijunka. Kaizen is a never-ending process of continuous improvement in all areas of the company and represents a way of thinking and a philosophy that is shared by all employees [15]. Heijjunka describes the leveled production. The aim is to harmonize the production flow as far as possible by balancing the incoming and outgoing elements in the production line in order to avoid queues, waste as well as idle and transport times [10].

In Lean Production, processes only use resources that are actually needed or are involved in the value creation of the process [16]. This is achieved by using certain principles and methods such as the flow, cycle and pull principles [15]. However, Lean Production encompasses much more than just individual methods and principles [15]. It is a strategy and a culture that is necessary for the effective use of the methods and principles [15].

The major goals of Lean Production are the consistent and continuous avoidance of the three "Mu's": Muda, Mura, and Muri [17]. "Muda" stands for waste and thus refers to all activities that do not add value [15]. There are seven different types of waste in "Muda", which are to be avoided [12]. These include overproduction, large inventories, unnecessary waiting times and transportation, scrap, and rework [14]. "Muri" aims to avoid the overloading of people and machines, which can lead to breakdowns and defects [15]. Excessive demands on employees or a lack of training can lead to stress and dissatisfaction, which can have a negative impact on employee performance. In the case of "mura", the imbalance created by poor coordination and information asymmetries should be avoided [14]. Unbalanced production can lead to suboptimal use of capacity. Furthermore, these three areas influence each other, since, for example, an overload of employees ("muri") can lead to an underutilization of other employees ("muda") [15]. For optimal Lean Production, all three "mu's" should therefore be eliminated equally. By continuously avoiding the above-mentioned wastes, production has to become more efficient, so that cost can be reduced [12]. At the same time, increasing quality and reducing delivery times are further central goals of Lean Production [15].

2.2. Industry 4.0 (I4.0)

In research and literature, there are different definitions of I4.0. However, it can basically be defined as the networking of all human and machine actors across the entire value chain as well as the digitalization and real-time evaluation of all relevant information with the aim of making the processes of value creation more transparent and efficient in order to optimize customer benefits with intelligent products and services [4].

A central feature of the definition is that the introduction of I4.0 has brought about a completely new organization and control of the entire supply chain [18]. This new organization consists of the individualization and hybridization of products, more flexible and efficient production, and the integration of business partners and customers into all value creation processes [19].

A prerequisite for the implementation of I4.0 is permanent access to all relevant information in real time. This is ensured by connected and embedded systems and machines that can take the right decisions even without human intervention [19]. The connection of all people, machines and systems participating in the supply chain enables optimized, independent and cross-company value creation networks [18].

However, I4.0 is often reduced solely to the use of new technologies, although many technologies such as radio frequency identification (RFID) have already been in production for quite a while [20]. Rather, I4.0 is about the further development, merging and combination of various existing technologies [20].

I4.0 enables the economical production of products with a wide range of variants, so that individual customer requirements can be met [3]. At the same time, the large volume of data and optimized decision-making allows a flexible response to disruptions [3]. Additionally, the increase in productivity and the optimized use of resources enhance production efficiency [3].

However, complete networking cannot always be achieved. The primary challenge is the growing complexity within production that goes hand in hand with increased networking [21]. In order to be able to reduce complexity, it helps to simplify the large volume of data and information and to use decentralized systems [21].

Table 2 summarizes the main five principles of I.40 relevant for this paper and the analysis of compatibility with Lean Production: Interoperability, Virtualization, Decentralization, Real-time capability and Modularization.

Table 2: Explanation of relevant principles of I4.0

I4.0 Principles	Explanation
Interoperability	Interoperability describes the ability of independent and different systems to work together as accurately as possible and thus exchange information efficiently [3].
Virtualization	Virtualization describes the ability of modern technologies to record physical processes via sensors and integrate them into the virtual world [22].
Decentralization	Decentralization describes a nonlocal self-control of production facilities [20].
Real-time capability	The real-time capability enables the collection and analysis of data in real time[23].
Modularization	Modularization enables easy adaptation in the event of fluctuations or changing product characteristics[23].

3. METHDOLOGY AND RESULTS

3.1. Systematic Literature Review

3.1.1. Methodology

This chapter maps the status quo of research on the compatibility of Lean Production and I4.0 with the help of a systematic literature analysis (SLA) [24, 25]. The findings from the status quo of research will then serve to derive a compatibility matrix and subsequently hypotheses. These hypotheses will further provide the basis for the empirical investigations of this paper.

