Received 29 November 2019
Revised 11 February 2020
Accepted 23 February 2020

QUALITY PAPER

Quality and lean practices synergies

A swift even flow perspective

George Onofrei
Department of Business, Letterkenny Institute of Technology, Letterkenny, Ireland
Brian Fynes
University College Dublin, Dublin, Ireland
Hung Nguyen
RMIT University, Melbourne, Australia, and
Amir Hossein Azadnia
Department of Business, Letterkenny Institute of Technology, Letterkenny, Ireland

Abstract

Purpose – The purpose of this study is to investigate the relationship between investments in quality and lean practices, and their impact on factory fitness. Using concepts originating in the theory of swift even flow, this study asserts that manufacturers, in order to improve their production swiftness and evenness, must leverage the potential synergetic effects between quality and lean practices.

Design/methodology/approach – This research uses data from the Global Manufacturing Research Group (GMRG) survey project (with data collected from 922 manufacturing plants, across 18 countries). The constructs and measurement model were assessed using confirmatory factor analysis (CFA) and the hypotheses were tested using ordinary least square (OLS) models.

Findings – This study highlights that both investments in quality and lean practices have direct impact factory fitness. The results provide insights into the efficacy of the investments in manufacturing practices and their role in augmenting the operational performance. The investments in quality practices were found to enhance the efficacy of investments in lean practices, which in turn impact the factory fitness.

Practical implications – From a practical perspective, the study informs managers on how to leverage investment in quality practices to enhance the impact of lean practice on performance. The results provide empirical evidence to support management decision-making concerning the development of competences in quality and lean practices, which may create competitive advantage.

Originality/value – This study contributes to the quality and lean literature and provides empirical evidence of the synergetic effects between investments in quality and lean practices. The analysis offers a greater understanding of the mechanisms that can be used to maximise the impact of investments in lean practices, from a global perspective. The findings are important to the advancement of theory in operations management, as it integrates three research streams: quality practices, lean practices and swift even flow research.

Keywords Quality practices, Lean Practices, Factory fitness, Operational performance

Paper type Research paper

1. Introduction

Manufacturing strategy has been identified as a formidable weapon to achieve competitiveness. Skinner (1969, p. 140) stated ‘manufacturing is part of the strategic concept that relates a company’s strengths and resources to opportunities in the market’. Manufacturing policy must stem from the corporate strategy and support it through a consistent pattern of decisions and trade-offs on competitive priorities (Garrido *et al.*, 2007; Zhang and Sharifi, 2007). The main challenge is in examining and explaining under which conditions and how these ‘patterns of decisions’ create competitive advantage (Kulkarni *et al.*, 2019). These decisions or choices that manufacturing companies consider are represented through the investments in manufacturing practices (Da Silveira and Sousa,

0265-671X
DOI 10.1108/IJQRM-11-2019-0360

2010; Arana-Solares *et al.*, 2019; Basu *et al.*, 2020). The literature debates whether these manufacturing practices represent a set of decisions that companies need to make based on either (1) trade-offs (e.g. cost versus flexibility, quality versus cost) or (2) whether they can be pursued in specific progression or cumulatively (Ferdows and De Meyer, 1990; Boyer and Lewis, 2002). More recently, the theory of swift even flow has been proposed as an emergent theory, underpinning manufacturing strategy (Schmenner, 2012; Devaraj *et al.*, 2013), providing a more holistic view on operational capabilities. The main focus of the theory is on speeding up the flow of materials along the factory by aiming to reduce the 'variability associated with the flow, be that variability associated with quality, quantities or timing' (Schmenner, 2004, p. 335). Ferdows and Thurnheer (2011) introduced the term 'factory fitness' within the context of production systems that become leaner when it reduces waste and non-value adding activities and fitter when it improves and expands its core capabilities. Factories, like athletes, can become fitter by taking certain decisions that add competitive value. Factories, in order to achieve production fitness, must improve the speed of material flow and reduce overall variability associated with their processes.

The view that lean manufacturing yield superior operational performance has been widely researched (Negrão *et al.*, 2017; Garza-Reyes *et al.*, 2018; Alexander *et al.*, 2019; Kumar *et al.*, 2019; Onofrei and Fynes, 2019; Sfakianaki and Kakouris, 2019); however, little research has been done on the role of quality practices in the effectiveness of lean practices and their synergetic impact on factory fitness. Wiengarten *et al.* (2013) highlighted the importance of investments in quality practices in the successful implementation of lean practices. In line with other studies (Patyal and Koilakuntla, 2015; Basu *et al.*, 2018; Asif, 2019), their results assert that quality practices impact plant performance and need to be considered when implementing lean practices.

Nicholas (2016) found that quality and lean practices can be implemented effectively in isolation; however, their combination further improves plant performance. Most of the studies tend to focus on the implementation of one set of practices (lean or quality), without considering the complementarity or interactions between them (Garza-Reyes *et al.*, 2015).

Psomas and Antony (2019) highlighted that further research into lean practices efficacy is required and that a more holistic perspective needs to be considered. This concurs with the study by Antony *et al.* (2019), which highlights the need for more systematic research in lean implementations from a global perspective. Therefore, this study attempts to fill this gap by exploring the following research questions:

RQ1. To what extent investments in quality and lean practices impact the factory fitness?

RQ2. How do investments in quality practices affect the relationship between investments in lean practices and factory fitness?

These questions will guide the investigations in this study. The remainder of the paper is structured as follows: first, we review the literature related to factory fitness, lean practices and quality practices, which will lead to the development of hypotheses. The following section presents the research methodology. Then, it follows the presentation of the results, discussion and conclusions.

2. Theoretical background and hypotheses development

2.1 Swift even flow theory

The term 'factory fitness' was coined by Ferdows and Thurnheer (2011) as the ability of a production system to reduce its waste and non-value adding activities, and expand its core capabilities. The concept is closely related to the term 'lean' and 'agile'; however, it provides a more holistic view of the development of production capabilities (Onofrei and Fynes, 2019). This idea that factories can build upon their fitness is new and no definition has been yet articulated. Therefore, in this study, using the theory of swift even flow as theoretical lens, we propose that similarly to the physical fitness, factory fitness refers to the production system ability to maintain over a period of time low levels of variation while improving the flow speed in their processes. The theory of ‘swift even flow (SEF)’ holds that the performance for any production system ‘rises with the speed by which materials flow through the process, and it falls with increases in the variability associated with the flow’ (Schmenner and Swink, 1998 , p. 102). This theory unifies five well established production principles: variability (Conway *et al.*, 1988; Kannan and Palocsay, 1999), bottlenecks (Goldratt, 1990), scientific methods (Box, 1994), quality (Deming, 1988; Gryna and Juran, 2001) and factory focus (Pesch and Schroeder, 1996).

