Lean in high variety, low volume production environments – A Literature Review and Maturity Model

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Abstract

Lean manufacturing has proven to be an efficient means improving mass production. Recently, Lean is of increasing interest for high-variety, low-volume production environments. However, little research has been done in this field. Yet, this contribution provides a systematic literature analysis in conjunction with expert interviews and qualitative data analysis not only to demonstrate the status quo of Lean in HV/LV but to develop a research agenda. In addition, a Maturity Model is developed analysing Lean implementation through a combination of tools, processes, and interoperability supporting the assessment of the application of Lean in various in HV/LV environments.

Keywords: Lean Management, Literature Review, Maturity Model

Introduction

Manufacturing is the key economic activity for creating added value by transforming materials and energy into products. Lean manufacturing has evolved into a widely accepted system and philosophy for the management and improvement of production systems (Holweg, 2007). Lean manufacturing was established as a more efficient means of organizing mass production (Ohno, 1988). However, the focus for the application of Lean is no longer limited to high-volume production. Lean is becoming increasingly common in high variety, low volume (HV/LV) production environments (e.g., for customized product manufacturing, single and small batch production) (Portioli-Staudacher and Tantardini, 2008). Improving process performance is vital to the survival of companies in today's markets with a steadily increasing demand for customization. Nevertheless, there are still research gaps concerning the possibilities for implementing Lean in the HV/LV production environment (Veldman and Klingenberg, 2009). Firstly, there is a variety of definitions and limitations of the HV/LV production environment which lead to confusion. Furthermore, there are various assertions about the effectiveness of Lean methods in the various production environments.

The objective of this article is to both describe the state of the art as well as to provide a research agenda for Lean within the HV/LV Lean context. We conducted a systematic literature review to capture scientific and practical (case studies) knowledge. We aspire to answer the following research questions:

- How can Lean in HV/LV production environments be defined (RQ1)?
- What is the current status quo in science and practice (RQ2)?
- How can Lean in HV/LV production environments be assessed (RQ3)?

The purpose of the research approach as applied in this article is to develop a Maturity Model applicable in practice. A Maturity Model enables companies to assess their own Lean maturity level. Self-assessments and Maturity Models have proven to be useful tools for companies to gradually introduce Lean into their processes. There is a lack of models and tools supporting the assessment, improvement and integration of Lean activities, especially for the HV/LV production environment (Caracchi et al., 2014).

Research methodology

Systematic Literature Review

We performed a systematic literature analysis (Fettke, 2006) in order to review the scientific knowledge of the past 10 years about Lean in HV/LV production environments. We used the keyword phrase <Lean AND (unique production OR unique manufacturing OR make to order production OR make to order manufacturing OR single part production OR single part manufacturing OR small batch production OR small batch manufacturing OR engineer to order OR customized production OR customized manufacturing OR demand flow OR flexible production OR flexible manufacturing OR high variety small volume OR high mix small volume)> and employed both the databasis EBSCOhost (Abstract or Author-Supplied Abstract) and Google Scholar (only title), which resulted in 60 research papers. Furthermore, five experts in the field of Lean Management were interviewed with the intention to retrieve more relevant literature. This resulted in 18 additional scientific articles. These research papers were examined for their relevance. In those cases where the relevance of a paper was still unclear, a second person was involved in the analysis. By means of this approach, we identified 26 relevant scientific contributions which represent the final database for our analysis. The database consists of 18 international journal and 8 periodic publications. The identified relevant contributions include 13 case studies representing the state of the art of Lean in HV/LV practise.

Qualitative Data Analysis

We performed a Qualitative Data Analysis (QDA) with the Software QDA Miner and its extension WordStat. The Software has been employed to perform Text Mining as well as

Content Analysis. Prior to the analysis we prepared the data according to the recommendations of Provalis' Research (2010) in five steps: 1. Spellchecking to avoid any spelling mistakes; 2. Deletion of hyphenations, brackets and unnecessary information; 3. Lemmatization and stemming whereby synonyms are removed; 4. Deletion of stop words; 5. Review results and extension of stop word list. After the data preparation, word frequencies (word count in a paragraph) and word co-occurrences (word pairs in a paragraph) are calculated. The results were visualized in form of a 2D graphic for illustrative purposes.

