Lean Manufacturing and Industry 4.0: a survey in Brazilian manufacturing companies

Guilherme Tortorella (UFSC) g.tortorella@ufsc.br

Glauco Silva (UFSC) - glaucogmpsilva@gmail.com

Diego Castro Fettermann (UFSC) - dcfettermann@gmail.com

Abstract:

Aims(s): This paper aims to examine the relationship between Lean Production (LP) practices and the implementation of Industry 4.0 in Brazilian manufacturing companies.

Methodology: To achieve that we use data from a survey carried out with 110 companies of different sizes and sectors, at different stages of LP implementation. Data collected was analyzed by means of multivariate analysis.

Results: Our findings indicate that LP practices are positively associated with Industry 4.0 technologies and their concurrent implementation leads to larger performance improvements.

Practical Implications: The contextual variables investigated do matter to this association, although not all aspects matter to the same extent and effect.

Keywords: Industry 4.0, Lean manufacturing, Manufacturing management, Lean production, Emerging economies, Empirical research.

1. Introduction

Lean Production (LP) is an approach widely deemed and spread among several industries that aims at reducing waste and improving productivity and quality according to customers' requirements (WOMACK et al., 2007; LAGE JUNIOR; FILHO, 2010; JASTI; KODALI, 2015). The implementation of LP means a systematic human-centered approach of various management principles and practices (SEPPÄLÄ; KLEMOLA, 2004). The principles are the elements of the strategic level and they represent the ideals of the system, such as identifying value from the customer's perspective, eliminating all kinds of waste, producing according to the pull of the customer, and continuous flow production (Liker, 2004; Papadopoulou and Ozbayrak, 2005). The practices are the elements that operationalize the principles (TORTORELLA et al., 2016b). In essence, the implementation of LP comprises a low-tech approach that excels for simplicity and effectiveness usually aligned with a shared business vision.

This context, this paper aims to examine the relationship between LP practices and the implementation of Industry 4.0 within a developing economy context, such as the Brazil. As previously indicated by Landscheidt and Kans (2016), Kolberg et al. (2016), and Gjeldum et al. (2016), there is a lack of studies that empirically investigate the relationship between a successful lean implementation and the progression into Industry 4.0. The literature that correlates LP and Industry 4.0 is scarce and only suggests a positive association between these approaches, but without testing empirically. To achieve that we use data from a survey carried out with 110 companies of different sizes and sectors, at different stages of LP implementation. Respondents were asked to provide answers to four questionnaires: Q1, which described the companies' contextual variables identified in the literature as influential in the adoption of both approaches; Q2, which assessed the implementation level of 41 inter-related and internally consistent LP practices, which have been empirically validated by Shah and Ward (2007); Q3, which comprised the identification of the adoption level of 10 inter-related Industry 4.0 technologies that are more likely to be implemented in this context, as suggested by Brazilian National Confederation of Industry (2016); and Q4, which aimed at identifying the operational performance improvement within the companies in last few years.

This rest of this paper is structured as follows. Section 2 presents the theoretical background. Section 3 describes the proposed method, with results of its application presented in section 4. Section 5 closes the paper presenting conclusions and future research opportunities.

2. Literature review

2.1. Industry 4.0

The term "Industry 4.0", coined in 2011 on the Hannover Fair in Germany, describes an industry whose main characteristics comprehend connected machines, smart products and systems, and inter-related solutions. Such aspects are put together towards the establishment of intelligent production units based on integrated computer and/or digital components that monitor and control the physical devices (LASI et al., 2014; ASHTON, 2009). In this sense, Industry 4.0 aims for an autonomous and dynamic production, which integrates Information and Communication Technologies (ICT) to enable a mass production of highly customized products.