The SLA gives a comprehensive and scientific overview of the current state of research in the topic area. The systematic approach makes it possible to reduce bias in the literature search and to increase the reliability of the search [26]. In addition, the inclusion of different types of publications allows to combine both theory and practice. The databases EBSCOhost, ScieneDirect, Econbiz, and Econis form the basis for this paper. These databases provide access to a comprehensive range of scientific publications in German and English. In order to achieve qualitative results, a filtering procedure was applied on the basis of previously defined criteria (a-d) to identify literature relevant to the topic. The defined keywords had to be found in the title (a). Only results in German and English language (b) were considered. I4.0 is a relatively new and dynamic topic area, so in order to ensure that the results are up-to-date, only results published in 2015-2020 were analyzed (c). Mostly academic journals and articles were considered (d), as there are also many non-academic and non-university articles concerning the topic area. In addition, duplicates (e) were removed and relevant articles were identified after reviewing the titles, abstracts, and contents (f). After applying all filters and removing duplicates, 133 hits remained. After reviewing the titles, abstracts, and content, 16 articles relevant to the study area were ultimately identified. The following keywords were used (see Table 3):

Table 3: Keywords used for the SLA

	German	English
Primary Keywords	„Industrie 4.0“ „Schlanke Automatisierung“ „Smarte Logistik“ „Logistik 4.0“ „Kaizen“	“Industry 4.0“ “Smart Factory“ “Lean Automation“ “Lean 4.0“ “Smart Logistics“ “Logistics 4.0“ “Lean“ “Continuous Improvement“ “JIT“ “Kanban“ “Milk-run“ “One-Piece-Flow“ “SMED“ “Jidoka“ “Andon“ “Poka Yoke“ “TPM“
Secondary Keywords	„Lean*“ „Digital“ „Logistik“ „Schlanke Produktion“ „Produktionssysteme“	“Lean*“ “Digital” “Logistics“ “Production Systems“

3.1.2. Results

3.1.2.1. Compatibility of Lean Production and Industry 4.0

Essentially, Lean Production and I4.0 pursue different approaches. While Lean Production pursues a methodical approach with continuous optimization and standardization, production in I4.0 is not method-based [8].

In Lean Production the focus is on the employee, who directly applies the lean methods at the point of the process and strives for a continuous improvement process [8]. In this context, organizational and methodological changes are made to processes through the active involvement of employees, thereby generating added value [8].

I4.0, on the other hand, focuses on a technology-driven approach that is characterized by the linking of the physical and virtual worlds [8]. In this context, assistance systems can independently discover optimization potential and support humans in the continuous improvement of processes with recommendations for action [7].

However, unlike in Lean Production, the increasing automation of processes can also derive improvement potential independently of humans through the latest technologies [7], so that humans or employees could increasingly take on a mere control function and thus no longer be at the center of processes. At the same time, automation will reduce the number of employees in companies [8], which could reduce the importance of employees, especially on the shopfloor, and change their role.

In terms of customer orientation, both approaches pursue similar goals. The Lean Production approach works with decentralized Kanban control loops according to the pull principle. As a result, there is a strong orientation toward the customer [7]. I4.0 supports decentralized control loops in the form of electrified Kanban loops [7] and enables customer-oriented production.

Further differences between the two approaches exist in the standardization of production processes. Lean Production relies on predefined structures and pursues standards to stabilize processes [7]. In I4.0, on the other hand, smart machines and objects predominantly take over communication and control their path in the factory depending on the situation and need. This makes it more difficult to comply with fixed standards within a digitized factory. However, a minimum of standardization is also necessary for introducing I4.0.

Nevertheless, both approaches generally pursue the same goal: increasing added value in the company [8]. In addition, both approaches aim to enhance productivity, flexibility, reduce costs [27] and avoid waste [7].

In summary, there is a fundamental compatibility between Lean Production and I4.0, even if their approach differs in certain areas.

In order to be able to make more precise statements about the compatibility of the two approaches and also to identify any differences or limitations, the following chapters examine some important Lean Production tools already mentioned in table 1 with regard to their compatibility with I4.0.

3.1.2.2. JIT and Industry 4.0

JIT production is one of the central tools of Lean Production and thus necessary for the implementation of Lean Production. If JIT production is implemented consistently, the company should not have any inventory in stock. Optimally, this means that produced parts are delivered directly from the supplier to the buyer's production without intermediate storage.

