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A Systematic Approach to Identify the Interdependencies of Lean Production and Industry 4.0 Elements

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Abstract

As a result of increasing globalization, manufacturing companies are confronted with rising cost and time pressure. They are countering these influences with the management approach of lean production. Since 2011, Industry 4.0 has been established as another promising approach in the production environment. The combination of both domains is referred to and discussed in science as Lean 4.0. In this paper, the one-to-one connection between the principles and methods of lean production and the technologies of Industry 4.0 is elaborated using the Delphi study method and Domain Mapping Matrices (DMM). This contribution shall serve as an essential basis for companies to implement Lean 4.0 in their production.

Keywords: Lean Production; Industry 4.0; Lean 4.0; Delphi study;

1. Introduction

With its principles and methods, the lean production approach is one of the leading production maxims in Germany's manufacturing companies [1]. Through its elements' systematic interaction, lean production pursues increasing process efficiency by consistently and thoroughly eliminating all types of non-value-adding activities [2].

Nowadays, the manufacturing environment is changing, and companies have to face a multitude of complex influencing factors, such as increasing globalization, growing demand for individualized products, or shortened technology and product lifecycles [3, 4]. As a result, complexity and dynamics in the production environment are continually rising. Further development of fundamental paradigms in industrial production is required to cope with these complex and novel challenges [5]. Regarding a fourth industrial revolution, Industry 4.0 was introduced at the Hannover Messe 2011 in Germany [6]. It focuses on real-time and intelligent networking of objects, humans, machines, and equipment across organizational boundaries [7]. The goal is to create a flexible, efficient, and customer-oriented production system with high economic potential [8]. The combination of lean production and Industry 4.0 seems profitable for organizations [9] as interdependencies can achieve synergy effects [10]. Many researchers have already investigated the interrelation between both domains, which led to the concept of Lean 4.0 [1, 11, 12]. In order to support manufacturing companies in systematically and holistically implementing Lean 4.0, further research is required to identify one-to-one interactions between essential elements of both paradigms.

Therefore, this scientific contribution provides a systematic approach to identify the interdependencies between relevant elements of both domains. It shall help companies to address the challenges that arise with transforming their production processes and serve as an essential basis for further research.

2. Background

The following chapter sets the reference frame of the scientific fields and presents an introduction of lean production (2.1) and Industry 4.0 (2.2). Moreover, section 2.3 describes the interrelation between lean production and Industry 4.0.

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2.1. Lean Production

After World War II, the Toyota Motor Company developed the Toyota Production System (TPS) [2]. Since then, it has been continuously evolved into a holistic production system, which today is known as lean production [13, 14]. With its interlinked methods and principles, lean production provides a management approach for operational excellence by focusing on customer value, standardizing and visualizing processes, and establishing a continuous improvement culture [15].

Over the last decades, the lean production paradigm has been systematically investigated in terms of its targets, culture, principles, and methods [13, 14, 16, 17]. The holistic approach of lean production is conceptualized in the VDI guideline 2870, which presents a general, cross-company description of lean production [18]. AULL [16] also provides a selection and structuring of eighteen lean production elements significant for manufacturing companies' competitiveness. He divides them into three areas: 'employee-oriented methods', 'quality-oriented methods', and 'logistics-oriented methods' (see figure 1).

