Industry 4.0 as a moderator on the relationship between lean and operational performance

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Abstract

Due to both convergent and divergent characteristics of Industry 4.0 and Lean Production (LP), it is unclear whether their concurrent implementation may increase performance. This paper examines the moderating effect of Industry 4.0 on the relationship between LP and operational performance improvement within a developing economy. A survey was distributed among 147 Brazilian manufacturing companies that had implemented both LP and Industry 4.0. Findings indicate that, although LP's low setup practices enhance performance, its effect varies when Industry 4.0 practices are also adopted. Managers should thus carefully prioritize the parallel adoption of different bundles of Industry 4.0 and LP practices.

Keywords: Industry 4.0, Lean, Operational performance improvement

Introduction

Increasingly, the fourth industrial revolution is in the spotlight of researchers, economic policy-makers and manufacturers (Liao et al., 2017). During the German 2011 Hannover Fair, this new production era was labelled as "Industry 4.0" (Liao et al., 2017); it stands for an industry characterized by connected machines, smart products and systems, and inter-related solutions (Tortorella and Fetterman, 2017). This involves implementing integrated computer and/or digital components that monitor and control the physical devices, sensors, Information and Communication Technologies (ICT) and internet-of-things applications (Lasi et al., 2014). Despite its growing notoriety, many companies are still struggling with how Industry 4.0's high-tech practices should be implemented into their operations (Sanders et al., 2016; Sanders et al., 2017; Erol et al., 2016). The feasibility and effectiveness of integrating Industry 4.0 technologies into existing production systems is still understudied (Kolberg et al., 2017). Especially in the case of manufacturing companies located in developing economies, overall lower technological intensity, restricted investment capital and human resources may undermine Industry 4.0 adoption. This raises different challenges for developed economies such as Brazil, Mexico and India, which seek to invest in Industry 4.0 (Brazil's National Confederation of Industry, 2016; Forbes India, 2016; Mexican Ministry of Economy, 2016).

Lean Production (LP), however, is common practice among several industries and countries: It entails a constant focus on reducing wasteful activities while also improving productivity and quality as seen from the customers' perspective (Junior and Godinho Filho, 2010; Kroes et al., 2018; Narayanamurthy et al., 2018; Soliman et al., 2018). Implementing LP successfully requires a human-centered, low-tech organizational change approach which involves the adoption of various LP practices (Bortolotti et al., 2015; Soliman et al., 2018), a consistent, shared strategic vision with an aligned HR policy, and highly involved employees who have enough resources for continuous process improvement (Van Dun and Wilderom, 2012). Many lean initiatives start at the shop floor (Shah and Ward, 2007), after which LP principles are gradually introduced in other units as well as at the corporate level (Hines et al., 2004; Mann, 2005).

Due to both convergent and divergent characteristics of Industry 4.0 technologies and LP practices, it remains unclear whether their concurrent implementation of Industry 4.0 practices in lean manufacturing systems may lead to increased performance. On the one hand, lean entails an underlying organizational culture in which problems and abnormalities become opportunities for everyone (Bortolotti et al., 2015; Narayanamurthy et al., 2018). This psychologically safe shop-floor culture enables the clear identification of process status quos and information sharing (Van Dun and Wilderom, 2012; 2016), which may be further reinforced by the interconnectivity and data acquisition and analysis inherent to Industry 4.0 technologies (Sibatrova and Vishnevskiy, 2016). On the other hand, LP entails socio-cultural changes that are stimulated daily through fast and simple work-floor experimentations (Dora et al., 2016), which may conflict with the high levels of capital expenditure and technological expertise demanded by Industry 4.0 (Lasi et al., 2014). These conflicts may occur especially when Industry 4.0 practices are implemented in lean production systems in a developing economy context but empirical evidence for this assumption is still lacking (Gjeldum et al., 2016; Landscheidt and Kans, 2016); Kolberg et al., 2017). Further, contradictory evidence found in the literature (e.g. Erol et al., 2016; Schumacher et al., 2016; Sanders et al., 2016) suggests a clear need to enhance our collective understanding. This study thus answers the question: *How can both LP practices and Industry 4.0 technologies converge to improve operational performance in a developing economy context?*

Literature review and hypotheses

We examined the association of the three most prominent, internally-related LP elements, namely pull, flow and low setup (Shah and Ward, 2007), with Industry 4.0 and operational performance improvement.

