Analyzing manufacturing strategies and Industry 4.0 supplier performance relationships from a resource-based perspective

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Abstract

Purpose – The purpose of this paper is to investigate the impact of manufacturing strategies on Industry 4.0 supplier performance. Suppliers play a crucial role in manufacturing supply chains, and firms are dependent on identifying and managing them to enhance Industry 4.0 supplier performance.

Design/methodology/approach – A descriptive to causal research is conducted with survey and tested via multiple regression analysis. Using the extant literature, four manufacturing strategies are identified and analyzed as the determinants of supplier performance pertaining to the fourth industrial revolution (Industry 4.0). A survey was designed and targeted to 200 samples of manufacturing firms in Thailand. Finally, the research model was tested to examine the hypothesized relationships.

Findings – Based on the results, it was found that better quality and flexibility in manufacturing positively impact Industry 4.0 supplier performance. However, the rate of delivery and cost reduction did not have any statistical influence on the Industry 4.0 supplier performance.

Research limitations/implications – The data for this study were collected from Thailand, only one country. Hence, the findings are indicative but not representative of other Asian countries. Also, the findings are not generalizable to other industries.

Practical implications – This study will enable supply chain professionals to understand the determinants of Industry 4.0 supplier performance within an Asian context, which will be valuable to them when sourcing from Asian suppliers. To compete successfully in increasingly globalized world, firms must use their resources effectively and productively. Firms must align their vital resources and capabilities to maximize competitive advantage.

Originality/value – The paper identifies the manufacturing strategies that significantly influence the Industry 4.0 supplier performance of manufacturing companies.

Keywords Cost, Flexibility, Quality, Delivery, Industry 4.0, Supplier performance

Paper type Research paper

1. Introduction

To respond to the fast changing customer demands, manufacturing strategies and processes need to be data-driven and instant (Bechtold *et al.*, 2014; Genovese *et al.*, 2014; Leitão *et al.*, 2016). The survival of manufacturing companies is determined by their agility, efficiency and responsiveness to customer preferences, as well as a focus on product quality and regulatory compliance (Brousell *et al.*, 2014). Industry 4.0 is a revolutionary wave shaping manufacturing processes. UNIDO (2017) define Industry 4.0 as the "Fourth Industrial Revolution" which aims to improve industrial efficiency with integrated technological approaches (e.g. cyber physical systems (CPS), IoT, cloud computing), methodologies and operational resources (Gates, 2017). Rajput and Singh (2018) argue that the two most influential enablers of Industry 4.0 are IoT ecosystem and IoT big data. This encompasses a wide range of technologies that includes production processes, efficiency, data management, relationships with consumers and competitiveness (Piccarozzi *et al.*, 2018). Industry 4.0 has contributed to greater horizontal, vertical and end-to-end digital integration (Bag *et al.*, 2018). In both developed countries and emerging industrialized countries, manufacturing firms face significant challenges resulting from mass customization, shortening product life cycles, increasing technological change and

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the entry of international competitors into their markets (Li, 2018). Industry 4.0 promises innovation for producers, system suppliers and the entire supply chain (Kamble *et al.*, 2018). Industry 4.0 enhances industrial capability through innovation-driven manufacturing which facilitates the production of the right products in the right quality and quantity, to be delivered to the right place for the right customers in the right time at the right cost, while keeping the environment safe (Gunasekaran *et al.*, 2019). Industry 4.0 creates an innovative platform for next generation supply chain management for industries to design novel solutions for future-oriented manufacturing, procurement and logistics management (Fatorachian and Kazemi, 2018).

