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Requirements for a methodology for the assessment and selection of technologies of digitalization for lean production systems

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Abstract

Since the beginning of lean production there have been two implementation waves. The first one failed as manufacturing companies implemented methods of lean production isolated from each other, whereas in the second wave these companies learned from this experience. Ever since then lean production has been used for production organization and waste reduction but has not evolved, even though markets are more demanding due to individualization and volatility. Digitalization offers methods to adapt lean production to such aggravated market conditions by expanding its abilities. Therefore, digitalization has the potential to initiate a third wave within the philosophy of lean production.

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Keywords: Lean production systems; Technologies of digitalization; Methodology; Assessment; Selection; Interdependency

1. Initial situation and motivation

Global and volatile markets demand for production systems that are characterized by their high productivity, flexibility and reliability [1]. Manufacturing companies are forced to act in an economical manner as these market conditions are steadily intensifying towards the future [2]. Because companies are exposed to such challenging circumstances, they need to focus on value-adding processes and reduce non-value-adding ones. The framework of lean production – which has its origin in the Toyota Production System – offers methods and tools to be more profitable within direct processes as it focusses on added value and reduces waste [3, 4, 5]. Hence, lean production systems (LPS) are a methodological set of rules for a thorough and consistent design of production processes. In their realization they respectively form a company-specific peculiarity of a production system in order to reduce waste [6, 7].

Lean production is not a technological achievement of the past industrial revolutions and ongoing fourth industrial revolution, but rather a change of paradigms with comparable extent [8]. Since lean production was externalized out of the Japanese automotive industry by the 1990s, it has had an unprecedented entry in Western European manufacturing companies of various branches [9, 10, 11].

In a first wave of lean production starting at the beginning of the 1990s, elements of this organizational set of regulations for organizing labor and reducing waste were implemented isolated from one another in production systems [12]. Therefore, the potential of lean production could not be fully realized [13]. This experience was reviewed and incorporated in the second wave starting in the mid-2000s, since lean production was implemented in a more holistic way in manufacturing companies. Elements of lean production were implemented together in this second implementation wave and therefore, synergies between these elements could be leveraged [14]. Methodologies contribute to the description of changes in lean production systems [15] within these implementation waves. Today, companies living the philosophy of lean production have reached an implementation rate of more than 90 % averaged within their manufacturing processes [14]. These production systems have a high maturity level due to their

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efficiency and added-value oriented process design [16]. However, lean production systems seem to have reached their limits since the analog implementation of its principles, methods and tools has not evolved, while framework conditions have been intensifying. For example, its synchronization and standardization of processes is not suitable for producing with individual cycle times down to batch size one [17, 18].

Technologies of digitalization are based on the deployment of information and communication technologies (ICT) and – in the context of production – they especially focus on the optimization of information flows along the added value of products. They also facilitate the intelligent interconnection of employees, objects and resources on the shop floor [19]. Therefore, digitalization in the context of manufacturing – also known as Industrie 4.0 in Germany – has the ability to affect processes and key performance indicators of LPS. Such ICT have the ability to adjust parameters of lean production elements in order to make them more efficient [16, 20]. This can be accomplished by raising flexibility and speed of reaction due to digital information transmission [21], which leads to an improved mastering of complexity in production processes despite the growth of product and process variants as well as time pressure [2]. Matured technologies are, for example, a digitally implemented Kanban (iBin) or Smart-Watches, which support the Pull principle and Kanban method by reducing process times, since such technological solutions transmit necessary information in a fraction of a second. Furthermore, technologies such as tablets, since they display the right order-specific manufacturing or assembly procedures, or pick-by-light-systems, since they support commissioning procedures by instructing workers, support the Poka Yoke method by raising process quality as error-proneness decreases. Figure 1 illustrates such positive effects of technologies of digitalization based on structures of LPS in a qualitative manner.

