Lean and agile manufacturing: complementary or competing capabilities?

Tahir Iqbal
Department of Engineering Management,
National University of Sciences and Technology, Islamabad, Pakistan
Muhammad Shakeel Sadiq Jajja
Suleman Dawood School of Business, Lahore University of Management Sciences,
Lahore, Pakistan
Mohammad Khurrum Bhutta
Department of Management, Ohio University, Athens, Ohio, USA, and
Shahzad Naeem Qureshi
Department of Engineering Management,
National University of Science and Technology, Islamabad, Pakistan

Received 29 April 2019
Revised 22 July 2019
7 October 2019
16 November 2019
15 December 2019
Accepted 16 December 2019

Abstract

Purpose – Lean (TQM and JIT) and agile manufacturing (AM) are viewed as strategic capabilities that can help firms to meet diverse set of market demands. However, the question whether lean manufacturing and AM are complementary or competing capabilities is still open to discussion. This research proposes an integrated research framework that draws on complementary theory, theory of systems, and concept of fit to examine this question regarding these two strategic capabilities.

Design/methodology/approach – Data are collected from 248 apparel exporting firms, and the proposed model is evaluated using structural equation modeling.

Findings – Results show that lean manufacturing, AM, and supporting management and infrastructural practices have positive and complementary effects on firm's performance. Further, results depict that lean manufacturing and AM complementarity is a complete organizational synergistic phenomenon, and piecemeal implementation of these initiatives may lead to suboptimal or unsatisfactory results. Results also indicate that there is no significant direct (correlated and uncorrelated) relationship of management, infrastructure, lean manufacturing, and AM practices with firm's performance and support that lean manufacturing and AM are not competing paradigms.

Research limitations/implications – This research is based on cross-sectional data from one industry. Future research should collect data from diverse sectors in different countries.

Practical implications – This study provides a key insight for manufacturing managers that piecemeal implementation of lean manufacturing and AM does not yield optimal outcomes. In addition, study suggests that lean manufacturing and AM complementarity builds on strong foundation of strategic management and internal and external infrastructure. Therefore, managers should focus on development of skilled and empowered human resources, technological advancements, and learning and virtually integrated organizations for effective implementation of lean manufacturing and AM.

Originality/value – Proposed framework is one of the first, if not the first, that seeks to resolve the question: whether lean manufacturing and AM are complementary or competing capabilities. Complementary effects of lean manufacturing and AM along with management, internal infrastructure, and common external infrastructure practices have positive impact on performance. This study also segregated infrastructure practices into internal and common external infrastructure practices.

Keywords Agile manufacturing, Lean manufacturing, Total quality management, Just-in-Time, Organizational performance, Structural equation modelling

Paper type Research paper

The authors want to extend their sincere gratitude to the reviewers for providing suggestions for the improvement of this paper. This work was partially supported by National University of Science and Technology, Islamabad, Pakistan.

Journal of Manufacturing Technology Management
Vol. 31 No. 4, 2020
pp. 749-774

1741-038X
DOI 10.1108/JMTM-04-2019-0165

Introduction

Increasing competition drives manufacturing organizations to adopt internal and supply chain level strategic improvement programs (Malhotra and Mackelprang, 2012). Dynamic customer preferences and expectations have been identified as critical driving forces for organizations to adopt certain improvement initiatives to meet these challenges (Ghobakhloo and Azar, 2018). As a result, organizations have adopted system-level improvement strategies such as agile manufacturing (AM) and lean manufacturing to enhance their competitive capabilities and maintain competitive advantage (Ghobakhloo and Azar, 2018; Inman *et al.*, 2011; Zelbst *et al.*, 2010). Lean manufacturing and AM initiatives have been regarded as 21st-century manufacturing paradigms (Crocitto and Youssef, 2003; Shah and Ward, 2003) and are generally considered as stepping stones toward achieving manufacturing excellence.

There is a conflicting perspective in the extant operations management literature on the mutually synergetic implementation between lean manufacturing and AM. This debate is covered later in the paper. A positive relationship between lean manufacturing and AM initiatives has been reported (Inman *et al.*, 2011; Narasimhan *et al.*, 2006), but at the same time, it is also reported that lean manufacturing and AM are competing streams from practices' perspective and also target different outcome capabilities (Hallgren and Olhager, 2009). Discussion in literature on the causes and dimensions of conflicts and incompatibility between lean manufacturing and AM has initiated a stream of research (Ghobakhloo and Azar, 2018; Iqbal *et al.*, 2018). This research study seeks to address the following questions:

Are lean manufacturing and AM competing or mutually exclusive paradigms?

Are lean manufacturing and AM complementary or mutually supportive paradigms?

If complementary capabilities, then what effects lean manufacturing and AM complementarity have on operational, market, and financial performance of a firm?

We propose an integrated framework that builds upon complementary theory (Milgrom and Roberts, 1995), theory of systems (ToS) (Skyttner, 2005), and concept of fit (Venkatraman, 1989) to assess complementary effects of lean manufacturing and AM. This study proposes and empirically examines whether lean manufacturing and AM are complementary or competing capabilities. Data from Pakistani apparel manufacturing and exporting industry are collected to test the proposed model using structural equation modeling approach. Apparel industry has in-built characteristics of responsiveness, shortened system changeover, high quality and product customization, and pressures of low cost and lead times. Pakistani apparel export industry is significantly losing its export share in global export industry (Pakistan Economic Survey, 2018-19), and this study will assist to understand how lean manufacturing and AM can help this sector to maintain competitiveness in the global export industry. This research work empirically validated that lean manufacturing and AM are complementary capabilities. We also found that lean manufacturing and AM complementarity has positive effects on operational, market, financial, and aggregate performance levels. Thus, this study provides insights to address the above research questions.

Research context and framework

Lean manufacturing and AM

Lean manufacturing and AM are two initiatives which have received wide acceptance in the field of operations management (Hallgren and Olhager, 2009; Kamble *et al.*, 2019; Narasimhan *et al.*, 2006; Zelbst *et al.*, 2010). Lean manufacturing has been defined in the literature as a set of interrelated practices primarily focusing toward reduction and ultimately elimination of waste (Ghobakhloo and Tang, 2014) and non-value-added activities from a firm's operations, thus enabling the firm to achieve sustainability (Kamble *et al.*, 2019; Shah and Ward, 2003), whereas AM is the capability to change operating states in response to uncertain and changing demands (Vázquez-Bustelo *et al.*, 2007). Just in Time (JIT) system or Toyota Production System (TPS) was the forerunner of lean manufacturing followed by Total Quality Management (TQM) (Flynn *et al.*, 1995a; Hallgren and Olhager, 2009). JIT focuses on waste elimination from organizational processes, whereas TQM helps to improve quality. JIT and TQM integrate to support the successful implementation of AM, which, in turn, builds organization's ability to respond rapidly to changes in market demand (Zelbst *et al.*, 2010). The term "bundles" is commonly used to capture depth of a multidimensional concept. For instance, Dal Pont *et al.* (2008) and Furlan *et al.* (2011b) classified TQM and JIT as core lean manufacturing bundles, and human resource management (HRM) as enabler bundle. From performance perspective, JIT and TQM help to reduce production cost and improve quality (Hallgren and Olhager, 2009). Thus, in this research, we define lean manufacturing as a set of core JIT and core TQM bundles.

AM has been defined as performance improvement program in the specific areas of responsiveness, shortened system changeover, product customization, cost and time, and efficient scaling up and down of operations (Narasimhan *et al.*, 2006). AM has been developed as an evolutionary (Hormozi, 2001), at the same time revolutionary (Jin-Hai *et al.*, 2003), manufacturing paradigm. An agile organization can be defined as one whose muscles are adept enough to produce at a cost of mass production (MP), response like time-compression manufacturing, and have flexibility of LP. The core aim of AM is not just to produce required products but rather to attain customer satisfaction throughout the product life cycle. From performance perspective, AM is associated with improved flexibility and delivery capabilities (Hallgren and Olhager, 2009).

An extensive review of literature, summarized in Iqbal *et al.* (2018), shows that the two manufacturing programs, lean (TQM and JIT) and AM, have certain core practices that are unique to each program and include some common internal and external infrastructure practices that are shared by both programs (Narasimhan *et al.*, 2006). The idea of common internal infrastructure (CII) and common external infrastructure (CEI) practices has very limited presence in the literature (Cua *et al.*, 2006; Lakhal *et al.*, 2006). Nevertheless, it is clear that lean manufacturing and AM indicate overlap to some of the common practices (Iqbal *et al.*, 2018). CII practices include strategic vision and planning, information system, cross training, empowered teams, and plant environment. CEI practices include relationships with customers and suppliers. Apart from unique and common practices, top management commitment is the foundation for implementation of lean manufacturing and AM programs.

Literature on the relationship between lean manufacturing and AM lacks consensus on whether or not these programs are complementary to each other. Lean manufacturing and AM differentiate in core dimensions such as TQM (entails product design, process management, and continuous improvement), JIT (entails setup time reduction, pull system production, lot size reduction, and just in time scheduling), and AM (entails change proficiency, knowledge management, advance manufacturing technology). From performance perspective, Naylor *et al.* (1999) and Narasimhan *et al.* (2006) classified quality and lead time core objective of both lean manufacturing and AM, whereas cost and flexibility are categorized as key metric to lean manufacturing and AM, respectively. On the other hand, Gunasekaran *et al.* (2008) and Bottani (2010) argued that lean manufacturing is a critical element required for agile performance. This relationship literature is maturing gradually, though paradoxically, to delineate with sufficient exactness between lean manufacturing and agile paradigms. In conclusion, two schools of thought have evolved in the literature related to the relationship between lean manufacturing and AM: two are mutually exclusive versus two are mutually supportive.