Definition of Lean in HV/LV production environments

In recent years, Lean implementations have started to aim at HV/LV companies (Portioli-Staudacher and Tantardini, 2008). In the following we will define Lean in HV/LV production environments by assessing three different aspects: first we evaluate all different terms used in the literature describing Lean in the HV/LV production environment to attain a unified terminology; second we deduct a clear definition of the HV/LV production environment and look at its characteristics; third we look at the applicability of Lean principles and tools reported in the literature in in the HV/LV production environment.

A QDA analysis was performed to 1) analyze the terminology used in the literature of HV/LV production environments in the context of Lean, and 2) to specify the HV/LV production environments.

Thematically related but other management philosophies such as "six sigma", "quick response manufacturing" or "agile manufacturing" are not included. Using QDA we analysed the 20 most frequent descriptions for HV/LV production environments in the context of Lean with the QDA software. The size of the circles in figure 1 corresponds with the number of word occurrences; the proximity of the circles to each other describes the proximity of the words of the analysed papers.

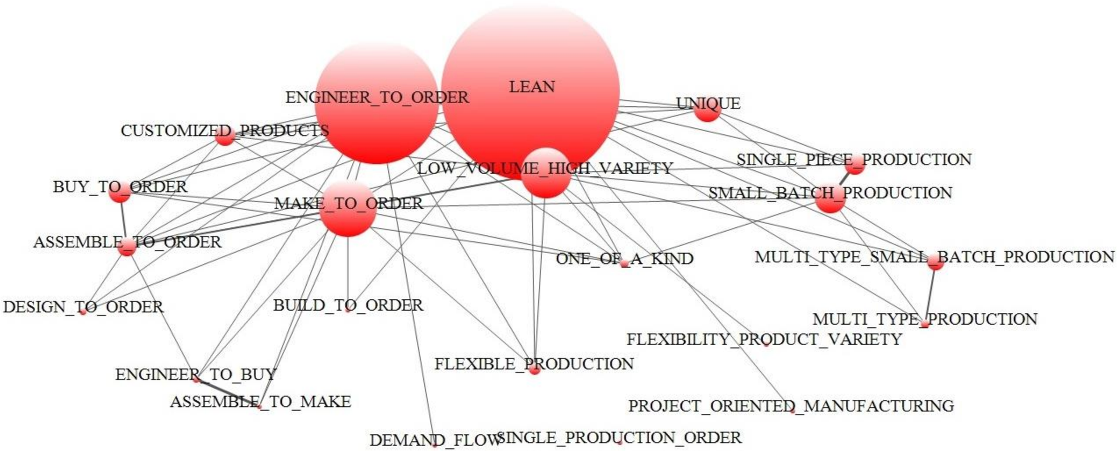

Figure 1 – QDA Result of scientific articles

The result of the QDA as displayed in figure 1, shows that the in the literature five most frequently used descriptions for HV/LV production environments are (1) engineer-to-order (ETO), (2) make-to-order (MTO), (3) HV/LV (summary of the various forms of writing as well spelling together or alone, e.g. high mix, small lot sizes), (4) small batch production and (5) unique production. The proximity of the circles with the five most frequently used descriptions for HV/LV production environments to the 'Lean' circle as depicted in figure 1 represents the degree of substantive similarity of these descriptions in the analyzed literature. Furthermore, it becomes apparent that some terminologies (e.g. flexible manufacturing, demand flow or design-to-order) are not widely used such as the description for HV/LV production environments in relationship with Lean.

