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The unique and complementary effects of manufacturing technologies and lean practices on manufacturing operational performance

Teerasak Khanchanapong [a], Daniel Prajogo [b,*], Amrik S. Sohal [b], Brian K. Cooper [b], Andy C.L. Yeung [c], T.C.E. Cheng [c]

[a] Department of Management, Dhurakij Pundit University, Thailand
[b] Department of Management, Monash University, Australia
[c] Department of Logistics and Maritime Studies, The Hong Kong Polytechnic University, PR China

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ABSTRACT

This study investigates the unique and complementary effects of manufacturing technologies and lean practices on operational performance of manufacturing firms. Despite the importance of understanding how various resources are interrelated within firms, there have been few studies focusing on this area. Using data collected from 186 manufacturing plants in Thailand, we found that both manufacturing technologies and lean practices have unique effects on a range of operational performance dimensions, including quality, lead-time, flexibility, and cost. More importantly, however, we also found that both organizational resources have complementary (or synergistic) effects on those operational performance dimensions. Based on the research findings, we offer theoretical and practical insights which support the importance of building strong manufacturing technologies and lean practices that maximize operational performance.

1. Introduction

Global competition has intensified pressure on manufacturing plants to improve along multiple dimensions of operational performance. These operational performance dimensions include product quality, lead-time, flexibility, and cost (Boyer and Lewis, 2002; Hayes and Wheelwright, 1984; Tan et al., 2004). Consequently, numerous studies have attempted to identify the various resources that can be utilized to help firms to excel on these multiple operational dimensions. Based on the past research on this topic (Das, 2001; Swamidass, 2003; Zahra and Das, 1993), manufacturing resources can be grouped into two major categories, namely manufacturing technologies and lean practices. Manufacturing technologies refer to certain types of technologies such as hardware and computer programs, including computer-aided design (CAD), computer-aided engineering (CAE), computer-aided manufacturing (CAM), computer numerical control (CNC) machines, robots, and enterprise resource planning (ERP) systems, whilst lean practices are concerned with manufacturing techniques and know-how such as total quality management (TQM) and just-in-time (JIT) manufacturing.

A number of empirical studies have investigated the effect of manufacturing technologies and lean practices on different measures of operations performance (Swamidass, 2003; Zahra and Das, 1993). However, most of these studies focus on either manufacturing technologies (Beaumont et al., 2002; Kotha and Swamidass, 2000) or lean practices (Cua et al., 2001; Flynn et al., 1995). It is now common for manufacturing firms to adopt both manufacturing technologies and lean practices and therefore, it is important to understand the synergistic effects of manufacturing technologies and lean practices on improving operational performance. However, only few studies (Challis et al., 2002) have brought together the aspects of manufacturing technologies and lean practices into a single study and tested their unique and synergistic effects.

Drawing on the resource-based view of the firm (RBV) theory and complementarity theory, we argue that combining different resource bundles may result in synergistic effects on operational performance (Jeffers et al., 2008). However, to date, only a few empirical studies have examined the interactive effects of manufacturing technologies and lean practices on multiple dimensions of operational performance. For example, Boyer et al. (1997) examined the interaction between different advanced manufacturing technologies (AMTs), which are similar to the manufacturing technologies in this study, and infrastructure on three performance measures,

* Correspondence to: Department of Management, Monash University, PO Box 197, VIC 3141, Australia. Tel.: +61 3 9903 2030; fax: +61 3 9903 2718.
E-mail addresses: teerasak.khg@dpu.ac.th (T. Khanchanapong), Daniel.Prajogo@monash.edu (D. Prajogo), Amrik.Sohal@monash.edu (A.S. Sohal), Brian.Cooper@monash.edu (B.K. Cooper), Andy.Yeung@inet.polyu.edu.hk (A.C.L. Yeung), Edwin.Cheng@inet.polyu.edu.hk (T.C.E. Cheng).

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namely growth, profitability, and flexibility. They argued that investments in AMTs are more likely to lead to improved performance, if these are supported by improvements in the manufacturing infrastructure of the company. Boyer et al. (1997) and Zhou et al. (2009) showed the interaction effects of the adoption of AMTs and investments in infrastructure on performance. Swink and Nair (2007) tested the interaction between the usage of AMTs and design-manufacturing integration (DMI) on five dimensions of operational performance. Their findings showed that the interaction effects were positive on quality, delivery, and process flexibility, but not on cost efficiency and new product flexibility. Our study builds on these two studies by testing the interactive effects of manufacturing technologies and lean practices on four major dimensions of operational performance, namely product quality, lead-time, flexibility, and cost. Specifically, we extend the works of Boyer et al. (1997) and Swink and Nair (2007) by expanding the scope of both lean practices and manufacturing operational dimensions.

The rest of the paper is organized as follows: first, we develop a set of hypotheses concerning the relationships between manufacturing technologies and lean practices, and their effects on four major operational dimensions of manufacturing performance, namely cost, product quality, lead-time, and flexibility. Then, we present the research methodology and the results of our analysis. Finally, we discuss the theoretical and practical implications of the findings.

2. Literature review and hypothesis development

In this study, the resource-based view (RBV) is used as a theoretical lens to examine the relationship between resources (e.g., manufacturing technologies and lean practices) and operational performance. RBV argues that business organizations, even within the same industry and the same operational environment, are heterogeneous in their resources and this heterogeneity can explain competitive, even sustainable, and performance differentials (Hackman and Wageman, 1995; Ketokivi and Schroeder, 2004). Resources are defined as all assets, organizational processes, firm attributes, information, knowledge, technologies etc. controlled by a firm that enables it to conceive of and implement strategies that improve its efficiency and effectiveness (Barney, 1991). Firm resources are the firm's strengths. Resources are thus defined by virtue of their relationship to performance, and the relationship between resources and performance is the key outcome of interest (Amundson, 1998).

RBV theory has been applied in a number of studies in the manufacturing context. By applying the RBV, Zahra and Das (1993) propose a framework that examines how manufacturing technologies and lean practices deployed as organizational resources are reflected in competitive performance. In the context of our study, RBV provides a theoretical lens for examining three issues. First, we draw from RBV to examine the effectiveness of both manufacturing technologies and lean practices as firms' resources which are valuable and non-imitable as reflected in the firms' performance. Second, RBV guides us to examine the unique effect of both manufacturing technologies and lean practices in predicting different types of performance. In their study, Ketokivi and Schroeder (2004) propose that, based on the premise that each practice–performance relationship might be unique, the organizational determinants of high conformance quality may be different from those of flexibility. Similarly, Cua et al. (2001) also argue that different configurations of basic techniques and common practices affect specific aspects of capabilities. Third, in the light of RBV, we examine the synergistic effects between manufacturing technologies and lean practices in predicting different types of manufacturing performance. This is because a combination of different resources increases the complexity of resources which makes it more difficult to imitate by competitors; and, if the combined resources produce synergy, these would deliver higher performance than each of them could deliver by itself.

In the next two sections, the eight hypotheses examining the effects of manufacturing technologies and lean practices on the four dimensions of operational performance are developed and presented.