Lean and agile manufacturing—mutually exclusive paradigms

Since long, lean manufacturing and AM compatibility has been "doubted" from philosophical, practical, and competitive priorities perspectives (Harrison, 1997). Lean manufacturing and AM are said to be effective in different competitive intensity of market, support different organizational strategy, and target different performance objectives. They are generally known as competing paradigms as these initiatives have entirely different approaches to external market (stable or dynamic) and organization strategy (cost leadership or differentiation) (Hallgren and Olhager, 2009). In stable market environment, lean manufacturing players are more effective and suitable for "make-to-stock" operations, whereas agile players are significantly more effective in "make-to-order" operations (Narasimhan *et al.*, 2006). Vázquez-Bustelo *et al.* (2007) and Hallgren and Olhager (2009) empirically conferred that lean manufacturing can be practiced more effectively when market conditions are stable, whereas AM is more appropriate for turbulent market environment. Lean manufacturing organization, due to its consistent and stable processes, is generally regarded as unable to meet the challenges of shrinking product life cycles, increased degree of customization, market fragmentation, and response to unanticipated spikes in the customer preferences. Scholars argue that coexistence of lean manufacturing and AM in one organization is not plausible because AM has been recognized as a manufacturing paradigm comprising manufacturing choices and tasks (Gunasekaran *et al.*, 2008). The word "choices" itself infers that manufacturing firms may have to tradeoff between lean manufacturing and AM (Harrison, 1997), thus they cannot completely coexist.

However, their conditional existence is only possible in the supply chain of an organization. Lean manufacturing and AM can only be assimilated as a concept of "leagility" in the supply chain of an organization, and "leagility" can only be attained with the help of a decoupling point (Naylor *et al.*, 1999). Organizations have flexibility to shift de-coupling point upstream or downstream of the supply chain, depending upon the requirements of organizational operations (Naylor *et al.*, 1999). An organization is said to be lean if the de-coupling point is toward downstream supply chain, and an organization is said to be agile if the de-coupling point is toward the upstream supply chain. When looking from competitive capabilities perspective, lean manufacturing pursues efficiency through waste reduction of all types including time, setup time reduction, schedule leveling, and reliable machines (Hallgren and Olhager, 2009; Shah and Ward, 2003), whereas AM pursues responsiveness (flexibility) through exploitation of market conditions by making best use of knowledge management and advanced manufacturing technologies in the supply chain (Bottani, 2010; Hallgren; Olhager, 2009).

Lean and agile manufacturing—mutually supportive paradigms

Scholars have argued that AM assimilates the full range of flexible production technologies and builds upon lessons learned from TQM and JIT (Shah and Ward 2003). AM is said to be conjoint set of flexible manufacturing system (FMS) and LP, synthesis of a set of practices and technologies, and fully compatible with TQM, computer integrated manufacturing (CIM), and JIT (Yusuf *et al.*, 1999). Lean manufacturing is said to be an overarching concept which is compatible with any production system and complements other approaches like adaptability and agility as well (Naylor *et al.*, 1999). Lean manufacturing and AM exhibit effective implementation in an enhanced production flow analysis model. Lean manufacturing is also said to be a holistic manufacturing paradigm, which possesses qualities of all production paradigms.

Some scholars view lean manufacturing as a form of manufacturing that can incorporate a broad set of desirable manufacturing practices. For example, Shah and Ward (2003) conceived AM as subpart of JIT bundle which is considered a part of lean manufacturing. Also, it is argued that TQM and JIT are precursors to AM (Iqbal *et al.*, 2018), and organizations may fail to achieve competitive advantage if lean manufacturing and AM are not implemented simultaneously. Manufacturing practices, typically linked with lean manufacturing paradigm, are also equally practiced by agile firms. For instance, Narasimhan *et al.* (2006) found that high-performing agile firms adopt lean manufacturing practices more rigorously as compared to high-performing lean manufacturing firms. From practices perspective, lean manufacturing may not imply AM, yet AM does imply that many of the lean manufacturing principles and techniques are in place. JIT and TQM being critical elements of lean manufacturing paradigm in combination with advanced technologies help in attaining excellence in agility (Ghobakhloo and Azar, 2018).

Theoretical foundation and hypotheses

Complementarity theory (Milgrom and Roberts, 1995), ToS (Skyttner, 2005), and concept of fit (Venkatraman, 1989) provide theoretical foundation for this research study. Complementarity theory enabled us to explore sub-additive and super-additive effects of lean manufacturing and AM on operational, market, financial, and cumulative performance measures of firms. Sub-additive effects are modeled through evaluating the direct performance effects of management, infrastructure (internal and external), lean manufacturing, and AM. Conversely, super-additive effects are modeled through treating management, infrastructure (internal and external), lean manufacturing, and AM as complementary elements of a manufacturing system. ToS explains that subsystem (core lean manufacturing) integrated with another subsystem (core AM), in combination with infrastructure and management practices, integrates and departs (under special requirements) from each other to achieve superior organizational results, which applied in isolation could not be attained (Jayaram and Xu, 2013). Subsystems (core lean manufacturing, core AM, management, and infrastructure practices) also modify and adapt themselves to establish their best suitability in system. A subsystem (e.g. internal infrastructure, external infrastructure, core lean manufacturing, core AM, and management practices) not only synchronizes with other subsystems but also synchronizes within (first order level) to generate synergy effects. Fit refers to the degree of mutual consistency of two or more variables or factors. Good fit implies that integrated (complementary) deployment of core lean manufacturing, core AM, management, and infrastructure practices produces better results (Venkatraman, 1989). These frameworks (i.e. complementary theory, ToS, and concept of fit) draw that piecemeal implementation of performance improvement initiatives is likely to produce negative or suboptimal results (Hallgren and Olhager, 2009), thus suggesting the presence of complementarity between lean manufacturing and AM (Iqbal *et al.*, 2018).

In addition, complementarity theory (Milgrom and Roberts, 1995), ToS (Skyttner, 2005), and concept of fit (Venkatraman, 1989) draw that lean manufacturing and AM require implementation of supporting functional mechanisms (management and infrastructure practices) to yield desirable results (Narasimhan *et al.*, 2006). Top management commitment is a critical element for implementation of any improvement program (e.g. TQM, JIT, and AM) irrespective of manufacturing or service industry (Cua *et al.*, 2001; Kaynak, 2003). Cua *et al.* (2006) emphasized that for effective implementation of any improvement program, top management has to lay a sound internal and external infrastructure. The institution of strategic management vision and dynamic internal and external infrastructure provides a solid foundation for lean manufacturing and AM. CII practices including long-term executable vision, investing in human resource through training and empowering, setting effective organizational-wide information system to improve internal and external processes, and regular plant maintenance help organizations to be more efficient through process waste elimination (Jayaram *et al.*, 2010). Similarly, CEI practices focus on building a strong relationship with customers through positive feedback and with suppliers through their involvement to improve the product design and quality (Jajja *et al.*, 2018). Supply base management is a key to business success, and long-term relationships with key suppliers produce competitive edge. Adoption of TQM, JIT, and AM in combination with management and infrastructure support helps organizations to achieve market competitiveness. Management practices that support effective functioning of infrastructure influence product quality through core practices (Lakhal *et al.*, 2006).

Moreover, it is argued in the literature that management programs (i.e. TQM, JIT, AM, CII, and CEI) are positively associated with various dimensions of organizational performance. For example, scholars have found that infrastructure practices positively influence operational and financial performance (Samson and Terziovski, 1999). Kaynak (2003) and Kannan and Tan (2005) found positive associations between lean manufacturing and operational, market, and financial performance. Dal Pont *et al.* (2008) found that HRM is an enabler of TQM and JIT, which, in turn, positively influence operational performance. Hybrid lean–agile adoption may provide optimal strategic blend for a manufacturing enterprise to meet cost-effectiveness and market fluctuation challenges. Ghobakhloo and Tang (2014) found that lean manufacturing is fully compatible with advanced manufacturing technology (core element of AM) and helps organization to improve financial performance through waste reduction. Similarly, Ghobakhloo and Azar (2018) found that lean manufacturing, in combination with advanced manufacturing technology, is a precursor to AM. Kamble *et al.* (2019) and Ghobakhloo and Fathi (2019) also found that lean manufacturing is fully compatible with advanced manufacturing technologies as well as Industry 4.0 digital technologies. It can thus be concluded that AM, supported by TQM and JIT, leads to better operational, market, and logistical performance. A list of empirical studies supporting the relationships between various lean manufacturing, AM, management, and infrastructural practices is provided in Table I. Hence, we hypothesize:

H1. Complementarity of lean manufacturing, AM, management, and infrastructural practices have positive effect on operational performance.

H2. Complementarity of lean manufacturing, AM, management, and infrastructural practices have positive effect on market performance.

H3. Complementarity of lean manufacturing, AM, management, and infrastructural practices have positive effect on financial performance.

H4. Complementarity of lean manufacturing, AM, management, and infrastructural practices have positive effect on aggregate performance.

Hypothesized complementary relationships of lean manufacturing and AM paradigms are depicted in Figure 1. Model A in Figure 1 proposes that management, infrastructure (internal and external), lean manufacturing, and AM have direct relationships with operational, market, and financial performance, whereas Model B shows that management, infrastructure (internal and external), lean manufacturing, and AM complementarity generates synergy effects on operational, market, and financial performance.