Production environments, may be defined in various ways. Many definitions of HV/LV production environments are related to supply chain structures and the customer order decoupling point (CODP). Based on Gosling et al. (2007) and other authors such as Hoekstra and Romme (1992), six different supply chain structures can be defined: (1) ETO, (2) buy-to order (BTO), (3) MTO, (4) assemble-to-order (ATO), (5) make-to-stock (MTS) and (6) ship-to-stock (STS). Figure 2 depicts the level of standardization and customization that takes place before a customer order is received in each of the different supply chain structures. The line representing the CODP indicates the point at which the customer order enters the supply chain. Wortmann (1995) demonstrates that although the timing and quantity of demand in HV/LV environments may be estimated to some extent, the sooner the CODP takes place in the process and the harder it is to estimate the precise nature of the product and its routing through the organization.

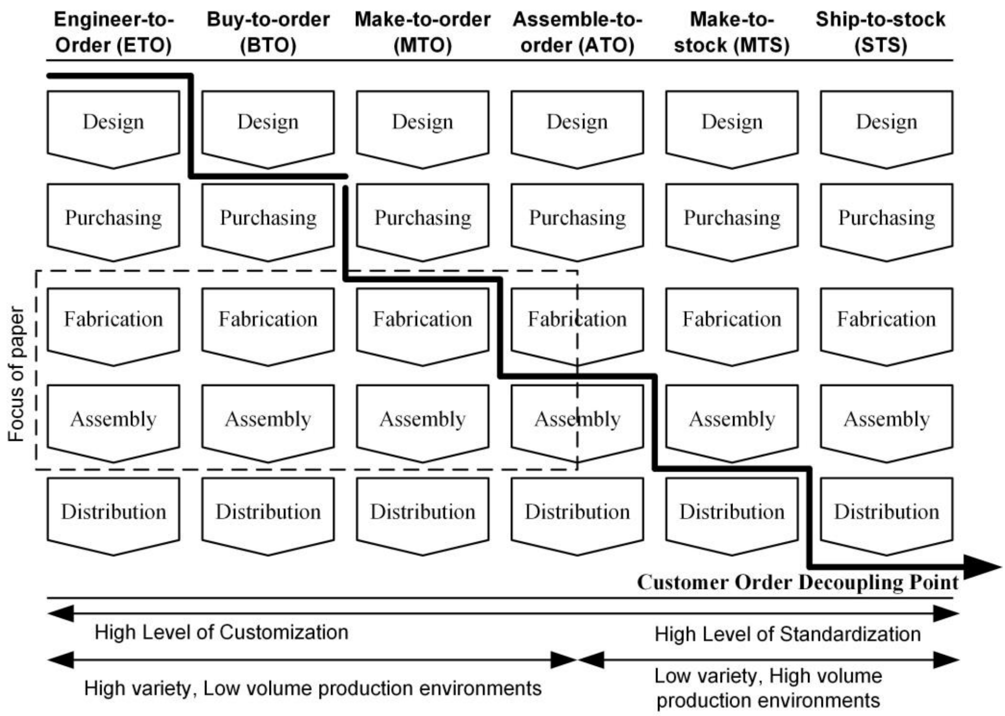

Figure 2 – The six different supply chain structures (based on Gosling et al., 2007)

HV/LV production environments include all of the following supply chain structures: ETO, BTO, MTO and partly ATO. The other three structures, ATO (partly), MTS and STS describe low variety, high volume (LV/HV) production environments. As we are specifically focusing on manufacturing, design, purchasing and distribution are not explicitly included in our definition though interrelations might exist to some extent. The dotted line shows the circumscription of our HV/LV manufacturing definition.

In addition to the supply chain structure definitions in relationship to the COPD other aspects of the HV/LV production definition are related to the lot size such as unique production or small batch production. The designations ETO, BTO, MTO, and unique production indicate mostly a classic one-of-a-kind production. Finished goods are built according to unique customer specifications. Sub-assemblies and raw materials may be stocked but are not assembled into the finished good until a customer order is received and the part is designed. ETO products are always unique and require a unique set of item numbers as well as bills of material and routings. The designation's small batch production identifies the production of low quantity of similar products. As a formal definition for HV/LV production environments we propose: "*High-variety, low-volume (HV/LV) production environments include the one-of-a-kind as well the small batch production environments*". As a formal definition (RQ1) for Lean in HV/LV production environments we propose: "*The adoption and deployment of Lean principles and techniques in HV/LV production environments*" (based on Powell and van der Stoel, 2016).

