On the synergy between smart industry technologies and lean principles

Jos A.C. Bokhorst
Department of Operations, Faculty of Economics and Business, University of Groningen, P.O. Box 800, 9700 AV Groningen, the Netherlands

Wilfred H. Knol (wilfred.knol@han.nl)
Research Group Lean/World Class Performance, HAN University of Applied Sciences, P.O. Box 2217, 6802 CE Arnhem, the Netherlands

Jannes Slomp
Research Group Lean/World Class Performance, HAN University of Applied Sciences, P.O. Box 2217, 6802 CE Arnhem, the Netherlands

Abstract

The advent of industry 4.0 and its related smart industry technologies calls for a better understanding of how these novel technologies can be put to good use in companies that often have already started their lean journey. Therefore, this paper aims to analyse how smart industry technologies and lean principles affect performance and whether combining lean and smart delivers added value. Survey data was collected of managers in the Netherlands and 61 responses were analysed using Necessary Condition Analysis (NCA). The results indicate the necessity of lean principles for implementation of smart industry technologies and their combined effect on performance.

Keywords: Smart industry, Lean principles, Operational performance

Introduction

In the past decades, many studies showed that lean manufacturing principles have a positive effect on operational performance (e.g. Cua et al., 2001; Shah and Ward, 2003). Meanwhile, smart industry technologies have been shown to accelerate operational performance as well, and even complementary performance effects of lean principles and smart industry technologies such as computer-aided design (CAD), computer-aided engineering (CAE), computer-aided manufacturing (CAM), CNC machines, robots, and ERP systems have been stated in the literature (Khanchanapong et al., 2014). However, the recent technological developments in the area of smart industry have not yet been explicitly considered. While the implementation of these smart industry technologies are rapidly changing production environments in many industries (Porter and Heppelmann, 2015; Kang et al., 2016), the performance interaction with companies' existing lean programmes remains unclear. This leads to many practically relevant questions, such as: How should companies deal with these new technologies? Do they need to switch from investing in lean principles to investing in smart technologies? Is it necessary to invest in lean principles to gain the full performance advantages of smart industry technologies, and/or the other way around? Are there any complementary performance effects of implementing lean principles and smart industry technologies? This study explores the relation between lean principles and smart industry technologies by considering their (combined) effects on operational performance.

The paper is structured as follows. First, a short overview of smart industry technologies and lean principles is provided. Second, the literature on synergies between smart industry and lean manufacturing is discussed. Third, the methodology for the empirical research is explained. Subsequently, the findings are provided and discussed and finally conclusions are stated.

Smart industry technologies

The initial vision of smart industry appeared in 1991. Weiser (1991) introduced the notion of 'ubiquitous computing', where computers are integrated with each other and with the world, including production. Currently, the advances in ICT have enabled integrated and collaborative manufacturing systems which combine the strengths of information, technology and humans to be able to respond to changing circumstances in real time. The physical world is merged with the virtual world, resulting in cyber-physical systems (Lee et al., 2015; Xu et al., 2018). These cyber-physical systems enable flexible and adaptive manufacturing processes by acquiring and processing data, self-controlling certain tasks and interacting with humans via interfaces (Brettel et al., 2014).

Smart industry is associated with many (new) technologies, such as sensors, wireless communication, visual computing, autonomous robots, augmented reality, artificial intelligence, etc. This does not contribute to the clarity of the concept. To create a better understanding of smart industry, Hermann et al. (2016) identified four underlying fundamental design principles, which are (1) interconnection, (2) information transparency, (3) decentralized decisions, and (4) technical assistance. All smart industry technologies will contribute to one or more of these design principles.

In this paper we will focus on five broad components of smart industry technologies. These can be related to the components of a reference architecture of a smart factory as developed by Yoon et al. (2012). They identified the following ubiquitous components: u-Human, u-Resource, u-Product, u-MES (manufacturing execution system), data acquisition and transmission on the shop floor as device to the ubiquitous system (D2U), and an information exchange infrastructure (UPLI: ubiquitous product lifecycle information highway) where information is transmitted, exchanged and retrieved by various stakeholders (Yoon et al., 2012). The five components of smart industry technologies that we consider in this paper are displayed and described in Table 1.