Several governmental institutions have started to study and assess the implementation of Industry 4.0 technologies in their countries, such as Germany, United States and Canada. Specifically within the developing economies' context, such as Brazil, the National Confederation of Industry (2016) has carried out a survey to identify the existing challenges for implementing Industry 4.0 technologies. High implementation costs were pointed as the main internal barrier for advancing on Industry 4.0, while lack of skilled workers was indicated as the biggest challenge among the external factors. Overall, ten digital technologies grouped into three different application areas were identified, as shown in Table 1. Results also indicated that a feature of digitalization in Brazilian industry is the focus on processes, i.e. on increased efficiency and productivity. These findings corroborate to the study undertaken in Mexico, which is responsible for producing 80% of high tech exports of Latin America (MINISTRY OF ECONOMY, 2016). Similarly, in India, the government has presented in 2014 an initiative with the purpose of positioning the country as one of the main hubs of global manufacturing and design (FORBES INDIA, 2016). However, despite these initiatives, there is still much to understand and deepen about the benefits and challenges posed by the adoption of Industry 4.0 technologies in these contexts.

Table 1 - Digital technologies surveyed within Brazilian industrial context

Focus	Technology
Process	i_1- Digital automation without sensors i_2- Digital automation with process control sensors i_3- Remote monitoring and control of production through systems such as MES* and SCADA** i_4- Digital automation with sensors for product and operating conditions identification, flexible lines
Development/ reduction in time to market	i_5- Integrated engineering systems for product development and product manufacturing i_6- Additive manufacturing, rapid prototyping or 3D printing i_7- Simulations/analysis of virtual models (finite elements, computational fluid dynamics, etc) for design and commissioning
Product/ new business models	i_8- Collection, processing and analysis of large quantities of data (big data) i_9- Use of cloud services associated with the product i_{10}- Incorporation of digital services into products (Internet of Things or Product Service Systems)

* MES - Manufacturing Execution Systems
** SCADA - Supervisory Control and Data Acquisition

Source: Adapted from National Confederation of Industry (2016)

2.2. Lean production and industry 4.0

In the past few decades, scientific journals have published a number of articles that focus on describing and characterizing the content of LP; yet, there is not a precise and agreed upon way of defining or measuring LP. Although, researchers usually agree upon several overlapping practices (MARODIN; SAURIN, 2013), and their positive association with operational performance, in both developed (SHAH and Ward, 2003; DEMETER; MATYUSZ, 2011; NETLAND et al. 2015) and emerging economies countries (TAJ; MOROSAN, 2011; PANIZZOLO et al., 2012; JASTI; KODALI, 2016). Kolberg et al. (2016) affirm that LP can be considered as a complement to the technological point of view emphasized in Industry 4.0. Both LP and Industry 4.0 favor decentralized and simple structures over large and complex systems; while aim for small and easily integrated modules with lower levels of complexity (ZÜEHLKE, 2010). However, contradictory evidences found in literature (e.g. EROL et al., 2016; SCHUMACHER et al., 2016; SANDERS et al., 2016) indicate that the comprehension of such association and its impact on operational performance still needs to be deepened and better explored. Hence, although research initiatives and practical experimentations already exist, they are mostly the application of a single or isolated aspect. In this study, we examine the relationship between the simultaneous implementation of LP – represented by 41 practices (see Table 2) proposed and validated by Shah and Ward (2007) – and Industry 4.0 readiness, and their influence on the companies' operational performance.

3. Research method

There are three stages to the research method proposed here: (i) questionnaire development and data collection, (ii) clustering of data, and (iii) data analysis. These stages are detailed in the sections to follow.

3.1. Questionnaire development and data collection

The questionnaire was sent by e-mail to 465 companies. The final resulting sample comprise 110 valid responses representing a response rate of 23.65%. The sample presents a balanced amount of companies for each contextual variable. Most respondents were from large companies (67.3%); the majority of companies belonged to metal-mechanics sector (61.8%); and most companies (70.9%) started their LP implementation more than 2 years ago.