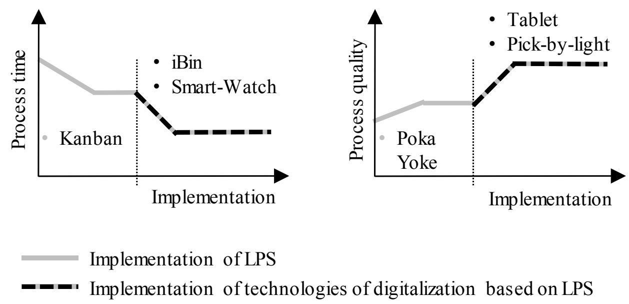

Fig. 1. Effects of technologies of digitalization based on structures of LPS

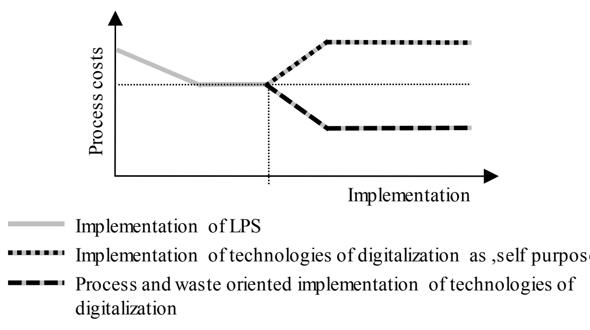

Fig. 2. Diverging effects of technologies of digitalization in an LPS

However, it is vital to focus on the process itself and the waste within the process in order to utilize synergies between structures of LPS and the implementation of technologies of digitalization in this context. Otherwise, negative consequences could result due to a high probability that non-value-adding processes are digitalized. Figure 2 exhibits the possible variation on process costs when a technology of digitalization is implemented according to process- and waste-oriented LPS-structures or is not implemented.

Technologies of digitalization have the ability to help overcoming limits within LPS by mobilizing further potentials of lean production and purposefully improving the use of its elements [17, 22]. The elements of lean production and a sufficient maturity level of a lean production system are enablers for the implementation of tools of digitalization [16, 23, 24], especially when the implementation is process- and waste-oriented. But choosing the correct technologies of digitalization for processes in an LPS is complex since the knowledge about benefits of implemented technologies is narrow [25].

Therefore, digitalization is an essential component in order to implement elements of LPS in a new manner. Technologies of digitalization already do increase abilities of LPS and thus, digitalization will initiate a third wave of LPS (see also Figure 3).

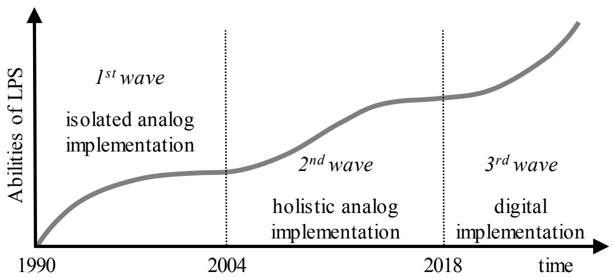

Fig. 3. Former waves and prospective wave of lean production

2. State of research

A profound knowledge about the impact of a technology of digitalization and its effects on an LPS is the basis for being able to choose a profitable technology. Hence, in a first step it is necessary to identify deficits in a company-specific LPS. Furthermore, the impact on an interdependency framework of LPS needs to be evaluated and the effects on a company-specific LPS estimated. In a fourth step a defined procedure should support the choice of an appropriate technology of digitalization. The following subchapters present the state of research regarding the mentioned objectives.

2.1. Identification of potentials for the improvement of company-specific LPS

Identified deficits in company-specific lean production systems are the basis for mobilizing further potentials by using technologies of digitalization. Existing procedures for assessing processes and infrastructure of LPS are maturity-based [26] as well as focusing on key performance indicators [6]. Others concentrate on identifying critical business processes for production procedures [27] or expected improvement of value streams by a digitalized observation of information flows within an LPS [28].

These approaches assess lean production systems from different perspectives and with respect to diverse objectives. Nevertheless, the identification of deficits in LPS is not considering technologies of digitalization to a sufficient extent.

2.2. Description of interdependencies of LPS-elements and objectives

Lean production systems do not develop their potentials when their elements are used isolated, but rather when these elements are used simultaneously and parallel with respect to occurring interdependencies as stated in the second implementation wave. Such interdependencies have been examined and research has enhanced this holistic consideration.