Table 1 – Smart industry technologies

Component	Description
Work on screen solutions [u-Human]	Work on screen solutions are "interface devices to provide operators with information anywhere, anytime for a comfortable and safe working environment" (Yoon et al., 2012 p.2180).
Product tracking [u-Product]	Product tracking means that products can be identified and are accessible to manage information on status or location in real time (Yoon et al., 2012).
Information systems [UPLI]	Current information systems, such as enterprise resource planning (ERP) and customer relationship management (CRM)

	are essential to ensure horizontal and vertical integration (Wang et al., 2016)
MES systems [u-MES]	"Application systems to manage and control the whole shop floor" (Yoon et al., 2012 p. 2180)
Flexible automation [u-Resource]	Digitized and interconnected physical resources (Lee et al., 2015), such as automated guided vehicles, autonomous robots, and machining centres that are all connected online to enable real-time monitoring.

Lean principles

Since the 1990s lean has spread into other sectors than the automotive sector and academic output in the context of lean steadily increased (Bhamu and Sangwan, 2014; Marodin and Saurin, 2013; Samuel et al., 2015). Lean has evolved over the years, starting from a simple set of practices with a shop floor focus on waste and cost reduction towards more complex lean business systems aimed at enhancing value in companies and their supply chain (Hines et al., 2004; Stentoft Arlbjørn and Vagn Freytag, 2013).

Womack and Jones (1996) provided five lean principles: "specify value, line up value-creating actions in the best sequence, conduct these activities without interruption whenever someone requests them, and perform them more and more effectively" which were specified in four rules characterizing the Toyota Production System by Spear and Bowen (1999). These four rules comprise (1) a direct customer-supplier connection, (2) standardization of products and processes, (3) flow production and reduced throughput times, and (4) continuous improvement (Spear and Bowen, 1999). In this study, we will use these four rules as they capture the essential aspects of lean systems on a strategic level.

Synergy between smart and lean

The literature on synergetic effects of introducing smart industry technologies in lean organizations or introducing lean principles in smart industries is scarce. Khanchanapong et al. (2014) show that lean principles and technologies as classified by Boyer et al. (1996) in design manufacturing technologies (e.g. CAD, CAE, CAPP), process manufacturing technologies (e.g. AMT, CNC, robots), and administrative technologies (e.g. MRP, ERP), have positive complementary effects on operational performance. They considered cost, quality, lead time and flexibility. However, smart technologies were not specifically addressed. Whereas lean manufacturing usually propagates to reduce the level of automation to keep the processes flexible, Bortolotti and Romano (2012) showed that it is logical to first streamline a process with lean and then automate the value-added activities in a pure service environment.

Other authors specifically focus on the combination of smart industry technologies and lean manufacturing. Sanders et al. (2016) consider the possibilities of industry 4.0 as possible solution for integration challenges faced when implementing lean. They discuss how industry 4.0 technologies may act as enablers for lean manufacturing by stating opportunities within each of the ten operational constructs of lean production as posed by Shah and Ward (2007). Based on conceptualisation, they conclude that smart technologies are able to overcome some of the earlier shortcomings of traditional (lean) systems, thereby improving productivity and eliminating waste. Dombrowski et al. (2017) analysed the literature on the synergies of lean and industry 4.0 and found evidence of lean forming a basis for industry 4.0, but also of industry 4.0 being able to complete lean and enhance the efficiency of lean activities, and even change lean principles. Through studying 260 use cases of Industry 4.0 implementations and relating these to principles of lean production systems, they found several interdependencies between industry 4.0 technologies and lean production system principles.