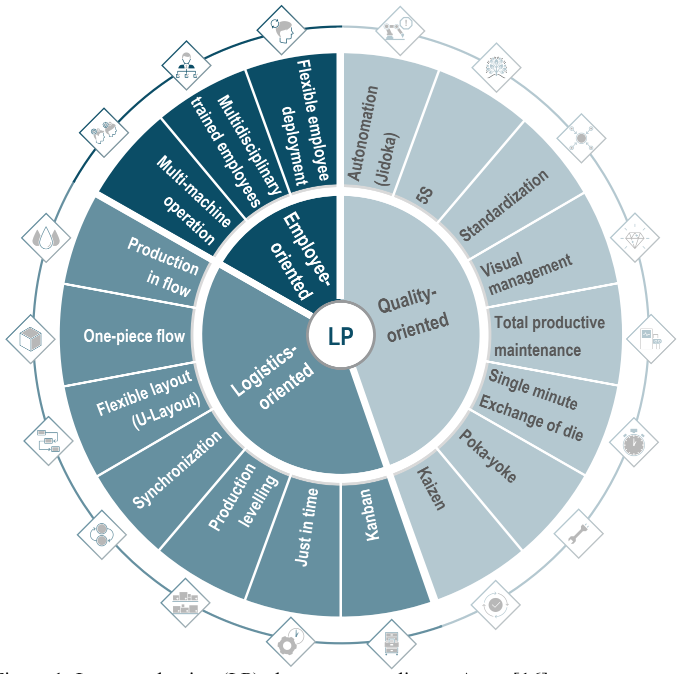

Figure 1: Lean production (LP) elements according to AULL [16]

2.2. Industry 4.0

The Industry 4.0 approach was introduced to meet the manufacturing industry's current and future challenges and to enhance the German manufacturing industry's competitiveness. [19, 20].

Therefore, the domain focuses on optimizing industrial value creation and is characterized by digitalization and networking of all value chain participants [21]. It affects companies' processes, products, and business models in the manufacturing industry [21, 22] and aims at the effective and efficient design of material and information flows along the value chain [23]. Various innovative technologies, such as augmented reality or automated guided vehicles, are available for this purpose. Based on a use case analysis, DOMBROWSKI ET AL. [11] have subdivided the Industry 4.0 elements into process-related 'characteristics', 'systems', and 'technologies' (see figure 2).

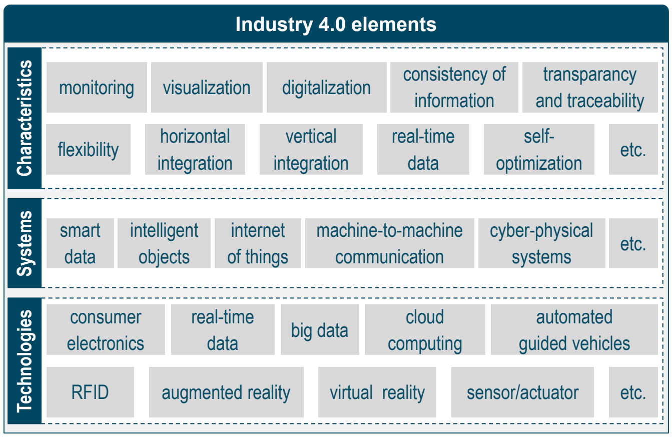

Figure 2: Industry 4.0 elements [11]

Besides this proposal, there are other approaches to structure Industry 4.0 elements [24, 25]. Due to the Industry 4.0 domain's novelty, there is still a need for further research investigations to structure the elements [11]. The approaches and scientific findings have in common that, like the three preceding industrial revolutions, Industry 4.0 is primarily a technology-driven one [9].

2.3. Interrelation between Lean Production and Industry 4.0

There are three main perspectives concerning the interdependencies of lean production and Industry 4.0 [1]. The first considers lean production as a necessary foundation for the successful realization of the fourth industrial stage [26]. This point of view is based on the idea that digitizing inefficient processes only leads to inefficient digitized processes [9, 14, 26]. The second one perceives Industry 4.0 as a new conceptual paradigm capable of addressing the challenges that lean production cannot overcome [27]. It underlines the influence of Industry 4.0 on the lean elements in terms of positive contribution to its effectiveness and goals [28, 29]. The last point of view is that Industry 4.0 and lean production generate additional synergy effects [10]. Both domains can achieve an increased benefit through the targeted combination of lean production and Industry 4.0 elements [30]. The integrated application of lean production and Industry 4.0 as a conjunction of these two approaches is called Lean 4.0 [31].