One approach focusses on adjusting the control variables of the selected lean methods Kanban, leveling, Single Minute Exchange of Die (SMED), Total Quality Management (TQM) and Total Productive Maintenance (TPM). In this research, the Kanban method, for example, has control variables such as container capacity and the number of Kanban cards or leveling the variables batch size and production mix. Therefore, an impact framework describes interdependencies between defined variables and the target variables flexibility, lead time, productivity, quality and delivery reliability by using sensitivity analysis. Furthermore, the combination of a material flow simulation with an optimizer contributes to the identification of the ideal configuration of these control variables regarding target values of a lean production system [29]. Further research enhances this approach since consequences of adjusted control variables are evaluated in regards to the profitability of a production system. Thus, the evaluation of robustness identifies the ideal time for the implementation of adjusted lean methods [30]. Interdependencies are respected even in the modelling of business processes [31]. Based on these concepts of identifying and measuring interdependencies between lean methods and its elements, Schnellbach (2016) augments the concept of interdependencies by a further aspect: energy. The developed method of Schnellbach (2016) aims at the reduction of energy waste by means of lean production systems and allows the assessment of the impact of different energy efficiency activities [32].

An approach that combines the concept of interdependencies in lean production systems with technologies of digitalization does not exist.

2.3. Effects on company-specific LPS by technologies of digitalization

In addition to the contemplation of interdependencies in a generic manner, the effects of a concrete technology on elements of LPS need to be identified.

In this context, Aull (2013) develops a model for the identification of an implementation strategy for lean methods. This model evaluates the effects of lean methods and tools and supports the identification of a suitable chronology of how to implement lean methods with respect to occurring effects [33]. Whereas another approach contrasts the effects between elements of LPS and technologies of digitalization in a 3-ary influence matrix [22], Liebrecht et al. (2017) concentrate on evaluating effects of such technologies in a probability-based manner by using a Monte-Carlo Simulation [25].

In summary, current approaches for estimating the effects of technologies of digitalization in LPS are mainly of qualitative nature or do not focus on technologies of digitalization.

2.4. Selection of technologies of digitalization for company-specific LPS

Existing approaches for choosing technologies for production environments are mounted on different levels. A generic methodology in the field of production management focusses on the selection of convenient manufacturing technologies [34]. Further approaches in the field of choosing appropriate technologies of digitalization have an encapsulated strategy. One approach selects such technologies according to the principles of LPS flow or pull [20]. Other specified possibilities conduct the selection according to the maturity level of technologies of digitalization [19] and another restricts the selection on the shop floor level [35].

Choosing a suitable technology of digitalization for a company-specific lean production system often turns out to be very complex due to the lack of knowledge regarding the consequences of a potential implementation. The mentioned approaches are inadequate to provide a pervasive and profound selection of technologies of digitalization in the context of LPS.

3. Shortcomings of the state of research

The subchapters *2.1* to *2.4* describe the state of research of technologies of digitalization within the framework of lean production. As stated there is no suitable procedure which focusses on technologies of digitalization when identifying potentials or deficits in a company-specific LPS. Systems for depicting interdependencies of elements of LPS do not consider technologies of digitalization. Furthermore, the evaluation of effects of technologies of digitalization on LPS does not sufficiently take into account the technologies of digitalization in regards to consequences on added value or waste. Thus, since procedures for choosing technologies of digitalization are mostly encapsulated, they are not practical.

Summarizing the state of research, no methodology exists that allows an extensive assessment of company-specific LPS and an evaluation of a technology of digitalization with respect to its effects on processes of LPS in order to select an appropriate technology. A specific methodology with requirements, as is described in the following chapter *4* and its subchapters *4.1* to *4.4*, is needed in order to overcome those shortcomings in the state of research.

4. Methodology for the assessment and selection of technologies of digitalization for LPS

The digitalization of lean production systems – respectively the digitalization of its elements – is the next logical step in order to improve and enhance implemented methodologies [35].

