On the relationship between Lean Supply Chain Management and performance improvement by adopting Industry 4.0 technologies

Guilherme Luz Tortorella, Rogério Feroldi Miorando and Carlos Ernani Fries
Department of Production and Systems Engineering
Federal University of Santa Catarina
Florianopolis, SC, 88000-900, Brazil
gluztortorella@gmail.com, miorando@gmail.com, carlos.fries@ufsc.br

Alejandro Mac Cawley Vergara
Department of Industrial and Systems Engineering
Pontifical Catholic University of Chile
Santiago, Chile
amac@ing.puc.cl

Abstract

This article investigates the moderating effect of the adoption of Industry 4.0 technologies on the relationship between Lean Supply Chain Management (LSCM) practices and supply chain performance improvement in the Brazilian industry. The study is based on a survey with manufacturing companies to capture the improvement of four supply chain performance indicators considering implementation level of seventeen LSCM practices, and ten digital technologies related to Industry 4.0. Data were analyzed through multivariate data analysis. Results indicate that the adoption of Industry 4.0 technologies does moderate the relationship between LSCM practices and supply chain performance in Brazilian industry. However, this moderating effect does not occur at the same extent as expected. The investigation on the effect of the concurrent adoption of Industry 4.0 technologies with already established practices, such as LSCM ones, in manufacturing companies of emerging countries provides a deeper comprehension of the benefits and challenges to entail greater supply chain performance.

Keywords
Industry 4.0; Lean Supply Chain Management; Performance; Lean Production.

1. Introduction

According to Frohlich and Westbrook (2001) and Krajewski et al. (2015), firms that present the highest likelihood of success are the ones that effectively link their internal processes with external customers and suppliers. The benefit obtained from linking internal processes with customer and suppliers reinforces the importance of a proper integration with suppliers and customers as a central element to improve competitiveness beyond the organizational boundaries (Flynn et al., 2010; Frazzon et al., 2015). In this sense, the establishment of an efficient Supply Chain Management (SCM), which comprises the flow of goods from supplier through manufacturing and distribution until the end user (Power, 2005), has been the focus of strategic discussion of several companies.

The need for systemic improvement of SCM has been motivating the incorporation of Lean Production (LP) principles and practices (Tortorella et al., 2017a), which mainly aims at reducing waste and increasing quality according to customers' perspective. Such actions called Lean Supply Chain Management (LSCM) are defined as a set of organizations that are directly linked by upstream and downstream flows of products, services, finances and information. The former ones work collaboratively aiming at the reduction of costs and waste, demonstrating in an efficient way what is necessary for customer's individual needs (Anand and Kodali, 2008; Vitasek et al., 2005).

Previous studies (e.g. Lewis, 2006; Cagliano et al., 2006; Blanchard, 2010) have reported a positive association between the adoption of LSCM practices and operational performance improvement.

The implementation of LSCM cannot be considered as a single source of competitive advantage for the organization. The advent of Industry 4.0 and the adoption of its inherent technologies have raised attention for the potential of achieving different levels of operational performance (Landscheidt and Kans, 2016). Industry 4.0 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 (Kagermann et al., 2013). This trend is especially true when taking into account the transformation that many industries (e.g. automotive and chemical process industry) are undergoing as a result of Industry 4.0 (Lasi et al., 2014).

At a first sight, one might expect that the concurrent implementation of LSCM practices, along with Industry 4.0 technologies would be synergistic. The first one, by supporting the change of habits and mindset of organizations within a certain supply chain (Naim and Gosling, 2011). The second one gives a higher level of flexibility and automation in production, supporting new manufacturing philosophies (Ashton, 2009). However, the way Industry 4.0 technologies can be integrated into existing management approaches and which processes they can support is still under investigation (Kolberg et al., 2016). For instance, the implementation of lean principles and practices means a systematic human-centered and low-tech approach (Seppälä and Klemola, 2004), composed by both technical and socio-cultural aspects (Tortorella et al., 2015). On the other hand, Industry 4.0 adoption entails a high level of capital expenditure, which is usually more feasible for high value-added products/services located in developed economies (Sanders et al., 2016). Therefore, specifically within the SCM, it is noteworthy the lack of studies that empirically investigate the integration of Industry 4.0 with current management approaches, such as lean, in order to provide higher performance levels (Landscheidt and Kans, 2016; Gjeldum et al., 2016).

Based on these arguments, a research question can be raised: "how do Industry 4.0 technologies moderate the relationship between LSCM practices and supply chain performance improvement?". Hence our research looks at the moderating effect between Industry 4.0 technologies and LSCM practices with relation to the supply chain performance improvement in the Brazilian industry. To achieve our objective, we applied a survey to the Brazilian manufacturing companies and capture 4 SCM performance indicators and 17 LSCM practices, previously used by Shah and Ward (2007). To determine the adoption of Industry 4.0, we asked for the adoption level of digital technologies related to manufacturing process and product development and service innovation, which are the most likely ones to be implemented in manufacturers in emerging economies (Brazilian National Confederation of Industry, 2016). Using multivariate data analysis, we expect to give light on the moderating effect of Industry 4.0 technologies between LSCM practices and SC performance.