In this paper we further explore the relation between lean principles and smart industry technologies in an empirical setting. Similar to Dombrowski et al. (2017) we investigate whether lean principles and smart industry technologies co-exist in companies or not, but we further analyse the necessity of using lean principles for using smart technologies with a Necessary Condition Analysis (Dul, 2016). More importantly, we extend the analysis by relating the use of smart industry technologies and the use of lean principles, individually and combined, to the internal and external performance of a firm.

Methodology

Primary data was collected through explorative survey research, to gain "preliminary insight" (Karlsson, 2009, p. 85) on the relation between lean principles, smart industry technologies, and operational performance. The exploratory survey was designed and distributed to a set of Dutch companies via Qualtrics, which is an online survey tool. The survey questions were constructed based on the literature as discussed in the previous sections of this paper.

The questions related to (1) the size of the company (in FTE), (2) the use of each of the five components of smart industry technologies, (3) the use of each of the four lean rules/principles, (4) the perceived impact of smart industry technologies on six internal performance measures, (5) the perceived impact of lean principles on six internal performance measures, and (6) the relative external performance of the company, measured with six external performance measures. All questions (except for the size of the company) were based on a 9-point Likert scale to collect interval data (Karlsson, 2009). Questions related to 2-5 were ranked with a 9-point Likert scale between 'not' (1-3), 'somewhat' (4-6) and 'considerably' (7-9). Questions related to 6 were ranked with a 9-point Likert scale between 'worse' (1-3), 'average' (4-6) and 'better' (7-9). All survey questions were translated into the Dutch language to ensure that all participants could understand the questions.

As a first step in the data analysis, a principal component analysis and factor analysis were done to identify relationships in the dimensions of either lean principles or smart industry technologies.

As a next step, a Necessary Condition Analysis (Dul, 2016) further identified the extent to which using lean principles is necessary for using smart industry technologies. In contrast to regular regression analyses that study variables in a probabilistic relationship to each other, NCA allows the study of variables that are necessary but no guarantee for a certain outcome. An outcome could for example be that using lean principles extensively is necessary for the implementation of certain smart industry technologies. Extensive implementation of lean principles, however, does not require these technologies. An NCA starts by drawing a ceiling line through the upper-left observations of an x-y plot. This line separates the 'empty space' and the 'full space' of the dataset (Goertz et al., 2012) and indicates the degree to which smart industry technologies (y-axis) could be implemented without presence of lean principles (x-axis). See, for example, Figure 2; the solid green line is a regular regression line, the broken red line is a ceiling envelopment line and the solid orange line is a ceiling regression line. The ceiling lines indicate the minimum presence of given lean principles to be able to implement a certain degree of smart industry technologies. This method of analysis follows other examples of NCA application such as Knol et al. (2018), who identified which success factors are critical for lean practice implementation, Sousa and Da Silveira (2017), who found necessary degrees of services in the process of servitisation, and Van

Der Valk et al. (2016), who determined the criticality of contracts and trusts for supplier relations.

Finally, to explore the performance effects of lean principles and smart industry technologies, their (perceived) effects on internal and external performance were considered. First, boxplots were used to estimate the perceived effect of lean principles and smart industry technologies on internal performance. Second, to find the (combined) impact of the use of lean principles and smart industry technologies on external performance, different groups of cases were identified. These groups were based on their score (either high or low) on use of lean principles and smart industry technologies. A stack chart subsequently was used to show the average of the scores of these groups on their external performance, relating external performance to the (combined) use of lean principles and smart industry technologies.

Findings

Company size

In our sample, 1/3 of the companies was large (>250 employees) and 2/3 of the companies could be considered as SME. Figure 1 shows that larger companies almost all use smart and lean 'somewhat' to 'considerably' (scores of 5 or higher). Smaller companies are seen to use lean principles and particularly smart industry technologies less intensively. With SMEs the variation in use is higher and various SMEs lag behind the larger companies. Figure 1 also shows that for all company sizes the level of activity in the field of smart industry is lower (M = 5.1, SD = 1.4) than that for lean (M = 6.6, SD = 1.4): the round dots are predominantly lower than the related triangles.