The variability principle focuses on the benefits that reductions in process variability can exert on the process throughput (Conway *et al.*, 1988; Kannan and Palocsay, 1999). Process variability may be due to the lack of process or product standardisation. Liu *et al.* (2006) noted that product variance was critical to manufacturing firm’s ability to engage in mass production. The variability can be defined as a decrease in uniformity (Spearman and Hopp, 2008, p. 308) which may be a consequence of randomness (e.g. unpredictable demand for products) or planned variation (e.g. the number of products on a line, ‘out of control’ machines – breakdowns). The second principle is focusing on bottlenecks and states that an operation’s productivity is improved by eliminating or managing its bottlenecks (Goldratt, 1990). A bottleneck or a constraint is defined as ‘anything that limits a system from achieving a higher performance versus its goal’ (Goldratt, 1990, p. 4). Examples of constraints limiting throughput include machine breakdowns, missing materials, quality problems and worker absenteeism (Blackstone and Cox, 2002). Watson *et al.* (2007) state that ‘within each system at least one constraint exist that limits the ability of the system to achieve higher level of performance relative to its goal’. Therefore, maximum utilisation of the constraint should lead to maximum output from that process. The third principle is based on scientific methods, which states that the rate of improvement can be augmented by applying scientific methods (Box, 1994). This represents means by which non-value-added motions and processes are removed from the production of goods or services. These methods involve statistics or mathematical models, which aid in the identification of non-value-added work and impact the number of bottlenecks in operations (Schmenner and Swink, 1998). The quality principle is widely recognised (Deming, 1988). Process flow can be adversely affected by quality problems and for a given throughput level, rework increases the cycle time of a process (Spearman and Hopp, 2008), therefore the overall productivity of a production line.

The last principle is factory focus and asserts that factories focusing on a limited number of products/processes will be more productive than similar factories with a broader array of tasks (Pesch and Schroeder, 1996). By grouping similar products together, the production flow of materials is exposed and permits the identification of bottleneck and of non-value-added work facilitating their removal. Taking in consideration the principles that underpin the theory of SEF, we conceptualise factory fitness using two elements: production swiftness (refers to throughput speed, cycle and delivery time of a production process) and production evenness (represents the variability in quality associated with that process at pre, during and post processing stages).

2.2 Lean practices impact on production swiftness and evenness

Lean was introduced as a description of Toyota manufacturing systems (Krafcik, 1988), and it has been described from two points of view (Shah and Ward, 2007). Firstly, lean represented a philosophy related to principles (Womack *et al.*, 1996) and secondly, from a practical perspective, as a set of manufacturing practices or tools (Shah and Ward, 2003; Demeter and Matyusz, 2010; Bortolotti *et al.*, 2015). Antony *et al.* (2019) recently conducted a review of lean tools used in healthcare and found eleven common factors that motivate the use of lean in organisations. Amongst these factors, six of them were related to standardisation, streamlining, operational time, process design, waste and efficiency. These factors are the focus of common practices associated with lean manufacturing, such as setup time reduction (Saravanan *et al.*, 2018; Curado, 2019), process redesign (Al-Salim and Choobineh, 2009; Keil *et al.*, 2011; Bergenwall *et al.*, 2012), cellular manufacturing (Angra *et al.*, 2008; Safaei *et al.*, 2010), throughput time reduction (Muthiah *et al.*, 2008, Van Der Heijden *et al.*, 2012) and factory automation (Muthiah *et al.*, 2008; Figueiredo and Martins, 2010).

The benefits and effects of the investments and implementation lean practices on the operational performance have been widely researched (Piercy and Rich, 2015; Negrão *et al.*, 2017; Psomas *et al.*, 2018; Onofrei *et al.*, 2019; Raju and Antony, 2019; Rodgers and Antony, 2019; Sfakianaki and Kakouris, 2019).

For example, Cakmakci (2009) found that setup time reduction positively impacts the operational performance and is suitable practice not only for manufacturing improvement but also for equipment design development. Saravanan *et al.* (2018) results indicate the setup-time reduction improves productivity by reducing the equipment downtime.

Factory automation has been portrayed as an important enabler in productivity improvement decision (Muthiah *et al.*, 2008). The use of automated systems provides real-time feedback to management with regards its design versus actual performance. Investments in factory automation lead to improvements in customer service and responsiveness (Kärkkäinen and Holmström, 2002). Fahmi and Hollingworth (2012) argued that throughput-time reduction practice positively influences the operational performance and facilitates the successful implementation of lean systems. Similarly, Van Der Heijden *et al.* (2012) study cited that reduction of throughput time lead to improved product availability and reduction inventory associated costs. Successful process redesign can be achieved through application of task composition, task elimination and use of new technologies (Netjes *et al.*, 2009). Recent studies (Fredendall *et al.*, 2009; Devaraj *et al.*, 2013) documented the important role that process redesign practices play in improving production flows, and the positive impact on efficiency and cost reduction. Bhat *et al.* (2020) investigated the impact of lean six sigma tools on workflow and resource consumption in Indian hospitals, and found common tools such as control charts, waste analysis, value stream mapping and process design have a positive impact on the performance of healthcare systems. Therefore, we posit the following hypotheses:

H1a. Investments in lean practices are associated with improvements in production swiftness.

H1b. Investments in lean practices are associated with improvements in production evenness.

2.3 Quality practices impact on production swiftness and evenness

Quality practices have been presented throughout the literature as a multifaceted concept, that focuses on quality wide improvement principles within the organisation (Asif, 2019; Basu *et al.*, 2020). There is a plethora of studies that explored their impact on operational performance (Asif, 2019; Kaur *et al.*, 2019; Khan *et al.*, 2019; Onofrei and Fynes, 2019; Shokri and Nabhani, 2019). However, some studies (Flynn *et al.*, 1995; Kaynak, 2003) argue that quality practices are not a source of competitive advantage and might not impact the operational performance. For example, Heras-Saizarbitoria (2018) reports mixed performance results with regards to quality standards, while Wiengarten *et al.* (2018) found no link between implementation of ISO 9001 and improvements in quality performance. Some researchers (Han and Chen, 2007; Kim *et al.*, 2011), state that implementation of certification standards is expensive, takes time and has no tangible effect on performance. Elshaer and Augustyn (2016) state that not all quality practices are positively associated with competitive advantage. Moreover, Nair (2006)'s meta-analysis study reported no association between quality practices (i.e. quality data analysis, product design, process management) and product quality.

Basu and Bhola (2016) used a sequential exploratory mixed method approach to explore and identify the contextual quality management practices (QMP) used in Indian SMEs. The study empirically examined the QMP impact on performance and the results show that all three dimensions of QMP identified have a positive impact on quality performance. Zu (2009) examined the impact of quality practices on operational performance and reported that companies that allocate resources to implement quality practices, outperform their competitors. Practices, such as statistical tools and simulations improve the controlling and monitoring process for quality measures (Colledani and Tolio, 2009). Significant impact of the use of statistical process control, has been cited particularly in management of production systems and improving process responsiveness (Da Silveira and Sousa, 2010).

Garza-Reyes *et al.* (2015) have highlighted the importance of the supplier relationship management in the successful implementation of quality practices. The purpose of this relationship is to develop common systems, to improve quality at source, minimise communication errors, and reduce inventory and duplication in inspection (Kull *et al.*, 2013).

Specifically, supplier integration and certification are commonly used by major automotive OEM's (such as Toyota and Honda) in order to achieve improvements in performance at the operational and supply chain level (Liker and Choi, 2004).

Recent studies (Antony, 2018, Haerizadeh and Sunder, 2019, Madhavan and Gurumurthy, 2019, Rodgers and Antony, 2019, Sunder *et al.*, 2019) have shown that firms implementing six sigma practices, have developed and enhanced a culture of continuous progress with significant operational improvements efforts. These companies tend to be more efficient, generate less waste and develop unique capabilities that outperform their competitors. Jiménez-Jiménez *et al.* (2020) surveyed Spanish CEOs and found a curvilinear effect between total quality management practise and innovation, which can be turned into operational improvements. Although some studies reported mixed results on the impact of quality practices, the overall literature consensus is that investments in quality practices can be viewed as a strategic initiative, which will generate value and offer enhanced operational performance. Therefore, we posit that:

H2a. Investments in quality practices are associated with improvements in production swiftness.