Research methods

Questionnaire and data collection

Research questionnaire is developed using already developed and operationalized constructs in the literature[1]. For example, top management commitment is estimated using five items measuring the extent to which top managers: (1) anticipate change in business/market and make plans to respond, (2) promote use of quality tools and techniques in manufacturing processes, (3) have received adequate training on quality tools and techniques, (4) provide adequate resources for product and process quality improvement, and (5) are held accountable for achieving quality, innovation, and improvement targets (Flynn *et al.*, 1995a; Grandzol; Gershon, 1998). The literature support and respective number of items used for

Table I. Summary of Lean (TQM and JIT) and AM relationship with firm performance in empirical studies

Studies	Pertinent key Finding(s) ("→" = lead(s) to or enhance(s))
Flynn *et al* (1995a)	TQM and JIT produce synergy effects. Common infrastructure practices → improve performance.
Dean and Snell (1996)	TQM → performance. JIT does not → performance. AMT does not contribute if competitive intensity is high.
Sakakibara *et al.*(1997)	JIT alone does not → performance. JIT with infrastructure practices → performance. Quality practices without JIT can → performance.
Samson and Terziovski (1999)	Soft factors like leadership, workforce management, and customer focus → performance. Planning, information system, and process management fail to → performance.
Cua *et al.* (2001)	JIT, TQM, and TPM and infrastructure practices synergy → performance.
Yusuf and Adeleye (2002)	Agility drivers → performance measures less % sales new product.
Shah and Ward (2003)	Lean bundles complementarity → performance improvement.
Kaynak (2003)	Core practices → operational, market, and financial performance.
Kannan and Tan (2005)	JIT, SCM, and TQM collaboration help to achieve strategic objectives.
Cua *et al.* (2006)	Integrated manufacturing → operational performance.
Narasimhan *et al.* (2006)	Lean group outperforms on all performance and practices measures, except MRP/ERP and supplier certification. Agile outperform lean on all performance measures except low cost. Lean and agile were at par on SPC & benchmarking.
Vázquez-Bustelo *et al.* (2007)	AM leads to better manufacturing strength, which increases financial and market performance.
Dal Pont *et al.* (2008)	HRM effect on performance is mediated through JIT and TQM. JIT and TQM → performance.
Hallgren and Olhager (2009)	Lean significantly improves all performance measures, whereas agile performers were more focused toward delivery and flexibility and are not associated with cost and quality.
Zelbst *et al.* (2010)	TQM → AM through process control. JIT and TQM does not → operational performance, however, positively mediated through AM. AM → logistic performance. JIT and TQM does not → operational performance.
Bottani (2010)	Agile group → response to change and production mix. Lean group efficiently → cost. TQM, AMT and time compression are characterized as AM enablers.
Furlan *et al.* (2011b)	TQM and JIT complementarity → operational performance. HRM acts as TQM and JIT complementarity enabler.
Yang *et al.* (2011)	Lean manufacturing → market and financial performance.
Inman *et al.* (2011)	JIT supply mediated the path between JIT production and AM. Environmental uncertainty did not moderate relationship between AM and operational performance.
Ghobakhloo and Tang (2014)	Lean manufacturing is a complementary capability with information technology and AMT. Their complementary → financial performance.
Ghobakhloo and Azar (2018)	AMT significantly contributes to → lean and agile manufacturing. Lean manufacturing → operational performance. AM does not → operational performance, however, contributes in market and financial performance.
Ghobakhloo and Fathi (2019)	Lean digitized manufacturing system decreased process waste, defects and maintenance cost. IT resources may not → financial performance. Lean digitized practices help to significantly improve ROA and ROI.
Kamble *et al* (2019)	Lean manufacturing is fully compatible with industry 4.0 technologies and positively mediates relationship between technologies and sustainability performance.

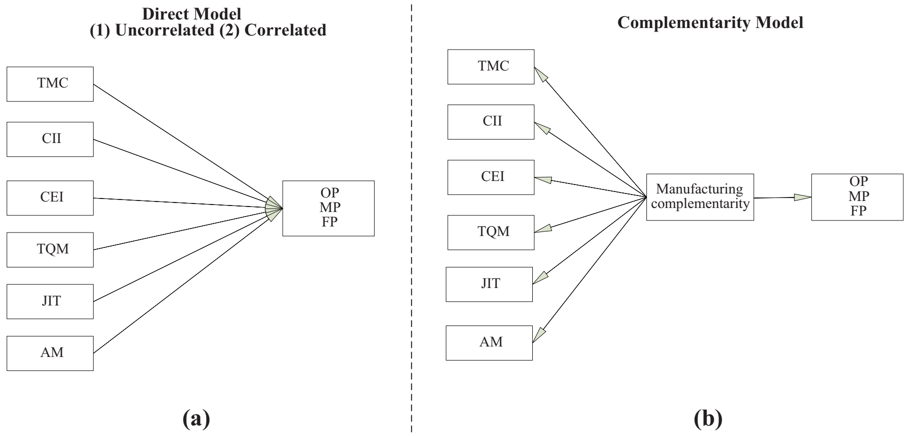


Figure 1.
Proposed models (a and b)

each construct are provided in Table III. Questionnaire items are measured using a seven-point Likert scale. Research questionnaire is categorized into three major sections. Section I comprises management, and internal and external infrastructure practices. Section II comprises core manufacturing practices. Section III comprises performance measures.

Apparel manufacturing and exporting firms from Pakistan were selected as the target population. Pakistan is the fourth largest producer and the third largest consumer of cotton in the world. Textile and clothing industry is the backbone of Pakistan's manufacturing industry, accounting for 46 percent share, makes up for 55–60 percent of the total export share, and contributes 8.5 percent to country's GDP (Pakistan Economic Survey, 2018–19). Unit of analysis is the apparel manufacturing and exporting firm. Respondents were identified as middle to senior managers because they have the needed job experience and understanding of business operations.

Data were collected using an e-mail-based questionnaire as suggested by Dillman (2007) using *Qualtrics web application*. Questionnaires were sent to 950 randomly selected firms from the sampling frame of 1,546 firms. Two reminders, first after fourth week and second after sixth week, were sent out. A total of 261 questionnaires were responded. However, 13 questionnaires were not completely filled out and were eliminated from the final sample used in this research, thus generating an effective response rate of 26.10 percent. A profile of respondents is presented in Table II.

Measurement model assessment

Covariance-based structural equation modeling (CB-SEM) approach using AMOS modeling software (Jajja *et al.*, 2012; Jajja *et al.*, 2017) was used for empirical examination (Inman *et al.*, 2011). CB-SEM is preferred over partial least squares-based structural equation modeling (PLS-SEM) when, like in the current study, the goal is theory testing, theory confirmation, or comparison of alternative theories (Hair *et al.*, 2016). A multi-phase approach is adopted to evaluate reliability and validity of first- and second-order factors (Jajja *et al.*, 2018). Standardized factor loadings (SFL) of all items are significant and above 0.70, except the two items mentioned in Table III (Hair *et al.*, 2010). Measurement models for each first-order factor indicate acceptable fit indices (Hair *et al.*, 2010) as presented in Table III. In the second phase, a correlated measurement model, with all first-order factors, comprising manufacturing practices and performance measures, is carried out. Measurement model statistics satisfied the criteria of fit indices as χ^2/df = 1.22, GFI = 0.75, CFI = 0.96, NNFI = 0.96, IFI = 0.95, and

Category	Number
Firm size (number of employees)	
1–50 (small)	49
51–250 (medium)	101
> 250 (large)	98
Job position	
CEO	32
GM	49
Production manager	60
Quality manager	45
Export manager	40
Supervisor	22
Job experience (years)	
< 3	6
3–5	39
6–10	101
11–20	71
20+	31
Firm major export business	
Readymade garments	97
Knitwear and hosiery	151

Note(s): Sample size is 248

Table II.
Profile of respondents

RMSEA = 0.03 (Hair *et al.*, 2010). In the third phase, CII, CEI, JIT, TQM, and AM are treated as second-order factors. Therefore, second-order CFA each for CII, CEI, JIT, TQM, and AM is carried out. CFA for CEI, having two items, cannot be performed. Nevertheless, a correlated measurement model is performed to evaluate psychometric properties. Second-order factors CII, CEI, JIT, TQM, and AM met nomological validity criteria and showed non-existence of confounding issues (Hair *et al.*, 2010). In the fourth phase, 17 first-order factors pertaining to second-order factors are converted into composite measure scales. Finally, a full measurement model with composite scales is evaluated. Model results indicate a satisfactory fit as χ^2/df = 1.12, GFI = 0.89, CFI = 0.98, NNFI = 0.99, and RMSEA = 0.02.

Moreover, discriminant validity was also assessed. Construct discriminant validity is established, if Cronbach's alpha (α) value of a construct is sufficiently greater than the average inter-scale correlation (AVISC) of that construct with other model constructs. To assess discriminant validity, first of all, AVISC of each construct is calculated by taking average of its correlation with all other constructs of the model. Then AVISC is subtracted from Cronbach's alpha to test for discriminant validity. Cronbach's alpha(α) and AVISC differences are sufficiently greater than 0.30 for all constructs, thus providing support for satisfactory discriminant validity (Jayaram *et al.*, 2010), Descriptive statistics, measurement scales validation indices, and inter-scale correlations results are presented in Table IV.

Structural model assessment

Before performing structural equation modeling (SEM), three measurement models (single factor comprising eighteen constructs, six uncorrelated factors, and six correlated factors) comprising management, infrastructure, lean manufacturing, and AM practices are examined to identify appropriate combination for SEM. Model 3 (six-correlated factors, χ^2/df = 1.13, GFI = 0.93) fit better as compared to Model 1 (single factor with 18 items, χ^2/df = 5.06, GFI = 0.67) and Model 2 (six uncorrelated factors making it indeterministic).