However, in practice the realization of JIT delivery is often difficult. Amongst other things, this is due to a lack of delivery status of the goods to be shipped, delivery of the wrong goods and unexpected time delays in transport [28]. Furthermore, production planning must match actual demand [29]. A high degree of information exchange is required between customer and supplier, as virtually no inventory is kept, so that there is a risk of production coming to a standstill due to missing parts. To minimize such risks, there must be excellent communication and collaboration between customer and supplier, which can be achieved and strengthened by I4.0 technologies [27].

In order to deliver the right quantity of parts to the right place at the right time, the demand forecast and the hence produced quantities must match the actual demand as accurately as possible. However, even with rather accurate forecasts, the risk of deviations remains. This can lead to overproduction and high inventories. The integration of I4.0 technologies can contribute to avoid these. In contrast to conventional forecast-based production planning, I4.0 technologies enable real-time-based production plans that can optimize themselves independently and dynamically [28]. The real-time-based production plans can be realized, for example, by using auto-ID technologies that are attached to production parts [29]. In this process, the movements of the production parts enable more precise demand patterns through real-time tracking [29].

Moreover, when a supply chain partner runs out of a part, in a collaborative network of supply chain partners and implemented traceability, all relevant partners automatically receive notification and can thus adjust their production in line with the updated conditions [29]. This can also avoid or reduce the so-called bullwhip effect [29], which can lead to fluctuations in demand due to the lack of communication between supply chain players and thus to excess stocks for all players in the supply chain. However, in order to be able to achieve a good communication across the supply chain and, for example, implement automated order triggering, it is necessary to connect the supply chain partners. This can be achieved by connecting machines, objects and parts across the supply chain with cloud-based ERP systems or blockchain technologies [29].

In this context, cloud computing in particular represents a great opportunity to establish integrated planning across the supply chain, since a cloud is comparatively easy to operate and at the same time has a good suitability for interfaces [29]. However, it is problematic to integrate all relevant players into a uniform system, since supply chain players have different standards with regard to the digitization of their production. Furthermore, today's supply chains have a large number of players and are becoming increasingly complex, making it difficult to integrate all players into an integrated system [29].

A prerequisite for the successful implementation of JIT delivery is therefore a continuous exchange of information between the recipient and the sender of the goods. This requires an adaptation or further development of JIT delivery, which can be designed primarily through I4.0 technologies. RFID technologies, for example, make it possible to track transported parts within the entire value chain in real time, which means that incorrect parts can be identified at any time and transparency is increased at the same time [27]. This enables necessary preparations in the event of delays in transport. In addition, real-time tracking allows the communication of the delivery status of parts to the customer at any time.

Furthermore, intelligent routing systems offer high optimization potential [29]. Telematics units can be used to track the location of the freight and retrieve data from sensors such as air pressure or temperature. At the same time they inform the truck driver about weather and traffic conditions during the journey to be able to continuously adjust the route [29]. It can be concluded that continuous tracking and tracing of parts supports JIT production and enables on-time delivery [28].

Closely linked to JIT production is Kanban. The integration of I4.0 technologies can help to optimize the Kanban systems [27]. With the help of digitalization, Kanban requirements can be determined precisely and Kanban signals can be transmitted more quickly, which in turn can generate time savings [29]. In order to fully automate the Kanban process, there are already intelligent containers that use sensors or cameras to identify parts' demand and automatically reorder parts accordingly [29].

SMED is another instrument of JIT that aims to reduce the set-up time of machines. I4.0 technologies can help to implement SMED more efficiently and thus also reduce set-up times. In the context of the smart factory, this involves the realization of flexible and modular workstations through IT interfaces that can be reconfigured into new production lines via plug & produce [1]. The prerequisite for flexible production lines are intelligent machines and parts that are able to communicate continuously with each other.

3.1.2.3 Jidoka and Industry 4.0

Andon is one of the key elements of Jidoka. It intends to enable rapid intervention by employees in the event of deviations and to increase transparency in the factory. A traffic light circuit represents signals in traditional Andon systems, indicating to employees an error in the production process. This is why the traffic lights must be in the field of view of the employees.

But the traffic light signal only informs employees of a production error not about the cause of the malfunction. Additional time is lost until employees find the fault location and contact the right person to remedy the issue.

One of the core principles of I4.0 is real-time capability. Appropriate I4.0 technologies hence have the potential to optimize Andon systems.

By connected intelligent machines with mobile devices and assistance systems such as tablets, smartphones or smart watches, the right contact person can be contacted in a targeted manner [27], regardless of the distance to the location of the relevant person. Through the smart watch, for example, employees can receive fault information and fault locations in real time [1]. This enables faster intervention, so that machine downtimes are reduced, which in turn can increase productivity.