H2b. Investments in quality practices are associated with improvements in production evenness.

2.4 Moderating role of quality practices

Most studies investigate the impact of quality practices (as individual or as a set) on operational performance, however very few take in consideration the synergetic effects that can be achieved when implemented alongside others, such as lean or environmental practices (Wiengarten *et al.*, 2013). Narasimhan *et al.* (2006) found that lean high performing companies tend to focus on quality practices and their cumulative effect contributes directly to manufacturing performance enhancements. Recent studies (Negrão *et al.*, 2017; Psomas *et al.*, 2018; Onofrei and Fynes, 2019; Psomas and Antony, 2019; Rodgers and Antony, 2019) have argued that lean and quality practices are co-dependent and firms implementing both sets of practices outperform those applying only one of them. The mutual support of these practices generates superior plant performance. Garrido *et al.* (2007) shows empirically that quality practices were paramount to the overall success of the operations strategy. Hung *et al.* (2010) investigate the impact of knowledge management and quality management on innovation performance. The results show that quality management practices act as a conduit, in the knowledge management's impact in innovation. Wiengarten *et al.* (2013) indicate that complementary effects between lean, quality and environmental practices are possible. Similarly, Fahmi and Hollingworth (2012) found that in addition to the primary effects of lean and total quality management practices, they tend to reinforce each other. The synergetic effects provide superior time-based performance and quality.

The literature identified that quality practices are complementary and investing in them, will support and enhance the efficacy of lean practices. Accordingly, the following hypotheses are proposed:

H3a. Investments in lean practices have a stronger positive impact on production swiftness, when combined with high levels of quality practices.

H3b. Investments in lean practices have a stronger positive impact on production evenness, when combined with high levels of quality practices.

The conceptual model and all proposed hypotheses are provided in Figure 1.

3. Research methodology

This study uses data from the survey developed Global Manufacturing Research Group (GMRG), a multinational group of OM researchers who focus on studying and improving operations and supply chains worldwide. Whybark *et al.* (2009) provides an overview of the GMRG project background, historical developments, data collection process and the theory underlying the survey instrument. The data used in this paper, is part of the fourth round, and over 1,400 responses have been collected, representing 23 countries in most regions of the world. The benefits of using this dataset are: the data comes from a multinational study, the sample size is large enough to carry out rigorous analysis of the data and the unit of analysis is the manufacturing plant, which increases the contextual validity of the results. Following a rigorous approach of only considering records for which we had no missing data for all our variables of interest, led us to a dataset containing 922 records. Table I provides an overview of the dataset in terms of country of company size, industry and country of origin.

3.1 Measures

To measure the level of investments in lean and quality practices, respondents were asked to indicate the extent to which their firm invested resources (money, time and people) in the

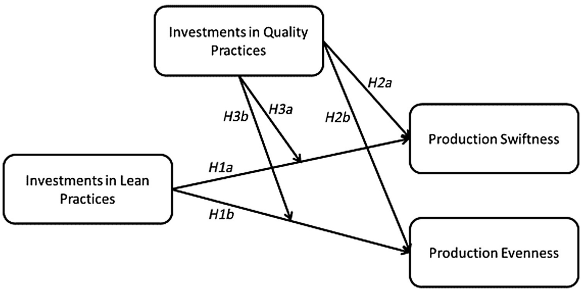

Figure 1.
Conceptual model

Number of employees	n	Industry	n	Country	n	Country	n
Less than 50	220	Food, drinks and kindred products	83	Australia	40	Ireland	31
51–250	445	Textile, apparel and leather products	58	Austria	11	Italy	38
250 +	257	Utility products	75	Canada	54	Macedonia	20
Total	922	Chemical and allied industries	41	China	52	Mexico	67
		Rubber and plastics	40	Croatia	62	Poland	48
		Metals and fabrications	143	Fiji	107	Sweden	23
		Industrial and commercial machinery	135	Finland	126	Swiss	21
		Electronic	177	Germany	47	Taiwan	47
		Automotive	35	Hungary	46	USA	65
		Furniture and fixtures	24	Total			922
		Stone, clay, glass and concrete	39				
		Miscellaneous	52				
		Total	922				

Table I.
Sample overview

previous two years. The measures used to depict the lean and quality practices have been extensively tested in previous research (Demeter and Matyusz, 2010; Prester, 2012; Wiengarten *et al.*, 2013; Onofrei and Fynes, 2019). In order to measure factory fitness, respondents were asked to indicate the level of improvement using an index of 100 as a starting point two years ago (for example a 5% increase would be 105 or 5% decrease would be 95). Production swiftness was conceptualised as the improvements in flow speed made by the plant in terms of manufacturing throughput time, cycle time and delivery speed (Zhang and Sharifi, 2007; Van Der Heijden *et al.*, 2012; Devaraj *et al.*, 2013). The production evenness was conceptualised as the improvements in quality variation associated with the process in terms of rejects of incoming material, rejects during processing, rejects at final inspection and customer returns (Wiengarten *et al.*, 2013; J. Power, 2014; Patyal and Koilakuntla, 2015). Three control variables were added: country of origin, plant size and industry type. Kull and Wacker (2010) used multilevel modelling and found differences in manufacturing practices effectiveness among different countries. Also, large companies are more likely to invest extensively in manufacturing practices in comparison to small firms (Shah and Ward, 2007). Several studies highlighted that certain industries are focusing more on manufacturing practices than others (i.e. automotive, food industry, textile) (Sila, 2007; Chen, 2013; Habidin and Yusof, 2013; Psomas *et al.*, 2018).

4. Results

4.1 Validity and reliability

Using AMOS24, confirmatory factor analysis (CFA) was conducted to validate the measures of all variable used. The results are presented in Table II.

Using the criteria for evaluation of the goodness-of-fit indices (Hu and Bentler, 1998), the resulting measurement model had an adequate fit to the data: GFI = 0.966, NFI = 0.97, CFI = 0.967, IFI = 0.966, RMSEA = 0.041. The ratio of chi-square to degrees of freedom was 2.577, which is below the threshold of 3 (Maccallum and Austin, 2000). To assess convergent validity, we analysed the construct loadings and standard error. The results indicated that each coefficient was greater than twice its associated standard error (Anderson and Gerbing, 1988). The reliability (internal consistency) was tested and all constructs had a minimum of

Construct	Indicators	Factor loadings	S.E.	C.R.	*P*
Investments in lean practices	Cellular manufacturing	0.586	0.069	13.822	
CR 0.783	Setup time reduction	0.667	0.068	14.987	***
AVE 0.424	Process redesign	0.627	0.062	14.406	***
Alpha 0.780	Throughput time reduction	0.598	0.061	13.400	***
	Factory automation	0.647			***
Investments in quality practices	ISO 9000	0.552	0.059	13.516	
CR 0.761	Supplier certification	0.700	0.054	16.627	***
AVE 0.452	Six sigma	0.490	0.046	12.848	***
Alpha 0.750	Statistical process control	0.797			***
Production swiftness	Cycle time	0.744	0.056	18.774	
CR 0.831	Throughput time	0.984	0.085	17.241	***
AVE 0.629	Delivery speed	0.606			***
Alpha 0.806					
Production evenness	Incoming material rejects	0.587	0.104	10.783	
CR 0.722	During processing rejects	0.730	0.179	10.819	***
AVE 0.417	Final inspection rejects	0.580	0.095	12.873	***
Alpha 0.715	Customer returns	0.524			***