2. Literature review and hypotheses

2.1 Supplier relationship and Industry 4.0

In a general approach, lean practices and principles aim at reducing waste and variability in the processes, adding more value to customers and providing operational performance improvement (Shah and Ward, 2003; Stentoft and Vagn, 2013). In this sense, Hines et al. (2004) affirm that the understanding about LP evolved from the application of simple practices at the workstation level to a supply chain or value systems across multiple organizations, as a natural organizational learning process expanding the knowledge boundaries. Further, several recent studies (e.g. Moyano-Fuentes and Sacristán-Díaz, 2012; Bhamu and Singh Sangwan, 2014; Jasti and Kodali, 2015) indicate that the value system, which consists in involving and understanding the suppliers, is considered to be one of the new frontiers of research on lean. Therefore, the application of supplier-related practices is aligned with such body of knowledge and comprised by three operational constructs, as suggested and validated by Shah and Ward (2007). The first one, 'supplier feedback', consists in providing regular feedback to suppliers about their performance. The second, 'JIT delivery', ensures that suppliers deliver the right quantity at the right time in the right place. Finally, the third construct denoted as 'suppliers development' objectives to develop suppliers so they can be more involved in the production process of the focal company.

In terms of technology, existing developments have been driven by increasing efficiency regarding manufacturing processes, mainly focusing on advances within an individual company rather than on the whole supply chain; hence, these advances have led to significant but isolated gains in process efficiency and product quality (Schumacher et al., 2016). With the introduction of Industry 4.0 suppliers are able to provide a technologic platform that can be integrated into customer's products by adjusting interfaces between product and technology. This platform not only

helps to handle software integration but also bundles competences to target customer's perceived quality (Kampker et al., 2016). Further, inappropriate transfer of information between manufacturers and suppliers might entail a significant source of waste. Suppliers need to be constantly informed about the status of the products and services provided by them in order to address an adequate and fast action to settle discrepancies (Sanders et al., 2016). In this sense, Industry 4.0 may support such interaction by providing the necessary tools and technologies to achieve immediate and automatic feedback to suppliers, and to overcome bureaucracies and inadequate communication channels (Dworschak and Zaiser, 2014).
Additionally, a LSCM stands for a timely delivery which is usually an issue to most of the companies, due to reasons such as: incomplete status of goods being shipped, mismatch between required and transported goods and unexpected time delays during transfer of goods (Flynn et al., 2010; Dora et al., 2016). The implementation of IoT (Internet of Things) presupposes the utilization of integrated devices for communication, managing information about goods transported and tracking them until their destination (Ashton, 2009; Shariatzadeh et al., 2016). This kind of technology might support not only timely delivery but also create the opportunity for optimizing delivery routes in logistics. Thus, based on these arguments, we formulated three hypotheses to investigate the effect of Industry 4.0 on the relationship between supplier-related lean practices and operational performance, as follows:

H1a: The adoption of Industry 4.0 technologies positively moderates the effect of Supplier Feedback on supply chain performance improvement.
H1b: The adoption of Industry 4.0 technologies positively moderates the effect of JIT Delivery on supply chain performance improvement.
H1c: The adoption of Industry 4.0 technologies positively moderates the effect of Suppliers Development on supply chain performance improvement.

2.2 Customer relationship and Industry 4.0

Actively involved customers enable companies to predict customer demand accurately. Thus, customer-related practices aim to focus on a company's customers and their needs (Shah and Ward, 2007). Such involvement can occur during several phases of the productive flow. For instance, the utilization of customer' s perception of value to create new and profitable value streams within the organization, exploring synergies between processes, people, tools and technology has been denoted as Lean Product Development (LPD), as reported by Tortorella et al. (2016). Jasti and Kodali (2015) emphasized the importance of customers' involvement for achieving a truly lean supply chain by suggesting the establishment of a bundle of practices named 'Customer relationship management'. They argue that successful organizations are based on how well they deliver products and services to customers. Therefore, organizations should give equal importance to both internal and external customers to provide better services to the final customer. In this sense, organizations have started to maintain long-term relationship with customers and performed analysis on various needs of these customers to provide better service in terms of cost and warranties with the help of flexible manufacturing system (Soni and Kodali, 2013).
With regards to Industry 4.0, Kampker et al. (2016) mention that as new technologies and practices are introduced in companies, a shift in customers' expectation can be observed. In this sense, technological possibilities concerning communication, virtual reality and connected systems play an important role on enabling a lean accelerated time-to-market, while avoiding costs for product development (Rauch et al., 2016). Traditional analysis tools (e.g. Quality Function Deployment – QFD) have limitations on the number of customers' requirements and their relationship with product design (Sanders et al., 2016). Big Data, for instance, seems to facilitate extreme complex calculation and processing of relationship between needs and functions for large volume of data (Li et al., 2015), allowing manufacturers to differentiate categories of customers and providing more assertive products and solutions (Shrouf et al., 2014). Thus, it is reasonable to expect that the integration of Industry 4.0 into customer-related lean practices opens new ways to manage customers' information. We argue that, if developed properly under the lean principles, digital technologies can support customer-related practices and increase its operational benefits. So, we propose the following hypothesis with regards to customer involvement and Industry 4.0:

H2: The adoption of Industry 4.0 technologies positively moderates the effect of customer-related practices on supply chain performance improvement.