2.1. Relationship between manufacturing technologies and operational performance

Manufacturing technologies entails various technologies which are employed in different activities in manufacturing operations. Given a wide variety of technologies used, a number of authors (Adler, 1988; Cardoso et al., 2012; Kotha and Swamidass, 2000; Meredith, 1987; Rosenthal, 1984; Sohal et al., 2006) have considered manufacturing technologies as a multi-dimensional construct. In this study, Boyer et al.'s (1996) classification was adopted as a basis for identifying three groups (or components) of manufacturing technologies that are distinct but related to one another. The first component is design manufacturing technologies that comprise tools such as (CAD), (CAE), and computer-aided production planning (CAPP) that focus on product and process design issues. The second component is process manufacturing technologies, which enables efficient and flexible manufacturing processes and include technologies such as automated manufacturing (AM), real-time process control systems, CNC machines, and robots. The third group is administrative manufacturing technologies, which aid in internal and external communication, as well as planning of critical firm resources. These technologies consist of material requirements planning (MRP), manufacturing resources planning (MRPII), and enterprise resources planning (ERP) systems. Swink and Nair (2007) point to general agreement in the literature on this classification scheme which identifies these three aspects of manufacturing technologies.

As mentioned earlier, the effect of manufacturing technologies on various dimensions of operational performance has been recognized. Below, we elaborate on the arguments which lead to the hypotheses concerning the relationship between manufacturing technologies and each of the four performance measures (cost, quality, lead-time, and flexibility).

Low cost is often cited as the primary, realized manufacturing objective of manufacturing technology implementation (Adler, 1988; Esan et al., 2013). Ettlie (1988) found positive significant effects of AMT on cost reduction. AMT, specifically CIM technology, was linked to reductions in inventory levels and costs resulting from scrap and re-work (Ettlie, 1988; Heim and Peng, 2010). Similarly, Zairi (1993) reported that AMT is primarily adopted in response to changes in demand at economical costs and is introduced to combat costs and to enable users to compete as economically as possible. For example, the adoption of a CAD/CAM system allows the production system to release extra machine time; hence reducing costs and increasing productivity (Heim and Peng, 2010; Pagell and Krause, 1999; Patterson et al., 2004). Literature has also suggested the positive effect of administrative technologies on cost performance. MRPII, for example, offers information integration business processes linked to a central database that stores and delivers more accurate data and information compared to paper-based information and communication systems which potentially produce numerous errors (e.g., missing data, redundant data, and numerical errors), resulting from incorrect keying into the system, incorrect calculations based on numerical errors, and bad decisions based on incorrect or old data, (Ward and Zhou, 2006). MRPII also allows for the coordination of raw materials purchasing, facilitates the development of a detailed production schedule that accounts for machine and labor capacity, and provides data about the cost of production, including machine time, labor, and raw materials used (Monk and Wagner, 2006). The above discussions suggest that manufacturing technologies, when used in a coordinated way (i.e., as a set), will have a significant effect on improving manufacturing operational performance in terms of costs. Accordingly, we hypothesize the following:

Hypothesis 1. Manufacturing technologies are positively associated with cost performance.

A number of researchers argue that hard technologies have not only reduced cost, but also contributed to improved quality (Goldhar and Jelinek, 1983; Heim and Peng, 2010; Zammuto and O'Connor, 1992). Specifically, Parthasarthy and Sethi (1993) suggest that manufacturing technologies also had the ability to offer a quick and efficient changeover from product design to processing when both design and manufacturing were integrated through a computer, such as CAD and CAM. The resulting competency, known as changeover or speed competency, facilitates design changes for improving quality or quickly substituting existing products with new products. Adding to this argument, Malhotra et al. (2001) suggest that increasing levels of CAD technology functionality and sophistication enhanced performance in quality. Therefore, we pose the following hypothesis:

Hypothesis 2. Manufacturing technologies are positively associated with product quality performance.

Previous literature supports the views suggesting that manufacturing technologies may allow production of widely varied or customized products with greater precision, speed and efficiency (Boyer and Lewis, 2002; Corbett and van Wassenhove, 1993; Esan et al., 2013). Specifically, CAD technology helps design engineering departments in reducing the design cycle time; thus, shortening the time required to get the products into full production. In addition, by eliminating manual activities, such as changing assembly drawings, assembly charts, and routing sheets, CAD technology reduces the time required for each product modification (Hutchison and Das, 2007). At the same time, MRPII, as part of administrative technologies, provides tighter control and flexibility, smooth manufacturing flow through a manufacturing plant, makes the flow more predictable, and cuts the overall throughput time; hence, allowing quicker delivery time (Ward and Zhou, 2006). Therefore, it is hypothesized as follows:

Hypothesis 3. Manufacturing technologies are positively associated with lead time performance.

The role of manufacturing technologies in enhancing manufacturing flexibility has also been recognized in the literature (Esan et al., 2013). Malhotra et al. (2001) found that increasing levels of CAD technology functionality and sophistication enhanced performance in flexibility. Gerwin (1987) examined how the use of reprogrammable robots could increase product mix flexibility, in terms of the potential for handling an increased number of different kinds of car bodies, and the way volume flexibility increased because of very high capacity limits. Similarly, the use of other automated technologies (e.g., CAM, FMS, real-time process control, CNC machines) increases various aspects of flexibilities of the firms, such as modification flexibility, volume flexibility, and product mix flexibility (Chang et al., 2005; Esan et al., 2013; Hutchison and Das, 2007; Suarez et al., 1996; Zairi, 1993).

Swink and Nair (2007) reported that both planning (administrative) and process (manufacturing) AMT have a positive effect on process flexibility and new product flexibility. Specifically, the use of administrative technologies assists firms managing the flow of materials and products from supplier sources to users as well as enabling cross-functional information sharing and may link the firm's problem solving efforts with customers and suppliers (Boyer and Leong, 1996; Kotha and Swamidass, 2000; Koufteros et al., 2001). Several studies show that administrative (IT-related) technologies enhances firms' ability to increase or decrease their production output levels economically; hence allowing volume flexibility (Heim and Peng, 2010; Raturi and Jack, 2004; Slack and Correa, 1992). Based on the above arguments and evidence, we hypothesize the following:

Hypothesis 4. Manufacturing technologies are positively associated with flexibility performance.

2.2. Relationship between lean practices and operational performance

As noted above, lean practices refer to manufacturing techniques and know-how, which represent operating policies concerning JIT and TQM. The recent literature suggests that JIT and TQM are among the most sustainable management philosophies to have been adopted for decades and still continue to add value to company performance (Dangayach and Deshmukh, 2001; McDonald et al., 2002; Vokurka et al., 2007). However, many authors have found it difficult to precisely list the practices that comprise JIT and TQM because of the extensive overlap between the two philosophies (Cowton and Vail, 1994; Dean Jr. and Snell, 1991; Flynn et al., 1995). Therefore, we adopt Flynn et al.'s (1995) approach to select the key components of lean practices in this study. Following the previous studies on JIT and TQM (Cua et al., 2001; Flynn et al., 1995; Kannan and Tan, 2005; Matsui, 2007; Sakakibara et al., 1993; Shah and Ward, 2003; Swink et al., 2005), we include the key aspects of lean practices such as production flow management, process management, customer focus, workforce management, and supplier management. Similar to Flynn et al. (1995), we do not suggest that each of these practices used in isolation leads to effective performance; rather, we advocate that these practices are complementary to one another and should be used as a set rather than in a piecemeal fashion. Below, we outline the arguments which support the relationship between lean practices and each of the four operational performance measures, leading to the hypotheses tested in this study.