Pull practices and Industry 4.0

Pull practices aim at facilitating Just-In-Time production so that companies produce the required units on time and in the required quantities (Ohno, 1988). This includes kanban cards, which serve as signals to start or stop production. The successful implementation of pull is highly dependent on effective information flow in order to assure that internal and/or external customers' demands are known, avoiding overproduction due to misinterpretations or erroneous production triggers (Netland et al., 2015).

The incorporation of modern ICT into pull systems or kanban systems has been denoted as e-kanban i.e., digitalization of the conventional kanban cards (Junior and Godinho Filho, 2010). The e-kanban allows the immediate detection of missing or empty bins, triggering automatic replenishment. The implementation of conventional physical kanban systems is usually undermined due to card losses during their loops between workstations or facilities, entailing mistakes in production control and, hence, negatively affecting operational performance (Marodin et al., 2015). Furthermore, adjustments to kanban inventory policies due to changes in batch sizes, market demands, work plans or cycle times tend to be much easier if ICT systems are incorporated into the pull system. However, the sole adoption of ICT (without effectively implemented pull systems) may facilitate the usual pushed systems and their underlying processes, but might not entail benefits for operational performance. Hence, our hypothesis:

H1. The adoption of Industry 4.0 technologies positively moderates the effect of pull practices on operational performance improvement.

Flow practices and Industry 4.0

Lean's principle of creating flow focuses on establishing mechanisms that enable and ease the achievement of a continuous production stream. According to Rother and Harris (2001), creating continuous flow is the ultimate objective of LP. Flow practices encompass improvements such as the definition of product families according to similar routines, layout arrangements planned according to these product families and balancing workstation cycle times (Doolen and Hacker, 2005). While providing inventory level and lead time reductions, flow ensures that production and quality issues are visible to all employees. Thus, its implementation is deemed to be beneficial to a company's operational performance (Duggan, 2012). However, if high levels of process stability are not achieved, implementing continuous flow can cause unwanted side-effects, such as loss of deliveries and increased costs (Dora et al., 2016).

In this sense, Industry 4.0 is argued to increase process and product connectivity and interaction, thereby enabling more efficient manufacturing (Hermann et al., 2016; Ganzarain and Errasti, 2016). Thus, enhanced interconnection and communication between cells and workstations may provide flexible, fast and high-quality material flow (Hermann et al., 2016; Erol et al., 2016). Such an improved material flow may facilitate the practical feasibility of continuous flow implementation. However, the lack of evidence of concurrent implementation of continuous flow and Industry 4.0 technologies hampers the verification and validation of the convergence of both approaches. Therefore, while there is an indication of a positive relationship between these approaches, little empirical evidence has been provided to confirm such association. So, we hypothesize:

H2. The adoption of Industry 4.0 technologies positively moderates the effect of flow practices on operational performance improvement.

Low setup practices and Industry 4.0

As customers' needs diversify, the product assortment also increases, and this entails the need to reduce batch sizes. Hence, high changeover times become an obstacle to high performance (Doolen and Hacker, 2005; Stone, 2012). Toyota popularized the 'single-minute exchange of die' (SMED) concept, in which changeover times are drastically reduced to enable smaller batches and shorter lead times (Shingo, 1988). In this context, 'low setup' comprises practices that aim at reducing process downtime between product changeovers. The full adoption of low setup practices is seen to improve the flexibility and agility in production delivery, since shorter setup times allow reductions on production batch sizes (Furlan et al., 2011). Furthermore, inventory levels are also likely to be reduced, which directly affects the organization's cash flow (Maskell et al., 2011).

A reduction in complexity by strict modularization is one of the main objectives of Industry 4.0. Plug'n'Produce and distributed systems are equipped with self-optimizing and machine-learning behaviours, allowing companies to adapt machines according to products and produce small batch sizes (Brettel et al., 2014; Sanders et al., 2016). Therefore, increased levels of automation and changeability tend to provide production flexibility, which likely reinforces the benefits of implementing low setup practices. However, empirical evidence of such synergy is still scarce and only conceptual assumptions are found in the literature. Therefore, we propose:

H3. The adoption of Industry 4.0 technologies positively moderates the effect of low setup on operational performance improvement.

Method

We targeted respondents from Brazilian manufacturing companies with experience in both lean and Industry 4.0 technologies. As few companies generally fit these criteria (Marodin et al., 2016; Tortorella and Fettermann, 2017), our sample included companies from different industrial sectors. We sent the survey to the 162 leaders of Brazilian manufacturing companies who were former students of four different executive education courses on lean offered by a large Brazilian University during 2017 (in February, April, July and September). 157 of them returned the survey. Because 10 responses were removed due to missing data, the response rate was 90.7%. Most of the 147 respondents were from large companies (55.1%); most of the companies belonged to the metal-mechanical sector (49.6%). 65.9% were involved in the first and second tiers. Regarding companies' technological intensity, 53.7% were categorized as high or medium-high, as indicated by the Brazilian National Confederation of Industry (2016). With regards to LP implementation, most companies (55.1%) had started their formal implementation more than 2 years ago although the majority (53.7%) of respondents' personal experience with LP was less than 2 years. Finally, 42.2% of the respondents were either engineers or analysts, 36.0% supervisors or coordinators and 21.8% managers or directors.