These three viewpoints do not contradict each other but underline that there is still no consensus in the scientific community according to the relationship between Industry 4.0 and lean. Previous studies have often been limited to a few selected elements and have primarily focused on examining the conceptual level, like the philosophy or the overall targets. For example, FISCHER & KOBLER [32], SANDERS ET AL. [26], or DOMBROWSKI ET AL. [11] mainly refer to lean principles, such as jidoka or flow principle. Other investigations include several lean production methods but only consider a few Industry 4.0 elements [33–35].

As analyzed by EJSMONT ET AL. [36], there is a lack of a comprehensive interdependency matrix that combines a targeted selection of lean and Industry 4.0 elements one-to-one.

Due to the high relevance for manufacturing companies and the experts' knowledge from practice, both the scientific and the industrial perspectives should be included in the interdependency analysis.

3. Methodical Approach

In the following, a methodical, application-oriented approach intended to identify the correlation of both domains is presented. Such a correlation matrix should be based on a clear production perspective and include lean methods and Industrie 4.0 technologies of considerable importance for manufacturing companies. Moreover, the targeted interdependency matrix development shall be based on a proven, systemic, and methodical planning procedure, as presented by AULL [16].

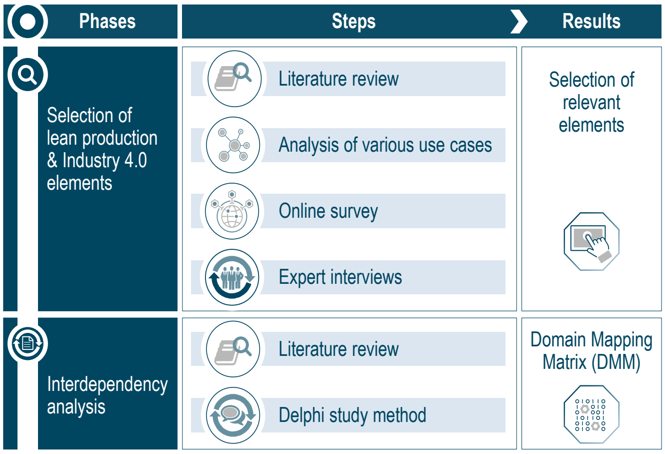

Figure 3: Procedure for the development of the interdependence matrix

The procedure can be divided into two main phases (see figure 3). In the first phase, the relevant elements need to be selected in order to analyze their interdependency in the second phase. For the selection of the elements, a structured literature analysis [37] is to be conducted. In addition, the selection needs to be validated and adjusted through online surveys or semi-structured expert interviews with participants from science and industry. This multistage procedure is intended to ensure that the research and industry perspectives are taken into account. The result of the first phase is a selection of relevant elements from Industry 4.0 and lean production.

In the second phase, the interaction of the selected elements and their one-to-one impact needs to be investigated. Therefore, Domain Mapping Matrices (DMM) [38] combined with a Likert scale are going to be used, which are elaborated by a literature review as well as the Delphi study method [39].

In general, the Delphi study method is an iterative feedback technique with a panel of five to twenty experts [40]. The feedback will be given anonymously to counteract group dynamics. In this way, single panelists do not have a disproportionately strong influence on the results [41]. For Delphi studies, the sampling of the experts is essential. The panel should be composed heterogeneously to avoid biases. [41, 42] The feedback process is repeated iteratively until the final matrix is obtained [40]. The following chapter describes the selection of the relevant elements and presents the DMM.

4. Interdependency Matrix for selected Lean Production and Industry 4.0 Elements

4.1. Selection of the Lean Production and Industry 4.0 Elements

A systematic literature review was carried out to preselect Industry 4.0 elements based on the literature database 'Scopus'. In total, 4087 relevant conference proceedings and journal contributions could be identified and investigated with a co-occurrence analysis using text mining algorithms [43]. The pre-selection of Industry 4.0 elements was supplemented by an analysis of 198 Industry 4.0 use cases from Germany [44] and 150 use cases from Japan [45].