The impact of lean practices on cost reduction has been recognized in the literature (Shah et al., 2008; Sunder, 2013; Vinodh and Joy, 2012). Lee and Ebrahimpour (1984) suggest by implementing a JIT system that firms will prefer suppliers who are able to offer small and frequent deliveries. This is because small and frequent deliveries will help in reducing in-plant inventory, and, therefore, inventory costs. One of the benefits of having long-term relationship with suppliers is lower manufacturing cost due to long-term and large volume of purchases (Prajogo and Olhager, 2012). Trygg (1993) reported how early involvement of customers in the product development process allowed the development of products that satisfied the customers' needs and led to the reduction of costs. Swink et al. (2005) have also reported that workforce development enhance people's skills in performing their tasks more effectively and efficiently; therefore, improving productivity and reducing costs. Yeung et al. (2006) explained that process control and improvement practices help workers investigate the root causes and take corrective action every time a failure is found, hence, reducing failure costs produced by poor quality products. Therefore, we hypothesize the following:

Hypothesis 5. Lean practices are positively associated with cost performance.

Previous studies also support the relationship between lean practices and quality performance (Shah et al., 2008; Sunder, 2013; Vinodh and Joy, 2012). Under the TQM philosophy aiming to improve the quality of goods and services (Ahire et al., 1996; Flynn et al., 1995; Prajogo and Sohal, 2006; Saraph et al., 1989; Sitkin et al., 1994), process management is one of the critical practices for developing quality performance. As discussed earlier, process control and improvement practices along with workforce commitment help plants to resolve quality problems in manufacturing processes (Yeung et al., 2006). Based on the TQM philosophy, Flynn et al. (1995) have highlighted the importance of an open relationship with customers in providing an input to the product design process by facilitating clarification of the customers' needs and desires, as well as examining how cross-functional teams become the basis for problem solving and production development (Swamidass, 2003). Statistical quality/process control (SQC/SPC) applies the laws of probability and statistical techniques for monitoring and controlling the quality of a process and its output (Heim and Peng, 2010; Swamidass, 2003).

Flynn et al. (1995) also suggested that supplier certification or qualification programs provide a means of conveying manufacturers' quality expectations to suppliers, and providing assurance about the quality of incoming materials and parts. Suppliers also contribute to the product design process through inclusion in product design teams, where they provide input about the performance of prospective materials and parts. In addition, supplier relationship is directly related to quality performance because purchased materials and parts are dominant sources of process variability which affects the quality performance. The contribution of suppliers in delivering value to customers, hence building competitive capabilities in terms of quality, has been well recognized (Prajogo and Olhager, 2012). As such, we hypothesized the following:

Hypothesis 6. Lean practices are positively associated with product quality performance.

Lean practices also have an impact on lead-time reduction; indeed, one of the key tenets of lean is to improve speed and efficiency of production flow (Shah et al., 2008; Sunder, 2013; Vinodh and Joy, 2012; Ward and Zhou, 2006). With a pull system, smooth flow is assured because upstream operations cannot act without the authorization of downstream operations, and therefore, cannot flood the operation with work-in-process inventory which slow down the flow of materials and increases throughput times (Ahire et al., 1996; Cua et al., 2001; Flynn et al., 1995; Hofer et al., 2012; Matsui, 2007; Saraph et al., 1989; Shah and Ward, 2003; Swink et al., 2005). In addition, lean concepts also emphasize the creation of efficient production layout which enhances flow and the speed by which a product is made. This smooth layout is accompanied by quick changeover of equipment and smaller lot size of materials to be processed. This setup time reduction eventually reduces internal lead-times (Alsmadi et al., 2012; Bartezzaghi and Turco, 1989), and the reduction of the lot size also reduces the internal lead-time because of shorter queues in the different phases of the production process (Flynn et al., 1995; Hayes and Wheelwright, 1984). Overall, the implementation of a JIT system which involves small and frequent deliveries will provide parts at the exact time and in the exact quantities needed at the production site (Lee and Ebrahimpour, 1984).

The contribution of suppliers in enhancing lead-time performance has also been recognized in the literature (Prajogo and Olhager, 2012) and scholars have suggested that early involvement of customers in the product development process shortens lead-time (Trygg, 1993). At the same time, building a network of suppliers for discrete product groups allows suppliers to react faster to these changes by making early commitment to raw materials and components to supply items over shorter lead-times (Hutchison and Das, 2007). Based on the above arguments, we hypothesize the following:

Hypothesis 7. Lean practices are positively associated with lead time performance.

The implementation of lean practices also enhances flexibility performance (Boyer et al., 1997; Swink et al., 2005; Vinodh and Joy, 2012). For example, building a strong relationship and close coordination between a manufacturer and its suppliers is very important (Prajogo and Olhager, 2012), particularly in the face of increasing demand. This is because the close relationship increases suppliers' willingness to absorb demand fluctuations or to provide slack capacity which will support manufacturers to more readily change production volumes without incurring high transition penalties or large changes in performance outcomes (Rosenzweig and Roth, 2004). In addition, a close relationship with suppliers also increases supplier responsiveness that will improve firms' flexibility in terms of the ability to conduct product modifications quickly and economically (Narasimhan and Das, 1999; Petroni and Bevilacqua, 2002). As mentioned earlier, lean concepts promote streamline layout in the production flow along with quick changeover of equipment and smaller lot sizes (Alsmadi et al., 2012; Bartezzaghi and Turco, 1989). While these practices improve speed, they also enhance firms' ability to change the product lines quickly, hence, increasing flexibility in terms of product variety or range.

The other aspect of lean which positively affects flexibility is workforce management. This is because lean practices promote multi-skilled workers who can easily be assigned from one work center to another as dictated by production volume (Lee and Ebrahimpour, 1984; Yazici, 2005). Similarly, Suarez et al. (1996) and Chang et al. (2005) have shown that cultivating multi-skilled workers who are able to handle different products and have the ability to transfer a variety of fixtures and tooling into and out of the production system is an important determinant of product mix flexibility. Apart from volume and mix flexibility, multi-skilled workers also have the ability to modify operating procedures and products, which allows redesigning parts and enhancing new product flexibility (Gerwin, 1987). Overall, there are sufficient arguments in support of the positive effect of lean practices on flexibility performance; therefore, we hypothesize the following:

Hypothesis 8. Lean practices are positively associated with flexibility performance.

2.3. *Complementarities between manufacturing technologies and lean practices*

The previous section outlined the theoretical arguments to support the unique and combinatorial effects of manufacturing technologies and lean practices. While the previous arguments are helpful in showing both manufacturing technologies and lean practices as valuable resources for firms, they do not suggest a potential interaction between the two resources in providing its benefits to the firms. Most studies examining these two resources were mainly focused on examining the unique effect of each resource (Challis et al., 2005; Cua et al., 2001; Das and Jayaram, 2007). While these findings strongly recommend that firms employ both resources, they did not show if the benefits realized from one resource is affected by the other resource by testing the interaction between the two resources.