In addition, the transmitted fault signals can be recorded in a database and investigated further as part of the continuous improvement program [30]. As technology advances, Andon boards are capable to display complex data in real time, such as machine states or capacity utilization, which can also be visualized on employees' mobile devices [27]. Additionally, intelligent machines equipped with Cyber Physical Systems (CPS) are able to further automate the Andon system by autonomously monitoring production [7]. The CPS, with sensors and an intelligent machine, continuously record specific conditions, such as temperature and malfunctions, and react in an event of deviations [7].

With Poka Yoke, no defective products should leave the process. This aspect is particularly important in today's multi-variant production [27]. For this reason, certain control mechanisms check the executed processes during production. Suitable I4.0 technologies accelerate and automate this checking process. For example, CPS can be integrated quickly and flexibly to support error-prone processes with the aid of computing power and sensor technology [1]. For instance, RFID or QR codes identify visually identical components automatically [1] and therefore avoid the risk of incorrect identification.

Furthermore, the mechanisms of Poka Yoke should prevent human caused errors. Suitable technological aids can support employees in avoiding errors in production and logistics. Solutions such as pick-by-light systems can be introduced, which, for example, facilitate the employee's picking process and in this way help to increase process quality in the context of the use of Poka Yoke [31]. The employee can use a visual display on the shelf to identify the picking location of a part in a shelf, so that the picking process is accelerated [32] and the risk of incorrect picking is reduced. In addition, the picking process can be further optimized by attaching sensors to the pick-by-light bars, which identify the number of parts already picked and at the same time check, whether the parts have been picked from the correct shelf [32]. Furthermore, the integration of tablets, which display the correct production and assembly procedures to the employee, can also increase process quality [31]. This ensures that the employee works according to the specified correct procedures, which reduces the risk of errors.

Newer technologies in error prevention are primarily in the area of assistance systems and Augmented Reality (AR) [8]. The use of AR in the picking process can support error prevention and improve performance at the same time [33]. For this purpose, employees are equipped with certain wearable devices and additionally supported with mobile devices [33]. For example, data glasses virtually display individual process and assembly steps to employees [7]. This can be seen as a further development of the tablet solution described above, whereby employees now have both hands free through the use of data glasses and can thus work more effectively. It is important that communication within the human-computer interaction is well designed so that employees can also work effectively [33]. However, the data glasses are not yet designed to be sufficiently employee-friendly and at the same time are not easy to implement [34], so the optimal introduction of these could still take some time.

The primary goal of TPM is to achieve maximum productivity of plant and machine availability. However, regular preventive maintenance and servicing cannot always eliminate machine failures [28]. Through I4.0, autonomous maintenance shifts the responsibility for routine maintenance tasks from maintenance technicians to machine operators [27]. Machine operators are equipped with appropriate I4.0 tools or assistance systems to take on more and more responsibility for maintenance and servicing [27]. At the same time, intelligent, self-maintaining machines, predictive maintenance and human-machine interaction can lead to better preventive maintenance and servicing and thus more efficient TPM within the factory [28]. Accordingly, TPM is very compatible with I4.0 technologies. One of the reasons for this is the fundamental approach of TPM, which comes very close to the smart factory approach with decentralized management and control.

3.1.2.4. Kaizen and Industry 4.0

The Kaizen approach with its fundamental process idea – continuous improvement – is included in all Lean Production tools. This highlights the importance of this Lean Production tool. However, in comparison to individual improvement projects, Kaizen is an everyday instrument for process improvement and increases the competence of employees [35]. Employees can be integrated more strongly into the continuous improvement approach through digital methods. For example, company goals for certain key performance indicators could be compared to the current actual values and visualized on the shop floor [35]. A presentation of department-specific goals or quality key performance indicators can help to increase the identification and motivation of employees more intensively, as they can better understand their personal contribution to the key performance indicators. In addition, the use of gamification and social networks can be used to increase employee motivation [35]. Through gamification, employees can compare themselves with each other, which could increase motivation at work, while social networks could increase recognition among employees, and employees with similar Kaizen activities could follow each other [35].

3.1.3. Compatibility Matrix and Derivation of Hypotheses

In order to illustrate the compatibility of Lean Production and I4.0, the seven elements of Lean Production in table 1 are coupled with the five principles of I4.0 in table 2. It is analyzed to what extent the tools of JIT, Jidoka and Kaizen are compatible with I4.0 principles and to what extent the principles can complement the Lean Production approaches. The compatibility matrix (figure 1) present the conclusions the authors drew from the SLA. The more points (max 3) and darker the fields, the higher is the compatibility between the respective Lean Tool and I4.0 characteristics.