As lean production has already been systematically investigated, its elements' pre-selection is primarily based on the VDI 2870 [18] and AULL [16], who has analyzed various lean production systems to identify the most appropriate methods and principles. Furthermore, a survey with experts from the industry concluded that, in addition to Aull's selection, shop floor management and value stream management are also highly relevant for manufacturing companies [17].

To verify and modify the pre-selection, semi-structured interviews with experts and an online survey with thirty experts from different industries were conducted. In total, 20 lean and 26 Industry 4.0 elements could be identified (see table 3).

4.2. Interdependency analysis for Lean and Industry 4.0 Elements

The DMM represents the interdependency from Industry 4.0 to lean and vice versa, focusing on the production perspective. A literature review was conducted to populate the DMM [37], using the database 'Scopus'. Forward and back literature searches were done to ensure a complete and exhaustive review, and new research contributions were identified using the snowballing effect [46]. In total, eighteen relevant research contributions could be selected and transformed into the DMM. In the following step, the Delphi study with fourteen experts was conducted over several rounds. The panel sampling was heterogeneously composed to avoid biases (see table 1) [41].

Table 1: Anonymized overview of the panelists

Experts	Job	Company	Company type
Expert 1	Head of Lean	A	Car manufacturer
Expert 2	Project leader	B	Consultant
Expert 3	Project leader	B	Consultant
Expert 4	Project leader	C	Research institute
Expert 5	Research group leader	D	Research institute
Expert 6	Project leader	D	Research institute
Expert 7	Project leader	D	Research institute
Expert 8	Project leader	E	Machine supplier
Expert 9	Engineer	F	Automotive supplier
Expert 10	Project leader	G	Consultant
Expert 11	Project leader	H	Research Institute
Expert 12	Head of Maintenance	I	Logistics
Expert 13	Head of Production	J	Machine supplier
Expert 14	Engineer	K	Car manufacturer

This is a resupply of March 2023 as the template used in the publication of the original article contained errors. The content of the article has remained unaffected.

For assessing the one-to-one impact between the elements, a seven-level Likert scale [47] was chosen (see table 2).

Table 2: Likert scale for assessing the impact between the elements

Impact	Description
-3	Strong negative correlation impact
-2	Medium negative correlation impact
-1	Low negative correlation impact
0	No correlation impact
1	Low positive correlation impact
2	Medium positive correlation impact
3	Strong positive correlation impact

In round one, the expert's opinion and the literature review results were used to identify a possible one-to-one interaction between the elements. The experts also could expand or reduce the selection of elements.

In the following two rounds, the panelists assessed each element's impact using the Likert scale (see Table 2). After the final round, the experts' individual domain mapping matrices were merged. Therefore, the mean value and the standard deviation were calculated for each element. Afterward, the DMM was sent to the experts for final verification. The following DMM presents the Delphi study result, including the one-to-one impact between the elements (see Table 3).