In this study, we advance our understanding by considering manufacturing technologies and lean practices as complementary resources. Following Milgrom and Roberts (1995), resources are mutually complementary if the return of one resource increases or decreases in the presence of the other resource. More specifically, complementarity between resources can be synergistic, i.e., when one resource magnifies the impact of another, multiplying the common effect, or suppressive, i.e., when one resource diminishes the potential impact of another (Jeffers et al., 2008). Based on this definition, we hold three notions concerning the complementarity between manufacturing technologies and lean practices, which we intend to demonstrate in this study following the theoretical perspective of complementarity. First, complementary resources are not identical (Harrison et al., 2001). We contend that manufacturing technologies and lean practices are distinct to each other as the former is more technical (hard) and the latter is more concerned with managerial practices, organizational infrastructure, and behavioral (soft) aspects of the firms. Therefore, firms practically can choose to build any of the two resources independently. Second, as mentioned earlier, complementarity theory suggests that the value of a resource in contributing to performance depends on its "complementary" resources. As such, the implementation failure of one resource will negatively affect the implementation of the other resource, leading to failure of the entire implementation effort in producing the desired outcomes (Colbert, 2004). In other words, complementary resources are expected to be positively correlated. Consistent with RBV (Barney, 1995), individual initiatives (resources) have limited ability to generate competitive advantage in isolation; rather they feed off one another. In this regard, while we hold that manufacturing technologies and lean practices are not identical resources, due to their complementarity, any of them cannot deliver the maximum return without the support of the other. As such, the need for building both resources is not simply "additive" (i.e., optional), but necessary. Third, following the second point, Amit and Schoemaker (1993) suggest that the synergistic value of complementary resources can be higher than the rent produced by each resource individually. This is because a complementary set of resources provides a unique value to the firm, and compared with the synergy arising from similar resources, the synergy arising from the complementarity of resources is much more difficult to observe and imitate (Tanriverdi and Venkatraman, 2005). In this regard, we hold that manufacturing technologies and lean practices, due to their complementarity, will produce synergistic effects on operational performance that are greater than their individual effects combined.

The operations management (OM) literature has also suggested or implied synergistic interrelationship between manufacturing technologies and lean practices. For example, the concept of integrated manufacturing (IM) promotes the notion that manufacturing technologies (e.g., AMTs) and lean practices (e.g., JIT and TQM) should work together collaboratively to improve manufacturing performance (Challis et al., 2002; Snell and Dean Jr., 1992). On the one hand, implementation of manufacturing technologies requires augmented and advanced manufacturing infrastructure (lean practices) (Boddy and Buchanan, 1986; Gerwin, 1988). On the other hand, lean practices, in turn, benefits from the use of manufacturing technologies such as CAD, which is useful in smoothing production flow (Chan and Smith, 1993).

In sum, a fair number of arguments have supported the complementarity between manufacturing technologies and lean practices in producing synergistic effects on different measures of operational performance. To our best knowledge, however, most arguments and studies we have found in the literature so far address this complementarity issue in a piecemeal manner. We have not found any studies that embrace comprehensive sets of both manufacturing technologies and lean practices, and examine their synergistic effects against the four measures of operational performance (cost, product quality, lead-time, and flexibility) at the operational level. Accordingly, we seek to investigate this matter.

A set of literature provides exemplary arguments on the synergistic effect between manufacturing technologies and lean practices on specific aspects of operational performance. Das and Jayaram (2007), for example, explain that while the use of CAD/CAM as a "stand alone" technology could result in an explosion of new parts, it also increases costs. However, when combined with efficient equipment layout based on identifying and grouping similar parts, CAD and CAM can exploit parts' similarities, leading to lower design costs. Therefore, we hypothesize the following:

Hypothesis 9. There is a synergistic relationship between manufacturing technologies and lean practices in predicting cost performance.

In conjunction with lean practices, manufacturing technologies have positive effect on product quality performance. The use of CAD/CAM technologies, which provide easy access and storage of design features during product design, assists the handling of complex information obtained from customers' voices (customer focus). As such, by using these technologies, more detailed designs can be developed, information and knowledge is codified and become less abstract, enabling the product design and development team to use design technologies (such as CAD) more effectively, hence ensuring customer voices are well incorporated, and quality is built into product design (Malhotra et al., 2001). Therefore, we hypothesize the following:

Hypothesis 10. There is a synergistic relationship between manufacturing technologies and lean practices in predicting product quality performance.

The synergistic (enhancing) relationship between manufacturing technologies and lean practices also leads to lead-time reduction. A number of companies provide on-site trainings by taking shop-floor employees to other leading companies to see how they make effective use of technologies (such as robots and CNC machines). This has resulted in decreasing setup times and eliminating machine breakdowns. Furthermore, focusing both on technologies and training reduces equipment-related waste, such as downtime, speed losses, etc. In particular, if speed losses are reduced, lead-times are also possibly reduced. Therefore, we hypothesize the following:

Hypothesis 11. There is a synergistic relationship between manufacturing technologies and lean practices in predicting lead time performance.

Manufacturing technologies and lean practices interact to allow pursuit of flexibility goal. JIT supply promotes use of design and manufacturing technologies by removing inventory constraints. Removal of inventory requires tighter integration of the supply-base with production; hence, encouraging active use of AMTs such as CAD and CAM for sharing drawings, designs and production information with key JIT suppliers (Das and Jayaram, 2003). Chan and Smith (1993) suggest that JIT implementation, in turn, has benefited from the use of technologies such as CAD, which has been useful in simulating production flow. Setup time reduction may require an increase in fixed capital investment (manufacturing technologies) to improve greater flexibility (Bartezzaghi and Turco, 1989). Burgess and Gules (1998) explain that, in practice, managers appear to blend manufacturing technologies into lean practices because these two are seen as mutually beneficial. In their case study-based research, Esan et al. (2013) found that the CAD/CAM system in conjunction with appropriate training program enhance the speed the firm's responses to market needs and frees users to focus on creativity and production at minimum possible cost. It does this by facilitating true collaborative engineering across the multidisciplinary extended enterprise, including mechanical design, tooling, systems engineering, machining analysis, simulation and tool path verification, collision checking and analysis of the in-process part. Therefore, we hypothesize the following:

Hypothesis 12. There is a synergistic relationship between manufacturing technologies and lean practices in predicting flexibility performance.

3. Methods

3.1. Sample and procedure

The context of this study is manufacturing firms in Thailand. While numerous studies on manufacturing technologies and lean practices have been conducted in Western countries, only a few studies have focused on understanding OM issues in emerging economies (Amoako-Gyampah and Boye, 2001), especially, those in Asia (Metters et al., 2010; Power et al., 2010). Having risen as one of the emerging economies, Thailand has been considered as an important production platform in South-East Asia and is the base for the regional headquarters of many multinational companies (Ferguson, 1997; Grewal and Tansuhaj, 2001; Intarakumnerd et al., 2002). The Thai manufacturing industry, especially, the automobile industry, has developed rapidly over the past decade. The total export value of the automobile industry in Thailand had increased dramatically from US$3965 million in 2003 to US $22,912 million in 2012 (Ministry of Commerce of Thailand, 2013). The development of the automobile industry in Thailand is particularly phenomenal where the export value has jumped about six times in the past 10 years. However, while Western manufacturers have implemented manufacturing technologies and lean practices widely since the 1980s, Thai manufacturing plants have only adopted these technologies since the 1990s (The Industrial Council of Thailand, 2007). The major challenge facing emerging economies, including Thailand, is how their firms can eventually exploit the benefits from using transferred or imported technologies (Thee, 2005).

Following previous studies (Koste et al., 2004; Swink and Nair, 2007), we use the manufacturing plant as the unit of analysis for this study. We randomly selected 1327 companies from a database provided by the Department of Industrial Work, Ministry of Industry of Thailand. We sent a questionnaire to each company with the request that it be completed by a senior manager who has major operations responsibility and is knowledgeable about the firm's manufacturing practices and performance.

We received 186 usable responses, constituting a 14% response rate. We checked the data for potential non-response bias by comparing the responses to industry sector and revenue between the early and late respondents. The chi-square tests for both categories indicated no statistically significant differences between the two groups of respondents. In the sample, the greatest proportion of the firms came from the automotive industry (31%), followed by fabricated metal (30%), machinery and equipment (24%), and the electronics, computers, and electrical appliances (13%) industries. Just over half of the sample was made up of small-to-medium-sized companies (fewer than 200 employees) and the remaining firms employed 200 people or more. The majority of responses to the survey were from top management (i.e., CEO/vice president of manufacturing and plant manager) (49%), followed by manufacturing/operations manager (32%), and other positions that are relevant to operations, e.g., product quality manager and production supervisor (18%).