Measures, construct validity and reliability

We assessed the *operational performance improvement* during the last three years according to five process- and people-related indicators (Bhasin, 2012): 1) productivity; 2) delivery service level; 3) inventory level; 4) quality; and 5) safety. Each indicator was measured on a five-point scale (1 = worsened significantly; to 5 = improved significantly). A Principal Components Analysis (PCA) with varimax rotation showed that all five indicators loaded on one factor, with an eigenvalue of 3.259 explaining 65.1% of the variation (Table 1). Its Cronbach alpha was 0.80.

Table 1 – PCA results for operational performance improvement indicators

Performance indicators	Factor1
Productivity	0.590
Delivery service level	0.792
Inventory level	0.858
Quality (scrap and rework)	0.802
Safety (accidents)	0.707
Eigenvalues	3.259
Initial percent of variance explained	0.571
Rotation sum of squared loadings (total)	2.854
Percent of variance explained	0.651
Cronbach's alpha	0.800

N = 147. Extraction method: principal component analysis. Rotation method: varimax with Kaiser normalization.

The adoption level of *lean practices* related to the pull, flow and low setup constructs was assessed via Shah and Ward's (2007) 11 items which had been translated into

Portuguese. Each practice, given as a statement, was evaluated according to a Likert scale that ranged from 1 (fully disagree) to 5 (fully agree). A Confirmatory Factor Analysis (CFA) using the lavaan package of the R programming language was done to confirm the convergent validity and unidimensionality of the three constructs, as presented in Table 2. First, the three CFA models were estimated, one for each construct: All factor loadings surpassed the threshold value of 0.45. We then re-assessed each CFA model; the results indicated an adequate fitness of the models using the chi-square test ($\chi 2$/df), Comparative Fit Index (CFI) and Root Mean Square Errors of Approximation (RMSEA). As thresholds, we used CFI values greater than 0.90 combined with RMSEA values greater than 0.10, resulting in the minimizing of the sum of the type I and II error rates of the CFA model, as suggested by Hu and Bentler (1999) for sample sizes lower than 250 observations. All items loaded satisfactory on their constructs (> 0.45, $p < 0.01$) with good Cronbach alpha's.

Table 2 – LP operational constructs, measures and CFA factor loadings

Construct	Survey item	Coef.	χ^2/df	CFI	RMSEA
Pull	Production is pulled by the shipment of finished goods	0.945	21.885/2	0.941	0.260
	Production at stations is pulled by the current demand of the next station	1.073			
	We use a pull production system	1.158			
	We use Kanban, squares, or containers of signals for production control	0.845			
Flow	Products are classified into groups with similar processing requirements	0.883	16.720/2	0.944	0.223
	Products are classified into groups with similar routing requirements	0.953			
	Equipment is grouped to produce a continuous flow of families of products	0.857			
	Families of products determine our factory layout	0.933			
Low setup	Our employees practice setups to reduce the time required	0.669	10.769/2	0.949	0.172
	We are working to lower setup times in our plant	0.747			
	We have low set up times of equipment in our plant	0.795			

Table 3 – PCA results for Industry 4.0 technologies

Industry 4.0 technologies focus	Industry 4.0 technologies	Average	Std. Dev.	Principal Components Factor_1	Factor_2
Process	i_1_non_sens_autom	2.63	1.22	**0.483**	0,133
	i_2_sens_autom	2.74	1.28	**0.810**	0,305
	i_3_remote	2.43	1.34	**0.781**	0,295
	i_4_prod_operationID	2.30	1.30	**0.748**	0,340
	i_5_integratedPD&Manuf	2.46	1.27	**0.562**	0,424
Product/Service	i_6_3Dprinting	2.01	1.18	0.416	**0.464**
	i_7_simulation	1.94	1.20	0.268	**0.505**
	i_8_big_data	2.27	1.28	0.268	**0.732**
	i_9_cloud	2.16	1.24	0.178	**0.820**
	i_{10}_services	2.10	1.22	0.383	**0.599**
	Eigenvalues			2.256	1.085
	Initial percent of variance explained			0.509	0.118
	Rotation sum of squared loadings (total)			2.871	2.529
	Percent of variance explained			0.287	0.253