The requirements for Lean in HV/LV production differ strongly due to the very different production characteristics as compared to the traditional Toyota Production System (TPS). Table 1 shows a summary of the main differences in terms of environmental characteristics.

Table 1 – Characteristics of the different production environments regarding a Lean implementation (based on Lander, E. and Liker, J.K., 2007; Gosling et al., 2007)

Characteristics	**LV/HV production environments (e.g. MTS)**	**HV/LV production environments (e.g. ETO)**
Volume	Very high –High	Low - Extremely low
Customization	Very low – Low	Moderate – Extremely high
Complexity	Very low – Low	Moderate – Extremely high
Lead time	Fixed	Variable
Job of operators	Repetitive	Different for each product
Work knowledge	Structured	Tacit
Specialization of people and equipment	High	Low

Both complexity and dynamism of the production environment significantly influence the performance of the Lean implementation in LV/HV production environments (Azadegan et al., 2013). As complexity and dynamics are the main attributes of HV/LV production environments, it is more difficult to introduce Lean Production principles successfully in this production environment.

The challenge of introducing Lean in HV/LV production environments is difficult to overcome, and not all Lean techniques and methodologies can be implemented (Portioli-Staudacher and Tantardini, 2008). Melchert et al. (2006) demonstrate in their case study that some principles including level scheduling, takt time and kanban cannot be applied to the HV/LV production environment. Matt (2014) as well as Portioli-Staudacher and Tantardini (2008) came to the same conclusions that a proper balance of the workflow does not work. Their reasoning is based upon the fact that the sequences and cycle times of the manufacturing processes vary too widely. Pacing production at takt time is much more difficult to achieve, and kanbans are of little use when pieces are designed to customer requirements. In addition, Braglia et al. (2006) ascertained that the method "value stream mapping" (VSM) cannot be used directly for very complex manufacturing processes with merging flows. Wiegel and Brouwer (2015) argue in similar vein that differences in output and demand variation, co-producership and input variation require an adaptation of Lean techniques and methods in order to work in different application domains.

Scholars such as Womack and Jones (1996), Birkie and Trucco (2016) and Powell and van der Stoel (2016) assume the general applicability of the Lean principles independent from the type of business strategy followed or the sector of application. Powell and van der Stoel apply the five Lean principles from Womack and Jones to a Lean ETO environment and indicate implications of this environment for the application of these principles. Table 2 summarizes their findings. For some of the Lean principles the tools need to be adapted significantly while for others a general application seems valid. In general the principles remain valid in HV/LV.

Table 2; Applicability and implications of HV/LV production environment on Lean principles (summarized and adapted from Powell and van der Stoel, 2016)

Lean principals (Womack and Jones, 1996)	**HV/LV production environment implications**
Specify customer value	Variability as strategic source of customer value should in contrast to traditional Lean not be eliminated.
Identify the value stream	VSM method difficult to apply. Swim lanes (SL) may be better applicable. Complex material flows require flexible control mechanisms. Distinguish between strangers, repeaters and runners to accommodate various degrees of variability.
Make value flow	Instead of paced lines, line balancing, higher level laws are applied: • Little's law: reduce lead time by reducing WIP. • Kingmans equation: utilization leads to longer lead times, amplified by increased variability. Focus on flow efficiency instead of resource efficiency (Kingman 1961). • Law of bottlenecks: use bottleneck pace for optimal throughput time in relation to utilization are used to create flow.
Customer pull	While pull production seems inherent to HV/LV production environments, production pull and takt time is often hard to accomplish as traditional Lean tools as min-max levels and kanban systems are inapplicable. Capacity pull systems like constant work-in-process (ConWIP), paired cell overlapping loops of cards with authorisation (POLCA), scrum and agile-kanban offer opportunities to generate pull.
Pursue perfection	Just in time (JIT), single minute exchange of die (SMED), total productive maintenance (TPM), 5S and the operator's involvement are in the same dimensions applicable. Standardization of product and processes more difficult. Continuous improvement (CI) tools equally applicable in HV/LV production environments.