Table III. Results of first-order confirmatory factor analysis

Construct		Literature support	No of items	Unidimensionality			Convergent validity		Reliability	
	Criteria			χ^2/df < 3	CFI > 0.95	RMR < 0.05	SFL (min–max) > 1.95	Average variance explained > 0.5	Composite reliability > 0.6	Cronbach's α > 0.7
Management practices	Top management commitment	Flynn *et al* (1995a), Grandzol and Gershon (1998)	5	1.38	0.99	0.009	0.76–0.85	0.64	0.90	0.905
Common internal infrastructure	Information system	Cua *et al.* (2001), Prajogo and Olhager (2012b)	4	0.20	1.00	0.003	0.75–0.86	0.65	0.88	0.883
	Empowered team	Cua *et al.* (2001), Jayaram *et al.*(2010), Narasimhan *et al.* (2006)	6*	2.07	0.99	0.009	0.79–0.89	0.69	0.91	0.923
	Strategic vision planning	Cua *et al.* (2001), 2006	4	2.65	0.99	0.009	0.81–0.90	0.73	0.91	0.917
	Cross training	(Cua *et al.* (2001), Flynn *et al* (1995a)	4	1.00	1.00	0.004	0.86–0.89	0.78	0.93	0.935
	Plant environment	(Cua *et al.* (2001), Flynn *et al* (1995a), Shah and Ward, 2007	4	1.39	0.99	0.003	0.77–0.87	0.68	0.89	0.904
Common external infrastructure	Relationship with customers	Jayaram *et al.*(2010), Narasimhan *et al.* (2006)	5	1.18	1.00	0.006	0.79–0.90	0.69	0.92	0.917
	Relationship with suppliers	Narasimhan *et al.* (2006), Prajogo *et al.* (2012)	5	1.31	0.99	0.009	0.83–0.89	0.73	0.93	0.931
Total quality management	Product design	Cua *et al.* (2001); Flynn *et al* (1995a); Zelbst *et al.* (2010)	5	0.85	1.00	0.004	0.79–0.87	0.69	0.91	0.924
	Statistical process control	Cua *et al.* (2001), Flynn *et al* (1995a), Zelbst *et al.* (2010)	3	0.00	1.00	0.000	0.83–0.92	0.79	0.92	0.919
	Continuous improvement	Curkovic *et al.* (2000), Rungtusanatham *et al.* (1998)	3	0.00	1.00	0.000	0.85–0.89	0.75	0.90	0.902

(continued)

Construct	Criteria	Literature support	No of items	Unidimensionality: χ^2/df < 3	Unidimensionality: CFI > 0.95	Unidimensionality: RMR < 0.05	Convergent validity: SFL (min–max) > 1.95	Convergent validity: Average variance explained > 0.5	Reliability: Composite reliability > 0.6	Reliability: Cronbach's α > 0.7
Just-in-time	Lot size reduction	Flynn *et al* (1995a), Zelbst *et al.* (2010)	3	0.00	1.00	0.000	0.76–0.88	0.69	0.87	0.870
	Set-up time reduction	(Cua *et al.* (2001), Flynn *et al* (1995a), Zelbst *et al.* (2010)	3	0.00	1.00	0.000	0.80–0.87	0.70	0.87	0.876
	Pull production system	(Cua *et al.* (2001), Flynn *et al.* (1995a), Shah and Ward (2007)	4	1.95	0.99	0.003	0.76–0.93	0.73	0.91	0.929
	JIT scheduling	Cua *et al.* (2001), Flynn *et al.* (1995a), Zelbst *et al.* (2010)	3	0.00	1.00	0.000	0.85–0.93	0.78	0.91	0.916
Agile manufacturing	Change proficiency	Inman *et al.* (2011), Iqbal *et al.* (2018), Zelbst *et al.* (2010)	7	1.99	0.99	0.011	0.80–0.89	0.73	0.95	0.952
	Knowledge management	Hakala and Kohtamäki (2011), Vázquez-Bustelo *et al.* (2007)	5	0.91	1.00	0.006	0.75–0.85	0.66	0.90	0.911
	Advanced manufacturing technology	Narasimhan *et al.* (2006)	5	2.52	0.99	0.011	0.64–0.87[a]	0.61	0.88	0.888
Performance	Operational performance	Cua *et al.* (2001), 2006, Hallgren and Olhager (2009)	6	1.67	0.99	0.015	0.78–0.84	0.64	0.91	0.916
	Market performance	Inman *et al.* (2011), Yang *et al.* (2011)	3	0.00	1.00	0.000	0.80–0.89	0.74	0.89	0.895
	Financial performance	Inman *et al.* (2011), Yang *et al.* (2011)	3	0.00	1.00	0.000	0.80–0.82	0.65	0.85	0.851

Note(s): *One item was excluded from analysis due to low factor loading; # factor loading of one item is (0.64) less than 0.7, but still retained in the analysis as it is significant and above the recommended threshold of 0.6 (Hair *et al.*, 2010)

Table III.

Table IV.
Second-order factors—descriptive statistics, measurement scales validation indices, and inter-scale correlations results

Construct	Descriptive statistics Mean	SD	Unidimensionality (GFI)	Reliability (α)	(CR)	Convergent validity (AVE)	Average inter-scale correlation (AVISC)	Inter-scale correlations TMC	CII	CEI	TQM	JIT	AM	OP	MP
Top management commitment	5.25	0.67	0.99[a]	0.90	0.91	0.64	0.33								
Common internal infrastructure	5.47	0.56	0.93[b]	0.86	0.89	0.62	0.31	0.36***[b]							
Common external infrastructure[@]	5.11	0.64	–	0.71	0.71	0.57	0.23	0.42***	0.22***						
Total quality management	5.13	0.51	0.97[b]	0.78	0.81	0.58	0.31	0.31***	0.40***	0.44***					
Just-in-time	5.48	0.59	0.94[b]	0.79	0.81	0.52	0.30	0.24***	0.30***	0.33***	0.21***				
AM	5.04	0.54	0.94[b]	0.72	0.76	0.51	0.40	0.26***	0.34***	0.37***	0.44***	0.32***			
Operational performance	5.23	0.77	0.98[a]	0.91	0.92	0.64	0.19	0.22***	0.22***	0.22***	0.19***	0.21***	0.23***		
Market performance	4.82	1.05	1.00[a]	0.95	0.90	0.74	0.26	0.28***	0.27***	0.25***	0.22***	0.12*	0.26***	0.28***	
Financial performance	4.89	0.95	1.00[a]	0.85	0.85	0.65	0.29	0.21***	0.29***	0.19***	0.19***	0.06	0.19***	0.19***	0.49***

Note(s): [a] GFI values were obtained from first-order measurement model runs; [b] GFI values were obtained from second-order measurement model runs; $*p < 0.1$, $**p < 0.05$, $***p < 0.01$; @ CFA cannot run because common external infrastructure factor comprises two items

Furthermore, difference between six correlated factors and higher-order factor of management, infrastructure, lean manufacturing, and AM practices are evaluated employing procedure suggested by Venkatraman and Prescott (1990). Chi-square ratio values of four models are 0.91, 0.87, 0.84, and 0.93 for operational performance, market performance, financial performance, and aggregate performance models, respectively. This suggests that our higher-order factors account for at least 84 percent of all relationship in first-order factors. Moreover, higher-order factor loadings for all models are significant and support rifeness of synergy effects among all higher-order constructs (Cua *et al.*, 2006; Malhotra and Mackelprang, 2012).

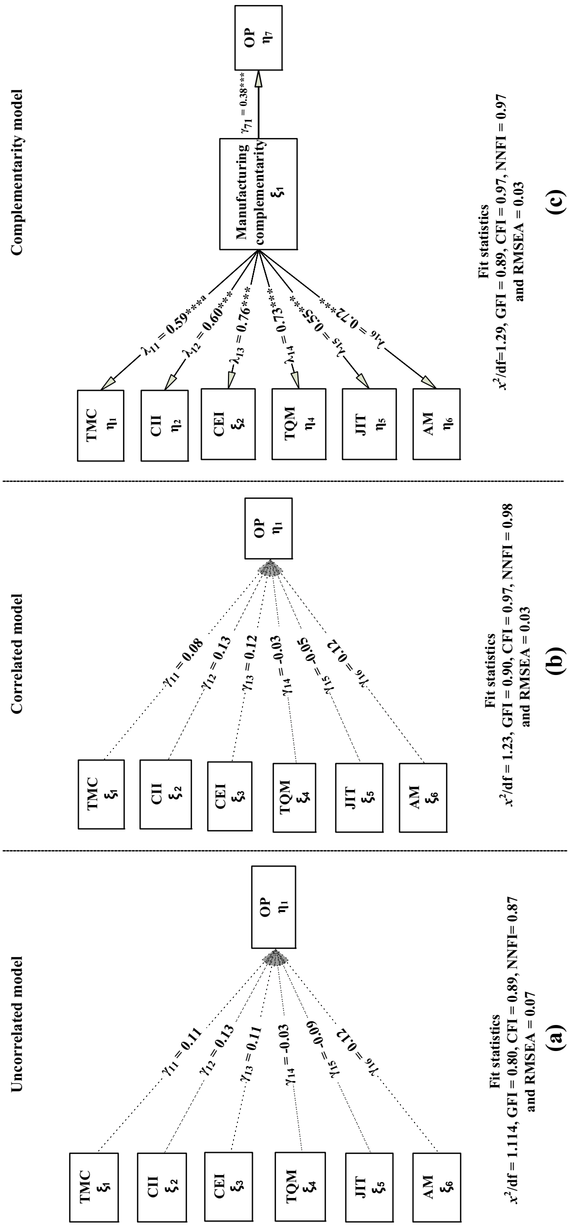
We adopted the technique suggested by Tanriverdi and Venkatraman (2005) to evaluate lean manufacturing and AM complementary system implications on performance. They suggest that it is unobtrusively imperative to compare individual system components performance effects with full system performance effects. If the individual system effects on performance are outweighed by full system effects on performance, then it provides an evidence of system complementarity. If lean manufacturing and AM integrated system effects outweigh individual lean manufacturing or AM system effects on operational, market, and financial performance, then it will determine that lean manufacturing and AM are complementary capabilities. Results failing to meet this criterion will determine that lean manufacturing and AM are competing capabilities. To assess the complementarity effects of lean manufacturing and AM, along with management and infrastructure practices on different performance outcomes, a series of models are developed and assessed employing SEM. Results of these structural models are presented in Table V.

To evaluate H1, regarding manufacturing complementarity (MC) effects of lean manufacturing and AM along with management and infrastructure practices on operational performance, three Models 4(a–c) are performed. All direct path relationships between uncorrelated Model-4a, correlated Model-4b, and operational performance are insignificant. Insignificant results of uncorrelated models indicate that lean manufacturing and AM are not competing. However, results of complementarity Model-4c show a significant structural relationship between MC and operational performance ($\gamma_{MC \to OP} = 0.38$, $t = 4.32$ at $p < 0.01$) and thus support H1. Results of Models 4(a–c) are shown in Figure 2(a–c).