3. Method

3.1 Sample selection and characteristics

A recent study from Kull et al. (2014) suggests that national culture could influence the implementation of lean practices. Since our study is focused on Brazilian manufacturing companies' context, we limited our sample only to leaders from these companies. Moreover, the respondents should have experience in lean and be aware of Industry 4.0 technologies. Due to these criteria, our sample included companies from different industrial sectors because of the limited number of companies in this country adopting both LP practices and minimally initiated at Industry 4.0. Additionally, although implementing LP is usually associated primarily with high volume and discrete part manufacturers, pervasiveness of practices across the industrial spectrum is unknown (Tortorella et al., 2015), which justifies our cross-industry sample. Such criteria that conduces to a non-random choice of companies for surveys and the search for companies is a commonly used strategy in other studies on LP (Shah and Ward, 2003; Shah and Ward 2007; Tortorella et al., 2016).

The questionnaire was structured in four main parts. The first part assessed the observed supply chain performance improvement during the last three years, according to four indicators: (i) productivity, (ii) delivery service level, (iii) inventory level, and (iv) quality. A five-point scale ranging from 1 (worsened significantly) to 5 (improved significantly) was used in the questionnaire. The second part aimed to collect demographic information of the respondents and their companies and supply chains. The third part of the questionnaire assessed the adoption level of the supplier- and customer-related lean practices, which comprises 17 questions related to four 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), as shown in Appendix A. Finally, the fourth 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 digital technologies, as suggested by Brazilian National Confederation of Industry (2016), which are the most likely ones for adoption in Brazilian manufacturing companies (see Appendix B). Similarly, the degree of adoption was measured in a 5-point Likert scale ranging from 1 (not used) to 5 (fully adopted).

Since there is a limited number of Brazilian companies that have mutually implemented lean practices into their SCM and initiated the adoption of Industry 4.0 technologies, collecting data is particularly difficult (Marodin et al., 2016; Tortorella and Fettermann, 2017). For this reason, the questionnaire was applied with 147 leaders of Brazilian manufacturing companies who were former students of executive education courses on lean offered by a large Brazilian University four times during 2017. A first data collection happened on February 2017 with students from the first class, followed by other three opportunities with the students from classes that occurred on April, July and September of the same year. The sample presented a balanced amount of companies for each contextual variable. Most respondents were from large companies (55.1%); the majority of companies belonged to metal-mechanic sector (49.6%). Most respondents (65.9%) were from the first and second tiers and, regarding companies' technologic intensity, 53.7% were from companies categorized as high or medium-high, as indicated by Brazilian National Confederation of Industry (2016).

3.2 Sample and method bias

Non-response bias was tested as proposed by Armstrong and Overton's (1977) using Levene's test for equality of variances and a t-test for the equality of means among respondents of each class. Results indicated no differences in means and variation in the four groups (p-value<5%). Thus, there is no statistical evidence that our sample is significantly different from the rest of the population.

Single respondents can be a source of common method bias, particularly when the same person is answering the dependent and independent variables with psychometric scales that represent their opinion, and not actual data. Therefore, several techniques were followed as remedies for common method bias. Regarding question formulation, the dependent variables were placed first and physically far from the independent variables in the questionnaire, and verbal midpoint labels were added to the scales. For respondent bias, a statement clarifying that the respondents were going to be kept anonymous and that there was no right or wrong answer was included at the beginning of the questionnaire. Also, respondents were appropriate key informants for the data collected, since all of them were directly involved in lean implementation in their organizations.

Regarding statistical remedies, Harman's single-factor test with an exploratory factor analysis is one of the most widely used for researchers to address common method bias. The Harman's test with all independent and dependent variables resulted into a first factor that included 31.94% of the variance. Consequently, as there was no single factor accounting for the majority of the variance in the model, Harman's test indicated that common method variance should not be a problem.