Note(s): $\chi^2 = 2.577 < 3$, GFI = 0.966, NFI = 0.946, IFI = 0.966, CFI = 0.967, all greater than 0.9, RMSEA = 0.041 has to be <0.05. ***significant at 0.001 level (two-tailed)

Table II.
CFA analysis of the model complete

0.7, indicating reliable measures (Raykov and Marcoulides, 2011). Discriminant validity was confirmed as acceptable, though testing inter-factor correlations, given the multi-country, cross industry and highly varying size of the plant used in this dataset. See Table III for the inter-factor correlations (Schreiber *et al.*, 2006). Additionally, common method variance was evaluated by re-running the CFA with an additional unmeasured factor. The results showed that the constructs continued to load on their latent variables, therefore it was determined that common method variance was not a serious threat to our study (Podsakoff *et al.*, 2003).

Finally, given that the study uses data collected in multiple countries, the measurement equivalence issue was addressed by assessing whether or not the constructs via their related scales are invariant across countries (Malhotra and Sharma, 2008). Measurement equivalence determines if under different conditions and phenomenon, the measurement items yield the same attributes. If measurement equivalence is evidenced across countries, then the collected data can be grouped together or compared with each other. Recent studies (Schoenherr and Narasimhan, 2012; Wiengarten *et al.*, 2013) have established measurement equivalence in the GMRG dataset through various tests.

4.2 OLS regression analyses

To test the proposed model, we used two ordinary least squares (OLS) regression analyses (Durach and Wiengarten, 2017; Onofrei *et al.*, 2019). The data characteristics were tested for

Constructs	Mean	(1)	(2)	(3)	(4)
Investments in lean practices (1)	3.88	0.424 (0.651)			
Investments in quality practices (2)	3.19	0.624**	0.452 (0.672)		
Production swiftness (3)	5.67	0.144**	0.170**	0.629 (0.793)	
Production evenness (4)	20.58	0.263	0.252	0.131	0.417 (0.645)

Note(s): Value on the diagonal is the AVE and its square root in brackets; **Correlation is significant at the 0.01 level (2-tailed)

Table III.
Inter-factor correlations

linearity and multicollinearity. The resulting variance inflation factor (VIF) indicated no multicollinearity (see Table IV). The step-by-step analysis was conducted in two separate OLS models reflecting the interaction terms. First, the control variables (plant size, country and industry type) were introduced. Second, the level of investments in quality practices (moderator) was added. Third, the level of investments in lean practices and lastly, the interaction term was introduced.

Our first set of hypotheses (H1a and H1b) did receive support, as evidenced by the significant and positive influence of the investments in lean practices on production swiftness and production evenness. Results indicate that manufacturing throughput reduction time, process redesign, cellular manufacturing, set-up reduction time and factory automation do improve the production swiftness ($\beta = 0.161$, $p < 0.001$), as well as the production evenness ($\beta = 0.332$, $p < 0.001$).

These findings concur with previous studies (Knol *et al.*, 2018; Haerizadeh and Sunder, 2019; Sunder *et al.*, 2019) and reinforce empirically the positive impact that lean practices have on operational performance.

The second set of hypotheses (H2a and H2b) posited that investments in quality practices impact the factory fitness. The results are in line with other studies (Parvadavardini *et al.*, 2016; Basu *et al.*, 2018; Asif, 2019) and support the positive role that investments in quality practices (such as ISO 9000, supplier certification, six sigma and statistical process control) play in augmenting the production swiftness ($\beta = 0.162$, $p < 0.001$) and evenness ($\beta = 0.176$, $p < 0.001$). The positive influence of quality practices on performance (Basu and Bhola, 2016) is recognised as an important source of competitive advantage and companies need to invest in such practices in order to continuously improve their operational performance.

	Model 1 Production swiftness	Model 2 Production evenness
Variable		
Step 1. Control variables		
Industry type	−0.021 (0.527)	−0.076 (0.210)
plant size	0.045 (0.170)	0.069 (0.350)
Country	0.005 (0.873)	0.044 (0.179)
Step 2. Independent Variables		
Investments in lean practices (ILP)	0.161***	0.332***
Step 3. Moderator		
Investments in quality practices (ILQ)	0.162***	0.176***
Step 4. Interaction		
ILP * IQP	0.031(0.354)	0.091***
Step 1. R square change/sig	0.002 (0.525)	0.011 (0.140)
Step 2. R square change/sig	0.024 ***	0.102***
Step 3. R square change/sig	0.012 ***	0.014***
Step 4. R square change/sig	0.001 (0.354)	0.008***
Max VIF	2.276	
R	0.198	0.369
Adjusted R^2	0.039	0.136
Sig	0.000	0.000
Outcome	H1a, H2a supported H3a not supported	H1b, H2b, H3b supported

Note(s): ***Significant at the 0.001 level

Table IV.
OLS analysis for moderation effects

4.3 Moderation effect

To analyse the synergies between the investments in lean and quality practices, interaction term was calculated by adding the two-way interaction term to the OLS models 1 and 2. In model 1, adding the two-way interaction term did not contribute to a significant change in the variance explained ($\Delta R^2 = 0.001, p = 0.354$). The results reveal no synergetic effects between investments in lean and quality practices, when impacting the production swiftness. This reflects previous research (Heras-Saizarbitoria, 2018; Asif, 2019; Rodgers and Antony, 2019) and highlights the complex effects between these practices. A possible interpretation of this finding could be the fact that production evenness is acting as a requirement for the production swiftness, which concurs with the swift even flow theory (Schmenner, 2012).

In model 2, the addition of the two-way interaction term contributed to a significant change in the variance explained ($\Delta R^2 = 0.008$, $p < 0.001$). To interpret this result, the interaction slopes were calculated at low and high (± one standard deviation) level of investments in quality practices (Preacher *et al.*, 2006; Dawson, 2014). The findings show that investments in investments in lean practices are strongly associated with high levels of production evenness, when the level of investments in quality practices is high (see Figure 2). This means that the investments in lean practices efficacy are enhanced by investments in quality practices, when firms want to improve their production evenness. In other words, there is empirical evidence of synergetic effects between lean and quality practices.

5. Discussion

This study was set out to explore the following research questions:

RQ1: To what extent investments in quality and lean practices impact the factory fitness?

RQ2: How do investments in quality practices affect the relationship between investments in lean practices and factory fitness?

Although partial support was found for our hypotheses (five out of six were supported), our findings significantly contributes to the body of knowledge in the area of lean and quality management. It provides empirical support on the impact of lean and quality practices on factory fitness, as well as insights into how lean and quality practices interact with each other.