3.2. Measures

Following Boyer et al. (1997), we measured manufacturing technologies by three major dimensions, namely design technologies, process technologies, and administrative technologies. Each of these three dimensions was measured several items which we derived from Boyer and Leong (1996) and Swink and Nair (2007). Design technologies comprise three items, process technologies comprise four items, and administrative (planning) technologies comprise three items. All of these items were rated on a five-point Likert scale from “no investment” (1) to “heavy investment” (5).

Lean practices were measured by five dimensions, namely production flow management, customer focus, process management, workforce management, and supplier management. Based on previous studies (Ahire et al., 1996; Cua et al., 2001; Flynn et al., 1995; Hofer et al., 2012; Matsui, 2007; Saraph et al., 1989; Shah and Ward, 2003; Swink et al., 2005), we define the content of each dimension with production flow management comprising five items, customer focus comprising five items, process management comprising five items, workforce management comprising six items, and supplier management comprising five items. All of these items were rated on a five-point Likert scale from “strongly disagree” (1) to “strongly agree” (5).

Operational performance comprises four dimensions, namely cost (four items), quality (five items), lead-time (three items), and flexibility (four items). These items were drawn from Droge et al. (2004), Jacobs et al. (2007), Machuca et al. (2011), and Rosenzweig et al. (2003). To measure operational performance, we asked the respondents to rate their firm's performance against its primary competitor in the industry on a five-point Likert scale from “much worse” (1) to “much better” (5).

The items used to operationalize the key constructs are presented in Table 1.

3.2.1. Control variables

Past research suggests that the use of manufacturing technologies and lean practices, and their effects on competitive performance, may be influenced by organizational size and manufacturing processes (Ahire and Dreyfus, 2000; Swamidass and Kotha, 1998; Swink and Nair, 2007). Following previous research conducted in the context of Thailand (Asasen et al., 2003), we classified firms with fewer than 50 employees, between 51 and 200 employees, and more than 200 employees as small-sized (coded as 1), medium-sized (coded as 2), and large-sized (coded as 3) enterprises, respectively. We measured manufacturing processes using a three-point ordinal scale scored as 1 = highly non-repetitive, 2 = batch, and 3 = highly repetitive (White, 1990).

4. Results

4.1. Scale validity and reliability

We conducted confirmatory factor analysis (CFA) using LISREL 8.52. As recommended by Graham (2009), we used the full-information maximum likelihood (FIML) estimation for handling missing data. We first ran a CFA (with scale items as indicators) for each of the three dimensions of manufacturing technologies, five dimensions of lean practices, and four dimensions of operational performance. The fit of the CFA was acceptable with χ^2 (df = 1208) = 1785.62 and RMSEA = 0.05 and CFI = 0.94; thus, supporting the unidimensionality and convergent validity of the 12 dimensions. The Cronbach's alpha coefficients demonstrate satisfactory internal consistency reliability for the 12 dimensions, with all coefficients exceeding 0.7 (Nunnally, 1978). The results of the item level CFA and reliabilities are presented in Table 1.

In our conceptual model, both manufacturing technologies and lean practices were treated as latent variables where we used each of the sub-dimensions as indicators of their respective constructs;

Table 1
Scale validity and reliability.

Scales	Items	Loading paths	Cronbach's alpha
Design technologies	Computer-aided design (CAD).	0.79	0.83
	Computer-aided engineering (CAE).	0.87	
	Computer-aided process planning (CAPP).	0.72	
Process technologies	Computer-aided manufacturing (CAM).	0.67	0.76
	Sophisticated robots.	0.66	
	Real-time process control systems.	0.77	
	Computerized numerical control machines (CNC).	0.59	
Administrative technologies	Material requirement planning (MRP).	0.82	0.88
	Manufacturing resource planning (MRPII).	0.84	
	Enterprise resource planning (ERP).	0.81	
Production flow management	We use a Kanban pull system for production control.	0.55	0.74
	We have a small amount of work-in-process inventory.	0.62	
	The layout of the shop floor facilitates low inventories and fast throughput.	0.73	
	Employees practice set-ups to reduce the time required.	0.57	
	We usually complete our daily schedule as planned.	0.57	
Customer focus	We actively and regularly seek customer inputs to identify their needs and expectations.	0.64	0.82
	Customer needs and expectations are effectively disseminated and understood throughout the workforce.	0.68	
	We systematically and regularly measure customer satisfaction.	0.83	
	We have an effective process for resolving customers' complaints.	0.74	
	We always maintain a close relationship with our customers and provide them an easy channel for communicating with us.	0.56	
Process management	We design processes in our plant to be “fool-proof” (preventive-oriented).	0.67	0.86
	We have clear, standardized and documented process instructions which are well understood by our employees.	0.77	
	We make an extensive use of statistical techniques (e.g., SPC) to improve the processes and to reduce variation.	0.71	
	The concept of the “internal customer” (i.e., the next process down the line) is well understood in our company.	0.78	
	We emphasize the continuous improvement of product quality in all work processes.	0.78	
Supplier management	Our suppliers are certificated, or qualified, for product quality.	0.54	0.77
	We have long-term arrangements with our suppliers.	0.56	
	Our suppliers deliver to us on short notice.	0.69	
	We can depend upon on-time delivery from our suppliers.	0.72	
	Our suppliers are linked with us by a pull system.	0.66	
Workforce management	Employees receive training to perform multiple tasks.	0.41	0.76
	Employees are cross-trained at this plant so that they can fill in for others if necessary.	0.46	
	During problem solving sessions, we make an effort to get all team members' opinions and ideas before making a decision.	0.75	
	Many problems have been solved through small group sessions.	0.64	
	Problem solving teams have helped improve manufacturing processes at this plant.	0.69	
	Employees inspect the product quality of their own work.	0.60	
Cost	Low production cost.	0.71	0.74
	Competitive pricing.	0.47	
	Production efficiency.	0.72	
	Inventory turnover.	0.63	
Product quality	Product durability.	0.74	0.88
	Product reliability.	0.76	
	Product performance.	0.78	
	Overall product quality as perceived by the customer.	0.74	
	Conformance to specifications.	0.80	
Lead time	Procurement lead time.	0.78	0.87
	Manufacturing lead time.	0.90	
	Delivery speed/customer lead-time.	0.79	
Flexibility	Easily change the production volume of a manufacturing process.	0.67	0.70
	Build different products in the same plants at the same time.	0.52	
	Changeover quickly from one product to another.	0.66	
	Easily modify products to a specific customer need.	0.58	

$\chi^2=1785.62$, df$=1208$, χ^2/df$=1.48$, RMSEA$=0.051$, CFI$=0.935$.

manufacturing technologies with three indicators and lean practices with five indicators. Table 2 presents the results of the measurement model for manufacturing technologies and lean practices. The results support the validity of the constructs for both manufacturing technologies and lean practices, with each indicator strongly loaded on its respective construct. We also calculated the construct reliabilities of the manufacturing technologies and lean practices constructs using the factor loadings and error variances (Hair et al., 2006), and the values exceeded the recommended cut-off point of 0.70; thus, supporting the reliabilities of both constructs.