Table 2 - LP constructs and practices

Underlying constructs	Operational constructs	Lean production practices
Supplier related	Supplier feedback	lp_1- We frequently are in close contact with our suppliers lp_2- We give our suppliers feedback on quality and delivery performance lp_3- We strive to establish long-term relationship with our suppliers
	JIT delivery	lp_4- Suppliers are directly involved in the new product development process lp_5- Our key suppliers deliver to plant on JIT basis lp_6- We have a formal supplier certification program
	Developing suppliers	lp_7- Our suppliers are contractually committed to annual cost reductions lp_8- Our key suppliers are located in close proximity to our plants lp_9- We have corporate level communication on important issues with key suppliers lp_{10}- We take active steps to reduce the number of suppliers in each category lp_{11}- Our key suppliers manage our inventory lp_{12}- We evaluate suppliers on the basis of total cost and not per unit price
Customer related	Involved customers	lp_{13}- We frequently are in close contact with our customers lp_{14}- Our customers give us feedback on quality and delivery performance lp_{15}- Our customers are actively involved in current and future product offerings lp_{16}- Our customers are directly involved in current and future product offerings lp_{17}- Our customers frequently share current and future demand information with marketing department
Internally related	Pull	lp_{18}- Production is pulled by the shipment of finished goods lp_{19}- Production at stations is pulled by the current demand of the next station lp_{20}- We use a pull production system lp_{21}- We use *kanban*, squares, or containers of signals for production control
	Flow	lp_{22}- Products are classified into groups with similar processing requirements lp_{23}- Products are classified into groups with similar routing requirements lp_{24}- Equipment is grouped to produce a continuous flow of families of products lp_{25}- Families of products determine our factory layout
	Low setup	lp_{26}- Our employees practice setups to reduce the time required lp_{27}- We are working to lower setup times in our plant lp_{28}- We have low set up times of equipment in our plant
	c_8- Controlled processes	lp_{29}- Large number of equipment/processes on shop floor are currently under SPC lp_{30}- Extensive use of statistical techniques to reduce process variance lp_{31}- Charts showing defect rates are used as tools on the shop floor lp_{32}- We use fishbone type diagrams to identify causes of quality problems lp_{33}- We conduct process capability studies before product launch
	c_9- Involved employees	lp_{34}- Shop floor employees are key to problem solving teams lp_{35}- Shop floor employees drive suggestion programs lp_{36}- Shop floor employees lead product/process improvement efforts lp_{37}- Shop floor employees undergo cross functional training
	c_{10}- Productive maintenance	lp_{38}- We dedicate a portion of everyday to planned equipment maintenance related activities lp_{39}- We maintain all our equipment regularly lp_{40}- We maintain excellent records of all equipment maintenance related activities lp_{41}- We post equipment maintenance records on shop floor for active sharing with employees

Source: Adapted from Shah and Ward (2007)

The questionnaire was structured in four parts. The first part aimed to collect demographic information of the respondents and their companies. The second part of the questionnaire assessed the level of LP practices adoption based on Shah and Ward's (2007) assessment model, which comprises 41 questions related to ten operational constructs. Each practice is described in a statement that was evaluated according to a Likert scale that ranged from 1 (fully disagree) to 5 (fully agree). The third part of the questionnaire aimed at measuring the degree of adoption of the Industry 4.0 technologies within the studied companies. For that, 10 questions were formulated according to different technologies as suggested by Brazilian National Confederation of Industry (2016), which are claimed as the most adopted ones by Brazilian manufacturing companies. Similarly, the degree of adoption was measured in a 5-point Likert scale ranging from 1 (not used) to 5 (fully adopted). Finally, the fourth part assessed the observed operational performance improvement during the last three years, according to five indicators: (i) productivity, (ii) delivery service level, (iii) inventory level, (iv) workplace safety (accidents) and (v) quality (scrap and rework). A 5-point scale ranging from 1 (worsened significantly) to 5 (improved significantly) is used in the questionnaire.

Further, we tested all responses related to the 41 LP practices, 10 technologies of Industry 4.0 and the 5 performance indicators for reliability, determining their Cronbach's alpha values. An alpha threshold of 0.6 or higher was used (MEYERS et al., 2006). Responses displayed high reliability, with an overall alpha value of 0.993, 0.857 and 0.834, respectively.