Figure 1 – Participating company size (FTE) versus their use of smart and lean

Relation between use of lean principles and use of smart technologies

We used principle component analysis and factor analysis on the data of use of lean principles and use of smart industry technologies to reduce the dimensions of the dataset. It turned out that the smart industry technologies can be divided in two groups: (1) Work on screen solutions & Information systems, with loadings of 0.963 and 0.53, respectively and (2) Product tracking, MES & Flexible automation, with loadings of 0.44, 0.73 and 0.62, respectively. Work on screen solutions need information systems and optimal deployment of flexible automation apparently often requires product tracking and MES control. We will refer to these two groups as Administrative (Adm) and Process (Proc) smart technologies. The principle component analysis and factor analysis on the data of use of lean principles showed that the four lean principles can be regarded as a single group with loadings of 0.60, 0.89, 0.89 and 0.80 for a direct customer-supplier connection, standardization, flow and continuous improvement, respectively.

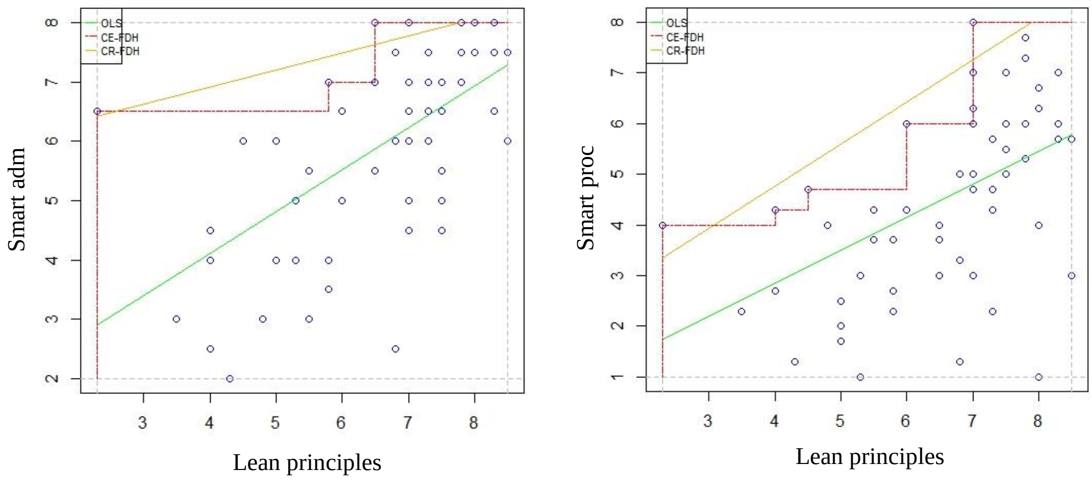

Figure 2 – Lean use versus smart use Adm (2a, left) and smart use Proc (2b, right)

The Necessary Condition Analysis (Dul, 2016) plots of Figure 2 clearly show that a high degree of implementation of smart technologies is accompanied by a high degree of implementation of lean principles. This is most prevalent in the Proc smart technologies group of product tracking, MES and flexible automation. The empty upper left corner in Figure 2b, is the largest there. This means that there are no companies that have invested ‘somewhat’ to ‘considerably’ (≥ 5) in product tracking, MES and flexible automation without having invested ‘somewhat’ to ‘considerably’ (≥ 6) in lean principles.

Figure 2 also indicates that lean principles can be applied without investments in smart industry. This again is particularly the case with investments in product tracking, MES and flexible automation: the bottom right-hand corner of Figure 2b is filled, which means that there are companies that use lean considerably, but do not invest in smart industry. In contrast, the bottom-right-hand corner of Figure 2a is empty, which indicates that companies that use lean principles ‘considerably’ (≥7) also invested ‘somewhat’ (>4) in smart Adm technologies. This would suggest a linear relationship, however, with substantial bandwidth.