At the same time, we also performed a discriminant validity test to examine whether the two constructs (i.e., manufacturing technologies and lean practices) were distinct from each other. We followed the method used by Ahire et al. (1996) by pairing the two constructs and subjecting them to two (CFA) measurement models (constrained and unconstrained). The result shows that the constrained model shows a significantly poorer fit to the unconstrained model, validating that the two constructs are distinct.

4.2. Common method bias

Since we surveyed a single respondent in each firm, common method variance may be a potential threat. We tested the potential existence of common method variance using Harman's single factor approach. According to this test, if common method variance exists, a single factor will emerge from a factor analysis of all the survey items (Podsakoff et al., 2003). Specifically, we tested a one-factor measurement model where we loaded all the items in the measurement model onto a single latent construct and compared the fit with a chi-square test with the original factor model (Singh, 2008). The results of these tests show that the one-factor model produced a significantly poorer fit. Therefore, we conclude from the results of the Harman's test that common method variance was not likely to be a significant issue in our data set.

4.3. Pearson correlations

Correlations among the six latent variables are presented in Table 3. A few insights can be drawn from the correlations analysis. First, firm size is strongly and positively correlated with manufacturing technologies ($r=0.51$ at $p<0.01$), indicating that larger firms have more resources to invest in manufacturing technologies. Second, firm size is also positively correlated with lean practices ($r=0.15$ at $p<0.05$), indicating that lean practices are relatively better implemented in higher volume production system. Third, process type is also correlated with manufacturing technologies ($r=0.28$ at $p<0.01$); suggesting that manufacturing technologies are more applicable in more repetitive processes. Finally, manufacturing technologies are relatively weakly correlated with lean practices ($r=0.17$ at $p<0.05$), indicating that firms do not tend to implement the two resources in parallel.

4.4. Structural relationships for the additive model

We performed latent variable structural equation modeling (SEM) using LISREL 8.52 to test Hypotheses 1 to 8. As illustrated in Fig. 1, manufacturing technologies and lean practices are treated as the exogenous variables, and the four operational performance dimensions (cost, quality, lead-time, and flexibility) are positioned as the endogenous variables, each treated as separate latent variable. In this way, we can examine the unique effects of both manufacturing technologies and lean practices on each performance dimension separately. Table 4 presents the results. The goodness-of-fit indices demonstrate acceptable fit of the hypothesized structural model (χ^2 (df=270)=427.13, χ^2/df=1.58, RMSEA=0.056).

Hypotheses H1–H4 predict that manufacturing technologies are positively associated with cost (H1), product quality (H2), lead-time (H3), and flexibility (H4). The standardized coefficients were $\beta=0.37$ ($p<0.01$), $\beta=0.27$ ($p<0.05$), $\beta=0.26$ ($p<0.05$), and $\beta=0.43$ ($p<0.01$), respectively, providing support for H1–H4. Hypotheses H5–H8 predict that lean practices are positively associated with cost (H5), product quality (H6), lead-time (H7), and flexibility (H8). The standardized coefficients were $\beta=0.19$ for cost ($p<0.05$), $\beta=0.39$ for product quality ($p<0.01$), $\beta=0.20$ ($p<0.05$) for flexibility, and $\beta=0.14$ ($p<0.10$) for lead time respectively, providing support for H5–H8. In summation, we find that manufacturing technologies and lean practices have a unique contribution to various dimensions of operational performance, hence confirming their role as valuable resources.

4.5. Structural relationships of the synergistic model

In order to test the four synergistic hypotheses (H9–H12), we adopted Ping Jr.'s (1995) two-step procedure for testing interaction effects between manufacturing technologies and lean practices. In their review of testing interaction in SEM, Cortina et al. (2001) concluded that the procedure developed by Ping Jr. (1995) is easy to conduct and recovers parameter values well when compared with other approaches (Jaccard and Wan, 1995; Jöreskog and Yang, 1996; Mathieu et al., 1992). After mean centering, as recommended in the literature to remove non-essential multi-collinearity (Cohen et al., 2003), the first step in Ping Jr.'s procedure is to compute the variables that represent the sums of the indicators of each latent variable (X and Z). Once this has been done, the product of these summed variables is computed to represent the interaction term.

Table 2
Measurement model of manufacturing technologies and lean practices.

Constructs	Measures	Factor loading	Construct reliability
Manufacturing Technologies	Design technologies	0.74	0.83
	Process technologies	0.81	
	Administrative technologies	0.85	
Lean practices	Production flow management	0.76	0.84
	Customer focus	0.65	
	Process management	0.88	
	Supplier management	0.80	
	Workforce management	0.67	

χ^2 (df=19)=30.02, χ^2/df=1.58, RMSEA=0.056.

Table 3
Mean, standard deviation, and bivariate correlations.

		Mean	S.D	V1	V2	V3	V4	V5	V6	V7
Firm's size	V1	2.35	0.77	1.00						
Process type	V2	2.22	0.91	0.16*	1.00					
Manufacturing technologies	V3	2.70	0.83	0.51**	0.28**	1.00				
Lean practices	V4	4.19	0.41	0.15*	0.03	0.17*	1.00			
Cost performance	V5	3.36	0.50	0.08	0.01	0.21**	0.14	1.00		
Quality performance	V6	3.69	0.56	0.12	0.03	0.21**	0.30**	0.50**	1.00	
Lead time performance	V7	3.51	0.60	0.01	−0.08	0.13	0.14	0.47**	0.52**	1.00
Flexibility Performance	V8	3.47	0.51	0.04	0.11	0.22**	0.15*	0.44**	0.43**	0.41**

* $p<0.05$.
** $p<0.01$.

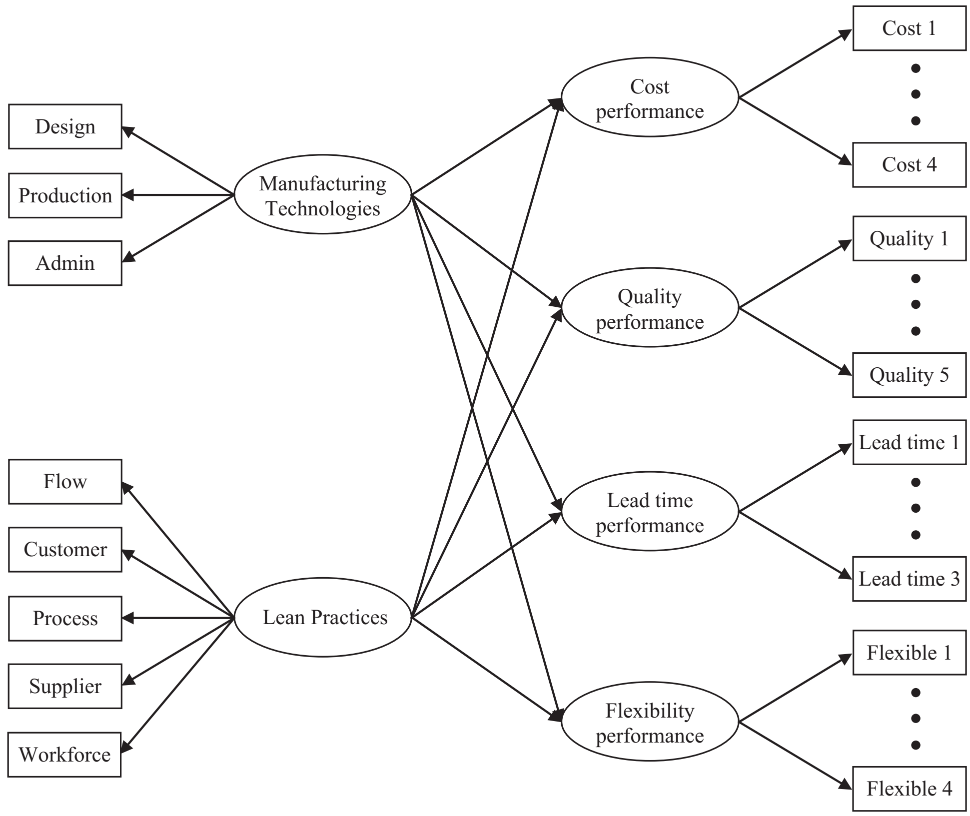

Fig. 1. Structural relationship diagram.