Table 3: Domain Mapping Matrix based on a Delphi study

			Lean production elements																			
			Logistics-oriented							Employee-oriented			Quality-oriented									
			One-piece flow	Flexible layout (U-Layout)	Production in flow	Synchronization	Production levelling	Just in time	Kanban	Multi-machine operation	Multidisciplinary trained employees	Flexible employee deployment	Autonomation (Jidoka)	5S	Standardization	Visual management	Total Productive Maintenance (TPM)	Single Minute Exchange of Die	Poka-yoke	Kaizen	Shop floor management	Value stream management
			L-1	L-2	L-3	L-4	L-5	L-6	L-7	L-8	L-9	L-10	L-11	L-12	L-13	L-14	L-15	L-16	L-17	L-18	L-19	L-20
Industry 4.0 elements	Big data [4]	I-1	2		2	2	2	1	2	1		1	2	1	2	1	2	1	1	1	2	2
	Analytics (e.g. Artificial Intelligence) [4]	I-2	2		2	2	3	2	2	2		1	2	1	2	2	3	2	1	2	2	3
	Autonomous robots/machines [48]	I-3	1		1			1		1			2	1	2	1	2	2		1		
	Autonomous guided vehicles (AGV) [19]	I-4	1		1	2		1	2	1		1	2	2	2	1	2	1	1	1		
	Computer aided x (CAx) [49]	I-5	1	1	1	2	1	1	1	1	1			1	1	1	1	1	1	1	1	2
	Predictive maintenance [50]	I-6	1		1	1	1	1		1	1		1		1		3	1		2	1	2
	Digital twin [51]	I-7	1	1	1	1	2	1	1	1	1			1	2	1	1	1	1	2	1	2
	Vertical integration [24]	I-8	1	1	1	1	1	2	1	1	1	1	1	1	2	1	2	1	1	2	3	1
	Machine-to-machine communication [48]	I-9	1		1	1	1	1	1	1	2	1	2		1	1	1	2				1
	Plug and produce [50]	I-10	2	1	2	1	2			2	2	1		2	2	1	1	3	2			
	Horizontal integration [24]	I-11	1	1	1	1	2	3	2	1	1	1	2	1	2	1	2	1	1	1	2	3
	Auto ID (e.g. RFID) [4]	I-12	1		1	1	1	2	2			1	1	1	1	1	1	1	1	1	1	2
	Sensor/actuator [48]	I-13	1		1	1	1	2	2	1		1	2	1	1	1	2	2	1	1	1	2
	Intelligent objects [48]	I-14	2	1	1		1	2	2			1	2		1	1	1	2	2	1	1	2
	Cyber-physical (production) systems [19]	I-15	2	1	2		2	2	1	1			2	1	2	1	2	2	1	1	1	3
	Real-time data [4]	I-16	1		1	1	2	3	1	1	1	1	3	1	1	2	2	1	1	1	2	3
	Security [52]	I-17																				
	Privacy [52]	I-18																				
	Cloud computing [24]	I-19			1	1	1	1	1			2	1	1	1	1	1	1	1	1	2	2
	Wireless networks/5G [48]	I-20					1	1	1			1	2		1	1	1				2	2
	Additive manufacturing [4]	I-21						1		2	1		3	1		1	2	2	1	1		
	Augmented reality [19]	I-22		1	1	1	1	1	1	3	2	2	1	2	2	2	2	2	1	1	1	1
	Virtual reality [48]	I-23		1	1	1	1	1		2	2	2	1	2	2	2	1	1	1	1	1	1
	Mobile electronics [24]	I-24			1	1			1	2	2	1	1	1	1	1	1	1	1	1	1	
	Human-machine interaction [48]	I-25		1	1	1	1	1	1	3	3	2	1	1	1	2	2	3	2	1		1
	Collaborative robots [53]	I-26	1	1		1				3	2	2	2	2	2	1	2	2	2	1		

5. Results and Discussion

In the following, the combined results of the interdependency analysis are presented. A total of 520 correlation possibilities were examined with a literature review and a Delphi study method. According to the presented Likert scale (see table 2), 251 elements have a low positive correlation, whereas 128 elements have a medium positive correlation and 18 elements have a strong positive correlation. Moreover, the panelists identified no negative correlation between the lean and Industry 4.0 elements. Therefore, it can be concluded that there is a positive correlation between both domains, which is also demonstrated due to the result that 76.3 % of the possible pairings show a positive interaction. However, there are significant differences between the impact of the one-to-one interrelations. Some elements do not have any direct correlation, such as the Industry 4.0 elements security (I-17) or privacy (I-18). In contrast, the logistics-oriented lean methods and principles (L-1 to L-7) have a distinctive positive correlation with the Industry 4.0 elements I-10 to I-16, as well as big data and data analytics. Artificial intelligence algorithms (I-2), for example, can significantly improve the efficiency and effectiveness of production levelling (L-5) and support production planning with the creation of the production sequence. Analogous to the logistics-oriented methods, the quality-oriented methods are closely linked to the Industry 4.0 elements I-1 and I-2. Besides, there are other significant combinations, such as shop floor management (L-19) combined with vertical integration (I-8) or value stream management (L-20) joined with horizontal integration (I-11). The latter pairing pursues making the processes transparent across the entire value chain and thus designing processes efficiently by eliminating all types of waste [55].