3.3 Construct validity and reliability

We have first applied a Confirmatory Factor Analysis (CFA) using STATA 14.2 to confirm convergent validity and unidimensionality of the four constructs that had multi-item: (i) Supplier feedback, (ii) JIT delivery, (iii) Developing suppliers and (iv) Involved customers. First, four CFA models were estimated, one for each construct. A threshold value of 0.45 was used for factor loadings as an acceptable cut-off value. Hence, practices lp7 and lp11 were excluded and the models were recalculated. Secondly, the single CFA models were re-assessed and results indicated an adequate fitness of the models using chi-square test ($\chi 2$/df), Comparative Fit Index (CFI) and Root Mean Square Error of Approximation (RMSEA). Results after the exclusion of lp7 and lp11 showed: Supplier feedback – $\chi 2$/df =183.4/3, RMSEA=0.000 and CFI=1.000; JIT delivery – $\chi 2$/df=92.9/3, RMSEA=0.000, CFI=1.000; Developing suppliers – $\chi 2$/df=94.4/6, RMSEA=0.000, CFI=1.000; and Involved customers – $\chi 2$/df=446.7/10, RMSEA=0.198, CFI=0.934. At the end, all items loaded satisfactory on their constructs (factor loading more than 0.45, p-value < 0.01) and all construct's reliability exceeded the acceptable level of Cronbach's alpha of 0.7 (Hair et al., 2006). Thirdly, the validity of the measures was evaluated by testing all constructs and their respective items in a single CFA model. This model produced also satisfactory fit indices ($\chi 2$/df=1215.0/105, RMSEA=0.099, CFI=0.89), and each construct's factor loading was significant. Therefore, the results from both steps provided an adequate model fit.

Regarding Industry 4.0 technologies, we performed an Exploratory Factor Analysis (EFA) to identify technologies that may grouped because they present much of their variance in common (Hair et al., 2006). In this sense, all ten Industry 4.0 technologies were entered for PCA (principal component analysis) and varimax rotation was used to extract orthogonal components, resulting in the extraction of two components classified according to their focus: (i) Process [PROCESS] and (ii) Product development and Service innovation [PROD_SERV]. The first one, [PROCESS], comprises technologies that are mainly focused on enhancing and facilitating the actual manufacturing processes, such as digital automation and manufacturing execution system. Complementarily, [PROD_SERV] technologies, such as virtual models and Internet of Things, aim at improving and supporting processes related to product development and services innovation. Both constructs were empirically validated using PCA with varimax rotation and reliability analysis (Cronbach's alpha). Results were replicated using oblique rotation as a check for orthogonality and the extracted components were similar. Additionally, unidimensionality of each component was verified and confirmed by applying PCA at the component level. A reliability assessment was performed determining the Cronbach's alpha values for each component, which depends upon the number of items in the scale and the average inter-item correlation. All components displayed high reliability, with alpha values above 0.80. Finally, the response value for each construct was obtained through the average of the corresponding technologies included in the construct weighed by their respective factor loadings from the PCA. Further, we have standardized the values for focal predictors and moderators to address possible multicollinearity.

Finally, with respect to supply chain performance improvement, a scale was constructed based on PCA of the four indicators aforementioned, and the factor scores were used as the dependent variable. All indicators' load on one factor, with an eigenvalue of 3.270 explaining almost 66% of the variation. Further, the obtained Cronbach's alpha value is 0.860. Thus, we assume that all four indicators are empirically related and represent a single dimension of supply chain performance.

4. Results and discussions

A set of OLS (ordinary least square) hierarchical linear regression models was performed to test both theoretical models proposed. The results, depicted in Table 1, report the unstandardized coefficients, as scales were standardized before the analysis, i.e. unstandardized coefficients will represent a standardized effect. The first stage (Model 1) of the hierarchical process analyzed only the effect of the control variable (Tier level) on the dependent variable (Supply chain performance improvement). Then, the direct effects of [SUP_FEED], [JIT_DEL], [DEV_SUP], [INV_CUST], [PROCESS] and [PROD_SERV] on the dependent variable were added (Model 2). Finally, the moderator effects (interaction terms) of [PROCESS] and [PROD_SERV] were added, indicated as

Model 3. The variance inflation factors (VIF) in the regressions models were all lower than 3.0, suggesting that multicollinearity was not a concern.

Our results show that for supply chain performance improvement, both the addition of the independent variables (Model 2) as well as the addition of the interaction term (Model 3) showed an incremental improvement of the model (i.e. Change in R2 was significant in both stages). Therefore, the model with the highest capacity of supply chain performance prediction was Model 3, which included the interaction terms (F-value=5.152; p-value<0.01) and explained 29.9% of the variance.

It is noteworthy that Tier level (control variable) appears to be positively impacting (β=0.518; p-value<0.05), which indicates that as companies become further from the end customer supply chain performance improvement tends to increase. Although it might seem a counterintuitive finding, it is aligned with findings from Marodin et al. (2016) and Tortorella et al. (2017a). These studies suggest that companies from tier levels closer to end consumer (e.g. first and second tiers) usually have to buy raw materials from larger companies, such as steel mills and foundries. Particularly in Brazilian industry context, the steel mills sector is an oligopoly, entailing a higher bargain power for these companies at negotiation and problem-solving activities with other supply chain agents. Therefore, since our study sample is comprised mostly by metal-mechanic companies (49.6%), this contextual effect might be perceived in our results. Additionally, the positive direct effect of [DEV_SUP] (β=0.772; p-value<0.05) suggests that much emphasis has been applied into improving the relationship with upstream agents of the supply chain, which also corroborates to a better performance from companies from tiers three and four.