To evaluate H2, regarding MC effects of lean manufacturing and AM along with management and infrastructure practices on market performance, three Models 5(a–c) are

Structural models	χ^2	χ^2/df	GFI	CFI	NNFI	RMSEA
H1. Operational performance						
Model 4a (uncorrelated direct effects)	711.30	2.01	0.8	0.89	0.87	0.07
Model 4b (correlated direct effects)	397.8	1.23	0.9	0.97	0.98	0.03
Model 4c (complementarity)	435.90	1.29	0.89	0.97	0.97	0.03
H2. Market performance						
Model 5a (uncorrelated direct effects)	609.7	2.3	0.81	0.88	0.86	0.07
Model 5b (correlated direct effects)	296.2	1.19	0.92	0.98	0.98	0.02
Model 5c (complementarity)	337.5	1.28	0.9	0.97	0.97	0.03
H3. Financial performance						
Model 6a (uncorrelated direct effects)	573.05	2.17	0.82	0.88	0.86	0.06
Model 6b (correlated direct effects)	259.34	1.04	0.92	0.99	0.99	0.01
Model 6c (complementarity)	306.01	1.16	0.91	0.98	0.98	0.02
H4. Aggregate performance						
Model 7a (uncorrelated direct effects)	886.80	1.78	0.81	0.91	0.9	0.05
Model 7b (correlated direct effects)	573.28	1.15	0.88	0.98	0.98	0.02
Model 7c (complementarity)	618.30	1.2	0.87	0.98	0.97	0.02

Table V.
Structural model results



Note(s): $^{**}p < 0.05$, $^{***}p < 0.01$, [a]parameter constrained to 1. For simplicity purpose correlated model relationship and coefficient are not shown

Figure 2.
Models 4(a–c) results

performed. All direct path relationship between uncorrelated Model-5a, correlated Model-5b, and market performance, except $\gamma_{TMC \rightarrow MP} = 0.14$ ($t = 2.14$ at $p < 0.05$), $\gamma_{CII \rightarrow MP} = 0.20$ ($t = 2.84$ at $p < 0.01$), and $\gamma_{AM \rightarrow MP} = 0.16$ ($t = 2.10$ at $p < 0.05$) of uncorrelated model, and $\gamma_{CII \rightarrow MP} = 0.22$ ($t = 2.14$ at $p < 0.05$) of correlated model, are insignificant. Results of complementarity Model-5c show a significant structural relationship between MC and market performance ($\gamma_{MC \rightarrow MP} = 0.43$, $t = 4.73$ at $p < 0.01$), thus supporting H2. Models 5(a–c) results are shown in Figure 3(a–c).

To evaluate H3, regarding MC effects of lean manufacturing and AM along with management and infrastructure practices on financial performance, three Models 6(a–c) are performed. All direct path relationships between uncorrelated Model-6(a), correlated Model-6(b), and financial performance, except $\gamma_{CII \rightarrow FP} = 0.30$ ($t = 4.05$ at $p < 0.01$) of uncorrelated model and $\gamma_{CII \rightarrow FP} = 0.36$ ($t = 3.25$ at $p < 0.05$) of correlated model, are insignificant. Results of complementarity Model-6c show a significant structural relationship between MC and financial performance ($\gamma_{MC \rightarrow FP} = 0.35$, $t = 4.04$ at $p < 0.01$), thus supporting H3. Results of Model 6(a–c) are shown in Figure 4(a–c).

To evaluate H4, regarding MC effects of lean manufacturing and AM along with management and infrastructure practices on aggregate performance, three Models 7(a–c) are performed. Four direct paths, that is, $\gamma_{TMC \rightarrow CP} = 0.17$ (t=2.0 at $p < 0.05$), $\gamma_{CII \rightarrow CP} = 0.33$ (t=3.14 at $p < 0.01$), $\gamma_{CEI \rightarrow CP} = 0.23$ (t=2.1 at $p < 0.05$) of uncorrelated Model-7a and one path $\gamma_{AM \rightarrow CP} = 0.2$ (t=2.1 at $p < 0.05$) of correlated Model-7b, are positively linked with aggregate performance, whereas all other direct paths are insignificant. Results of complementarity Model-7c show a significant structural relationship between manufacturing complementarity and aggregate performance ($\gamma_{MC \rightarrow CP} = 0.57$, $t = 3.81$ at $p < 0.01$), thus supporting H4. Results are shown in Figure 5(a–c). Summary of results of all hypotheses is presented in Table VI.

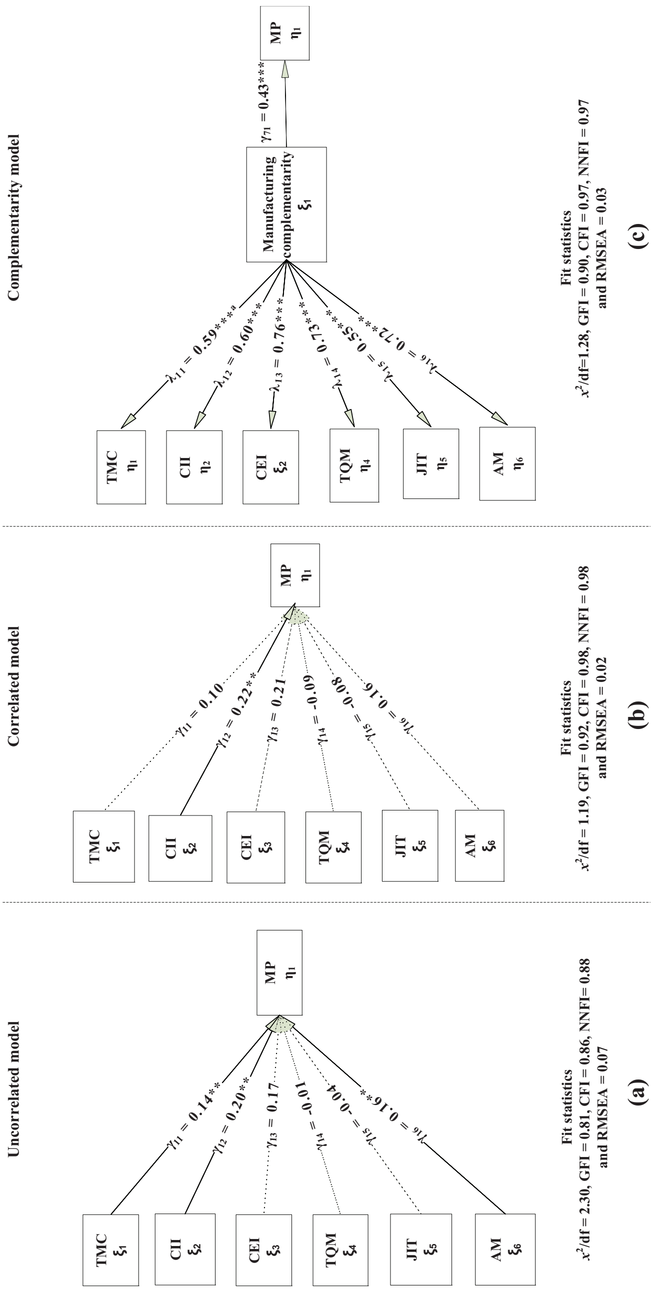
Discussion

Our research study explicitly demonstrates that lean manufacturing and AM are complementary capabilities in predicting organizational performance in apparel export industry. Our results show strong empirical alignment between lean manufacturing and AM, and support that lean manufacturing and AM complementarity is positively associated with operational, market, and financial performance (supporting H1,H2,H3,H4), suggesting their strategic importance in achieving business advantage. Our results are consistent with the literature; that lean (TQM and JIT) and AM are complementary capabilities (Narasimhan *et al.*, 2006; Zelbst *et al.*, 2010) and differ from extant expositions of lean manufacturing and AM as competing capabilities (Hallgren and Olhager, 2009). Findings of our study extend complementarity of lean manufacturing and AM on operational, market, and financial performance, more than just on operational (Narasimhan *et al.*, 2006) or logistic performance (Zelbst *et al.*, 2010).

Our study's findings thus suggest that apparel firms should invest in both lean manufacturing and AM simultaneously. Our results also provide significant insight that just focusing on lean manufacturing or AM will not deliver optimum performance results. Apart from the positive complementary effects between core lean manufacturing and core AM (H1,H2,H3,H4), they are distinct from each other as well. Discriminant validity results demonstrate that lean manufacturing and AM are distinct. Therefore, our results confirm complementarity between lean manufacturing and AM. Detailed theoretical and practical implications of the findings are discussed below.