Further literature review demonstrates that the Lean techniques SMED and TPM function very well in HV/LV production environments. This increases the uptime and makes the process more productive. Reduced setup times also enable a flexible production where the manufacturer can more efficiently produce a wider variety of products (Azadegan et al., 2013 and Portioli-Staudacher and Tantardini, 2008). Other methods such as streamlining processes, 5S and operators involvement are actively applied, and in many cases implemented (Portioli-Staudacher and Tantardini, 2008). However, these methods are not as effective in the HV/LV production environment as in a LV/HV production environment. Non-effective methods such as kanban have already been further developed for the HV/LV environment. New pull systems such as agile-kanban and POLCA have a wide applicability in the HV/LV production environment (Slomp et al., 2009). While some Lean tools are reported dysfunctional, most underlying principles appear to be equally applicable in HV/LV. On a toolbox level some tools need to be adapted while others seem universal.

Development of a Research Agenda

While analyzing the literature as well as the case studies, we identified several open research topics. We compiled relevant research theses and listed them in table 3.

Table 3 – Research Thesis based of Lean in HV/LV production environments

	Research Thesis	**Based on**
RT1	Development of new tools and technologies to support ETO companies in deploying the new principles in pursuit of the Lean ideal.	Powell et al., 2014
RT2	Developments and innovative applications of IT with respect to the application of Lean production principles in engineer-to-order industries and industrial services.	Riezebos and Klingenberg, 2009

RT3	Extending the applicability of Lean principles to an intermittent HV/LV manufacturing with a particular focus on the scheduling functions.	Melchert et al., 2006
RT4	Research into the effects of the environmental context on the relationship between various Lean practices and their performance.	Azadegan et al., 2013
RT5	Quantitative analysis of the effectiveness of Lean methods in a small batch production considering of time or financial effort for the realization of the Lean methods.	Lanza et al., 2008
RT6	How to improve the production system towards a better service for the multi-types, small batch production process?	Florent et al., 2009
RT7	Developing tailored strategies for the ETO supply chain and the identifications of appropriate applications of Lean and agile philosophies in the ETO sector.	Gosling and Naim, 2009
RT8	More research on adopting Lean principles and management of information, supply chain, planning, and coordination in the ETO environment is needed.	Forsman et al., 2012
RT9	Investigation of the Capability Maturity Model Integration in other engineer-to-order segments.	Caracchi et al., 2014

Current state of the art both in science and practice (RQ2) can be summarized as follows: Future research should explore the traditional as well as the already for HV/LV production environments configured Lean methods and techniques in a more a detailed and appropriable way to find answers to RT1 throughout RT6. Azadegan et al. (2013) demonstrate that the effects of an environmental context on the relationship among various Lean practices and their performance must be explored. Powell et al. (2014) as well as Riezebos and Klingenberg (2009) point out that apart from the further development of methods and techniques the exploration of technologies and innovative applications of IT is important. Melchert et al. (2006) identified the applicability of Lean principles to intermittent HV/LV manufacturing with a particular focus on the scheduling functions as a future area of research. Research approaches of Gosling and Naim (2009) and Forsman et al. (2012) aim on the further development of supply chain strategies in the ETO environment as a success factor for Lean management (RT7 to RT8). Caracchi et al. (2014) and Klingenberg & Veltman (2009) recommend further research to the Capability Maturity Model in ETO environments as an effective tool for organizing, controlling and monitoring production processes (RT9).