Table 1. Results of hierarchical regression analysis for supply chain performance improvements

Variables	Supply chain performance improvement		
	Model 1	Model 2	Model 3
Tier level	0.498**	0.473**	0.518**
[SUP_FEED]		0.107	-0.034
[JIT_DEL]		0.072	-0.212
[DEV_SUP]		0.228*	0.772**
[INV_CUST]		0.075	0.208
[PROCESS]		0.163*	1.263***
[PROD_SERV]		-0.026	-0.873**
[PROCESS] *X* [SUP_FEED]			-0.027
[PROCESS] *X* [JIT_DEL]			0.115
[PROCESS] *X* [DEV_SUP]			-0.112
[PROCESS] *X* [INV_CUST]			-0.279**
[PROD_SERV] *X* [SUP_FEED]			0.100
[PROD_SERV] *X* [JIT_DEL]			-0.026
[PROD_SERV] *X* [DEV_SUP]			-0.138
[PROD_SERV] *X* [INV_CUST]			0.270**
F-value	4.042**	8.850***	5.152***
R^2	0.027	0.308	0.371
Adj. R^2	0.020	0.273	0.299
[b]Change in R^2		0.281***	0.026*

Notes: *n*=147
[a]Unstandardized regression coefficients are reported.
[b]Change in R^2 reports results compared with the previous model.
* Significant at 10%; ** Significant at 5%; *** Significant at 1%.

When analyzed separately, this model shows that, [PROCESS] technologies have a significant positive association with supply chain performance (β=1.263; p-value<0.01); while [PROD_SERV] seems to be negatively associated (β=-0.873; p-value<0.05). Koufteros et al. (2005) show a similar result in which supplier product integration on product innovation has a negative effect. They indicate that assigning more product development responsibilities to suppliers may have a negative effect on the ability of the organization to offer new products and features, which leads to deterioration in product innovation. However, surprisingly, results indicate that when the interaction terms are taken into consideration, the concurrent adoption of [PROCESS] technologies negatively moderates (β=-0.279; p-value<0.05) the effects of [INV_CUST]. This was also observed by Ray et al. (2005) which concluded that, at low levels of shared knowledge, the investment in generic information technology may even reduce process performance. On the other side, [PROD_SERV] positively moderates (β=0.270; p-value<0.05) the effects of the same bundle of LSCM practices on supply chain performance improvement. As the implementation level of

[INV_CUST] practices increases, the adoption of [PROCESS] technologies should be reduced to perceive better performance improvement levels. On the other hand, for high implementation levels of [INV_CUST], companies tend to achieve higher improvement levels for supply chain performance when there is a high adoption level of Industry 4.0 technologies denoted as [PROD_SERV]. In both cases, despite the fact that the moderator variables (PROCESS and PROD_SERV) have opposite effects, the increment on [INV_CUST] implementation seems to override this moderation and shows an overall positive increment in the dependent variable. This was also noted by Fang (2008), who showed that new product development speed is drastically increased when customer participation and information are used to identify and resolve problems. These findings provide empirical evidence to support that hypothesis H2 at both [PROCESS] and [PROD_SERV] significantly influence the effect of customer relationship practices on supply chain performance. Nevertheless, Industry 4.0 technologies related to manufacturing processes were found to be negatively moderating, meanwhile technologies focused on product development and service innovation are positively moderating. Those results were interesting outcomes of the present study and deserve further discussions.

First, regarding the [PROD_SERV] moderation, it is reasonable to expect that Industry 4.0 technologies that primarily aim at supporting and facilitating product development and service innovation are positively moderating the effect of customer-related LSCM practices. In fact, recent research on Industry 4.0 (e.g. Lee et al., 2014; Porter and Heppelmann, 2015) have already pointed such potential benefit. Our results add new insights to this body of knowledge. We argue that the incorporation of an acknowledged technology into ill-structured product development and service innovation processes will not bring the expect results, which is observed by the negative direct effect of [PROD_SERV]. However, if customer-related practices are minimally established within the company and, hence, modifications on organizational mindset with respect to the importance of a healthy collaboration with customers are observed, Industry 4.0 technologies (e.g. 3D printing and cloud services associated with product) can significantly improve the performance of delivery, quality, productivity and inventory.