At first sight, the results show a good compatibility between the Lean Production tools and I4.0 principles. The best correlations are in the principles of real-time capability, interoperability and decentralization. This is due to the increasing transparency and efficiency through real-time data, the connectivity in the factory and the decentralized decision-making, which is already an element of Lean Production. The interoperability of JIT production is the main challenge or contradiction, as the different standards of the IT architecture between companies within a supply chain can make the cross-company integration of I4.0 difficult. It is also notable that Andon, Poka Yoke and TPM correlate positively with most I4.0 principles. This is due to the basic approach of Jidoka, which already refers to autonomous automation, so that this approach can further be expanded and optimized by I4.0 technologies. It is also noticeable that modularization has a low compatibility with the Jidoka tools. This is due to the fact that Jidoka is basically concerned with error prevention tools and the display of disturbances. Therefore, modular machine features are not in the primary focus of achieving its goals.

In summary, 88 out of a possible 120 points were achieved in the scoring of the matrix – so more than

		Real-Time Capability	Decentralization	Virtualization	Interoperability	Modularity
Just-in-time	Just-in-time-production	3	2	3	0	3
	Kanban	3	3	2	3	3
	One-Piece-Flow	3	2	0	3	3
	SMED	2	2	2	3	3
Jidoka	Andon	3	2	3	3	0
	Poka Yoke	1	3	3	1	0
	TPM	3	3	2	3	1
Kaizen	Kaizen	3	1	2	3	0

Legend 3 Points 2 Points 1 Point 0 Points

Figure 1: Compatibility matrix

two-thirds of the points. This means that there is good compatibility between Lean Production and I4.0. It can be observed that the I4.0 principles often complement the Lean Production tools and help to achieve their goals more efficiently and consistently. The status quo of the literature thus mainly showed the potentials of merging both concepts.

Based on the results of the SLA and the derived compatibility matrix, corresponding hypotheses were developed, and these were later verified and answered with the help of the empirical investigation. The hypotheses are based on the status quo of research, the gaps in research and knowledge in the literature. On the other hand, they represent an anticipation of the findings of the empirical investigation.

The first hypothesis represents the fundamental statement of the results of the SLA:

– T1: "Lean Production is a key success factor for the successful implementation of I4.0 in companies."

As already described, Lean Production and I4.0 pursue similar goals, so that I4.0 Technologies could support Lean Production in achieving these goals. The following hypothesis can be derived from this:

– T2: "I4.0 Technologies and Principles support the achievement of the central Lean Production goals: the avoidance of waste, the increase in productivity, the continuous improvement process and increasing decentralization."

The technologies developed by I4.0 ensure increasing automation, so that many activities of production and logistics employees are eliminated. As a result, there is a risk that employees will no longer be at the center of value creation, as stated in the lean philosophy. Based on this, the following hypothesis can be formulated:

– T3: "By integrating I4.0 into Lean Production concepts, the fundamental philosophy of Lean Production is lost, as the human/employee is no longer at the center."

The fourth thesis deals with one of the biggest challenges of implementing I4.0 technologies within existing lean production concepts. Due to the increasing number of actors within a supply chain, it is becoming more complex. From this, the fourth hypothesis can be formulated:

– T4: "The cross-company integration of uniform I4.0 solutions is made more difficult by companies' different IT standards and the increasing complexity of supply chains."

In addition to the risk of job losses, new technologies are leading to a change in the work roles of employees. Employees must therefore increase their competences so that I4.0 runs successfully in the company.

– T5: "The integration of I4.0 technologies into production and logistics increases the demands on employees. The successful training of employees in new technological solutions is considered a central challenge of companies."

3.2. Empircal Study

3.2.1. Methodology

As already described, there is a lack of research that focuses on the challenges of integrating I4.0 into Lean Production and on practical solutions for I4.0. The goal of the empirical part of this paper is the analysis of success factors and challenges when introducing I4.0 technologies in existing processes, practical technological solutions and the verification or falsification of the hypotheses determined from the status quo of the literature from the point of view of practitioners.

Semi-structured interviews with experts are at the center of the data collection in this study. The selected eight interview partners have different backgrounds to account for a broad range of perspectives. Five work in the sector of automotive industry, one in the IT Service, one in a research institute and one in a multi-sector manufacturing company. They all have in common, that they are experts in the field of Lean Production, I4.0 or innovation management on a management level. They bring along experience in practical I4.0 solutions and were able to contribute comprehensively to the research questions. They therefore support the study's purpose even though the selection of interview partners might not be representative.