Perceived impact of lean use and smart use on internal performance

In order to estimate the effect of lean principles on internal performance we asked respondents of companies that used lean considerably (average score of a 6.5 or higher on lean use) to indicate how they perceived this contribution. We distinguished six internal performance measures: Costs, Quality, Lead time, Delivery reliability, Flexibility, and Sustainability. Figure 3 shows the perceived impact of lean principles on these six internal performance measures in boxplots. For some internal performance distributions, the median equals either the first quartile or the third quartile.

Using lean thus seems to have a somewhat larger impact on time-related performance (i.e. lead time and delivery reliability) than on costs, quality and flexibility, while sustainability is affected least.

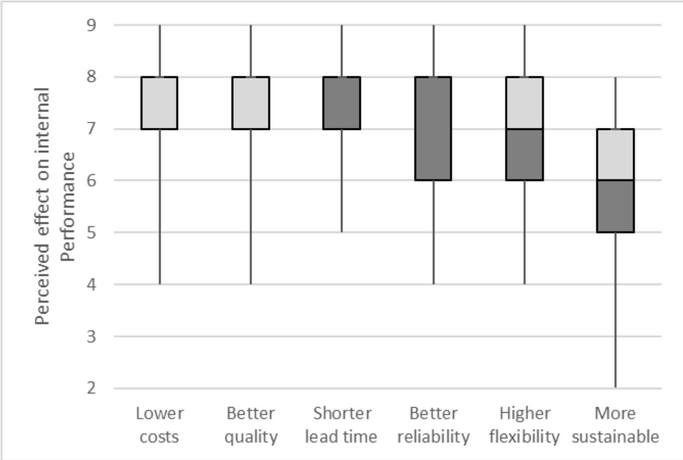

Figure 3 – Perceived effects of lean principles on internal performance (Note that dark grey rectangles depict the area between the first quartile and the median, while light grey rectangles represent the area between the median and the third quartile)

Similarly, in order to estimate the effect of Adm smart technologies and Proc smart technologies, we asked respondents of companies that used these technologies considerably (average score of a 6.5 or higher on Adm smart use and Proc smart use, respectively) to indicate how they perceived this contribution. Figure 4a and 4b show the impact of Adm smart technologies and Proc smart technologies, respectively, on six internal performance measures in boxplots.

Overall, the perceived effects of smart Proc on internal performance seem somewhat higher than those of smart Adm. Similar to what we saw for lean principles, sustainability is effected least by Adm and Proc smart technologies and for smart Proc the largest impact seems to be on time-related performance.

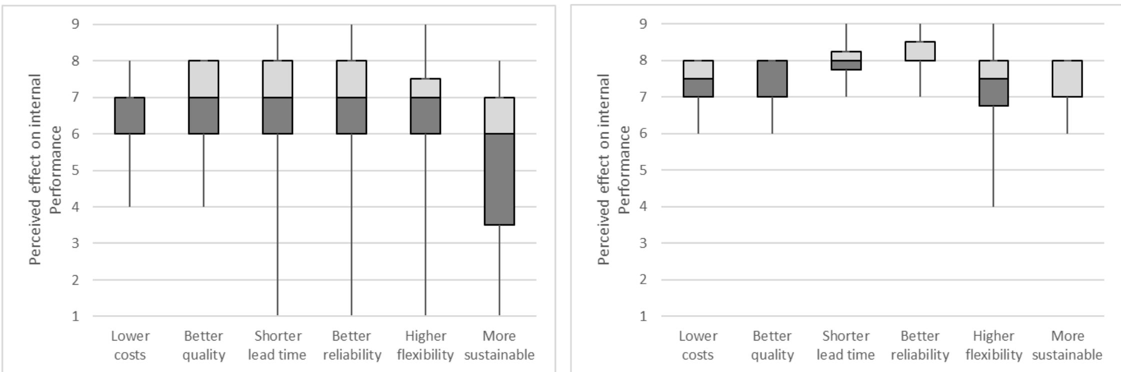

Figure 4 – Perceived effects of smart Adm (4a, left) and smart Proc (4b, right) on internal performance