Secondly, the negative moderating effect of [PROCESS] technologies on the relationship between [INV_CUST] and supply chain performance indicates that Brazilian manufacturing companies are still presenting a disconnected improvement approach. Koufteros et al. (2005) found similar results in the US indicating that assigning more product developing responsibilities to suppliers may have a negative effect on the ability of the organization to offer new products and features. In other words, while our findings show that manufacturing process-related technologies do contribute to supply chain performance when separately adopted, the same does not occur when customer-related lean practices are considered. This outcome is somewhat consistent with the findings from Marodin et al. (2017) and Tortorella et al. (2017b), who suggest that Brazilian companies usually present their internally-related (manufacturing shop floor) continuous improvement initiatives apart from the perspective on the supply chain flow of value. In this sense, our research provided empirical evidence to argue that, particularly for the performance of Brazilian companies' supply chain, the implementation focus of customer-related lean practices might be diverging and, thus, competing with the benefits provided by the adoption of [PROCESS] technologies, such as Supervisory Control and Data Acquisition (SCADA) and machine/process control sensors.

Overall, the obtained results partially confirm H2, indicating that Industry 4.0 technologies do moderate the effects of Involved Customers on supply chain performance improvement, although the direction of such moderation may depend on the focus of the adopted technologies. In opposition, our findings do not bear any Industry 4.0 moderating effect claimed in hypotheses H1a, H1b and H1c, which are related to LSCM practices focused on supplier relationship.

5. Conclusions

This paper presented a survey-based research with data from 147 manufacturing companies located in Brazil to test the moderating effect of the adoption of Industry 4.0 technologies on the relationship between LSCM practices and supply chain performance. Two major contributions can be obtained from this study.

First, in theoretical terms, we provided empirical evidence to affirm that Industry 4.0 actually moderates the effects of LSCM implementation, although its extension may not occur always as expected. This fact was especially observed for LSCM practices focused on customer relationship, which highlights the need for reinforcing the integration between supplier-related lean practices and Industry 4.0 technologies. Further, our study indicates that the single implementation of cutting-edge technologies will not necessarily lead to better supply chain performance. In fact, the application of these technologies over ill-structured processes, either manufacturing or product/service processes, can jeopardize performance, leading to negative outputs contrary to expectations. In this sense, while Industry 4.0 adoption can change the nature of LSCM by leading companies to superior levels of excellence, it may also raise the need for a more mature continuous improvement mindset within organizations in order to avoid the illusion of achieving higher performance levels through the simple acquisition of technology and not by actually changing managerial habits and practices.

Second, with regards to practical implications, our findings indicate that manufacturing companies in Brazil may still lack a systemic continuous improvement approach that integrates the whole value system, which is claimed to be the new frontier of LP (Hines et al., 2004). In other words, companies' improvement initiatives tend to be myopic, providing changes on shop floor processes regardless their effect on supply chain, and vice-versa. Therefore, our research indicates the need for a holistic approach for implementing both Industry 4.0 and LSCM. In this sense, managers must find the right balance for change in order to successfully compete under this paradoxical scenario where technology and human-based simplicity must concurrently exist. With the support from advanced ICT on manufacturing, product development and service innovation processes along with a properly established LSCM, manufacturing companies can indeed move into new performance standards at a supply chain level.

This research presents some drawbacks that must be highlighted. First, respondents were located in Brazil; their answers might thus be linked to geographical and cultural issues. That may be relevant since lean implementation has been claimed to be highly dependent on cultural characteristics. Thus, as this limitation restricts the results to this cultural condition, it also increases the certainty that they apply to those companies and to others in regions with similar characteristics. However, it is noteworthy the need for expanding the sample to other emerging countries with cultural similarities in order to provide a more robust findings that could be compared to developed economies' context. Second, the data were collected from delegates of a specific Lean conference using a perceptual research instrument, which offers some limitations. Although the proper procedures have been carefully addressed to avoid possible sample biases, future work should consider the sample restriction and maybe conduct similar studies in a broader population. Regarding the perceptual research instrument, another limitation relies specifically on the supply chain performance indicators. Therefore, future studies could benefit from collecting actual supply chain data for this metrics.

References

Anand, G.,and Kodali, R., A conceptual framework for lean supply chain and its implementation, *International Journal of Value Chain Management*, vol. 2, no. 3, pp. 313-357, 2008.

Armstrong, J., and Overton, S., Estimating nonresponse bias in mail surveys, *Journal of Marketing Research*, vol. 14, no. 3, pp. 396-402, 1977.

Ashton, K., That 'internet of things' thing, *RFID Journal*, vol. 22, pp. 97-114, 2009.

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

Blanchard, D., *Supply chain management best practices*, 2nd ed., John & Wiley Sons, UK, 2010.

Brazilian National Confederation of Industry, Industry 4.0: a new challenge for Brazilian industry, *CNI Indicators*, vol. 17, no. 2, 2016.

Cagliano, R., Caniato, F., and Spina, G., The linkage between supply chain integration and manufacturing improvement programmes, *International Journal of Operations & Production Management*, vol. 26, no. 3, pp. 282-299, 2006.

Dora, M., Kumar, M., and Gellynck, X., Determinants and barriers to lean implementation in food-processing SMEs – a multiple case analysis, *Production Planning & Control*, vol. 27, no. 1, pp. 1-23, 2016.

Dworschak, B., and Zaiser, H., Competences for cyber-physical systems in manufacturing – first findings and scenarios, *Procedia CIRP*, vol. 25, pp. 3-8, 2014.