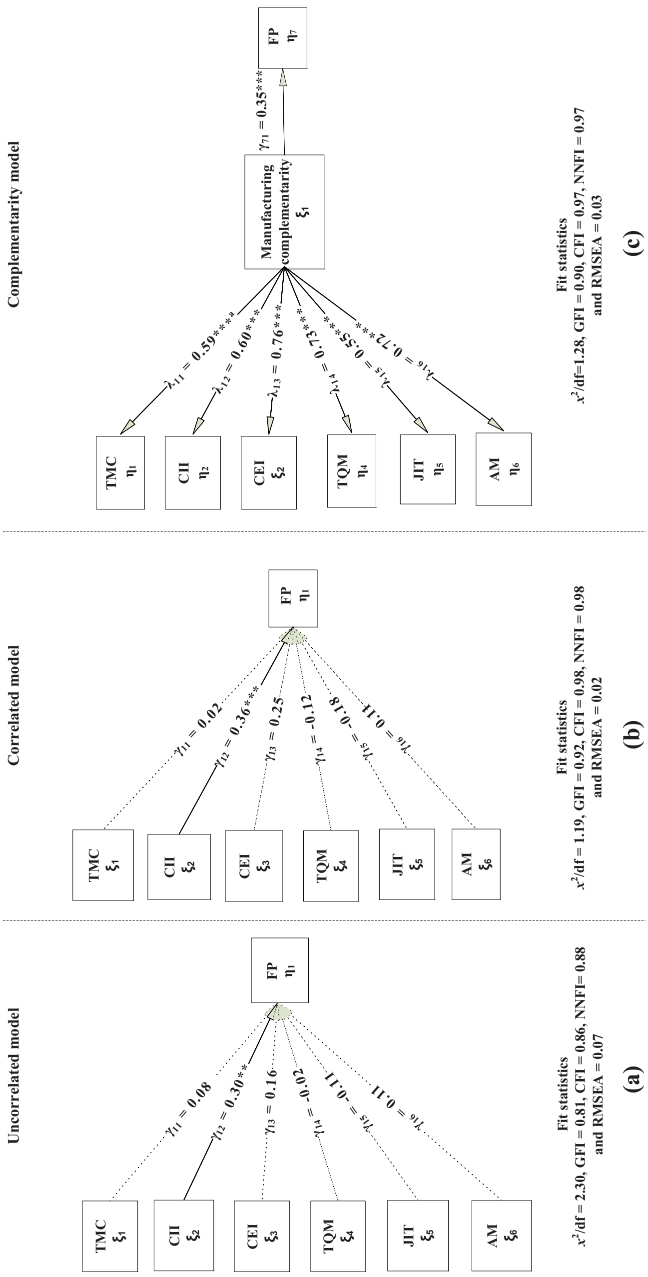
Theoretical implications

From theoretical perspective, our study contributes to manufacturing strategy and operations management (OM) literature identifying drivers of high performance (Narasimhan *et al.*, 2006; Zelbst *et al.*, 2010) as follows: first, by using complementarity



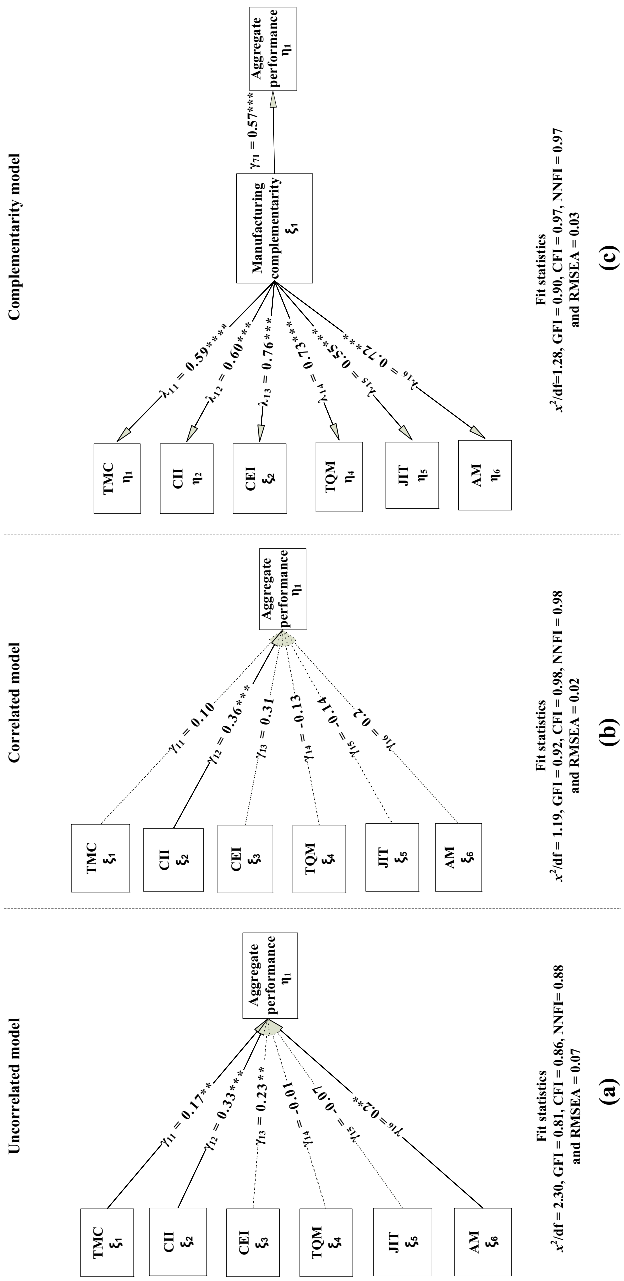
Note(s): $^{**}p < 0.05$, $^{***}p < 0.01$, [a]parameter constrained to 1. For simplicity purpose correlated model relationship and coefficient are not shown

Figure 3.
Models 5(a–c) results



Note(s): $^{**}p < 0.05$, $^{***}p < 0.01$, [a]parameter constrained to 1. For simplicity purpose correlated model relationship and coefficient are not shown

Figure 4.
Models 6(a–c) results



Note(s): $**p < 0.05$, $***p < 0.01$, [a]parameter constrained to 1. For simplicity purpose correlated model relationship and coefficient are not shown

Figure 5.
Models 7(a–c) results

theory and ToS as a theoretical lens, our study suggests that lean manufacturing and AM complementarity has high predictive power across operational, market, and financial performance. Our findings expand previous studies on lean manufacturing and AM complementarity (Narasimhan *et al.*, 2006; Zelbst *et al.*, 2010) by demonstrating complementarity between lean manufacturing and AM. From complementary perspective, we can interpret that lean manufacturing and AM synergy provides a competitive advantage and generates better returns. Plausible reason is that combination of two complementary resources increases compatibility between heterogeneous resources, and thus makes them more advantageous. Each component of lean manufacturing and AM possesses competitive value in itself, and their combination produces synergistic effects (Narasimhan *et al.*, 2006; Zelbst *et al.*, 2010). Findings of this study also support complementarity theory and ToS. Our results demonstrate that complementarity between lean manufacturing and AM enhances operational, market, and financial performance in apparel exporting firms, suggesting that simultaneous investment in complementary resources will produce higher competitive advantage as compared to focusing on one kind of resource (Milgrom and Roberts, 1995).

Lean and AM complementarity effects. The findings of our study suggest that lean manufacturing and AM complementarity has positive impact on multiple dimensions of performance. Earlier research on complementarity of lean manufacturing and AM, mostly anecdotal in nature, has also indicated that firms adopting agile paradigm cannot operate in competitive environment without adoption of lean manufacturing (Bottani, 2010; Inman *et al.*, 2011; Narasimhan *et al.*, 2006; Zelbst *et al.*, 2010). For instance, Narasimhan *et al.* (2006) found that firms adopting AM outperformed lean manufacturing firms and were far better in implementation of core lean manufacturing practices as compared to firms that adopted lean manufacturing only. This seems to be one of the plausible reasons for lack of support for competing effects. Therefore, our findings explicitly indicate that AM is neither new nor an exclusive paradigm; rather, it is evolutionary in nature and has evolved over existing performance improvement initiatives like lean manufacturing (Bottani, 2010; Hormozi, 2001; Jin-Hai *et al.*, 2003; Zelbst *et al.*, 2010). Our findings also support the argument by Hormozi (2001) that AM is "next logical step" toward production revolution, and its roots are deeply linked with its predecessors like lean manufacturing and mass production.

Recent studies conceptualized lean manufacturing as multidimensional construct, but AM has been conceptualized as single dimensional construct (Inman *et al.*, 2011; Zelbst *et al.*, 2010). Accordingly, this study contributes to AM literature by theoretically and empirically developing AM multidimensional construct comprising three first-order factors: advanced manufacturing technology, change proficiency, and knowledge management.

Our empirical findings also answer research questions raised by Narasimhan *et al.* (2006) such as "do plants evolve in this way? should they seek to do?" Empirical evidence provided in the current research suggests "Yes," that is, firms do and should evolve to meet changing market requirements through adoption of lean manufacturing and AM concurrently. More specifically, our results empirically support "manufacturing phase shifts" argument about

Hypothesis	Relationship	Standardised path estimate	Results
H1	Manufacturing complementarity → OP	0.38***	Supported
H2	Manufacturing complementarity → MP	0.43***	Supported
H3	Manufacturing complementarity → FP	0.35***	Supported
H4	Manufacturing complementarity → Aggregate performance	0.57***	Supported

Note(s): ***Significant at $p < 0.01$

Table VI.
Structural path results

agility by Hormozi (2001). Our results are also in line with findings of Yusuf *et al.* (1999), who report that AM is a set of synthesized practices and technologies, and is fully compatible with lean manufacturing (TQM and JIT).

According to Amit and Schoemaker (1993), a firm's resources exhibit complementarity in deployment phase, that is, strategic value of each resource's relative magnitude may increase with an increase in relative magnitude of other resource. Under complementarity theory and ToS, aggregate capability of a firm's capability may be higher than if each resource is deployed individually. Our findings (uncorrelated and correlated models) reflect that randomly engaging lean and AM fails to produce competitive advantage (Inman *et al.*, 2011; Zelbst *et al.*, 2010). For instance, Zelbst *et al.* (2010) and Iqbal *et al.* (2018) report that TQM and JIT alone are not sufficient to improve operational performance. However, their complementarity produces maximum benefits (Inman *et al.*, 2011; Narasimhan *et al.*, 2006).

Management, infrastructure, lean and AM complementarity. Top management commitment and infrastructure practices play a vital role in capitalizing benefits from lean (TQM and JIT) and AM initiatives (Lakhal *et al.*, 2006; Narasimhan *et al.*, 2006). Top management commitment and common (internal and external) infrastructure practices enable lean manufacturing and AM practices to achieve organizational excellence. Our findings support that organizations, working in dynamic working environment, must invest in their internal resource (employees) and integrate external resources (customer and supplier), to attain organizational agility (Bottani, 2010; Crocitto and Youssef, 2003). Management and infrastructure practices provide a platform for integration of improvement initiatives, for example, TQM, JIT, and total productive maintenance (Cua *et al.*, 2001, 2006).