N = 147. Extraction method: principal component analysis. Rotation method: varimax with Kaiser normalization. Bartlett's test of sphericity (Chi square) = 196.51; Kaiser-Meyer-Olkin factor adequacy = 0.74

Table 4 – Correlation matrix

Variables	1	2	3	4	5	6
1- Pull	-					
2- Flow	0.667**	-				
3- Low setup	0.634**	0.784**	-			
4- Process-related technologies	0.258**	0.368**	0.401**	-		
5- Product/service-related technologies	0.319**	0.291**	0.348**	0.143*	-	
6- Operational performance improvement	0.356**	0.423**	0.505**	0.381**	0.216**	-
7- Technological intensity	-0.188**	-0.147	-0.192*	-0.077	-0.164*	-0.164*
Cronbach's alpha	0.871	0.850	0.770	0.810	0.800	0.860
Composite reliability	0.881	0.855	0.784	0.842	0.807	0.867

**$p < 0.01$ level (2-tailed); *$p < 0.1$

Regarding *Industry 4.0 technologies*, 10 items were formulated based on the ten most adopted digital technologies by Brazilian manufacturing companies, as suggested by the Brazilian National Confederation of Industry (2016). The degree of adoption was measured by a 5-point Likert scale ranging from 1 (not used) to 5 (fully adopted). A principal component analysis (PCA) with varimax rotation was used to extract orthogonal components. Two components were extracted: 1) Process-related and 2) Product/Service-related technologies (see Table 3). Similar results were obtained using oblique rotation as a check for orthogonality. Additionally, we verified the unidimensionality of each component by applying PCA at the component level. All components displayed high reliability, with alpha values above 0.80.

Data analysis

Non-response bias was analysed on each of the four executive education classes using Levene's test for equality of variances and a t-test for the equality of means (Armstrong and Overton, 1977). There were no significant differences in means and variation in the four groups ($p < 0.05$). This indicates that our sample did not differ significantly from the rest of the population.

Following Podsakoff and Organ (1986) and Podsakoff et al. (2003) we took various countermeasures to curb the effects of common method and source bias. First of all, we separated the dependent variable items from the independent variables that were placed at the very end of the survey. We also clarified that the responses would be treated anonymously and that there was no right or wrong answer. Finally, Harman's single-factor test, with all independent and dependent variables, resulted in a first factor that included only 23.5% of the variance. Hence, common method variance was not a problem in our dataset (Malhotra et al., 2006). Consequently, we performed a set of Ordinary Least Square hierarchical linear regression models to test our hypotheses.

Results

As shown in Table 4, all independent variables correlated positively with operational performance improvement. Technological intensity was negatively correlated with pull and low setup practices as well as product/service-related technologies.

Regression results with operational performance improvement as the dependent variable are shown in Table 5. The variance inflation factors (VIFs) in the regressions models were all < 3.0, suggesting that multicollinearity was not a concern. The results show that the addition of both the independent variables (Model 2) and the interaction terms (Model 3) led to an incremental improvement of the model (i.e., the Change in Adj. R^2 was significant in both stages). Therefore, Model 3, which explains 30.1% of the variance ($F = 6.277$; $p < 0.01$), shows that the addition of the interaction terms significantly improved the prediction capacity of operational performance improvement, as indicated by the Change in Adj. R^2.

Surprisingly, from the three LP constructs investigated, only low setup presented a significant positive association ($\beta = 0.291$; $p < 0.05$) with operational performance improvement. This finding contradicts previous research which showed the influence of LP practices on operational performance (e.g. Shah and Ward, 2003; Shah and Ward, 2007; Taj and Morosan, 2011). However, in the Brazilian manufacturing context, the effect of pull and flow practices do not seem to be as pervasive as in other contexts. Saurin et al. (2010), Tortorella et al. (2015), Marodin et al. (2016) and Tortorella et al. (2017), already stressed that LP implementation in Brazilian manufacturing companies is shallow and most companies are still struggling to implement practices that are focused on providing minimum process stability.