Furthermore, it is noticeable that the employee-oriented lean methods (L-8 to L-10) show a very high interaction with the Industry 4.0 elements augmented reality (I-22), virtual reality (I-23), mobile electronics (I-24), human-machine interaction (I-25), and collaborative robots (I-26). These Industry 4.0 elements are primarily cognitive or physical assistance systems, which aim to support employees in executing their activities [4]. Through augmented reality (I-22) in production, additional worker-specific information concerning their activities can be displayed to strengthen the employees' multidisciplinarity.

Due to the structured literature review and the Delphi study, various positive one-to-one interdependencies could be identified. It can therefore be assumed that lean production and Industry 4.0 not only complement each other on a conceptual basis, but also have positive interactions at the technology and method level for elements.

6. Conclusion and Outlook

This research contribution presents a comprehensive and structured Delphi study with a heterogeneously composed panel of experts. The study was conducted anonymously over several iterative feedback rounds, based on a thorough selection of lean production and Industry 4.0 elements highly relevant for the manufacturing industry. The study and additional literature reviews were able to identify profound one-to-one impacts between a variety of elements of both domains at the technology and methodology level by using a Domain Mapping Matrix.

Building on these findings, the relationship between the elements needs to be explored in more detail. Future studies should investigate the interaction from both directions separately. It should also be investigated whether there is a supporting or a requiring connection between the elements of both domains. A Lean 4.0 implementation strategy for manufacturing companies could then be derived.

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References

[1] Mayr, A., Weigelt, M., Kühl, A., Grimm, S. *et al.*, 2018. Lean 4.0 - A conceptual conjunction of lean management and Industry 4.0 *72*, p. 622.
[2] Ono, T., 2013. *Das Toyota-Produktionssystem: Das Standardwerk zur Lean Production,* 3rd edn. Campus-Verlag, Frankfurt am Main.
[3] Abele, E., Reinhart, G., 2011. *Zukunft der Produktion: Herausforderungen, Forschungsfelder, Chancen*. Carl Hanser Verlag, s.l.
[4] Reinhart, G., Editor, 2017. *Handbuch Industrie 4.0: Geschäftsmodelle, Prozesse, Technik*. Hanser.
[5] Lasi, H., Fettke, P., Kemper, H.-G., Feld, T. *et al.*, 2014. Industry 4.0 *6*, p. 239.
[6] Drath, R., Horch, A., 2014. Industrie 4.0: Hit or Hype? *8*, p. 56.
[7] Schumacher, A., Erol, S., Sihn, W., 2016. A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises *52*, p. 161.
[8] Kempkes, J., Suprano, F., Wömpener, A., 2018. Produktion 4.0 mit den richtigen Kennzahlen steuern, p. 56.
[9] Prinz, C., Kreggenfeld, N., Kuhlenkötter, B., 2018. Lean meets Industrie 4.0 – a practical approach to interlink the method world and cyber-physical world *23*, p. 21.
[10] Wee, D., Breunig, M., Kelly, R., Mathis, R., 2016. *Industry 4.0 after the initial hype: Where manufacturers are finding value and how they can best capture it*.
[11] Dombrowski, U., Richter, T., Krenkel, P., 2017. Interdependencies of Industrie 4.0 & Lean Production Systems: A Use Cases Analysis *11*, p. 1061.
[12] Dillinger, F., Formann, F., Reinhart, G., 2020. Lean Production und Industrie 4.0 in der Produktion: Eine Studie zur Wechselwirkung und den gemeinsamen Potenzialen *115*, p. 738.
[13] Womack, J., Jones, D., Roos, D., 1990. *The machine that changed the world: based on the Massachusetts Institute of Technology 5-milliondollar 5-year study on the future of the automobile.* Rawson Associates, New York.
[14] Dombrowski, U., 2015. *Lean Development*. Springer Berlin Heidelberg, Berlin, Heidelberg.
[15] Liker, J.K., 2004. *The Toyota way: 14 management principles from the world's greatest manufacturer*. McGraw-Hill, New York.