3.2. Clustering of data

In this step, we perform three clustering of observations using questions on (i) implementation level of LP practices, (ii) adoption level of Industry 4.0 technologies, and (iii) operational performance improvement as clustering variables. Clustering tools are used to analyze relationships within a database in search of a summarized representation of data, grouping observations in a small number of clusters (EVERITT, 1980). According to Rencher (2002), observations in a cluster should be similar to those assigned to the same cluster, and different from those assigned to other clusters. In all clusterings performed on the same sample of observations, we first applied a hierarchical method to identify the proper number (say k) of clusters – we used Ward's method for that – and then the k-means clustering method, to rearrange observations into k clusters. See Rencher (2002) for more details.

When clustering using the implementation level of LP practices as clustering variables, two clusters were identified. An ANOVA (Analysis of Variance) was performed to verify differences in means of clustering variables calculated using data from each cluster. For all 41 clustering variables, we found significant differences in means (p-values < 0.05 in all cases).

The 48 observations assigned to cluster 1 presented a high average adoption level of LP practices, and the cluster was labeled HLP (high level of lean production implementation); the 62 observations assigned to cluster 2 presented a low average adoption level of LP practices, and the cluster was labeled LLP (low level of lean production implementation).

The same observations were clustered using the adoption level of the 10 technologies of Industry 4.0 as clustering variables. The same procedure was used and found two clusters. Among the 10 clustering variables an ANOVA (Analysis of Variance) identified significant differences in means (p-values < 0.01 in all technologies). The 78 observations assigned to cluster 1 presented a low average adoption level of Industry 4.0 technologies, and the cluster was labeled LTC (low level of Industry 4.0 technologies implementation); the 32 observations assigned to cluster 2 presented a high average adoption level of Industry 4.0 technologies, and the cluster was labeled HTC (high level of Industry 4.0 technologies implementation).

Finally, a third cluster analysis was performed taking into account the operational performance improvement. Results for the five performance indicators were similarly processed, indicating the existence of two clusters, whose significant differences in means (p-values<0.01) were verified through an ANOVA. The first cluster corresponds to 42 observations whose average improvement level of operational performance was lower, being named as LPI (low level of performance improvement); the second cluster is comprised of the 68 remaining observations that presented a high average improvement level of operational performance, and labeled HPI (high level of performance improvement).

3.3. Data analysis

In step 3.2, three sets of clusters became available. In the first set, observations were grouped in clusters HLP and LLP according to LP implementation level; in the second set, observations were grouped in clusters HTC and LTC according to the adoption level of Industry 4.0 technologies; and the third one, with regards to the performance improvement level, grouped into HPI and LPI. We now test for differences in the means of two contextual variables (company's size and time of LP implementation in the company) across clusters in each set.

First, we tested whether the frequency of observations from the cluster of LP implementation (LLP and HLP) was associated to the adoption level of Industry 4.0 technologies (LTC and HTC) according to the level of operational performance improvement

(LPI and HPI). Second, we tested data from each contextual variable according to Industry 4.0 technologies and to LP implementation levels. We considered significant associations with adjusted residual values larger than |1.96| and |2.58|, corresponding a significance level of 0.05 and 0.01, respectively.

4. Results

Table 3 presents the contingency table and chi-square results for all combinations of levels (LLP and HLP) of LP practices implementation and Industry 4.0 technologies (LTC and HTC), according to the performance improvement level of the companies. Frequencies indicate the number of companies assigned to each cluster combination; for example, there are 16 companies appearing simultaneously in clusters LLP, LTC and LPI. Adjusted residual values indicate that, for companies that have not observed higher levels of operational performance improvement in the last three years, none of the associations between Industry 4.0 and LP are significant. Contrary to conventional expectation, despite the existence of companies that claim to be widely implementing LP practices and/or Industry 4.0 technologies within this group, none of them perceived a relevant operational performance improvement. An explanation for such outcome relies on the arguments presented by Pay (2008), Liker and Rother (2011) and Longoni et al. (2013), which highlight that any improvement approach, regardless of its methods, when misunderstand or misapplied in a company may have its benefits reduced, causing even contrary effects to the expected ones. Consequently, before deciding to implement any productivity improvement approach, management must first examine its business strategy and verify if such approach can contribute directly to the company's strategy.