Multiple elaborations regarding interdependencies of lean methods prove the necessity of taking the network of implemented lean elements into account when measuring the impact of single or several methods on a production system. Since technologies of digitalization have the ability to affect the impact of lean methods [36], consequences need to be regarded. Therefore, when implementing tools of digitalization with the purpose of affecting lean methods consequences within interconnected elements of complex lean production systems need to be considered, since the impact on interdependent elements is consectaneous.

Digitalization offers a vast number of technologies for production applications, which are in a rapid transition as new technologies keep emerging. Manufacturing companies with lean production structures are confronted with the question of which technologies have the biggest potential to improve these structures. Therefore, this paper describes these requirements for a methodology to quantify the impacts of technologies of digitalization on lean production systems and to select suitable technologies of digitalization for a company-specific lean production system. This methodology consists of four modules described in the following.

4.1. Identification of processes and methods for improvement within a company-specific LPS

At the beginning of an aspired improvement of an LPS, such a company-specific system needs to be evaluated regarding its processes. Therefore, analog implemented lean methods and processes within an LPS and their specific goals regarding waste need to be ascertained. In a further step, a maturity-based comparison enables the identification of the degree of fulfillment of the goals and the degree of conversion regarding lean methods. This procedure allows the identification of deficiently fulfilled goals with respect to the use of lean methods. Such criteria are fundamental for further investigation in order to deduce potentials for improvement in languishing lean methods.

4.2. Development of a system for describing interdependencies and for categorizing technologies of digitalization

An interdependency framework allows the depiction of correlations between elements of LPS in general. Hence, these elements, i.e., control variables that represent influenceable objects in an LPS such as the number of Kanban-cards, need to be identified. The combination of these control variables, key performance indicators and the goals of LPS – the elimination of waste – forms an interdependency grid, which describes the propagation of changed control variables in the developed grid. A raster for categorizing and characterizing technologies of digitalization needs to be developed based on this grid, since it makes it possible to generally match technologies of digitalization with the control variables. Therefore, the combination of such an interdependency grid and the raster described above makes it possible to generally depict correlations and the propagation of technologies of digitalization in lean production systems.

4.3. Assessment of technologies of digitalization regarding effects on elements of a company-specific LPS

Whereas the previous subchapter describes correlations and propagation with a general system, the effects of a concrete technology of digitalization have thus far not been assessed. Therefore, a method has to identify primarily affected control variables of a concrete technology of a concrete process in a lean production system as well as the intensity of these effects. The developed raster enables the identification of primarily affected control variables. Furthermore, an LPS-specific failure mode and effects analysis (FMEA) supports the identification of intervals of the primarily affected control variables. Therefore, this model makes it possible to describe the behavior of an LPS-process in regards to the results on waste within a reviewed process by a potential use of a technology of digitalization.

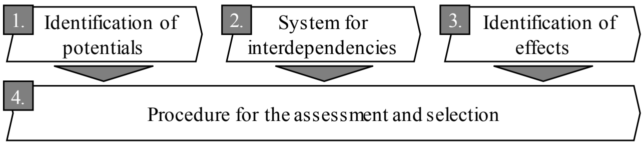

Fig. 4. Structure of the modules of the methodology

4.4. Procedure for deploying the identification of a suitable technology of digitalization in a company-specific LPS

This step transfers the three previous modules into an applicable procedure for assessing and selecting technologies of digitalization for company-specific lean production systems. A defined approach allows assessing an LPS according to subchapter *3.1* in order to depict a reference model of an existing production system including its lean methods. A further step contributes to the characterization of technologies of digitalization as well as to the identification of potential intervals of control variables according to subchapter *3.2*. Hence, a practical approach is used for the evaluation of effects on waste in a lean production system considering a potential assignment of a technology of digitalization based on the method of subchapter *3.3*. A selective and consequent conducting of this procedure with different technologies of digitalization allows identifying their impact on a company-specific LPS and as a consequence to make these reviewed technologies comparable for their probable selection.

These four modules or steps describe the requirements of a methodology for the assessment and selection of technologies of digitalization for company-specific lean production systems. Since the first three steps are the basis for the fourth step, the methodology has a structure as seen in Figure 4.