The Maturity Model for Lean in HV/LV production environments

The Maturity Model for Lean in HV/LV production environments Model presented in this section is derived from the approaches of Shah and Ward (2007), Caracchi et.al, (2014), and Doolen, and Hacker (2005). The classification scheme from Shah and Ward (2007) is employed to indicate the level of maturity in HV/LV environments and they are shown in table 4.

Table 4 – Stages of maturity in HV/LV environments

Level	Description
Level 1: no implementation	Some awareness of lean; sporadic improvement activities may be underway in a few of the impact areas.
Level 2: little implementation	General awareness of lean; informal approach deployed in impact areas
Level 3: some implementation	Lean implementation is now a part of the organization's strategy and projects and activities are planned on the basis of established goals and objectives
Level 4: extensive implementation	Lean activities occur continuously from all areas of the organization. Improvement gains are sustained.
Level 5: complete implementation	Lean implementation fully deployed across the extended enterprise (across internal and external value streams); recognized as best practice.

To address RT9 we spent time to build on the understanding of the lean manufacturing philosophy in an HV/LV production environment. The focus of this article is limited to production processes in HV/LV environments as shown in figure 2. In table 5, the impact areas are adapted based on Doolen and Hacker (2005), while the Lean principles are practices based on our detailed literature review. The Lean maturity will become only apparent when an organization fullfills its strategic objectives through Lean. We have adapted Shah and Ward (2007, Appendix B), Dale and Lascelles (1997), Caffyn (1999) as reference to further develop the components of our Maturity Model for an HV/LV production environment.

Table 5 – Lean practices maturity levels in HV/LV production environments

Impact areas	Lean principles and practices	No implementation	Little implementation	Some implementation	Extensive implementation	Complete implementation
Manufacturing Processes	Streamlining processes	No process improvement policies exists	Individual process improvements have been carried out	Area-related process improvements have been carried out	Comprehensive SL analysis and process improvements have been carried out	Comprehensive SL analysis and process improvements are continuously performed
	Cellular manufacturing	No separate manufacturing cell for HV/LV products	A single work cell is establish	A subassembly is manufactured in work cells	A complete product is manufactured in work cells	All products are manufactured in work cells
	Value identification	No improvement of wastes	Continuous improvement of 2 wastes	Continuous improvement of 4 wastes	Continuous improvement of 6 wastes	Continuous improvement of all the 7 wastes
	Setup time reduction	Internal and external setup not used	Separation of internal and external set-ups	Conversion of internal to external setup operations	Optimization and standardization of internal and external set-ups	Continuous application of the SMED method
	5S	Continuous sort and set, not in order	Continuous sort and set in order	Continuous sort, set in order and shine	Continuous sort, set in order, shine and standardize	Continuous sort, set in order, shine, standard-ize and sustain
	TPM	No awareness program to obtain management commitment and support	Establish a comprehensive maintenance system which covers all levels of maintenance	Involve all functions including design, production, operations, maintenance, finance, and personnel	Ensure partici-pation of all employees from top management to shop floor workers.	Achieving CI through autonomous team activities.
	Quality/Jidoka	Yet to start a formal process	Engaged in a process of CI for up to three years	Engaged in a process of CI for 3 to 5 years	Engaged in a process of CI for 5 to 8 years	Total integration of CI and business strategy to delight the customer
Shop-Floor Management	Pull flow control (POLCA, ConWIP, agile-kanban)	No use of pull production system	Production is pulled by shipment of final goods	Production at stations is pulled by the current demand of next stations	Pull system performance is monitored	Pull system parameters are optimised
	JIT	No JIT control concept	Individual parts are controlled JIT	All A-class items are controlled JIT	All A- and B-class items are controlled JIT	All parts are controlled JIT
	Flexibility	No reuse; no metrics	Standardization of data and resources	Shop floor redesign	Full set of shop floor metrics in place	Autonomic systems
	Kaizen / CI	Ad hoc and short term	Employees demonstrate awareness and understanding of the organization's aims and objectives	The enabling mechanisms used to encourage involvement in CI are monitored and developed	Managers at all levels display active commitment to, and leadership	People are guided by a shared set of cultural values underpinning