Fang, E., Customer participation and the trade-off between new product innovativeness and speed to market, *Journal of Marketing*, vol. 72, no. 4, pp. 90-104, 2008.

Flynn, B., Huo, B., and Zhao, X., The impact of supply chain integration on performance: A contingency and configuration approach, *Journal of Operations Management*, vol. 28, no. 1, pp. 58-71, 2010.

Frazzon, E., Albrecht, A., Hurtado, P., de Souza Silva, L., and Pannek, J., Hybrid modelling approach for the scheduling and control of integrated production and logistic processes along export supply chains, *IFAC-PapersOnLine*, vol. 48, no. 3, pp. 1521-1526, 2015.

Frohlich, M., and Westbrook, R., Arcs of integration: an international study of supply chain strategies, *Journal of Operations Management*, vol. 19, no. 2, pp. 185-200, 2001.

Gjeldum, N., Mladineo, M., and Veza, I., Transfer of model of innovative smart factory to Croatian economy using lean learning factory, *Procedia CIRP*, vol. 54, pp. 158-163, 2016.

Hair, J., Tatham, R., Anderson, R., and Black, W., *Multivariate data analysis*, Pearson Prentice Hall, Upper Saddle River, NJ, 2006.

Hines, P., Holweg, M., and Rich, N., Learning to evolve: a literature review of contemporary lean thinking, *International Journal of Operations and Production Management*, vol. 24, no. 10, pp. 994-1011, 2004.

Jasti, N., and Kodali, R., Lean production: literature review and trends, *International Journal of Production Research*, vol. 53, no. 3, pp. 867-885, 2015.

Kagermann, H., Helbig, J., Hellinger, A., and 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.

Kampker, A., Deutskens, C., Heimes, H., Ordung, M., and Haunreiter, A., Using e-mobility as an enabler for a fast and lean product development to optimize the return of engineering with the example of Lithium-ion battery, *Procedia CIRP*, vol. 50, pp. 166-172, 2016.

Kolberg, D., Knobloch, J., and Züehlke, D., Towards a lean automation interface for workstations, *International Journal of Production Research*, forthcoming, pp. 1-12, 2016.

Koufteros, X., Vonderembse, M., and Jayaram, J., Internal and external integration for product development: the contingency effects of uncertainty, equivocality, and platform strategy, *Decision Sciences*, vol. 36, no. 1, pp. 97-133, 2005.

Krajewski, L., Malhotra, M., and Ritzman, L., *Operations management: Processes and supply chains*, New York: Prentice Hall, 2015.

Kull, T., Yan, T., Liu, Z. and Wacker, J., The moderation of lean manufacturing effectiveness by dimensions of national culture: testing practice-culture congruence hypotheses, *International Journal of Production Economics*, vol. 153, pp. 1-12, 2014.

Landscheidt, S., and Kans, M., Automation practices in Wood product industries: lessons learned, current practices and future perspectives, *Proceedings of the 7th Swedish Production Symposium SPS*, October 22-25, Lund, Sweden, 2016.

Lasi, H., Fettke, P., Kemper, H., Feld, T., and Hoffmann, M., Industry 4.0, *Business & Information Systems Engineering*, vol. 6, pp. 239-242, 2014.

Lee, J., Kao, H., and Yang, S., Service innovation and smart analytics for industry 4.0 and big data environment, *Procedia CIRP*, vol. 16, pp. 3-8, 2014.

Lewis, M., Lean production and sustainable competitive advantage, In *Supply Chain and Total Product Systems: a reader*, edited by Rhodes, E., Warren, J., Carter, R., Milton Keynes: The Open University, pp. 306-326, 2006.

Li, J., Tao, F., Cheng, Y., and Zhao, L., Big data in product lifecycle management, *The International Journal of Advanced Manufacturing Technology*, vol. 81, no. 1-4, pp. 667-684, 2015.

Marodin, G., Frank, A., Tortorella, G., and Saurin, T., Contextual factors and Lean Production implementation in the Brazilian automotive supply chain, *Supply Chain Management: An International Journal*, vol. 21, no. 4, pp. 417-432, 2016.

Marodin, G., Frank, A., Tortorella, G., and Fetterman, D., Lean production and operational performance in the Brazilian automotive supply chain, *Total Quality Management & Business Excellence*, (forthcoming), 2017.

Moyano-Fuentes, J., and Sacristán-Díaz, M., Learning on lean: a review of thinking and research, *International Journal of Operations & Production Management*, vol. 32, no. 5, pp. 551-582, 2012.

Naim, M., and Gosling, J., On leanness, agility and leagile supply chains, *International Journal of Production Economics*, vol. 131, pp. 342-354, 2011.

Porter, M., and Heppelmann, J., How smart, connected products are transforming companies, *Harvard Business Review*, vol. 93, no. 10, pp. 96-114, 2015.