Table 3 - Chi-square test among levels of Industry 4.0 technologies and LP implementation according to operational performance improvement

Operational performance improvement	Industry 4.0 technologies	LLP		HLP		Total frequency
		Frequency	Adjusted residual	Frequency	Adjusted residual	
LPI	LTC	32	-1.01	4	1.01	36
	HTC	4	1.01	2	-1.01	6
	Total frequency	36		6		42
HPI	LTC	24	2.88**	18	-2.88**	42
	HTC	2	-2.88**	24	2.88**	26
	Total frequency	26		42		68

* significant at 5%; ** significant at 1%

Table 4 displays the results for chi-square tests among implementation levels of Industry 4.0 and LP according to companies' size. Previous researchers (e.g. SHAH; WARD, 2003; KAGERMANN et al., 2013) have argued that the implementation of both approaches may be positively influenced by the size of the company, since larger companies usually present a higher capital expenditure capability. Our results raise a different discussion, since they demonstrate that the association between Industry 4.0 and LP is significant regardless the companies' size. Indeed, they indicate that both small- and large-sized companies that are highly adopting Industry 4.0 technologies are more likely to be widely implementing LP practices. This finding suggests that, although smaller companied may face different challenges than larger ones, the concurrent adoption of Industry 4.0 and LP is feasible in both contexts and size should not be seen as an impediment for that. Further, within the studied sample, it is worth noticing that the frequencies of small and large companies that are poorly implementing LP and Industry 4.0 is higher than the other combinations. As suggested by Saurin and Ferreira (2009) and Tortorella et al. (2015), LP implementation in Brazil is still rare and focused mainly on case studies with a few selected companies. When considering the adoption of Industry 4.0 technologies in Brazilian context, this gap is even larger, according to Anderl (2014) and National Confederation of Industry Brazil (2016). Therefore, it is quite reasonable to expect such low frequency of companies adopting both approaches and our results corroborate to this assumption.

Table 4 - Chi-square test among levels of Industry 4.0 technologies and LP implementation according to companies' size

Companies' size	Industry 4.0 technologies	LLP		HLP		Total frequency
		Frequency	Adjusted residual	Frequency	Adjusted residual	
Small and medium	LTC	20	2.21*	6	-2.21*	26
	HTC	2	-2.21*	8	2.21*	10
	Total frequency	22		14		36
Large	LTC	36	2.84**	16	-2.84**	52
	HTC	4	-2.84**	18	2.84**	22
	Total frequency	40		34		74

* significant at 5%; ** significant at 1%

Finally, regarding the contextual variable "time of LP implementation" Table 5 shows results of the contingency table with chi-square test values. For companies that have been implementing LP for less than 2 years (usually categorized as beginners), results do not indicate a significant association between Industry 4.0 and LP. Generally, the experience on

LP implementation experience is associated with a higher level of awareness, which provides a better understanding of its practices and underlying principles. Since LP is a forerunner approach and these companies are not quite experienced on it, it is reasonable that no association was found between LP and the technologies from Industry 4.0, which is an even newer approach. This fact is also observed in companies that claim to be widely implementing LP and Industry 4.0. However, as companies become more experienced on LP implementation (>2 years), results show a significant association with Industry 4.0. Analogously to the obtained results for companies' size, experienced companies that claim to be highly adopting Industry 4.0 technologies are the ones that also implement LP practices more extensively. In turn, despite their experience, it appears that the frequency of companies that still struggle in implementing LP practices is much higher when they also poorly adopt Industry 4.0 technologies. Therefore, our results converge to previous studies (Hines et al., 2004; Jasti and Kodali, 2015) and bear that company's experience on LP implementation is an important variable to be considered when associating LP practices to other improvement approaches, such as Industry 4.0.

Table 5 - Chi-square test among levels of Industry 4.0 technologies and LP implementation according to companies' time of LP implementation (years)

Time of LP implementation	Industry 4.0 technologies	LLP Frequency	LLP Adjusted residual	HLP Frequency	HLP Adjusted residual	Total frequency
≤ 2 years	LTC	20	1.33	4	-1.33	24
	HTC	4	-1.33	4	1.33	8
	Total frequency	24		8		32
> 2 years	LTC	36	3.36**	18	-3.36**	54
	HTC	2	-3.36**	22	3.36**	24
	Total frequency	38		40		78

* significant at 5%; ** significant at 1%

5. Conclusions

We provide a deeper understanding on how Industry 4.0 can support the implementation of LP practices, allowing companies undergoing lean implementation to better manage their change processes while they move towards the fourth revolution. As companies continue to focus on implementing LP and efficient ways of doing business, there will be an increasingly demand for incorporating novel technologies.