Impact lean principles and smart industry technologies on external performance

The previous analyses showed to what extent the companies made use of lean principles and/or smart industry technologies (Figure 2) and what the perceived effects are on internal performance when companies use lean principles (Figure 3) or smart industry technologies (Figure 4) considerably (≥ 5). Next, it is relevant to see what the (combined) impact of the use of lean principles and smart industry technologies is on external performance. To get a clearer picture of this, we first defined 8 groups based on all possible combinations of companies scoring Low (≤ 5) or High (>5) on the use of lean principles (Lean-H/L), the use of Proc smart technologies (Proc-H/L), and the use of Adm smart technologies (Adm-H/L). Figure 5 shows the stacked scores on the external performance measures Price, Quality, Delivery time, Delivery reliability, Flexibility and Sustainability for each group.

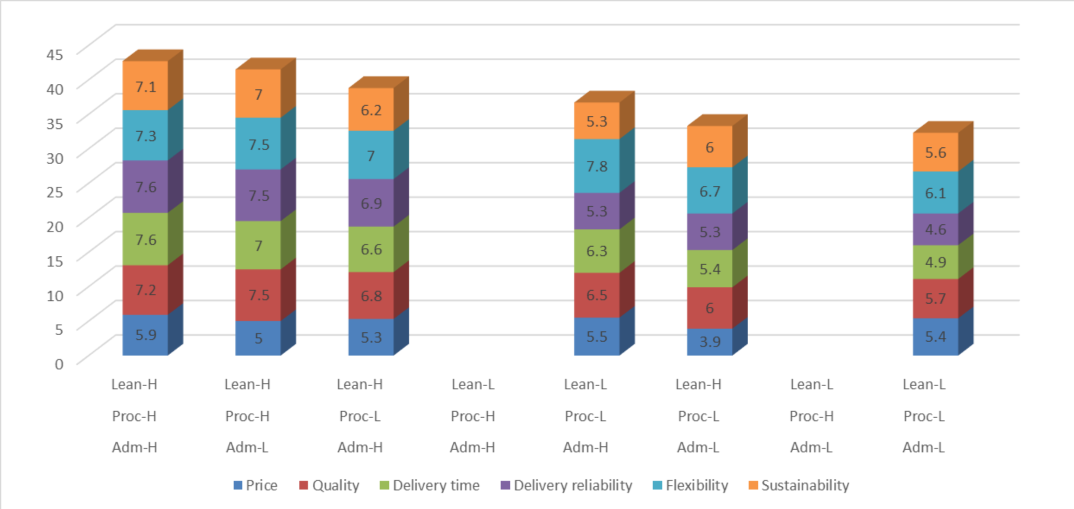

Figure 5 – Impact of lean principles and smart industry technologies on External performance

A first observation is that not all eight groups are represented by companies in our dataset. The combinations low use of lean and high use of smart technologies (Lean-L/Proc-H/Adm-H) and of ‘low use of lean, high use of Proc smart technologies and low use of Adm smart technologies (Lean-L/Proc-H/Adm-L) were non-existent. This shows that the companies in our dataset did not invest in the full range of smart industry technologies nor did they invest in Proc smart technologies without also investing in lean principles.

When considering the division of companies over the groups, we noted that some groups were larger than others. The number of companies in each group was, from left to right, 18, 4, 21, 0, 4, 7, 0 and 7, respectively. The largest groups scored High on all aspects (Lean-H/Proc-H/Adm-H: 18 companies) or High on Lean and Adm smart industry technologies and Low on Proc smart industry technologies (Lean-H/Proc-L/Adm-H: 21 companies). A further analysis revealed that the percentage of large companies (>250) was 68% for the group that scored high on all aspects. This means that, compared to the total sample (33% large companies), this group is heavily populated by large companies. The share of large companies in the Lean-H/Proc-L/Adm-H group was 24%. An explanation for this could be that especially Proc smart technologies require substantial investments and larger companies probably have more funds available to (also) invest in that type of technology.