Power, D., Supply chain management integration and implementation: a literature review, *Supply Chain Management: An International Journal*, vol. 10, no. 4, pp. 252-263, 2005.

Ray, G., Muhanna, W., and Barney, J., Information technology and the performance of the customer service process: A resource-based analysis, *MIS quarterly*, vol. 29, no. 4, pp. 625-652, 2005.

Rauch, E., Dallasega, P., and Matt, D., The way from lean product development (LPD) to smart product development (SPD), *Procedia CIRP*, vol. 50, pp. 26-31, 2016.

Sanders, A., Elangeswaran, C., and Wulfsberg, J., 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, 2016.

Schumacher, A., Erol, S., and Sihn, W., A maturity model for assessing Industry 4.0 readiness and maturity of manufacturing enterprises, *Procedia CIRP*, vol. 52, pp. 161-166, 2016.

Seppälä, P., and 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*, vol. 14, no. 2, pp. 157-180, 2004.

Shah, R., and Ward, P., Lean manufacturing: context, practice bundles, and performance, *Journal of Operations Management*, vol. 21, no. 2, pp. 129-149, 2003.
Shah, R., and Ward, P., Defining and developing measures of lean production, *Journal of Operations Management*, vol. 25, no. 4, pp. 785-805, 2007.
Shariatzadeh, N., Lundholm, T., Lindberg, L., and Sivard, G., Integration of digital factory with smart factory based on Internet of Things, *Procedia CIRP*, vol. 50, pp. 512-517, 2016.
Shrouf, F., Ordieres, J., and Miragliotta, G., Smart factories in Industry 4.0: a review of the concept and of energy management approached in production based on the Internet of Things paradigm, *Proceedings of 2014 IEEE International Conference on Industrial Engineering and Engineering Management*, Dec. 9-12, 2014, Bandar Sunway, Malaysia, pp. 697-701, 2014.
Soni, G., and Kodali, R., A critical review of supply chain management frameworks: proposed framework, *Benchmarking: An International Journal*, vol. 20, no. 2, pp. 263-298, 2013.
Stentoft, A., and Vagn, F., Evidence of lean: a review of international peer-reviewed journal articles, *European Business Review*, vol. 25, no. 2, pp. 174-205, 2013.
Tortorella, G., and Fettermann, D., Implementation of Industry 4.0 and lean production in Brazilian manufacturing companies, *International Journal of Production Research*, (forthcoming), 2017.
Tortorella, G., Marodin, G., Miorando, R., and 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*, vol. 78, no. 9-12, pp. 1879-1892, 2015.
Tortorella, G., Marodin, G., Fettermann, D., and Fogliatto, F., Relationships between lean product development enablers and problems, *International Journal of Production Research*, vol. 54, no. 10, pp. 2837-2855, 2016.
Tortorella, G., Miorando, R., and Tlapa, D., Implementation of lean supply chain: an empirical research on the effect of context, *The TQM Journal*, vol. 29, no. 4, pp. 610-623, 2017a.
Tortorella, G., Miorando, R., and Marodin, G., Lean supply chain management: Empirical research on practices, contexts and performance, *International Journal of Production Economics*, vol. 193, pp. 98-112, 2017b.
Vitasek, K., Manrodt, K., and Abbott, J., What makes a lean supply chain, *Supply Chain Management Review*, vol. 9, no. 7, pp. 39-45, 2005.

Biographies

Guilherme Luz Tortorella is Associate Professor in the Department of Production and Systems Engineering of the Federal University of Santa Catarina (UFSC), Florianópolis, Brazil. His Master in Production Systems and PhD in Production Engineering were earned from UFRGS. He also has several years of experience in the automotive industry with international activities in Mexico, England, USA, and Uruguay.

Rogério Feroldi Miorando is Associate Professor in the Department of Production and Systems Engineering of the Federal University of Santa Catarina (UFSC), Florianópolis, Brazil. He holds a master's degree and a PhD in Production Engineering from the Federal University of Rio Grande do Sul with postdoctoral studies at Politecnico di Milano, Italy. He has experience in the area of Production Engineering, with emphasis in Risk Analysis, Economic Analysis of Projects, Risk Analysis in Projects and Project Portfolio Management.

Carlos Ernani Fries is Associate Professor in the Department of Production and Systems Engineering of the Federal University of Santa Catarina (UFSC), Florianópolis, Brazil. Mr. Fries holds a Bachelor degree in Civil Engineering as well as a Master and PhD in Production Engineering from UFSC. He has taught courses in Operations Research applied to Manufacturing and Logistics, Decision Theory, Statistics and Forecasting Models among others. He is member of IEOM and INFORMS.

Alejandro Mac Cawley Vergara teaches at the Department of Industrial and Systems Engineering of Pontifical Catholic University of Chile. He holds a Master of Science in Engineering and Ph.D. of the Georgia Institute of Technology. He teaches and do research about agro-food chains, operations management, logistics, quantitative models applied to biological systems among others related to optimization.