[16] Florian Aull, 2013. *Modell zur Ableitung effizienter Implementierungsstrategien für Lean-Production-Methoden*. Herbert Utz Verlag.
[17] Martin Busse, 2017. *Implementierung Lean Management - Ein ganzheitliches Vorgehensmodell zur nachhaltigen Implementierung des Lean Managements in KMU*, Cottbus.
[18] VDI 2870-1, 2012. *Ganzheitliche Produktionssysteme. Grundlage, Einführung und Bewertung*.
[19] Bauernhansl, T., Hompel, M. ten, Vogel-Heuser, B., 2014. *Industrie 4.0 in Produktion, Automatisierung und Logistik*. Springer Fachmedien Wiesbaden, Wiesbaden.
[20] Kagermann, H., Wahlster, W., Helbig, J., 2013. *Umsetzungsempfehlungen für das Zukunftsprojekt Industry 4.0: Abschlussbericht des Arbeitskreises Industry 4.0.*
[21] Kellner, F., Lienland, B., Lukesch, M., 2020. *Produktionswirtschaft: Planung, Steuerung und Industrie 4.,* 2nd edn. Springer Berlin Heidelberg, Berlin, Heidelberg.
[22] Obermaier, R., 2016. *Industrie 4.0 als unternehmerische Gestaltungsaufgabe*. Springer Fachmedien Wiesbaden, Wiesbaden.
[23] Ramsauer, C., 2013. Industrie 4.0 – Die Produktion der Zukunft, p. 6.
[24] Rüßmann, M., Lorenz, M., Gerbert, P., Waldner, M., Justus, J., Engel, P., Harnisch, M., 2015. *Industry 4.0: The Future of Productivity and Growth in Manufacturing*.
[25] Gilchrist, A., 2016. *Industry 4.0: The Industrial Internet of Things*. APRESS L.P., Berkeley, CA.
[26] Sanders, A., Elangeswaran, C., Wulfsberg, J., 2016. Industry 4.0 implies lean manufacturing: Research activities in industry 4.0 function as enablers for lean manufacturing *9*, p. 811.
[27] Rüttimann, B.G., Stöckli, M.T., 2016. Lean and Industry 4.0—Twins, Partners, or Contenders? A Due Clarification Regarding the Supposed Clash of Two Production Systems *09*, p. 485.
[28] Wagner, T., Herrmann, C., Thiede, S., 2017. Industry 4.0 Impacts on Lean Production Systems *63*, p. 125.
[29] Pokorni, Schlund, S., Findeisen, S., Tomm, A. *et al.*, 2017. Produktionsassessment 4.0: Entwicklung eines Reifegradmodells zur Bewertung der Lean Management und Industrie-4.0-Reife von produzierenden Unternehmen *112*, p. 20.
[30] Mrugalska, B., Wyrwicka, M.K., 2017. Towards Lean Production in Industry 4.0 *182*, p. 466.
[31] Rauen, H., Mosch, C., Metternich, J., Meudt, T., Hartmann, L., 2018. *Leitfaden Industrie 4.0 trifft Lean: Wertschöpfung ganzheitlich steigern*. VDMA Verlag.
[32] Fischer, T., Köbler, J., 2018. Lean-Management und Industrie 4.0: Warum Lean-Management eine solide Grundlage für die vierte industrielle Revolution darstellt *2018*, p. 53.
[33] Kolla, S., Minufekr, M., Plapper, P., 2019. Deriving essential components of lean and industry 4.0 assessment model for manufacturing SMEs *81*, p. 753.
[34] Shahin, M., Chen, F.F., Bouzary, H., Krishnaiyer, K., 2020. Integration of Lean practices and Industry 4.0 technologies: smart manufacturing for next-generation enterprises *107*, p. 2927.