Figure 5 furthermore clearly shows that the highest external performance is obtained by companies scoring High on the use of all three aspects (Lean-H/Proc-H/Adm-H) and the lowest external performance is seen with the group that scores Low on all aspects. In-between, groups that score High twice and Low once perform better than groups that score High once and Low twice. This shows that investing in lean principles and in smart industry technologies pays off in terms of external performance and that the combination of lean and smart is most favourable.

Conclusions

In this study we investigated the performance effects of investments in lean principles and smart industry technologies. There is a clear positive relationship between these investments and the performance of companies. It is also clear that developments in the field of smart industry and lean are related to each other. Without work-on-screen and information systems (administrative smart technologies) it is difficult to realize a high level of lean. Furthermore, a high level of lean seems to be a prerequisite for intensive use of MES, product tracking and flexible automation (process smart technologies). Since process smart technologies require substantial investments, the share of larger companies (> 250 employees) was found to be high in the group that actually invested in it. These aspects will have to be taken into account in the development of lean-smart industry roadmaps. Making roadmaps for SMEs is specifically relevant, as evidenced by the variation in performance effects of investments in lean and smart industry: not every investment yields the same result. It is therefore important to develop methods for SMEs with which they can make sensible choices over time. With these methods they can create an appropriate roadmap for their development in the field of lean and smart industry.

References

Bhamu, J. and Singh Sangwan, K. (2014), "Lean manufacturing: literature review and research issues", *International Journal of Operations & Production Management*, Vol. 34, No. 7, pp.876-940.

Bortolotti, T. and Romano, P. (2012). "'Lean first, then automate': a framework for process improvement in pure service companies. A case study", *Production Planning & Control*, Vol. 23, No. 7, pp.513-522.

Boyer, K.K., Ward, P.T. and Leong, G.K. (1996), "Approaches to the factory of the future. An empirical taxonomy", *Journal of Operations Management*, Vol. 14, No. 4, pp.297-313.

Brettel, M., Friederichsen, N., Keller, M. and Rosenberg, M. (2014), "How virtualization, decentralization and network building change the manufacturing landscape: An Industry 4.0 Perspective", *International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering*, Vol. 8, No. 1, pp.37-44.

Cua, K.O., McKone, K.E. and Schroeder, R.G. (2001), "Relationships between implementation of TQM, JIT, and TPM and manufacturing performance", *Journal of Operations Management*, Vol. 19, No. 6, pp.675-694.

Dombrowski, U., Richter, T. and Krenkel, P. (2017), "Interdependencies of Industrie 4.0 & Lean Production Systems: A Use Cases Analysis", Procedia Manufacturing, Vol. 11, pp.1061-1068.

Dul, J. (2016), "Necessary Condition Analysis (NCA): Logic and Methodology of 'Necessary but Not Sufficient' Causality", *Organizational Research Methods*, Vol. 19, No. 1, pp. 10–52.

Goertz, G., Hak, T. and Dul, J. (2013) "Ceilings and floors: Where are there no observations?", *Sociological Methods & Research*, Vol 42, No. 1, pp.3-40.

Hermann, M., Pentek, T. and Otto, B. (2016) "Design principles for industrie 4.0 scenarios", In *Proceedings of 49th Hawaii International Conference on System Sciences*, pp. 3928-3937.

Hines, P., Holweg, M. and Rich, N. (2004), "Learning to evolve: a review of contemporary lean thinking", *International journal of operations & production management*, Vol. 24, No. 10, pp.994-1011.

Kang, H.S., Lee, J.Y., Choi, S., Kim, H., Park, J.H., Son, J.Y., Kim, B.H. and Do Noh, S. (2016), "Smart manufacturing: Past research, present findings, and future directions", *International Journal of Precision Engineering and Manufacturing-Green Technology*, Vol. 3, No. 1, pp.111-128.