5.1 Theoretical contributions

In exploring the research questions, this study made a number of theoretical contributions. The positive impact of lean and quality practices on operational performance was identified

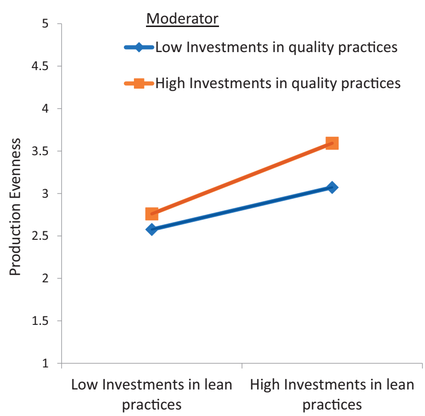

Figure 2. Moderating role of investments in quality practices

by previous studies (Bortolotti *et al.*, 2015; Elshaer and Augustyn, 2016; Basu *et al.*, 2018; Garza-Reyes *et al.*, 2018; Alexander *et al.*, 2019; Curado, 2019). Furthermore, our study confirms the argument that investments in lean and quality practices positively impact the production swiftness (throughput speed, cycle and delivery time of a production process) and evenness (variability in quality associated with that process at pre, during and post processing stages). The results suggest that companies that invest in lean and quality practices outperform their competitors on multiple performance dimensions. In other words, companies can improve their factory fitness cumulatively (Bortolotti *et al.*, 2015).

Our findings are in line with previous studies that elicit the positive impact of quality practices on performance (Asif, 2019; Shokri and Nabhani, 2019; Basu *et al.*, 2020; Jiménez-Jiménez *et al.*, 2020). This is an important finding and provides empirical support from a global perspective. Negrão *et al.* (2017) investigated the studies related to lean practices and their effect on performance.

Their results suggest that most of the studies tend to focus on the direct effect of lean practices on performance; however, very few studies examine how or what can enhance their efficacy. Our study attempts to fill this gap by providing empirical evidence of the interaction between lean and quality practices. The moderation result (on production evenness) highlights the role of quality practices as a mechanism that enhances the impact of lean practices. This is an important contribution to the quality management literature as it further explains the conduit role of quality related practices. It is important to note that we did not find a moderation effect between the lean and quality practices in order to improve the production evenness. Lean practices tend to focus on waste elimination (Curado, 2019) and as a result, the production swiftness will improve (shorter throughout/cycle time, setup and delivery time reduction). The focus of the quality practices is on the reduction of errors pre, during and post a production process, ensuring the product/service is fit for purpose and meets customer requirements. Therefore, when introducing quality practices, the operators may slow down the production process initially, to ensure high quality performance levels are achieved, at the expense of speed. As a result, when companies implement lean and quality practices, the production swiftness might not improve. This is in line with our results and may be a plausible explanation of the lack of interaction between lean and quality practices.

This research supports the argument proposed by Sakakibara *et al.* (1997) that quality practices enhance the efficacy of lean practices and improves the quality performance. The impact of investments in lean practices on production evenness was moderated by investments in quality practices. This means that in order to reap superior benefits from the implementation of lean, companies must invest in quality practices: create systems and standards, develop supplier relationships, six sigma training and continuously monitor the performance through the use of process controls (Zu, 2009; Psomas *et al.*, 2018; Sfakianaki and Kakouris, 2019). We found that when it comes to reducing variability associated with quality, the lean practices when coupled with investments in quality practices have a higher impact on production evenness.

5.2 Managerial implications

From a practitioner point of view, our study provides valuable insights on how high performing manufacturers compete. It informs management decision making concerning the development of production capabilities that may provide competitive advantage (Zu, 2009). The results offer empirical evidence of the positive effect that lean and quality practices have on factory fitness. As a result, managers can understand the operational consequences. Quality and lean practices represent complementary investments through which firms can improve their performance. The empirical results highlight the need for investments in quality and lean practices and managers must realise that the efficacy of these practices can be enhanced through their cumulative effect (Albliwi *et al.*, 2017; Antony *et al.*, 2017; Alexander *et al.*, 2019). Also, the findings can help practitioners to appreciate how different competitive priorities (speed, quality) should be enhanced. Firms that want to improve their production swiftness should focus more on lean or quality practices, where companies that are looking to enhance their evenness should aim for a synergetic approach by jointly implementing lean and quality practices (Wiengarten *et al.*, 2013; Onofrei and Fynes, 2019). Our study highlights that the investments in lean practices have a higher impact on production evenness, when the firm has increased levels of investments in quality practices. This will aid managers to prioritise their investments and make better decisions with regards to development of production capabilities. The interdependence nature of these manufacturing practices suggests that managers need to implement all the practices effectively in order to maximise the operational returns. This study found that the investments in quality practices influence to a large extend the impact of lean practices, which in turn directly lead to improvements on performance (Shokri and Nabhani, 2019). Therefore, when developing the manufacturing strategy, companies are better informed as to how each set of practices affect their operational performance.

This study highlights that managers must create an ambidextrous learning environment, where employees are involved in quality and lean implementations, in order to allow knowledge transfer and effectively implement both set of practices. Manufacturing practices should be implemented as an integrated approach of different practices (Kumar *et al.*, 2019; Tasleem *et al.*, 2019).

5.3 Limitations and further research

Despite its contributions, this study is subject to limitations. Firstly, we recommend that further studies encapsulating more manufacturing practices should be conducted, in order to better understand the interaction effects between them. Secondly, our study assessed the impact of lean and quality practices on factory fitness, which focuses on speed and variability associated with quality. The use of additional performance measures, such as cost or flexibility, could provide further insights into the effect of these practices. Thirdly, we used a cross-sectional design in our data collection method. Conducting a longitudinal study on the development of factory fitness could explain the causal patterns of lean and quality practices and how these change over a period of time. Lastly, some of our constructs use perceptual measures, which can raise the issue of measurement error and bias. Therefore, we suggest that researchers use alternative ways of quantifying the impact on manufacturing practices and provide a more objective view.

6. Conclusion

Our study contributes to operations management research by empirically assessing the impact of lean and quality practices on factory fitness. The results show that these practices have a positive impact on performance, and thus providing clarity to some conflicting views in the literature regarding how the quality practices impact and interact with lean practices. The findings have important managerial implications. They provide insights on the way better performing plants compete. Also, they offer insights into how to build production fitness and how lean practices and quality practices affect its development. This helps managers making better decisions with regard investments in lean and quality practices recognise the operational consequences. Thus, as practitioners develop their manufacturing programs, adequate resources in terms of money, time and people must be allocated to both quality and lean practices, in order to enhance the factory fitness.

References

Al-Salim, B. and Choobineh, F. (2009), "Redesign of production flow lines to postpone product differentiation", *International Journal of Production Research*, Vol. 47, pp. 5563-5590.

Albliwi, S.A., Antony, J., Arshed, N. and Ghadge, A. (2017), "Implementation of lean six sigma in Saudi Arabian organisations: findings from a survey", *International Journal of Quality and Reliability Management*, Vol. 34, pp. 508-529.

Alexander, P., Antony, J. and Rodgers, B. (2019), "Lean Six Sigma for small-and medium-sized manufacturing enterprises: a systematic review", *International Journal of Quality and Reliability Management*, Vol. 36, pp. 378-397.

Anderson, J.C. and Gerbing, D.W. (1988), "Structural equation modeling in practice: a review and recommended two-step approach", *Psychological Bulletin*, Vol. 103, pp. 411-423.

Angra, S., Sehgal, R. and Samsudeen Noori, Z. (2008), "Cellular manufacturing—a time-based analysis to the layout problem", *International Journal of Production Economics*, Vol. 112, pp. 427-438.