The interviews were anonymized after the transcription followed by a qualitative content analysis. Qualitative content analysis is suitable for guided interviews with the aim of generating new information [36]. The MAXQDA2020 software served as the analysis tool for the content analysis, as it enables a detailed and qualitative analysis of the transcribed data. The authors analyzed the transcribed interviews according to Kuckartz's content-structured content analysis, which is suitable for both deductive and inductive category formation.

3.2.2. Results

3.2.2.1. Introduction of Industry 4.0 technologies into existing processes: Success Factors

Most important factors for the successful implementation of I4.0 Technologies are how the technology is introduced and integrated into the company and at what point in the process it makes sense to do so.

Almost all the experts agree that technology is merely a supplement to the process. A poor and wasteful process does not become better and more efficient through digitization and automation. On the contrary, the implementation of a technology in an uncoordinated and non-standardized process can lead to the process becoming even more complex and inefficient than it would have been without the technology. The reason for this is the risk that non-standardized workarounds or processes lacking documentation get lost in the course of automation or digitization. Standardized and lean processes are therefore a prerequisite for the introduction of I4.0 technologies. The first step should therefore always be primarily on process improvements without the introduction of technologies.

In the second step, I4.0 gets introduced after weak points such as production problems, inefficiencies, bottlenecks or information breaks in the Lean Process are identified with the help of e.g. value stream mapping. Often, these weak points in the processes are decisive for the introduction of technologies. Based on this, suitable and appropriate I4.0 solutions and technologies can then be derived and implemented. I4.0 technologies should only be introduced if they are really needed and eliminate problems or inefficiency in the process.

Moreover, the integration of technologies that are already available in the company and the cooperation with IT partners can increase the chances of success of the introduction of I4.0.

3.2.2.2. Practical I4.0 technologies and solutions

After having described how companies can integrate I4.0 solutions, the following section will now present practical I4.0 technologies and solutions. These have already been implemented in the interviewed companies and have helped to increase the efficiency of the processes.

Data analytics

Data analytics is one of the central I4.0 solutions. Accordingly, seven out of the eight interviewees are dealing with the analysis of data and pursue different purposes in doing so. The central goal of data analysis is to create transparency in real time within production, logistics and the supply chain, and also showing important real time information about operational and supply chain conditions, machines and quality of products. In order to achieve a high level of transparency, existing data from different systems must be combined in a database and analyzed, such as the creation of supply chain dashboards with continuous tracking of statuses and inventory levels within the supply chain. Additionally, data analytics can optimize packaging units through the comprehensive analysis of data. Small packaging units result in a larger handling effort and lead to higher quality issues, as they are less protected than large packaging units. Also, the probability of counting errors by the employee is significantly higher with smaller packaging units, which can lead to customer complaints. Data analytics can be used to compare the effort involved in handling smaller packaging units with the quantities ordered by customers. In order to cut down the mentioned expenses, rounding quantities for the articles to be picked can then be derived in the next step, leading to fewer counting errors and, at the same time, more reliable shipping due to larger packaging units. As a result, within the framework of Lean Production, productivity increases, since less handling effort is required for the picker, and quality is improving, since the number of customer complaints can be reduced.

Automation

Half of the interviewees deal with the automation of material flows, mainly by talking about so-called "automated guided vehicles" (AGV). These are driverless transport vehicles which replace the manual milk run carried out by the employee and thus enable an automated material flow. This means a significant reduction in the number of personnel required for internal transportation, resulting in potential savings and increased productivity. A prerequisite for automated material transport via AGVs is that the material flows must be available digitally. In addition, unlike the classic milk run, there is no longer a cyclical material supply, but a demand-related material supply. This is realized through complete connectivity within the factory and the information and data about the respective requirements that are obtained as a result. Accordingly, the AGVs supply the respective production lines on a demand-related basis. Interviewee 5 (innovation manager) mentions the introduction of a transport robot – conceptually similar to the AGVs – which automatically carries out the transportation from incoming goods to outgoing goods. Compared to the classic AGV, the autonomous robot offers the advantage that it does not have to travel on a specific line, but can move freely in the warehouse independently of a line. Thus, the transport robot can be considered as a next automation level of AGVs. It is able to detect obstacles on its defined route by means of sensors and adjust its route accordingly. Furthermore, it stores information about obstacles and passes this on to the other transport robots in the warehouse.