Table 5 – Ordinary Least Squares regression results

Variables	Operational performance improvement Model 1	Model 2	Model 3
Technological intensity (control)	-0.184	-0.081	-0.108
Pull		0.041	0.038
Flow		0.020	0.072
Low setup		0.367***	0.291**
Process		0.218***	0.244***
Product/Service		0.037	0.032
Pull *X* Process			-0.096
Flow *X* Process			0.117
Low setup *X* Process			-0.295**
Pull *X* Product/Service			-0.031
Flow *X* Product/Service			0.284**
Low setup *X* Product/Service			-0.127
F-value	2.640	10.080***	6.277***
R^2	0.018	0.300	0.360
Adjusted R^2	0.011	0.270	0.303
Change in Adj. R^2	-	0.259	0.033*

N =147. Unstandardized regression coefficients are reported. Change in Adj. R^2 reports results compared with the previous model.
*p < 0.10; **p < 0.05; ***p < 0.01

Furthermore, a direct effect of Industry 4.0 technologies was observed for the process-related technologies. These are primarily related to improving and facilitating manufacturing processes and appear to have a positive relationship with operational performance improvement ($\beta = 0.244$; $p < 0.01$). On the other hand, the product/service-related technologies, which mainly focus on supporting and enhancing product development and service innovation, do not show a significant direct effect on performance improvement. Such a finding may be justified by the fact that manufacturing companies located in emerging countries usually present a lower capital expenditure capacity than those in more developed economies.

However, when the interaction terms are taken into consideration, process-related technologies seem to moderate the effect of low setup negatively ($\beta = -0.295$; $p < 0.05$). These results are contrary to common belief, which suggests that Industry 4.0 technologies that are primarily focused on manufacturing process should positively reinforce the relationship between (lean) management practices and operational performance indicators (Subramaniam et al., 2009; Dworschak and Zaiser, 2014). Our results do not bear such moderating assumption. One explanation is that, although both low setup practices and process-related technologies seem to positively affect performance when analysed separately, Brazilian companies may not understand yet how to benefit from their concurrent adoption. As indicated by Landscheidt and Kans (2016), the isolated initiative of investing in cutting-edge technology, without dealing with systemic process improvement and design, does not imply better operational performance. In other words, the incorporation of an acknowledged technology into ill-structured manufacturing processes will not give the expect results.

In turn, technologies related to products or services appear to positively moderate the relationship between flow and operational performance improvement ($\beta = 0.284$; $p < 0.05$). In fact, if product development and service innovation are properly supported by these Industry 4.0 technologies, it is reasonable to expect a positive impact on the effect of flow practices, through the reduction of time-to-market and, hence, a more reliable flow of value. Furthermore, an assertive prototyping and integrated design and commissioning approach may anticipate manufacturing issues due to the availability, processing and analysis of big data (Hermann et al., 2016). These technologies might support problem-solving activities and thereby enable continuous flow strategies.

Conclusions

With the advent of the fourth industrial revolution, the concurrent implementation of LP acquires special importance. Lean's principles and practices are likely to become more relevant as the new industrial revolution makes it possible to understand better the structure of customers' demand and to speed up the process of data exchange and information. A major theoretical contribution is the evidence that purely technology adoption does not lead to the expected results. LP practices help to install organizational habits and mindsets that favour systemic process improvements. Although LP may impact performance at a certain level, its effect might change when Industry 4.0 practices are implemented simultaneously. In other words, the socio-technical organizational changes that coincide with LP reinforce practices and behaviours that, when combined properly with today's high-technological advancements, enable companies to successfully compete.

As companies continue to focus on implementing efficient and economic ways of doing business, there will be an ever-increasing appetite for incorporating novel technologies, such as the ones from Industry 4.0. Industry 4.0 is claimed to provide higher performance levels, while creating new business models and services. However, its adoption entails additional challenges to companies, especially for those in emerging economies. Therefore, our findings provide managers and practitioners with an indication of the right balance between the adoption of Industry 4.0 technologies and LP practices for driving operational performance improvement within their companies. In fact, our study provides arguments to support manager's decision-making processes: If they have many flow-related LP practices in place, they should prioritize the adoption of product/service-oriented technologies such as cloud services, internet-of-things, or big data analysis, in order to achieve high operational performance levels.

There are some limitations, due to the nature of the sample used in the survey, that must be highlighted. First, the respondents were mostly from companies located in Southern Brazil; their answers might be linked to regional issues, where the spread of lean may have come under local influences. Second, the sample size effectively confirmed only some of the hypothesized moderating effects of Industry 4.0 on the effects of LP practices implementation. Although we took various countermeasures to curb any bias, our cross-sectional study is based on a single method and source. Future, longitudinal studies must try to collect more objective output measures or involve front-line supervisors in the rating of local lean and Industry 4.0 practices. Nevertheless, this exploratory study provides important evidence for the need to develop more structured models that should be tested empirically, and longitudinally, with larger samples.

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