Antony, J. (2018), "A conceptual lean six sigma framework for quality excellence in higher education institutions", *International Journal of Quality and Reliability Management*, Vol. 35 No. 4, pp. 857-874.

Antony, J., Rodgers, B. and Cudney, E.A. (2017), "Lean six sigma for public sector organizations: is it a myth or reality?", *International Journal of Quality and Reliability Management*, Vol. 34, pp. 1402-1411.

Antony, J., Sreedharan, R., Chakraborty, A. and Gunasekaran, A. (2019), "A systematic review of lean in healthcare: a global prospective", *International Journal of Quality and Reliability Management*, Vol. 36, pp. 1370-1391.

Arana-Solares, I.A., Ortega-Jiménez, C.H. and Alfalla-Luque, R. (2019), "Contextual factors intervening in the manufacturing strategy and technology management-performance relationship", *International Journal of Production Economics*, Vol. 207, pp. 81-95.

Asif, M. (2019), "Exploring the role of core and infrastructure quality management practices in ambidexterity", *Total Quality Management and Business Excellence*, Vol. 30, pp. 990-1004.

Basu, R. and Bhola, P. (2016), "Impact of quality management practices on performance stimulating growth", *International Journal of Quality and Reliability Management,* Vol. 33, pp. 1179-1201.

Basu, R., Bhola, P. and Das, M.C. (2020), "A framework of quality management practices for Indian service SMEs", *Quality Management Journal*, Vol. 27, pp. 62-75.

Basu, R., Bhola, P., Ghosh, I. and Dan, P.K. (2018), "Critical linkages between quality management practices and performance from Indian IT enabled service SMEs", *Total Quality Management and Business Excellence*, Vol. 29, pp. 881-919.

Bergenwall, A.L., Chen, C. and White, R.E. (2012), "TPS's process design in American automotive plants and its effects on the triple bottom line and sustainability", *International Journal of Production Economics*, Vol. 140 No. 1, pp. 374-384.

Bhat, S., Antony, J., Gijo, E. and Cudney, E.A. (2020), "Lean six sigma for the healthcare sector: a multiple case study analysis from the Indian context", *International Journal of Quality and Reliability Management*, Vol. 37, pp. 90-111.

Blackstone, J.H. Jr and Cox, J.F. III (2002), "Designing unbalanced lines-understanding protective capacity and protective inventory", *Production Planning and Control*, Vol. 13, pp. 416-423.

Bortolotti, T., Danese, P., Flynn, B.B. and Romano, P. (2015), "Leveraging fitness and lean bundles to build the cumulative performance sand cone model", *International Journal of Production Economics*, Vol. 162, pp. 227-241.

Box, G. (1994), "Statistics and quality improvement", *Journal of the Royal Statistical Society. Series A (Statistics in Society)*, Vol. 157, pp. 209-229.

Boyer, K.K. and Lewis, M.W. (2002), "Competitive priorities: investigating the need for trade-offs in operations strategy", *Production and Operations Management*, Vol. 11, pp. 9-20.

Cakmakci, M. (2009), "Process improvement: performance analysis of the setup time reduction-SMED in the automobile industry", *International Journal of Advanced Manufacturing Technology*, Vol. 41, pp. 168-179.

Chen, S.-H. (2013), "Integrated analysis of the performance of TQM tools and techniques: a case study in the Taiwanese motor industry", *International Journal of Production Research*, Vol. 51, pp. 1072-1083.

Colledani, M. and Tolio, T. (2009), "Performance evaluation of production systems monitored by statistical process control and off-line inspections", *International Journal of Production Economics*, Vol. 120, pp. 348-367.

Conway, R., Maxwell, W., Mcclain, J.O. and Thomas, L.J. (1988), "The role of work-in-process inventory in serial production lines", *Operations Research*, Vol. 36, pp. 229-241.

Curado, A. (2019), "Application of lean methodologies in the reduction of setup times in the pharmaceutical industry", *Millenium*, Vol. 8 No. 2, pp. 37-52.

Da Silveira, G.J. and Sousa, R.S. (2010), "Paradigms of choice in manufacturing strategy: exploring performance relationships of fit, best practices, and capability-based approaches", *International Journal of Operations and Production Management,* Vol. 30, pp. 1219-1245.

Dawson, J.F. (2014), "Moderation in management research: what, why, when, and how", *Journal of Business and Psychology*, Vol. 29, pp. 1-19.

Demeter, K. and Matyusz, Z. (2010), "The impact of lean practices on inventory turnover", *International Journal of Production Economics*, Vol. 133 No. 1, pp. 154-163. doi: 10.1016/j.ijpe.2009.10.031.

Deming, W.E. (1988), *Out of the Crisis: Quality, Productivity and Competitive Position*, Cambridge University Press, Cambridge.

Devaraj, S., Ow, T.T. and Kohli, R. (2013), "Examining the impact of information technology and patient flow on healthcare performance: a theory of swift and even flow (TSEF) perspective", *Journal of Operations Management*, Vol. 31, pp. 181-192.

Durach, C.F. and Wiengarten, F. (2017), "Environmental management: the impact of national and organisational long-term orientation on plants' environmental practices and performance efficacy", *Journal of Cleaner Production*, Vol. 167, pp. 749-758.

Elshaer, I.A. and Augustyn, M.M. (2016), "Direct effects of quality management on competitive advantage", *International Journal of Quality and Reliability Management*, Vol. 33, pp. 1286-1310.

Fahmi, S.M. and Hollingworth, D.G. (2012), "Revisiting the roots of JIT and LEAN manufacturing", *Journal of Supply Chain and Operations Management*, Vol. 10, p. 29.

Ferdows, K. and De Meyer, A. (1990), "Lasting improvements in manufacturing performance: in search of a new theory", *Journal of Operations Management,* Vol. 9, pp. 168-184.

Ferdows, K. and Thurnheer, F. (2011), "Building factory fitness", *International Journal of Operations and Production Management*, Vol. 31, pp. 916-934.

Figueiredo, J. and Martins, J. (2010), "Energy production system management–renewable energy power supply integration with building automation system", *Energy Conversion and Management*, Vol. 51, pp. 1120-1126.

Flynn, B.B.,Sakakibara, S. and Schroeder, R.G. (1995), "Relationship between JIT and TQM: practices and performance", *Academy of Management Journal,* Vol. 38 No. 5, pp. 1325-1360.

Fredendall, L.D.,Craig, J.B.,Fowler, P.J. and Damali, U. (2009), "Barriers to swift, even flow in the internal supply chain of perioperative surgical services department: a case study", *Decision Sciences*, Vol. 40, pp. 327-349.

Garrido, E.D., Martin-Peña, M.L. and Garcia-Muina, F. (2007), "Structural and infrastructural practices as elements of content operations strategy. The effect on a firm's competitiveness", *International Journal of Production Research*, Vol. 45, pp. 2119-2140.

Garza-Reyes, J.A.,Ates, E.M. and Kumar, V. (2015), "Measuring lean readiness through the understanding of quality practices in the Turkish automotive suppliers industry", *International Journal of Productivity and Performance Management*, Vol. 64, pp. 1092-1112.

Garza-Reyes, J.A.,Betsis, I.E.,Kumar, V. and Radwan Al-Shboul, M.D.A. (2018), "Lean readiness–the case of the European pharmaceutical manufacturing industry", *International Journal of Productivity and Performance Management*, Vol. 67, pp. 20-44.