Shop-Floor Management	Scrum	Absence of goals for process definition or improvement.	Practices appear more structured and complete	Has major focus on the relationship with clients and on timely deliveries	Monitors all the suggested practices	Measure and analyse their own actions and processes in order to self-improve

Now that the proposed Maturity Model is described, the objective is to improve upon the maturity of the overall Lean implementation through a combination of tools, processes, and interoperability. There is no one-size-fits-all solution as Lean in HV/LV needs to be adapted to environments such as ETO, BTO, MTO and partly ATO (with a focus on fabrication and assembly of single pieces and small batches). There are different requirements for these solutions for depending on the HV/LV Lean maturity. Hence the Maturity Model should be dynamic and evolving.

Conclusions

This article proposes a delineation and definition of the HV/LV production environment in the context of Lean. Based on a literature study and the Research Agenda were all traditional as well customized Lean methods and techniques successfully applied in the HV/LV production environment are identified. Furthermore, the open research topics are summarized. Another virtue of the paper is a framework for a Maturity Model for producers in the HV/LV environment. Relevant criteria such as streamlining processes are identified and maturity levels proposed. The Maturity Model enables HV/LV producers to assess their own Lean maturity level.

Acknowledgments

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References

Azadegan, A., Patel, P.C., Zangoueinezhad, A. and Linderman, K. (2013), “The effect of environmental complexity and environmental dynamism on lean practices”, *Journal of Operations Management*, Vol. 31, No. 4, pp. 193-212.

Birkie, S.E. and Trucco, P. (2016), “Understanding dynamism and complexity factors in engineer-to-order and their influence on lean implementation strategy”, *Production Planning & Control*, Vol. 27, No. 5, pp. 345-359.

Braglia, M., Carmignani, G. and Zammori, F. (2006), “A new value stream mapping approach for complex production systems”, *International journal of production research*, Vol. 44, No. 18-19, pp. 3929-3952.

Caffyn, S. (1999), “Development of a continuous improvement self-assessment tool”, *International Journal of Operations & Production Management*, Vol. 19, No. 11, pp. 1138-1153.

Caracchi, S., Sriram, P.K., Semini, M. and Strandhagen, J.O. (2014), “Capability Maturity Model Integrated for Ship Design and Construction”, in *Advances in Production Management Systems, Innovative and Knowledge-Based Production Management in a Global-Local World*, Springer, Berlin Heidelberg, pp. 296-303.

Dale, B.G. and Lascelles, D.M. (1997), “Total quality management adoption: revisiting the levels”, *The TQM Magazine*, Vol. 9, No. 6, pp. 418-428.

Doolen, T.L. and Hacker, M.E. (2005), “A review of lean assessment in organizations: an exploratory study of lean practices by electronics manufacturers”, *Journal of Manufacturing systems*, Vol. 24, No. 1, p. 55.

Fettke, P. (2006), “State-of-the-Art des State-of-the-Art”, *Wirtschaftsinformatik*, Vol. 48, No. 4, pp. 257-266.

Florent, T.M., Zhen, H. and Romaric, A.A. (2009), “The Continuous Improvement Model of Lean Production Based on Multi-type and Small-Batch Production”, *International Conference on Information Management, Innovation Management and Industrial Engineering*, Vol. 1, pp. 469-472.

Forsman, S., Björngrim, N., Bystedt, A., Laitila, L., Bomark, P. and Öhman, M. (2012), "Need for innovation in supplying engineer-to-order joinery products to construction: A case study in Sweden", *Construction Innovation*, Vol. 12, No. 4, pp. 464-491.

Gosling, J. and Naim, M.M. (2009), "Engineer-to-order supply chain management: a literature review and research agenda", *International Journal of Production Economics*, Vol. 122, No. 2, pp. 741-754.