[35] Valamede, L.S., Akkari, A.C.S., 2020. Lean 4.0: A New Holistic Approach for the Integration of Lean Manufacturing Tools and Digital Technologies *5*, p. 851.
[36] Ejsmont, K., Gladysz, B., Corti, D., Castaño, F. *et al.*, 2020. Towards 'Lean Industry 4.0′ – Current trends and future perspectives *7*.
[37] Webster, J., Watson Rochard T. Analyzing the Past to Prepare for the Future: Writing a Literature Review.
[38] Lindemann, U., Maurer, M., Braun, T., 2009. *Structural Complexity Management: An Approach for the Field of Product Design*. Springer Berlin Heidelberg, Berlin, Heidelberg.
[39] Linstone, H.A., Turoff, M., 1975. *The Delphi method: Techniques and applications. Ed. by Harold A[drian] Linstone, Murray Turoff*. Addison-Wesley, Reading, Mass. usw.
[40] Grime, M.M., Wright, G., 2014. Delphi Method, in *Wiley StatsRef: Statistics Reference Online*, John Wiley & Sons, Ltd, Chichester, UK, p. 1.
[41] Schmidt, R.C., 1997. Managing Delphi Surveys Using Nonparametric Statistical Techniques *28*, p. 763.
[42] Nakatsu, R.T., Iacovou, C.L., 2009. A comparative study of important risk factors involved in offshore and domestic outsourcing of software development projects: A two-panel Delphi study *46*, p. 57.
[43] van Eck, N.J., Waltman, L., 2011. *Text mining and visualization using VOSviewer*.
[44] Federal Ministry for Economic Affairs and Energy. Plattform Industrie 4.0. https://www.plattform-i40.de/PI40/Navigation/Karte/SiteGlobals/Forms/Formulare/EN/map-use-cases-formular.html. Accessed 15 February 2021.
[45] Robot Revolution & Industrial IoT Initiative. Robot Revolution & Industrial IoT Initiative. http://usecase.jmfrri.jp/#/en. Accessed 20 February 2021.
[46] Okli, C., Schabram, K., 2010. *A Guide to Conducting a Systematic Literature Review of Information Systems Research*.
[47] Harpe, S.E., 2015. How to analyze Likert and other rating scale data *7*, p. 836.
[48] Alcácer, V., Cruz-Machado, V., 2019. Scanning the Industry 4.0: A Literature Review on Technologies for Manufacturing Systems *22*, p. 899.
[49] Vaidya, S., Ambad, P., Bhosle, S., 2018. Industry 4.0 – A Glimpse *20*, p. 233.
[50] Oztemel, E., Gursev, S., 2018. Literature review of Industry 4.0 and related technologies.
[51] Tao, F., Zhang, H., Liu, A., Nee, A.Y.C., 2019. Digital Twin in Industry: State-of-the-Art *15*, p. 2405.
[52] Lenhard, T.H., 2017. *Datensicherheit*. Springer Fachmedien Wiesbaden, Wiesbaden.
[53] Schuh, G., Potente, T., Wesch-Potente, C., Weber, A.R. *et al.*, 2014. Collaboration Mechanisms to Increase Productivity in the Context of Industrie 4.0 *19*, p. 51.
[54] Pereira, A., Dinis-Carvalho, J., Alves, A., Arezes, P., 2019. How Industry 4.0 can enhance Lean practices *47*, p. 810.
[55] Hartmann, L., Meudt, T., Seifermann, S., Metternich, J., 2018. Value stream method 4.0: holistic method to analyse and design value streams in the digital age.