Goldratt, E.M. (1990), *What Is This Thing Called Theory of Constraints and How Should it Be Implemented?*, North River Press Croton-on-Hudson, New York.

Gryna, F.M. and Juran, J.M. (2001), *Quality Planning and Analysis: From Product Development through Use*, McGraw-Hill Science/Engineering/Math, New York.

Habidin, N.F. and Yusof, S.R.M. (2013), "Critical success factors of lean six sigma for the Malaysian automotive industry", *International Journal of Lean Six Sigma*, Vol. 4, pp. 60-82.

Haerizadeh, M. and Sunder, M.V. (2019), "Impacts of lean six sigma on improving a higher education system: a case study", *International Journal of Quality and Reliability Management*, Vol. 36, pp. 983-998.

Han, S.B. and Chen, S.K. (2007), "Effects of ISO 9000 on customer satisfaction", *International Journal of Productivity and Quality Management*, Vol. 2, pp. 208-220.

Heras-Saizarbitoria, I. (2018), *ISO 9001, ISO 14001, and New Management Standards*, Springer, Springer AG.

Hu, L.-T. and Bentler, P.M. (1998), "Fit indices in covariance structure modeling: sensitivity to underparameterized model misspecification", *Psychological Methods,* Vol. 3, pp. 424-453.

Hung, R.Y.-Y.,Lien, B.Y.-H.,Fang, S.-C. and Mclean, G.N. (2010), "Knowledge as a facilitator for enhancing innovation performance through total quality management", *Total Quality Management*, Vol. 21, pp. 425-438.

Power, D.J. (2014), "Competence and capability in quality in the high-tech sector: an international comparison", *International Journal of Operations and Production Management*, Vol. 34, pp. 1184-1209.

Jiménez-Jiménez, D., Martínez-Costa, M. and Para-Gonzalez, L. (2020), "Implications of TQM in firm's innovation capability", *International Journal of Quality and Reliability Management*, Vol. 37, pp. 279-304.

Kannan, V.R. and Palocsay, S.W. (1999), "Cellular vs process layouts: an analytic investigation of the impact of learning on shop performance", *Omega*, Vol. 27, pp. 583-592.

Kärkkäinen, M. and Holmström, J. (2002), "Wireless product identification: enabler for handling efficiency, customisation and information sharing", *Supply Chain Management: International Journal*, Vol. 7, pp. 242-252.

Kaur, M., Singh, K. and Singh, D. (2019), "Synergetic success factors of total quality management (TQM) and supply chain management (SCM) A literature review", *International Journal of Quality and Reliability Management*, Vol. 36, pp. 842-863.

Kaynak, H. (2003), "The relationship between total quality management practices and their effects on firm performance", *Journal of Operations Management*, Vol. 21, pp. 405-435.

Keil, S., Schneider, G., Eberts, D., Wilhelm, K., Gestring, I., Lasch, R. and Deutschlander, A. (2011), "Establishing continuous flow manufacturing in a Wafertest-environment via value stream design", *Advanced Semiconductor Manufacturing Conference (ASMC), 2011 22nd Annual IEEE/SEMI, IEEE*, pp. 1-7.

Khan, M.N., Malik, S.A. and Janjua, S.Y. (2019), "Total quality management practices and work-related outcomes: a case study of higher education institutions in Pakistan", *International Journal of Quality and Reliability Management*, Vol. 36, pp. 864-874.

Kim, D.-Y., Kumar, V. and Kumar, U. (2011), "A performance realization framework for implementing ISO 9000", *International Journal of Quality and Reliability Management*, Vol. 28, pp. 383-404.

Knol, W.H., Slomp, J., Schouteten, R.L. and Lauche, K. (2018), "Implementing lean practices in manufacturing SMEs: testing 'critical success factors' using necessary condition analysis", *International Journal of Production Research*, Vol. 56 No. 11, pp. 1-19.

Krafcik, J.F. (1988), "Triumph of the lean production system", *Sloan Management Review*, Vol. 30, pp. 41-52.

Kull, T.J. and Wacker, J.G. (2010), "Quality management effectiveness in Asia: the influence of culture", *Journal of Operations Management*, Vol. 28, pp. 223-239.

Kull, T.J., Ellis, S.C. and Narasimhan, R. (2013), "Reducing behavioral constraints to supplier integration: a socio-technical systems perspective", *Journal of Supply Chain Management*, Vol. 49, pp. 64-86.

Kulkarni, S., Verma, P. and Mukundan, R. (2019), "Assessing manufacturing strategy definitions utilising text-mining", *International Journal of Production Research*, Vol. 57, pp. 4519-4546.

Kumar, R., Singh, K. and Jain, S.K. (2019), "An evaluation of agile manufacturing initiatives in the Indian manufacturing industry", *International Journal of Quality and Reliability Management*, Vol. 37, pp. 156-187.

Liker, J.K. and Choi, T.Y. (2004), "Building deep supplier relationships", *Harvard Business Review*, Vol. 82 No. 12, pp. 104-113.

Liu, G.J., Shah, R. and Schroeder, R.G. (2006), "Linking work design to mass customization: a sociotechnical systems perspective", *Decision Sciences*, Vol. 37, p. 519.

Maccallum, R.C. and Austin, J.T. (2000), "Applications of structural equation modeling in psychological research", *Annual Review of Psychology*, Vol. 51, pp. 201-226.

Madhavan, V. and Gurumurthy, A. (2019), "Development of lean six sigma training module: evidence from an emerging economy", *International Journal of Quality and Reliability Management*, Vol. epub ahead-of-print No. epub ahead-of-print.

Malhotra, M.K. and Sharma, S. (2008), "Measurement equivalence using generalizability theory: an examination of manufacturing flexibility dimensions", *Decision Sciences*, Vol. 39, pp. 643-669.

Muthiah, K.M.,Huang, S.H. and Mahadevan, S. (2008), "Automating factory performance diagnostics using overall throughput effectiveness (OTE) metric", *International Journal of Advanced Manufacturing Technology*, Vol. 36, pp. 811-824.

Nair, A. (2006), "Meta-analysis of the relationship between quality management practices and firm performance—implications for quality management theory development", *Journal of Operations Management*, Vol. 24, pp. 948-975.

Narasimhan, R., Swink, M. and Kim, S.W. (2006), "Disentangling leanness and agility: an empirical investigation", *Journal of Operations Management*, Vol. 24, pp. 440-457.

Negrão, L.L.L., Godinho Filho, M. and Marodin, G. (2017), "Lean practices and their effect on performance: a literature review", *Production Planning and Control*, Vol. 28, pp. 33-56.

Netjes, M., Mansar, S.L., Reijers, H.A. and Van Der Aalst, W.M. (2009), *Performing Business Process Redesign with Best Practices: An Evolutionary Approach*, Enterprise Information Systems. Springer, Funchal.

Nicholas, J. (2016), "Hoshin kanri and critical success factors in quality management and lean production", *Total Quality Management and Business Excellence*, Vol. 27, pp. 250-264.

Onofrei, G. and Fynes, B. (2019), "Quality practices as a mediator of the relationship between lean practices and production fitness", *International Journal of Lean Six Sigma*, Vol. 10, pp. 500-522.

Onofrei, G., Prester, J., Fynes, B., Humphreys, P. and Wiengarten, F. (2019), "The relationship between investments in lean practices and operational performance: exploring the moderating effects of operational intellectual capital", *International Journal of Operations and Production Management*, Vol. 39, pp. 406-428.