Gosling, J., Naim, M.M., Fearne, A. and Fowler, N. (2007), "Defining the Lean and Agile Characteristics of Engineer-to-Order Construction Projects", *International Journal for Agile Manufacturing*, Vol. 10, No. 2, pp. 219-231.

Hoekstra, S. and Romme, J. (1992), *Integral logistics structures: developing customer oriented goods flow*, McGraw-Hill, London.

Holweg, M. (2007), "The genealogy of lean production", *Journal of Operations Management*, Vol. 25, pp. 420-437.

Kingman, J. (1961), "The single server queue in heavy traffic", *Mathematical Proceedings of the Cambridge Philosophical Society*, Vol. 57, No. 4, p. 902.

Lander, E. and Liker, J. K. (2007), "The Toyota Production System and art: making highly customized and creative products the Toyota way", *International Journal of Production Research*, Vol. 45, No. 16, pp. 3681-3698.

Lanza, G., Peter, K. and Broos, A. (2008), "Quantitative analysis and optimization of the effectiveness of lean methods in small batch production", in *5th Optimization and Stochastic Days*, pp. 1-9.

Matt, D.T. (2014), "Adaptation of the Value Stream Mapping approach to the design of lean engineer-to-order production systems: a case study", *Journal of Manufacturing Technology Management*, Vol. 25, No. 3, pp. 334-350.

Melchert, E.R., de Mesquita, M.A. and Francischini, P.G. (2006), "Lean manufacturing on make-to-order suppliers: a case study", in *12th International Conference on Industrial Engineering and Operations Management (ICIEOM)*, pp. 1-9.

Ohno, T. (1988), "Toyota production system: beyond large-scale production", *Productivity Press*, New York.

Portioli-Staudacher, A. and Tantardini, M. (2008), "Lean production implementation: a comparison between repetitive and non-repetitive companies", in *15th International Working Seminar on Production Economics*, Vol. 1, pp. 405-416.

Powell, D. and van der Stoel, A. (2016), "Lean Engineer-to-order Manufacturing" in Powel, D. and Netland, T. (Ed), *The Routledge Companion to Lean Management*, Routlegde, New York.

Powell, D., Strandhagen, J. O., Tommelein, I., Ballard, G. and Rossi, M. (2004), "A New Set of Principles for Pursuing the Lean Ideal in Engineer-to-Order Manufacturers", *Procedia CIRP*, Vol. 17, pp. 571-576.

Provalis Research (2010), WordStat 6: "Content Analysis Module for QDA Miner & SimStat", *Provalis Research*, pp. 1-172.

Riezebos, J. and Klingenberg (2009), "Advancing lean manufacturing, the role of IT", *Computers in Industry*, Vol. 60, No. 4, pp. 235–236.

Shah, R. and Ward, P.T. (2007), "Defining and developing measures of lean production", *Journal of operations management*, Vol. 25, No. 4, pp. 785-805.

Slomp, J., Bokhorst, J. and Germs, R. (2009), "A lean production control system for high-variety/low-volume environments: a case study implementation", *Production Planning & Control*, Vol. 20, No. 7, pp. 586-595.

Veldman, J. and Klingenberg, W. (2009), "Applicability of the capability maturity model for engineer-to-order firms", *International Journal of Technology Management*, Vol. 48, No. 2, pp. 219-239.

Wiegel, V. and Brouwer-Hadzialic, L. (2015), „Lessons from higher education: adapting Lean Six Sigma to account for structural differences in application domains", *International Journal of Six Sigma and Competitive Advantage*, Vol. 9, No. 1, pp. 72-85.

Womack, J.P. and Jones, D.T. (1996), "Lean thinking: banish waste and create wealth in your corporation", Simon and Schuster, New York.

Wortmann, J.C. (1995), "Comparison of information systems for ETO and make-to-stock situations", *Computers in Industry*, Vol. 26, pp. 261-271.