Findings also reveal that CII like empowered teams, employees' training on multiple skills, reward system, supportive culture, and CEI like customer early involvement in product design and redesign process, and strategic partnership with suppliers enable lean manufacturing and AM complementarity (Inman *et al.*, 2011). Similarly, McCullen and Towill (2001) also highlighted that knowledgeable, highly skilled, and empowered workers are an asset to the organization. This integration process surges organizational flexibility and responsiveness (Jajja *et al.*, 2018). Our results also support that management, CII, and CEI alignment with lean manufacturing and AM help to breakthrough by capitalizing advance manufacturing and information technologies (Ghobakhloo and Azar, 2018; Ghobakhloo and Tang, 2014; Kamble *et al.*, 2019). Resultantly, high-quality and innovative products and services are offered to customers at competitive prices (Crocitto and Youssef, 2003; Zelbst *et al.*, 2010).

Contrary to our complementarity understanding, an interesting result is observed. CII results remained significant in all models (i.e. uncorrelated, correlated, and integrated). It reflects that CII is independent of any improvement program, as suggested by earlier research (Lakhal *et al.*, 2006; Sakakibara *et al.*, 1997; Samson and Terziovski, 1999), and significantly can contribute in organizational performance. A possible explanation of this finding is that infrastructure practices like empowered teams and strategic vision and planning alone can improve performance as compared to performance improvement initiatives such as TQM and JIT, which require specific enablers (Lakhal *et al.*, 2006; Sakakibara *et al.*, 1997; Samson and Terziovski, 1999). However, CEI, similar to CII, fails to contribute independently. A possible explanation is that effects of customer and supplier's relationships are only realized once management, CII, and improvement initiatives (i.e. TQM, JIT, and AM) are fully configured in the system (Inman *et al.*, 2011; Iqbal *et al.*, 2018). Our findings endorse that strategic partnership with customers and suppliers, in combination with JIT production and information technologies, is an important enabler of AM (McCullen and Towill, 2001).

Lean–AM complementarity and performance. Lean manufacturing and AM complementarity has a positive impact on performance measures at multiple levels. It also rejects the notion that AM does not affect cost and quality. For instance, Hallgren and

Olhager (2009) argue that cost and quality are not associated with AM. Our results explicitly demonstrate that lean manufacturing and AM complementarity is positively associated with cost and quality as well as other measures of performance (Cua *et al.*, 2006; Inman *et al.*, 2011; Vázquez-Bustelo *et al.*, 2007). In addition, literature is replete with the notion that lean manufacturing performance range is limited to operational performance (Cua *et al.*, 2006; Dal Pont *et al.*, 2008; Hallgren; Olhager, 2009; Kannan and Tan, 2005).

Our results indicate that lean manufacturing in combination with AM becomes a business-wide performance improvement initiative. Our integrated performance-related empirical results demonstrate that lean manufacturing and AM complementarity is not only limited to practices, it holds squarely compatible from performance perspective as well (Narasimhan *et al.*, 2006). Our study's empirical findings also demonstrate that lean manufacturing and AM complementarity effects on aggregated performance are much higher than effects on sublevel performance dimensions, i.e. operational, market, and financial.

Lean and AM competing effects. Competing effects are tested using un-correlated (independent) and correlated (partially integrated) models. Empirical results of uncorrelated (independent) and correlated (partially integrated) models explicitly indicate that lean manufacturing and AM are not competing paradigms, and fail to perform, once employed in independent or partially integrated format.

Hallgren and Olhager (2009) argue that lean manufacturing and AM manufacturing could be clearly delineated from strategy, core practices, and competitive priorities perspectives, respectively. They found that AM is linked with dynamic market environment. They argue that lean manufacturing is less sensitive to market change as compared to agile. According to them, these paradigms operate in different competitive environments and focus on different performance parameters. For example, lean manufacturing focuses on cost and quality (Shah and Ward, 2003), whereas AM focuses on flexibility and delivery (Crocitto and Youssef, 2003; Yusuf *et al.*, 1999; Zelbst *et al.*, 2010).

However, our empirical findings did not find support to conform to this argument. Nevertheless, the examination of fit indices of uncorrelated and correlated models indicates that there is an underlying common theoretical thread among lean manufacturing and AM, thus implicitly supporting complementarity and rejecting competing notion (Iqbal *et al.*, 2018).

Managerial implications

Our study provides valuable direction to manufacturing managers in general, and apparel sector manufacturers in particular. One man one machine is the hallmark of apparel manufacturing firms. Apparel export sector is exceptionally highly human- and technology-intensive and offers an opportunity to benefit from lean manufacturing (human-intensive) and AM (technology-intensive) complementarity. Our finding clearly demonstrate that lean manufacturing and AM complementarity is a valuable resource to enhance multiple dimensions of business performance (operational, market, financial) of apparel exporting firms. This study also helps to provide clarity to manufacturing managers that lean manufacturing and AM complementarity builds on strong foundation of strategic management and dynamic infrastructure (internal and external) setups. This study, nonetheless, provides insight that concurrent, as opposed to piecemeal, implementation of lean manufacturing and AM is likely to produce desirable results.

Concept of implementation of lean manufacturing and AM is not new to managers in apparel export industry of Pakistan, a developing country. Our results show that apparel export sector is maintaining its orientation with competitive requirements of the market (Iqbal *et al.*, 2018). Managers have understanding of lean manufacturing and AM complementarity effects on business performance. They should focus on development of skilled and empowered human resources and invest in advanced manufacturing technology and information management system to make a continuously learning and integrated organization. Then they will be in a position to benefit from the strength of customer and supplier's integration (Ghobakhloo and Azar, 2018; Ghobakhloo and Tang, 2014).

Lean manufacturing and AM complementarity can effectively assist Pakistani apparel exporting firms to meet specific challenges of competitive environment that is attributed as having shorter product life cycle, requirements of product customization and efficient scaling up and down of operations, and pressures of reducing cost and lead times. Export data of Pakistani apparel manufacturing firms show that this sector's performance and market share in international market are declining (Pakistan Economic Survey, 2018–19). This study's results provide an insight to apparel manufacturers on how to keep themselves abreast with lean manufacturing and AM complementary and improve their business performance. This study demonstrates that lean manufacturing and AM complementary can help to revive this industry. Results also demonstrate that focus on advanced manufacturing technologies by Pakistani firms is low as compared to other leading apparel exporting countries such as China and Bangladesh (Iqbal and Khan, 2012). A plausible reason can be that acquiring and implementing advanced manufacturing technologies require huge investments, which many plants cannot afford. Apparel managers need to bear in mind that advanced manufacturing technology involves both costs and benefits. Replacing existing manufacturing technology and systems and costs of training employees are examples of many lean manufacturing and AM costs. Effective lean manufacturing and AM would increase the employees' productivity, thus improving time to market and customer satisfaction. Our study shows that in addition to benefiting from cheap labor factor, firms must invest in advanced manufacturing technologies to enhance their organizational performance.

Conclusion, limitations and future research

Basic objectives of this study were to explore lean manufacturing and AM complementarity and competing effects on different performance measures. From theoretical perspective, our study of apparel manufacturing plants in Pakistan makes a valuable contribution to manufacturing strategy and operations management literature. Drawing from complementarity theory, ToS, and concept of fit, we seek to argue that lean manufacturing and AM are complementary capabilities and proposed a complementary model. SEM results of uncorrelated (independent) and correlated (partially integrated) models indicate that lean manufacturing and AM are not competing paradigms. This study demonstrates presence of complementary effects of lean manufacturing and AM on operational, market, and financial performance. In doing so, this research is an initial attempt at examining complementarity of lean manufacturing and AM, and combining management and infrastructure within a strategic system to assess combined impact on operational, market, and financial performance. The support from literature and empirical findings suggest that "evolution" to an agile state would help acquire greater performance gains (Jin-Hai *et al.*, 2003; Narasimhan *et al.*, 2006). In particular, as compared with earlier research in developed countries, we find that lean manufacturing and AM complementarity appears to be consistent in setting of an emerging economy where assumingly management skills and advance manufacturing technologies are in the evolving phase.

This research has certain limitations that provide opportunities for future research. This research is based on data of apparel sector in a developing economy; thus, one should use prudence in generalizing findings to other manufacturing or service industries. It is recommended that future research should use data from other manufacturing and service sectors to seek more generalizability. Second, due to single firm, single respondent common method bias may affect results. Future research studies should consider this aspect by incorporating multiple respondents – single firm to exterminate any possibility of potential common method bias. Thirdly, findings of this study are based on cross-sectional data, whereas nature of lean (TQM and JIT) and AM complementarity is continuous and dynamic. Longitudinal data regarding lean manufacturing and AM practices and performance can unfold insights that might be missing in findings of current study. Thus, it would be interesting to conduct a longitudinal study to understand dynamics of lean manufacturing and AM complementary vis-à-vis firm performance in future research. Fourth, lean manufacturing is an overarching paradigm and fully compatible with latest advanced and digital manufacturing technologies in the Industry 4.0 era. A future study should be undertaken to examine lean manufacturing and AM complementarity vis-à-vis firm performance in organizations that are seeking to digitalize and have digitalized their manufacturing operations.

Note

1. Questionnaire items are available from authors on request.

References

Amit, R. and Schoemaker, P.J. (1993), "Strategic assets and organizational rent", *Strategic Management Journal*, Vol. 14, pp. 33-46.

Bottani, E. (2010), "Profile and enablers of agile companies: an empirical investigation", *International Journal of Production Economics*, Vol. 125, pp. 251-261.

Crocitto, M. and Youssef, M. (2003), "The human side of organizational agility", *Industrial Management and Data Systems*, Vol. 103, pp. 388-397.

Cua, K.O., McKone, K.E. and Schroeder, R.G. (2001), "Relationships between implementation of TQM, JIT, and TPM and manufacturing performance", *Journal of Operations Management*, Vol. 19, pp. 675-694.