We presented empirical evidences on how Industry 4.0 technologies and implementation of LP practices are associated. Results showed that the frequency of both small- and large-sized companies that claim to be barely implementing LP and Industry 4.0 is higher. On the other hand, most companies that are have a higher adoption level of Industry

4.0 technologies also state a higher implementation level of LP. Such evidence indicates that size may not be a barrier for a concurrent implementation, and smaller companies may be encouraged to follow the same path. Overall, evidences presented here suggest that the studied Industry 4.0 technologies are significantly associated with the implementation level of LP practices. Analyzing those results, companies undergoing lean implementation may be able to set and adopt these technologies in order to achieve higher operational performance improvements.

References

ANDERL, R. **Industrie 4.0**: advanced engineering of smart products and smart production, Proceedings of International Seminar on High Technology, 19, Piracicaba, Brazil, 2014.

ASHTON, K. That "Internet of Things" thing. **RFID Journal**, 22, 97-114, 2009.

DEMETER, K., MATYUSZ, Z. The Impact of Lean Practices on Inventory Turnover. **International Journal of Production Economics**, 133, 154–163, 2011.

EROL, S., SCHUMACHER, A., SIHN, W. Strategic guidance towards Industry 4.0 – a three-stage process model, **Proceedings** of International Conference on Competitive Manufacturing (COMA16), Stellenbosch, South Africa, 2016.

EVERITT, B. **Cluster Analysis**. Halsted Press, New York, 1980.

FORBES INDIA. **Industry 4.0**: the next industrial revolution demystified, 2016. Available at http://www.forbesindia.com/article/nasscom-india-leadership-forum-2016/industry-4.0-the-next-industrial-revolution-demystified/42239/1. Accessed on March 6th 2017.

GJELDUM, N., MLADINEO, M., VEZA, I. Transfer of model of innovative smart factory to Croatian economy using lean learning factory. **Procedia CIRP**, 54, 158-163, 2016.

HINES, P., HOLWEG, M., RICH, N. Learning to evolve: a literature review of contemporary lean thinking. **International Journal of Operations and Production Management**, 24(10), 994-1011, 2004.

JASTI, N., KODALI, R. Lean production: literature review and trends. **International Journal of Production Research**, 53(3), 867-885, 2015.

JASTI, N., KODALI, R. An empirical study for implementation of lean principles in Indian manufacturing industry. **Benchmarking: An International Journal**, 23(1), 183-207, 2016.

KAGERMANN, H., HELBIG, J., HELLINGER, A., WAHLSTER, W. **Recommendations for implementing the strategic initiative INDUSTRIE 4.0**: securing the future of German manufacturing industry, final report of the Industrie 4.0 Working Group, Forschungsunion, 2013.

KOLBERG, D., KNOBLOCH, J., ZÜEHLKE, D. Towards a lean automation interface for workstations. **International Journal of Production Research**, forthcoming, 1-12, 2016.

LAGE JUNIOR, M., GODINHO FILHO, M. Variations of the kanban system: literature review and classification. **International Journal of Production Economics**, 125(1), 13-21, 2010.

LANDSCHEIDT, S., KANS, M. Automation practices in Wood product industries: lessons learned, current practices and future perspectives, **Proceedings** of the 7th Swedish Production Symposium SPS, 25-27 October, Lund-Sweden, 2016.

LASI, H., FETTKE, P., KEMPER, H., FELD, T., HOFFMANN, M. Industry 4.0. **Business & Information Systems Engineering**, 6, 239-242, 2014.

LIKER, J. The Toyota Way: 14 management principles from the world's greatest manufacturer, 2004.