In addition to the automation of the material flow, three of the interviewees are also working on the automation of incoming goods. The aim here is to reduce the manual effort involved in handling shipping documents, etc. in the goods receiving process. According to one interviewee (I4.0 coordinator), four different automation levels can be implemented. In the first stage, the supplier digitally sends the goods receipt information in advance. This way, there is no need to type the goods receipt information manually into the computer from the delivery documents. Within the second automation stage, the supplier attaches a barcode to the goods receipt pallet. By scanning the barcode the goods receipt employee successfully books the articles with the respective quantity into the system. In the third automation stage, the delivery information is located on an RFID transponder. RFID enables automated goods receipt booking because it does not require an employee to scan a barcode on the pallet. In the last automation stage, which is still in the future, cameras are used in the goods receiving area, which automatically record the incoming goods on the basis of a barcode or a label.

All of the automation systems aim to reduce the manual effort involved in receiving goods. These are cross-company solutions, as the suppliers must meet certain requirements so that the automation solutions can be implemented. This necessitates cooperative suppliers. According to one interviewee (I4.0 coordinator), however, as a customer you can usually prescribe certain specifications to the supplier regarding delivery and the communication of delivery information.

Once the I4.0 technology software or digitization solution has been determined and the desired information and functions are known, the next step is to select the display devices or assistance systems. Digital assistance systems in the form of mobile devices, watches or glasses enable the employees in carrying out their activities and communicate with the I4.0 software. Various assistance systems can be distinguished, which are described below as examples.

Glove scanner

Three interviewees have successfully introduced glove scanners in their company for picking articles. In contrast to conventional scanners, which have to be operated by the employee with one hand, the glove scanner allows the employee to scan the respective items to be picked from the wrist. The scanner is located on the back of the glove. This enables unrestricted picking, as the employee has both hands free and can therefore carry packages more easily. Furthermore, the use of glove scanners can increase employee satisfaction and motivation, as work is made easier. At the same time, the glove scanners enable an increase in productivity within the order picking process due to the time advantages in contrast to conventional manual scanners.

Data glasses

The same three interviewees also tested the introduction of data glasses in their respective companies. Data glasses are the next level of assistance systems that can support employees in order picking, for example. These can automatically identify and scan the correct barcode with the help of a camera, so that the employee – unlike with manual scanners or glove scanners – no longer has to search for and identify the correct barcode independently. Furthermore, the employee has both hands completely free for picking. This significantly simplifies the picking process. In addition, the necessary work steps to be completed are virtually displayed to the employees through the data glasses by means of AR. In this way, newly hired employees could already pick items with the help of the data glasses without extensive training. However, the technology for data glasses is not yet very mature, so that a comprehensive use of data glasses is currently out of the question. Furthermore, the economic viability of data glasses must be viewed critically due to the high investment costs. With the technology available today, employees work faster and therefore more effectively with the glove scanners than with the data glasses, so that picking has so far been carried out via the glove scanners.

3.2.2.3. Challenges of integrating I4.0 into Lean Production processes and approaches to overcoming the challenges

Employee acceptance of new technologies is one of the key challenges in integrating I4.0 technologies into existing Lean Production processes. Accordingly, almost all interview partners have had experiences with employees who are averse to new technologies. Job hazards and habituation to existing processes are the main reasons for employees' aversion to new technologies. Therefore, employees must be convinced that new technologies are necessary to ensure the competitiveness of the company so that jobs are secure for the future. Furthermore, the technology should be a supporting function that only automates standardized and monotonous work, so that more demanding activities with greater creative freedom for the employees arise and the employees remain in the focus. In general, employees need to be aware of the relevance and benefits of the technology. Only if employees realize the potential of the technology and understand the reasons for the introduction, they are able to embrace it and use it at work.

Limited resources are another key challenge for the introduction of I4.0 technologies into existing Lean Production processes. These are primarily financial resources, people skills, but also IT resources and a lack of data availability. In order to minimize these challenges, sufficient support from management and the targeted recruitment and development of employees are essential.

3.2.2.4. Verification and falsification of the hypotheses

The empirical evidence indicates a full confirmation of hypotheses 1, 2 and 4. This section examines hypotheses 3 and 5 in more detail.

T3: "By integrating I4.0 into Lean Production concepts, the fundamental philosophy of Lean Production is lost, as the human/employee is no longer at the center."

Empirical evidence suggests, that this hypothesis has been completely falsified. I4.0 should support employees in their work, simplify their work, but not replace them. Humans are flexible and universally applicable and still have many advantages over technologies. Furthermore, technologies are not yet developed enough to be able to independently execute, control and monitor all processes without humans. The expertise and process knowledge of humans are needed to design new technologies according to the process requirements. In addition, automated and digitalized processes must also be monitored and controlled by humans. The human being is therefore still the centre of attention, just the place of work has changed.