Parvadavardini, S., Vivek, N. and Devadasan, S. (2016), "Impact of quality management practices on quality performance and financial performance: evidence from Indian manufacturing companies", *Total Quality Management and Business Excellence,* Vol. 27, pp. 507-530.

Patyal, V.S. and Koilakuntla, M. (2015), "Infrastructure and core quality practices in Indian manufacturing organizations: scale development and validation", *Journal of Advances in Management Research*, Vol. 12, pp. 141-175.

Pesch, M.J. and Schroeder, R.G. (1996), "Measuring factory focus: an empirical study", *Production and Operations Management*, Vol. 5, pp. 234-254.

Piercy, N. and Rich, N. (2015), "The relationship between lean operations and sustainable operations", *International Journal of Operations and Production Management*, Vol. 35, pp. 282-315.

Podsakoff, P.M., Mackenzie, S.B., Lee, J.-Y. and Podsakoff, N.P. (2003), "Common method biases in behavioral research: a critical review of the literature and recommended remedies", *Journal of Applied Psychology*, Vol. 88, pp. 879-903.

Preacher, K.J., Curran, P.J. and Bauer, D.J. (2006), "Computational tools for probing interactions in multiple linear regression, multilevel modeling, and latent curve analysis", *Journal of educational and behavioral statistics*, 31, pp. 437-448.

Prester, J. (2012), "Competitive priorities, capabilities and practices of best performers: evidence from GMRG 4 data", *Total Quality Management and Business Excellence*, Vol. 24 No. 1/2, pp. 1-20.

Psomas, E. and Antony, J. (2019), "Research gaps in lean manufacturing: a systematic literature review", *International Journal of Quality and Reliability Management*, Vol. 36, pp. 815-839.

Psomas, E., Antony, J. and Bouranta, N. (2018), "Assessing lean adoption in food SMEs: evidence from Greece", *International Journal of Quality and Reliability Management*, Vol. 35, pp. 64-81.

Raju, R. and Antony, J. (2019), "Assessment of lean six sigma readiness (LESIRE) for manufacturing industries using fuzzy logic", *International Journal of Quality and Reliability Management*, Vol. 36 No. 2, pp. 137-161.

Raykov, T. and Marcoulides, G.A. (2011), *Introduction to Psychometric Theory*, Routledge, New York.

Rodgers, B. and Antony, J. (2019), "Lean and Six sigma practices in the public sector: a review", *International Journal of Quality and Reliability Management,* Vol. 36, pp. 437-455.

Safaei, N., Banjevic, D. and Jardine, A.K. (2010), "Impact of the use-based maintenance policy on the performance of cellular manufacturing systems", *International Journal of Production Research*, Vol. 48, pp. 2233-2260.

Sakakibara, S., Flynn, B.B., Schroeder, R.G. and Morris, W.T. (1997), "The impact of just-in-time manufacturing and its infrastructure on manufacturing performance", *Management Science*, Vol. 43, pp. 1246-1257.

Saravanan, V., Nallusamy, S. and Balaji, K. (2018), "Lead time reduction through execution of lean tool for productivity enhancement in small scale industries", *International Journal of Engineering Research in Africa*, Trans Tech Publications, Vol. 34, pp. 116-127.

Schmenner, R.W. (2004), "Service businesses and productivity", *Decision Sciences*, Vol. 35, pp. 333-347.

Schmenner, R.W. (2012), *Getting and Staying Productive: Applying Swift, Even Flow to Practice*, Cambridge University Press, New York.

Schmenner, R.W. and Swink, M.L. (1998), "On theory in operations management", *Journal of Operations Management*, Vol. 17, pp. 97-113.

Schoenherr, T. and Narasimhan, R. (2012), "The fit between capabilities and priorities and its impact on performance improvement: revisiting and extending the theory of production competence", *International Journal of Production Research,* Vol. 50, pp. 3755-3775.

Schreiber, J.B., Nora, A., Stage, F.K., Barlow, E.A. and King, J. (2006), "Reporting structural equation modeling and confirmatory factor analysis results: a review", *The Journal of Educational Research*, Vol. 99, pp. 323-338.

Sfakianaki, E. and Kakouris, A. (2019), "Lean thinking for education: development and validation of an instrument", *International Journal of Quality and Reliability Management*, Vol. 36, pp. 917-950.

Shah, R. and Ward, P.T. (2003), "Lean manufacturing: context, practice bundles, and performance", *Journal of Operations Management*, Vol. 21, pp. 129-149.

Shah, R. and Ward, P.T. (2007), "Defining and developing measures of lean production", *Journal of Operations Management*, Vol. 25, pp. 785-805.

Shokri, A. and Nabhani, F. (2019), "Quality management vision of future early career operations managers", *International Journal of Quality and Reliability Management*, Vol. 36, pp. 162-185.

Sila, I. (2007), "Examining the effects of contextual factors on TQM and performance through the lens of organizational theories: an empirical study", *Journal of Operations Management*, Vol. 25, pp. 83-109.

Skinner, W. (1969), "Manufacturing - missing link in corporate strategy", *Harvard Business Review*, Vol. 47 No. 4, pp. 136-145.

Spearman, M.L. and Hopp, W.J. (2008), *Factory Physics*, McGraw Hill, New York.

Sunder, M.V., Ganesh, L. and Marathe, R.R. (2019), "Lean six sigma in consumer banking–an empirical inquiry", *International Journal of Quality and Reliability Management*, Vol. 36 No. 8, pp. 1345-1369.

Tasleem, M., Khan, N. and Nisar, A. (2019), "Impact of technology management on corporate sustainability performance", *International Journal of Quality and Reliability Management*, Vol. 36, pp. 1574-1599.

Van Der Heijden, M., Alvarez, E. and Schutten, J. (2012), "Inventory reduction in spare part networks by selective throughput time reduction", *International Journal of Production Economics*, Vol. 143 No. 2, pp. 509-517.

Watson, K.J., Blackstone, J.H. and Gardiner, S.C. (2007), "The evolution of a management philosophy: the theory of constraints", *Journal of Operations Management,* Vol. 25, pp. 387-402.

Whybark, C., Wacker, J. and Sheu, C. (2009), "The evolution of an international academic manufacturing survey", *Decision Line*, Vol. 40, pp. 17-19.

Wiengarten, F., Fynes, B. and Onofrei, G. (2013), "Exploring synergetic effects between investments in environmental and quality/lean practices in supply chains", *Supply Chain Management: International Journal*, Vol. 18, pp. 148-160.

Wiengarten, F., Onofrei, G., Humphreys, P. and Fynes, B. (2018), *A Supply Chain View on Certification Standards: Does Supply Chain Certification Improve Performance Outcomes? ISO 9001, ISO 14001, and New Management Standards*, Springer, Springer AG.

Womack, J.P., Jones, D.T., Simon and Schuster, A. (1996), *Lean Thinking*, Simon & Schuster Audio, New York.

Zhang, Z. and Sharifi, H. (2007), "Towards theory building in agile manufacturing strategy—a taxonomical approach", *Engineering Management, IEEE Transactions on*, Vol. 54, pp. 351-370.

Zu, X. (2009), "Infrastructure and core quality management practices: how do they affect quality?", *International Journal of Quality and Reliability Management*, Vol. 26, pp. 129-149.

Corresponding author
George Onofrei can be contacted at: george.onofrei@lyit.ie