Table 4
Results of structural equation modeling.

	Model 1				Model 2			
	Cost	**Quality**	**Lead time**	**Flexibility**	**Cost**	**Quality**	**Lead time**	**Flexibility**
Control variables								
Organizational size	−0.16	−0.14	−0.19	−0.21	−0.13	−0.11	−0.16	−0.18
Process types	0.18*	−0.02	0.04	−0.08	0.18*	−0.01	0.05	−0.07
Main effects								
Manufacturing tech	0.37**	0.27*	0.26*	0.43**	0.27*	0.19	0.17	0.34**
Lean practices	0.19*	0.39**	0.14†	0.20*	0.23	0.37**	0.11	0.16
Interaction effect								
Manufacturing × lean					0.32**	0.23*	0.28**	0.31**
R^2	0.19	0.22	0.07	0.19	0.27	0.26	0.14	0.27

Standardized coefficients reported.

† $p < 0.10$.
* $p < 0.05$.
** $p < 0.01$.

This product variable then serves as the indicator of the latent product.

The next step is to estimate the values associated with the additive measurement model. Because the values on the right side of these equations are available from the additive version of the measurement model, Ping Jr. (1995) recommends that the additive model be established first. The relevant values from this analysis can then be used to fix the paths associated with the latent product in the multiplicative (interaction) model. Since Ping Jr.'s (1995) procedure assumes normality, we examined the skewness and kurtosis of the observed variables. It is recommended that the absolute values of kurtosis should not be greater than 10 and the absolute values of skewness should not be greater than 3 (Kline, 2011). All the skewness and kurtosis statistics were within acceptable ranges, suggesting that the data did not violate the normality assumption.

The results of structural equation modeling on the interaction effect between manufacturing technologies and lean practices are presented in Table 4. The goodness-of-fit indices support an acceptable fit of the structural model (χ^2=454.19 (df=288), χ^2/df=1.58, RMSEA=0.056). The coefficients of the interaction terms were statistically significant and positive, supporting all four hypotheses. Hypotheses H9–H12 predict that there is a positive interaction between manufacturing technologies and lean practices in predicting cost (H9), product quality (H10), lead-time (H11), and flexibility (H12). The standardized coefficients were β=0.32 ($p < 0.01$), β=0.23 ($p < 0.05$), β=0.28 ($p < 0.01$), and β=0.31 ($p < 0.01$), respectively, providing support for H9–H12. Table 4 also shows that there was an increase in the R^2 value between the additive and interaction (synergistic) models with the R^2 values increasing by 4% for quality, 8% for cost and flexibility, and 7% for lead-time (all increases were statistically significant).

5. Discussion

The findings of our study demonstrate the importance of both manufacturing technologies and lean practices in predicting operational performance in manufacturing. Our results show that both manufacturing technologies and lean practices are associated with the four dimensions of operational performance (supporting both H1–H4 and H5–H8), suggesting that they are both valuable resources for achieving operational advantage. More importantly, our findings also demonstrate the synergistic relationship between manufacturing technologies and lean practices in predicting the four dimensions of operational performance (H9–H12). These findings provide further confirmation of previous studies (Boyer et al., 1997; Das and Jayaram, 2003; Malhotra et al., 2001; Swink and Nair, 2007), which find partial support for the interaction effect between manufacturing technologies and lean practices. Our study extends the findings of Boyer et al. (1997) by demonstrating the interaction effect of manufacturing technologies and lean practices on four different dimensions of operational performance, rather than on just flexibility. Our findings also concur with those of Swink and Nair (2007) confirming that design-manufacturing integration (DMI) plays the role as complementary asset to AMT usage when quality, delivery and process flexibility are considered, except for cost efficiency. However, our findings show that the interaction between manufacturing technologies and lean practices produces positive effects across four key dimensions of operational performance, including cost efficiency.

The positive interaction effect between manufacturing technologies and lean practices provides important insights. First, the interaction effect suggests that manufacturing technologies and lean practices should not be considered as resources that are independent of each other. While the support for H1–H4 and H5–H8 suggests that manufacturing technologies and lean practices have unique effects on performance (as also shown in previous studies), the support for H9–H12 strongly demonstrates that the effect of one is dependent of the other. Our findings therefore suggest that firms should invest in both resources simultaneously, rather than choosing one over the other. Moreover, our results provide a compelling message that solely focusing on manufacturing technologies or lean practices will not deliver maximum performance. Second, and more importantly, the findings support the complementarity between manufacturing technologies and lean practices, following the method used by Narasimhan et al. (2010). Apart from the positive interaction between the two complementary resources (H9–H12), they have been shown to be distinct to each other. The results of the discriminant validity demonstrate that manufacturing technologies and lean practices are not identical. Therefore, our findings demonstrate the complementarity between manufacturing technologies and lean practices.

5.1. Implications for theory

From a theoretical perspective, our study contributes to the manufacturing strategy literature and operations management (OM) research that seeks to identify the drivers of high performance (Hackman and Wageman, 1995; Ketokivi and Schroeder, 2004) as follows: first, by using RBV as a theoretical lens, our study suggests that manufacturing technologies and lean practices have predictive power across four dimensions of operational performance. More importantly, our findings expand previous studies on manufacturing technologies and lean practices (Burgess and Gules, 1998; Swamidass, 2003; Swamidass and Nair, 2004) by demonstrating the positive interaction between manufacturing technologies and lean practices, which demonstrates the synergistic (enhancing) relationships that emerge when one resource magnifies the impact of another resource, multiplying the common effect (Black and Boal, 1994; Jeffers et al., 2008). From the RBV perspective, we can interpret this interaction in two ways. First, the interaction suggests that building both manufacturing technologies and lean practices as resources provides a competitive advantage and generates above-average returns. This is because the combination of the two complementary resources increases the heterogeneity of resources, and thus, make it more difficult to imitate (Peteraf, 1993). At the same time, as each component of manufacturing technologies and lean practices possesses competitive value in itself, their combination produces synergistic effects that exceed the sum of their individual effect (Jeffers et al., 2008). Second, the positive interactions suggest that the value of manufacturing technologies as resources could be dependent upon the extent of adoption of lean practices in the firm, and vice versa. In this regard, RBV also supports the notion that individual initiatives (resources) may have limited ability to create competitive advantage in isolation but rather feed off one another (Barney, 1995). In the light of this concept, our findings show that manufacturing technologies may need to be supported by lean practices in the sense that the effect of manufacturing technologies on performance increases when accompanied with a higher level of adoption of lean practices.