5. Summary and outlook

The methodological set of rules of lean production has pervaded the Western European producing industry in two waves of implementation since the 1990s. Since the framework conditions for manufacturing companies keep intensifying, the elements of lean production seem to have reached their limits of abilities by their analog implementation in regards to the organization of production processes and the reduction of waste within these processes. The combination of this widespread set of rules with digitalization makes it possible to implement the principles, methods and tools in a new manner – in a digital manner – in order to reduce waste regarding time, cost and quality.

This paper illuminates the initial situation and the necessity of a methodology that supports the assessment of existing lean production systems as well as the selection of suitable technologies of digitalization. This paper describes the basic structure for such a methodology and the content of the four elements of this methodology. Two challenges are the development of a universal description of production systems in the context of LPS and the technologies of digitalization. Whereas LPS is a static set of rules, the dynamic advancement of technologies of digitalization needs to be considered.

References

[1] Westkämper E, Löffler C. Strategien der Produktion. Technologien, Konzepte und Wege in die Praxis. Berlin, Heidelberg: Springer Vieweg; 2016.

[2] Bauernhansl T. Die Vierte Industrielle Revolution – Der Weg in ein wertschaffendes Produktionsparadigma. In: T Bauernhansl et al. (Ed.): Industrie 4.0 in Produktion, Automatisierung und Logistik. Anwendung, Technologien, Migration. Wiesbaden: Springer Vieweg; 2014:5-35.

[3] Ohno T. Toyota Production System. Beyond Large-Scale Production. New York: Productivity Press; 1988.

[4] Bhamu J, Sangwan KS. Lean manufacturing: literature review and research issues. International Journal of Operations & Production Management 2014; 34 (7):876-940.

[5] Salonitis K, Tsinopoulos C. Drivers and Barriers of Lean Implementation in the Greek Manufacturing Sector. In: Elsevier B.V. (Ed.): Procedia CIRP, 49th CIRP Conference on Manufacturing Systems. Stuttgart, May 25 - 27; 2016:189-194.

[6] VDI e.V. (2870-1). Ganzheitliche Produktionssysteme. Grundlagen, Einführung und Bewertung. Berlin: Beuth 2012.

[7] Dombrowski U, Mielke T. Einleitung und historische Entwicklung. In: U Dombrowski et al. (Ed.): Ganzheitliche Produktionssysteme. Aktueller Stand und zukünftige Entwicklungen. Berlin, Heidelberg: Springer Vieweg; 2015:1-24.

[8] Reinhart G, Zühlke D. Von CIM zu Industrie 4.0. In: G Reinhart (Ed.): Handbuch Industrie 4.0. Geschäftsmodelle, Prozesse, Technik. München: Hanser; 2017:XXXI-XL.

[9] Womack JP, Jones DT, Roos D. The Machine that Changed the World. New York: Macmillan Publishing Company; 1990.

[10] Martínez Sánchez A, Pérez Pérez M. Lean indicators and manufacturing strategies. International Journal of Operations & Production Management 2001; 21 (11):1433-1452.

[11] Abdulmalek FA, Rajgopal J. Analyzing the benefits of lean maufacturing and value stream mapping via simulation: A process sector case study. International Journal of Production Economics 2007; 107 (1):223-236.

[12] Dombrowski U, Ebentreich D, Krenkel P. Impact analyses of lean production systems. In: Elsevier B.V. (Ed.): Procedia CIRP, 49th CIRP Conference on Manufacturing Systems. Stuttgart, May 25 - 27; 2016:607-612.

[13] Shingo S, Dillon AP. A Revolution in Manufacturing: The SMED System. Cambridge: Productivity Press; 1985.

[14] Staufen AG. 25 Jahre Lean Management. Lean gestern, heute und morgen; 2016.

[15] Karlsson C, Åhlström P. Assessing changes towards lean production. International Journal of Operations & Production Management 1996; 16 (2):24-41.

[16] Dombrowski U, Richter T. Ganzheitliche Produktionssysteme und Industrie 4.0. ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb 2016; 111 (12):771-774.