T5: "The integration of I4.0 technologies into production and logistics increases the demands on employees. The successful training of employees in new technological solutions is considered a central challenge of companies."

This hypothesis could be neither fully verified nor falsified, as not all experts agreed or disagreed with the hypothesis. The successful training of employees is a challenge, as employees are not always positive about changes in the process at the beginning. It is therefore necessary to involve the employees early on and to communicate changes to the employees in the right way. In respect to increased requirements the opinions of the interviewees are diverse. Two types of employees can be distinguished. The activities of operational employees will be facilitated in the long term by I4.0 technologies, as all inspection steps are automated and assistance systems support employees in carrying out their activities. In the short term, however, older operational employees in particular may have initial difficulties with new technologies, so that extensive familiarization and training is necessary. On the other hand, the demands on the key users of I4.0 technologies are increasing. These employees must continuously develop and be very technology-savvy in order to be able to control I4.0 technologies.

4. DISCUSSION

The findings elaborated in the status quo of research and empirics confirm the fact described in the introduction that the integration of I4.0 into Lean Production offers both potentials and challenges. It was examined whether and to what extent Lean Production is compatible with I4.0.

Lean Production and I4.0 generally pursue the same goals, which are, however, realized with different methods and approaches. The integration of I4.0 into Lean Production can increase the efficiency of processes, flexibility, and transparency in the factory, especially with the help of technologies and automation. Thanks to the large database, weak spots in the process can be better identified and analyzed with the help of I4.0, so that a superior continuous improvement process can be realized in the sense of Kaizen.

However, lean and efficient processes, which are designed according to the Lean Production approach, are a prerequisite for the successful interaction of Lean Production and I4.0. The process must always come before the technology, as a non-standardized and inefficient process that is digitalized and automated only leads to an increase in complexity and does not offer any major improvements. Accordingly, lean processes form the basis for the successful integration of I4.0 technologies and solutions.

Some limitations of the SLA and the empirical study should be pointed out. With regard to the SLA, the expansion of the databases, the keywords as well as the consideration of sources in other languages would lead to further contributions and insights. In addition, only a limited number of Lean Production tools relevant to the authors were considered in the literature search.

Furthermore, the combination of Lean Production and I4.0 is more pertinent in medium-sized and large companies, in which the majority of the interviewed experts are located, so that the significance of the results for smaller companies must be viewed critically. Additionally, six of the interviewed experts work in the automotive industry, so that the general validity of the results for all industries must be questioned. The results of the empirical study base on subjective perceptions and experiences of a limited number of experts, whereby an attempt was made to achieve differentiated results by selecting experts from different work roles. However, their management perspective may overlook or misinterpret aspects pertinent to shopfloor workers, who were not part of this empirical study.

Nevertheless, the results of the paper can assist practitioners to successfully establish I4.0 in their company. It presented the prerequisites for the implementation of I4.0 and showed exemplarily and theoretically, which I4.0 technologies can increase the efficiency of the logistic processes. The paper also revealed differences and similarities between the results of the theory and the practice on the compatibility of Lean Production and I4.0.

5. CONCLUSION

Lean Production is fundamentally compatible with I4.0 and its principles and technologies in terms of its concepts and tools. The combination of both concepts – together with an early involvement of employees and a focus on processes – can offer added value for companies by achieving efficiency advantages as well as increasing flexibility and transparency. Unlike Lean Production, where the employee identifies and implements process improvements independently, in I4.0 the optimizations are integrated into the process from the outside, so that communication with employees is crucial for the success of the technology. If these aspects are considered, the combination of Lean Production and I4.0 can create potentials that can hardly be achieved by other measures and that are absolutely necessary in the age of digitalization and the COVID 19 pandemic in order to remain competitive.

Lean Production emerged in Japan in the 1950s out of the need to compete with European and American companies. Today, European companies must effectively integrate I4.0 into their existing Lean Production concepts in order to withstand the increasing competitive pressure from China and Eastern Europe. Ultimately, however, each company must consider on a case-by-case basis whether standardized and lean processes are already in place, whether the technology is mature enough and whether the implementation will thus pay off economically for the company in the medium to long term.

Future research could focus on the further development of Lean Production. The concepts of Lean Production may change in the future due to the increasing integration of technologies and the digitalization of production, but also due to the raising importance of sustainability. Even new production concepts could emerge. In addition, further innovative technologies will emerge within production and logistics in the coming years, raising again the question of compatibility.

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