The findings of this study also support the complementarity theory and, specifically, the synergy theory, between manufacturing technologies and lean practices. According to Amit and Schoemaker (1993), a firm's resources may further exhibit complementarity in deployment or application, i.e., the strategic value of each resource's relative magnitude may increase with an increase in the relative magnitude of other resource. Our results demonstrate the positive interaction between manufacturing technologies and lean practices in enhancing four dimensions of operational performance in manufacturing firms, suggesting that investment in several complementary resources simultaneously will produce better performance than focusing on one kind of resource (Milgrom and Roberts, 1995). Under complementarity theory, the combined value of a firm's resources may be higher than deploying each resource individually. As such, our findings are also consistent with the complementarity theory in the sense that the synergistic effects of manufacturing technologies and lean practices (H9–H12) are significantly higher than the combination of their unique effects (H1–H8). Consequently, the findings highlight that the joint optimization of the two resources – manufacturing technologies and lean practices – bring better results than optimizing either resource alone (Das and Jayaram, 2007; Taylor and Asadorian, 1985). The findings regarding the complementarity also concur with the study by Challis et al. (2002) among Australian firms which show that the stronger the AMT environment, the stronger the explanatory power of TQM and JIT on manufacturing performance. However, unlike Challis et al. (2002) who combined the multiple dimensions of operational performance (i.e., quality, cost, and delivery) into one composite construct, our study segregates different dimensions of manufacturing performance (i.e., cost, quality, lead-time, and flexibility) into separate constructs; thus, allowing us to examine different effects of manufacturing technologies and lean practices on each dimension of operational performance.

5.2. Implications for practice

Our findings clearly demonstrate the effectiveness of both manufacturing technologies and lean practices as valuable resources to enhance multiple dimensions of operational performance (cost, product quality, lead time, and flexibility). In particular, the findings suggest that the unique effects of manufacturing technologies on the four dimensions of operational performance are relatively stronger than those of lean practices. However, the findings also demonstrate that manufacturing technologies need support from lean practices in maximizing their effect on operational performance. This could be one of the major challenges to Thai firms since further analysis of our dataset shows that manufacturing plants in Thailand have relatively lower levels of manufacturing technologies implementation than the implementation of lean practices. This situation could be caused by the fact that acquiring and implementing manufacturing technologies require large investments, which many local plants cannot afford (Thailand Automotive Institute (TAI), 2012; The Industrial Council of Thailand, 2007). Therefore, our findings have implications not only for firms' managers but also, to a certain extent, for the Thai government in that they should implement policy to support Thai manufacturing industries to invest in manufacturing technologies, especially among smaller firms.

Secondly, consistent with the Boyer et al. (1997) study which was conducted in a developed economy, our study finds positive interaction effects between manufacturing technologies and lean practices on manufacturing performance in the context of a developing country. However, unlike those earlier studies, we find more consistent interactive effects. In other words, the level of interdependence between manufacturing technologies and lean practices in Thai firms might be higher than that among firms in developed countries. One possible explanation is that since Thai firms are still relatively weak and rare in the use of AMT, the increasing use of such manufacturing technologies will need considerable support of lean practices in order to yield high performance in operations. This situation could be different from the case of developed countries where firms have had more experience in implementing manufacturing technologies and extracting their benefits without being dependent on lean practices. This contextual finding therefore suggests that the complementarity between manufacturing technologies and lean practices is likely to be stronger among firms that are still at an early stage of adopting the resources. Consequently, it also implies that such synergy or complementarity appears to be more visible at an early stage of learning and may slowly taper off as firms become more mature in the use of the resources, making their effect on performance more independent to other resources.

Finally, while the synergistic relationship between manufacturing technologies and lean practices offers an opportunity for capitalizing on the potential complementarity between the two, our findings also show a weak association between manufacturing technologies and lean practices among Thai firms, which suggests that Thai firms seem to be “dichotomising” the two resources and treat them separately. As a result, they still view manufacturing technologies and lean practices as “either – or”, rather than “both – and”. This signals another challenge for managers of manufacturing plants with large investments in manufacturing technologies in balancing their technological investments. Swink and Nair (2007) suggest that these are important issues because many manufacturing firms have sunk enormous amounts of capital into investment in manufacturing technologies over the last three decades. In this regard, firms in developing countries also feel the same global pressures as their counterparts in developed countries, but with additional burdens due to the lagging effect of knowledge and experience in dealing with manufacturing technologies. This could also be the case for Thai firms in the future. Operating in an emerging economy, Thai firms could be fascinated with modernizing their technologies, particularly the manufacturing technologies ones, and may easily neglect the lean practices, which appear to be simpler and cheaper. This is a pitfall to be avoided where firms do not see the real benefits of implementing manufacturing technologies because they fail to unlock their potential as shown by Boyer et al. (1997). This study, therefore, has provided an important understanding for managers in balancing investments in their technological portfolio and acquiring the maximum benefits from their investments.

6. Limitations and directions for future research

We identify the following limitations of this study. First, since we use the cross-sectional survey method, causal inferences must be made with caution (Nair and Swink, 2007). We recommend a longitudinal or experimental study to strengthen casual inference. The second limitation relates to data collection using a single source. Although not a definitive test, the Harman's single-factor test we conducted indicates that common method bias did not appear to be a serious threat to our study. Nevertheless, we recommend that future research should replicate the present findings using data gathered from multiple sources. For example, data on performance could be gathered using objective organizational records, rather than perceptual reports from organizational informants. Third, we acknowledge a couple of limitations with regard to the measurement used in this paper. First, by using investment as a proxy for degree of implementation or use of each technology category, we assume that the higher the investment, the higher the degree of implementation. We acknowledge that the two measures may not be necessarily the same; therefore, we note this as a limitation of the study. Secondly, in measuring lean practices, we had a focus on JIT and TQM at the beginning of our research and used measures developed by Flynn et al. (1995). Hence, our definition of lean practices relatively focuses on the two major philosophies of JIT/TQM. Future research should use a more comprehensive measure of lean practices, see for example Shah and Ward (2003). Fourth, this study provides unique insights into the relationships between manufacturing technologies and lean practices, and manufacturing performance in plants in Thailand. Our findings may be applicable to other emerging economies (such as those in Asia). Hence replicating and extending our work in other emerging economies may provide a basis for external validation of the findings of our study. Finally, future studies could incorporate other variables related to performance which are not captured in this study, such as organizational strategy and culture.

7. Conclusion

In conclusion, this study demonstrates the additive and synergistic effects of manufacturing technologies and lean practices on cost, product quality, lead-time, and flexibility. From a theoretical perspective, our study of 186 manufacturing plants in Thailand makes a valuable contribution to the manufacturing strategy literature and OM research, which seeks to identify the drivers of high performance. Drawing on RBV, our results suggest that different dimensions of performance require specific configurations of resources, so providing a more nuanced view of the relationships between manufacturing technologies and lean practices, and multiple facets of manufacturing performance. At the same time, in the light of the concept of complementarity, this study highlights the importance of the synergistic (enhancing) relationship between manufacturing technologies and lean practices in improving multiple dimensions of operational performance. The synergistic relationship between manufacturing technologies and lean practices presents one of the means by which firms can develop unique operations resources and advantages. This study suggests that the performance impact of manufacturing technologies is shaped and influenced by their interactions with lean practices. Therefore, failure to recognize these enhancing interactions could lead to an unnecessary overemphasis on certain categories of investment. As many manufacturing firms have sunk enormous amounts of capital into investments in these technologies over the past three decades, our findings can be translated into specific implications for strategic decision-making, technology justification, and performance improvement efforts. In particular, compared with previous research conducted in developed countries, we find that the synergistic and enhancing effects of manufacturing technologies and lean practices appear to be particularly consistent in the context of an emerging economy where both management skills and technologies are likely to be less developed, i.e., complementarity seems to be more important in such a context.

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