LIKER, J., ROTHER, M. **Why lean programs fail, Knowledge Center of Lean Enterprise Institute**, Available at: http://www. lean. org/common/display. Accessed on May 13th 2017, 2011.

LONGONI, A., PAGELL, M., JOHNSTON, D., VELTRI, A. When does lean hurt? – an exploration of lean practices and worker health and safety outcomes. **International Journal of Production Research**, 51(11), 3300-3320, 2013.

MARODIN, G., SAURIN, T. Implementing lean production systems: research areas and opportunities for future studies. **International Journal of Production Research**, 51(22), 6663-6680, 2013.

MEYERS, L., GAMST, G., GUARINO, A. **Applied Multivariate Research**, Sage Publications, Thousand Oaks, 2006.

MINISTRY OF ECONOMY. **Crafting the future**: a roadmap for industry 4.0 in Mexico, 1st edition, Mexico City, 2016. Available at: www.gob.mx/se. Acessed on 2017.

NATIONAL CONFEDERATION OF INDUSTRY BRAZIL. **Industry 4.0**: a new challenge for Brazilian industry, CNI Indicators, 17(2), 2016.

NETLAND, T., SCHLOETZER, J., FERDOWS, K. Implementing lean: The effect of takt time, **Proceedings** of Euroma 2015, Nêuchatel, Switzerland, 2015.

PANIZZOLO, R., GARENGO, P., SHARMA, M., GORE, A. Lean manufacturing in developing countries: evidence from Indian SMEs. **Production Planning & Control**, 23(10–11), 769–788, 2012.

PAPADOPOULOU, T., OZBAYRAK, M. Leanness: experiences from the journey to date. **Journal of Manufacturing Technology Management**, 16(7), 784–807, 2005.

PAY, R. Everybody’s jumping on the lean bandwagon, but many are being taken for a ride. **Industry Week**, 5, 2008.

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. **Journal of Industrial Engineering and Management**, 9(3), 811-833.

SAURIN, T., FERREIRA, C. The impacts of lean production on working conditions: A case study of a harvester assembly line in Brazil. **International Journal of Industrial Ergonomics**, 39(2), 403-412, 2009.

SCHUMACHER, A., EROL, S., SIHN, W. A maturity model for assessing Industry 4.0 readiness and maturity of manufacturing enterprises. **Procedia CIRP**, 52, 161-166, 2016.

SEPPÄLÄ, P., KLEMOLA, S. How do employees perceive their organization and job when companies adopt principles of lean production? **Human Factors and Ergonomics in Manufacturing & Service Industries**, 14(2), 157-180, 2004.

SHAH, R., WARD, P. Lean manufacturing: context, practice bundles, and performance. **Journal of Operations Management**, 21(2), 129-149, 2003.

SHAH, R., WARD, P. Defining and developing measures of lean production. **Journal of Operations Management**, 25(4), 785-805, 2007.

TAJ, S., MOROSAN, C. The impact of lean operations on the Chinese manufacturing performance. **Journal of Manufacturing Technology Management**, 22(2), 223–240, 2011.

TORTORELLA, G., MARODIN, G., FETTERMANN, D., FOGLIATTO, F. Relationships between lean product development enablers and problems. **International Journal of Production Research**, 54(10), 2837-2855, 2016a.

TORTORELLA, G., MARODIN, G., MIORANDO, R., SEIDEL, A. The impact of contextual variables on learning organization in firms that are implementing lean: a study in Southern Brazil. **The International Journal of Advanced Manufacturing Technology**, 78(9-12), 1879-1892, 2015.

TORTORELLA, G., VERGARA, L., FERREIRA, E. Lean manufacturing implementation: an assessment method with regards to socio-technical and ergonomics practices adoption. **The International Journal of Advanced Manufacturing Technology**, 1-12, 2016b.

WOMACK, J., JONES, D., ROOS, D. **The machine that changed the world**: the story of lean production - Toyota's secret weapon in the global car wars that is revolutionizing world industry, 1st ed., New York, NY, Free Press, 2007.

ZÜEHLKE, D. Smart factory – towards a factory-of-things. **Annual Reviews in Control**, 34(1), 129-138, 2010.