[17] Kolberg D, Zühlke D. Lean Automation enabled by Industry 4.0 Technologies. IFAC 2015; 48 (3):1870-1875.

[18] Stump B, Badurdeen F. Integrating lean and other strategies for mass customization manufacturing: a case study. Journal of Intelligent Manufacturing 2012; 23 (1):109-124.

[19] Pokorni B, Schlund S, Findeisen S, Tomm A, Euper D, Mehl D, Brehm N, Ahmad D, Ohlhausen P, Palm D. Produktionsassessment 4.0. ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb 2017; 112 (1-2):20-24.

[20] Dombrowski U, Richter T, Ebentreich D. Ganzheitliche Produktionssysteme und Industrie 4.0. Ein Ansatz zur standardisierten Arbeit im flexiblen Produktionsumfeld. Industrie 4.0 Management 2015; 31 (3):53-56.

[21] Ernst & Young. Industrie 4.0 - das unbekannte Wesen?; 2016.

[22] Wagner T, Herrmann C, Thiede S. Industry 4.0 impacts on lean production systems. In: Elsevier B.V. (Ed.): Procedia CIRP, 50th CIRP Conference on Manufacturing Systems. Taichung City, May 3 - 5; 2017:125-131.

[23] McKinsey & Company. Industry 4.0. How to navigate digitization of the manufacturing sector; 2015.

[24] McKinsey & Company. Ops 4.0: Fueling the next 20 percent productivity rise with digital analytics; 2017.

[25] Liebrecht C, Jacob A, Kuhnle A, Lanza G. Multi-Criteria Evaluation of Manufacturing Systems 4.0 under Uncertainty. In: Elsevier B.V. (Ed.): Procedia CIRP, 50th CIRP Conference on Manufacturing Systems. Taichung City, May 3 - 5; 2017:224-229.

[26] Nightingale DJ, Mize JH. Development of a Lean Enterprise Transformation Maturity Model. Information Knowledge Systems Management 2002; 3 (1):15.

[27] Lock C, Reinhart G. A Meta-Model for Analyzing the Influence of Production-Related Business Processes. In: Elsevier B.V. (Ed.): Procedia CIRP, 49th CIRP Conference on Manufacturing Systems. Stuttgart, May 25 - 27; 2016:79-84.
[28] Meudt T, Rößler M, Böllhoff J, Metternich J. Wertstromanalyse 4.0. Ganzheitliche Betrachtung von Wertstrom und Informationslogisitik in der Produktion. ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb 2016; 111 (6):319-323.
[29] Peter K, Lanza G. Company-specific quantitative evaluation of lean production methods. Production Engineering 2011; 5 (1):81-87.
[30] Jondral A. Simulationsgestützte Optimierung und Wirtschaftlichkeitsbewertung des Lean-Methodeneinsatzes. Diss. KIT (2013). Aachen: Shaker; 2013.
[31] Magenheimer KA. Lean Management in indirekten Unternehmensbereichen: Modellierung, Analyse und Bewertung von Verschwendung. Diss. TU München (2014). München: Herbert Utz; 2014.
[32] Schnellbach P. Methodik zur Reduzierung von Energieverschwendung unter Berücksichtigung von Zielgrößen Ganzheitlicher Produktionssysteme. Diss. TU München (2015). München: Herbert Utz; 2016.
[33] Aull F. Modell zur Ableitung effizienter Implementierungsstrategien für Lean-Production-Methoden. Diss. TU München (2012). München: Herbert Utz; 2013.
[34] Greitemann J. Methodik für die systematische Identifikation von Produktionstechnologien. Diss. TU München (2016); 2016.
[35] Kolberg D, Knobloch J, Zühlke D. Towards a lean automation interface for workstations. International Journal of Production Research 2017; 55 (10):2845-2856.
[36] Thürer M, Pan YH, Qu T, Luo H, Li CD, Huang GQ. Internet of Things (IoT) driven kanban system for reverse logistics: solid waste collection. Journal of Intelligent Manufacturing 2016.