Cua, K.O., McKone, K.E. and Schroeder, R.G. (2006), "Improving performance through an integrated manufacturing program", *Quality Management Journal*, Vol. 13, pp. 45-60.

Curkovic, C., Vickery, S. and Dröge, C. (2000), "Quality-related action programs: their impact on quality performance and business performance", *Decision Sciences*, Vol. 31, pp. 885-905.

Dal Pont, G., Furlan, A. and Vinelli, A. (2008), "Interrelationships among lean bundles and their effects on operational performance", *Operations Management Research*, Vol. 1, pp. 150-158.

Dean, J.W. Jr and Snell, S.A. (1996), "The strategic use of integrated manufacturing: an empirical examination", *Strategic Management Journal*, Vol. 17, pp. 459-480.

Dillman, D.A. (2007), *Mail and Internet Surveys: The Tailored Design Method*, 2nd ed. John Wiley and Sons, Hoboken, NJ.

Flynn, B.B., Sakakibara, S. and Schroeder, R.G. (1995a), "Relationship between JIT and TQM: practices and performance", *Academy of Management Journal*, Vol. 38, pp. 1325-1360.

Furlan, A., Vinelli, A. and Dal Pont, G. (2011b), "Complementarity and lean manufacturing bundles: an empirical analysis", *International Journal of Operations and Production Management*, Vol. 31, pp. 835-850.

Ghobakhloo, M. and Azar, A. (2018), "Business excellence via advanced manufacturing technology and lean-agile manufacturing", *Journal of Manufacturing Technology Management*, Vol. 29, pp. 2-24.

Ghobakhloo, M. and Fathi, M. (2019), "Corporate survival in Industry 4.0 era: the enabling role of lean-digitized manufacturing", *Journal of Manufacturing Technology Management*, Vol. 31 No. 1, pp. 1-30.

Ghobakhloo, M. and Tang, S.H. (2014), "IT investments and business performance improvement: the mediating role of lean manufacturing implementation", *International Journal of Production Research*, Vol. 52, pp. 5367-5384.

Grandzol, J.R. and Gershon, M. (1998), "A survey instrument for standardizing TQM modeling research", *International Journal of Quality Science*, Vol. 3, pp. 80-105.

Gunasekaran, A., Lai, K. and Edwin Cheng, T.C. (2008), "Responsive supply chain: a competitive strategy in a networked economy", *Omega*, Vol. 36, pp. 549-564.

Hair, J.F., Black, W.C., Babin, B.J. and Anderson, R.E. (2010), *Multivariate Data Analysis A Global Perspective*, 7th ed., Pearson Education reprinted by Dorling Kindersley India, New Delhi.

Hair, J.F. Jr, Hult, G.T.M., Ringle, C. and Sarstedt, M. (2016), *A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM)*, Sage, Thousand Oaks, CA.

Hakala, H. and Kohtamäki, M. (2011), "Configurations of entrepreneurial-customer-and technology orientation: differences in learning and performance of software companies", *International Journal of Entrepreneurial Behaviour and Research*, Vol. 17, pp. 64-81.

Hallgren, M. and Olhager, J. (2009), "Lean and agile manufacturing: external and internal drivers and performance outcomes", *International Journal of Operations and Production Management*, Vol. 29, pp. 976-999.

Harrison, A. (1997), "From leanness to agility", *Manufacturing Engineer*, Vol. 76, pp. 257-260.

Hormozi, A.M. (2001), "Agile manufacturing: the next logical step", *Benchmarking: An International Journal*, Vol. 8, pp. 132-143.

Inman, R.A., Sale, R.S., Green, K.W. Jr and Whitten, D. (2011), "Agile manufacturing: relation to JIT, operational performance and firm performance", *Journal of Operations Management*, Vol. 29, pp. 343-355.

Iqbal, T., Huq, F. and Bhutta, M.K.S. (2018), "Agile manufacturing relationship building with TQM, JIT, and firm performance: an exploratory study in apparel export industry of Pakistan", *International Journal of Production Economics*, Vol. 203, pp. 24-37.

Iqbal, T. and Khan, N. (2012), "Export performance a vital indicator for measuring industry competitiveness: evidence from Pakistan textile and clothing industry", *Life Science Journal*, Vol. 9, pp. 3816-3822.

Jajja, M.S.S., Brah, S.A. and Hassan, S.Z. (2012), "The impact of supply chain management on suppliers functions and organizational performance", *POMS 23rd Annual Conference*, Chicago, Illinois, USA, pp. 1-23.

Jajja, M.S.S., Chatha, K.A. and Farooq, S. (2018), "Impact of supply chain risk on agility performance: mediating role of supply chain integration", *International Journal of Production Economics*, Vol. 205, pp. 118-138.

Jajja, M.S.S., Kannan, V., Brah, S.A. and Hassan, S.Z. (2017), "Linkages between firm innovation strategy, suppliers, product innovation, and business performance: insights from resource dependence theory", *International Journal of Operations & Production Management*, Vol. 37, pp. 1054-1074.

Jayaram, J., Ahire, S.L. and Dreyfus, P. (2010), "Contingency relationships of firm size, TQM duration, unionization, and industry context on TQM implementation—a focus on total effects", *Journal of Operations Management*, Vol. 28, pp. 345-356.

Jayaram, J. and Xu, K. (2013), "The relative influence of external versus internal integration on plant performance in China", *International Journal of Production Economics*, Vol. 146, pp. 59-69.

Jin-Hai, L., Anderson, A.R. and Harrison, R.T. (2003), "The evolution of agile manufacturing", *Business Process Management Journal*, Vol. 9, pp. 170-189.

Kamble, S., Gunasekaran, A. and Dhone, N.C. (2019), "Industry 4.0 and lean manufacturing practices for sustainable organisational performance in Indian manufacturing companies", *International Journal of Production Research*, Vol. 58 No. 5, pp. 1319-1337.

Kannan, V.R. and Tan, K.C. (2005), "Just in time, total quality management, and supply chain management: understanding their linkages and impact on business performance", *Omega*, Vol. 33, pp. 153-162.

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.

Lakhal, L., Pasin, F. and Limam, M. (2006), "Quality management practices and their impact on performance", *International Journal of Quality and Reliability Management*, Vol. 23, pp. 625-646.

Malhotra, M.K. and Mackelprang, A.W. (2012), "Are internal manufacturing and external supply chain flexibilities complementary capabilities?", *Journal of Operations Management*, Vol. 30, pp. 180-200.

McCullen, P. and Towill, D. (2001), "Achieving lean supply through agile manufacturing", *Integrated Manufacturing Systems*, Vol. 12, pp. 524-533.

Milgrom, P. and Roberts, J. (1995), "Complementarities and fit strategy, structure, and organizational change in manufacturing", *Journal of Accounting and Economics*, Vol. 19, pp. 179-208.

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.

Naylor, J.B., Naim, M.M. and Berry, D. (1999), "Leagility: integrating the lean and agile manufacturing paradigms in the total supply chain", *International Journal of Production Economics*, Vol. 62, pp. 107-118.

Pakistan Economic Survey (2018-19), *Ministry of Finance*, Government of Paksitan, Paksitan.

Prajogo, D., Chowdhury, M., Yeung, A.C. and Cheng, T. (2012), 'The relationship between supplier management and firm's operational performance: a multi-dimensional perspective", *International Journal of Production Economics*, Vol. 136, pp. 123-130.

Prajogo, D. and Olhager, J. (2012b), "Supply chain integration and performance: the effects of long-term relationships, information technology and sharing, and logistics integration", *International Journal of Production Economics*, Vol. 135, pp. 514-522.

Rungtusanatham, M., Forza, C., Filippini, R. and Anderson, J.C. (1998), "A replication study of a theory of quality management underlying the Deming management method: insights from an Italian context", *Journal of Operations Management*, Vol. 17, pp. 77-95.

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.

Samson, D. and Terziovski, M. (1999), "The relationship between total quality management practices and operational performance", *Journal of Operations Management*, Vol. 17, pp. 393-409.

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.

Skyttner, L. (2005), *General Systems Theory: Problems, Perspectives, Practice*, World Scientific, New York; Hackensack, NJ.

Tanriverdi, H. and Venkatraman, N. (2005), "Knowledge relatedness and the performance of multibusiness firms", *Strategic Management Journal*, Vol. 26, pp. 97-119.

Vázquez-Bustelo, D., Avella, L. and Fernández, E. (2007), "Agility drivers, enablers and outcomes: empirical test of an integrated agile manufacturing model", *International Journal of Operations and Production Management*, Vol. 27, pp. 1303-1332.

Venkatraman, N. (1989), "The concept of fit in strategy research: toward verbal and statistical correspondence", *Academy of Management Review*, Vol. 14, pp. 423-444.

Venkatraman, N. and Prescott, J.E. (1990), "Environment-strategy coalignment: an empirical test of its performance implications", *Strategic Management Journal*, Vol. 11, pp. 1-23.

Yang, M.G., Hong, P. and Modi, S.B. (2011), "Impact of lean manufacturing and environmental management on business performance: an empirical study of manufacturing firms", *International Journal of Production Economics*, Vol. 129, pp. 251-261.

Yusuf, Y.Y. and Adeleye, E.O. (2002), "A comparative study of lean and agile manufacturing with a related survey of current practices in the UK", *International Journal of Production Research*, Vol. 40, pp. 4545-4562.

Yusuf, Y.Y., Sarhadi, M. and Gunasekaran, A. (1999), "Agile manufacturing:: the drivers, concepts and attributes", *International Journal of Production Economics*, Vol. 62, pp. 33-43.

Zelbst, P.J., Green, K.W. Jr, Abshire, R.D. and Sower, V.E. (2010), "Relationships among market orientation, JIT, TQM, and agility", *Industrial Management and Data Systems*, Vol. 110, pp. 637-658.

Corresponding author
Muhammad Shakeel Sadiq Jajja can be contacted at: ssj@lums.edu.pk