Karlsson, C. (Ed.) (2009), *Researching Operations Management*, Routledge, New York.

Khanchanapong, T., Prajogo, D., Sohal, A.S., Cooper, B.K., Yeung, A.C.L. and Cheng, T.C.E. (2014), "The unique and complementary effects of manufacturing technologies and lean practices on manufacturing operational performance", *International Journal of Production Economics*, Vol. 153, pp. 191–203.

Knol, W.H., Slomp, J., Schouteten, R.L. and Lauche, K. (2018), "Implementing lean practices in manufacturing SMEs: testing 'critical success factors' using Necessary Condition Analysis", *International Journal of Production Research*, https://doi.org/10.1080/00207543.2017.1419583.

Lee, J., Bagheri, B., and Kao, H. A. (2015), "A cyber-physical systems architecture for Industry 4.0-based manufacturing systems", *Manufacturing Letters*, Vol. 3, pp. 18–23.

Marodin, G.A. and Saurin, T.A. (2013), "Implementing lean production systems: research areas and opportunities for future studies", *International Journal of Production Research*, Vol. 51, No. 22, pp.6663-6680.

Porter, M.E. and Heppelmann, J.E. (2015), "How smart, connected products are transforming companies", *Harvard Business Review*, Vol. 93, No. 10, pp.96-114.

Samuel, D., Found, P. and Williams, S.J. (2015), "How did the publication of the book The Machine That Changed The World change management thinking? Exploring 25 years of lean literature", *International Journal of Operations & Production Management*, Vol. 35, No. 10, pp.1386-1407.

Sanders, A., Elangeswaran, C. and Wulfsberg, J. (2016), "Industry 4.0 implies lean manufacturing: research activities in industry 4.0 function as enablers for lean manufacturing", *Journal of Industrial Engineering and Management*, Vol. 9, No. 3, pp.811-833.

Shah, R. and Ward, P.T. (2003), "Lean manufacturing: Context, practice bundles, and performance", *Journal of Operations Management,* Vol. 21, No. 2, pp. 129–149.

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.

Sousa, R. and da Silveira, G.J. (2017), "Capability antecedents and performance outcomes of servitization: Differences between basic and advanced services", *International Journal of Operations & Production Management*, Vol. 37, No. 4, pp.444-467.

Spear, S. and Bowen, H.K. (1999), "Decoding the DNA of the Toyota production system", *Harvard business review*, Vol. 77, No. 5, pp.96-106.

Stentoft Arlbjørn, J. and Vagn Freytag, P. (2013), "Evidence of lean: a review of international peer-reviewed journal articles", *European Business Review*, Vol. 25, No. 2, pp.174-205.

Van der Valk, W., Sumo, R., Dul, J. and Schroeder, R.G. (2016), "When are contracts and trust necessary for innovation in buyer-supplier relationships? A necessary condition analysis", *Journal of Purchasing and Supply Management*, Vol. 22, No. 4, pp.266-277.

Yoon, J.S., Shin, S.J. and Suh, S.H. (2012), "A conceptual framework for the ubiquitous factory", *International Journal of Production Research*, Vol. 50, No. 8, pp.2174-2189.

Wang, S., Wan, J., Li, D. and Zhang, C. (2016), "Implementing smart factory of industrie 4.0: an outlook", *International Journal of Distributed Sensor Networks*, Vol. 12, No. 1, pp.1-10.

Womack, J. P. and Jones, D. T. (1996), *Lean Thinking: Banish Waste and Create Wealth in Your Corporation*, Simon & Schuster, New York.

Weiser, M. (1991), "The computer for the 21st century", *Scientific American*, 265(3), pp.94-104.

Xu, L.D., Xu, E.L. and Li, L. (2018), "Industry 4.0: state of the art and future trends", *International Journal of Production Research*, pp.1-22, https://doi.org/10.1080/00207543.2018.1444806.