To improve overall performance all these areas require an appropriate alignment between Industry 4.0 and long-term strategic objectives (Ardito *et al.*, 2018). Many large-scale multinational firms are embracing Industry 4.0 to remain relevant to their competitors. For example, companies like Caterpillar (Caterpillar Energy Solutions GmbH, 2017) and Renault have adopted Industry 4.0 to enhance their efficiency and reduce costs. Automobile and electronic companies like BMW, Jaguar Land Rover, Rolls-Royce, GE and Philips have successfully implemented Industry 4.0. In the food sector, Mondelez, the owner of many leading consumer brands like Cadbury, Milka, Oreo and Toblerone, at their Global Centre of Excellence for chocolate in Bournville, UK, has adopted Industry 4.0 based practices (Mondelez International, 2017) aiming to improve process efficiency in their supply chains through efficient manufacturing systems, minimal packaging waste and improved productivity. In Germany, Nestlé has participated actively in the Industry 4.0 agenda to improve their resource efficiency, reduce the environmental impact of packaging waste and enhance productivity through digitization of operations (Nestlé, 2018). de Sousa *et al.* (2018) claim that one immediate impact of Industry 4.0 is environmentally sustainable manufacturing. All these initiatives indicate that there is an industry-wide shift toward creating responsive supply chains. Xu *et al.* (2018) argue that there is a need for research on Industry 4.0 to provide systematic insights into design, implementation and management. There are calls for research into the capabilities a supplier requires to support Industry 4.0 manufacturing (Sony and Naik, 2019). A supplier's core competency will define the success of Industry 4.0. It is important to understand the antecedents or drivers of Industry 4.0 supplier performance.

This paper provides a new perspective on Industry 4.0 supplier performance, an emerging technology. The objective of this paper is to analyze and explain the key determinants of Industry 4.0 supplier performance. This paper is organized as following. First, Industry 4.0 supplier performance is explored in terms of resource-based theory and enablers of Industry 4.0 supplier performance. Second, a framework for operationalizing Industry 4.0 supplier performance is proposed. The subsequent section describes the research methodology, data analysis and key findings, and the findings are discussed. The penultimate section summarizes the implications of the research findings. The conclusions and limitations of the study are described in the last section.

2. Literature review and research hypotheses

Industry 4.0 has become a topic of interest in supply chain management research. Industry 4.0 forms the technological capability (e.g. manufacturing digitization to achieve greater efficiency, competency and competitiveness) of a manufacturing supply chain (Xu *et al.*, 2018). Unique, firm-specific capability is considered to be a resource. Industry 4.0 has an important long-term strategic impact on global industrial development. Manufacturing capability is imperfectly imitable due to Barney's (1991) condition of social complexity requiring social engineering that may be beyond the capabilities of many firms. The resource-based view (RBV) argues that if an organization possesses and exploits resources and capabilities that are both valuable and rare, it will be able to improve its performance (Newbert, 2008). Specialized manufacturing knowledge/skills are one of the decisive elements for acquiring, transforming and integrating other resources. Collaboration and maintaining a network of capable suppliers is a key success factor to create a firm's core competency. A supply base is an important resource for manufacturers, and suppliers' competitive performance is dependent on their manufacturing technology. Suppliers can play a direct role in the cost, quality, technology and time-to-market of new products. For a company to gain a competitive advantage it must lower costs and differentiate its products or services. Understanding the factors that affect Industry 4.0 supplier performance will help companies to respond and achieve competitive advantage in the long run. In many industries, the management of suppliers can account for as much as 60–80 percent of manufacturing costs (Asmus and Griffin, 1993). Christopher (1997) stated that supplier management can take costs out of the supply chain. The management of supplier relationships is critical for manufacturers as it can contribute to competitiveness and profitability (Lemke *et al.*, 2000).

The key to a resource-based theory is understanding the relationships between resources, capabilities, competitive advantage, and profitability, and the mechanisms through which competitive advantage can be sustained over time. Resources are defined as those tangible or intangible assets that are tied semi-permanently to the firm (Maijoor and Witteloostuijn, 1996). Examples of such unique resources related to manufacturing are differentiation in quality, flexibility, delivery speed and cost-leadership (Wernerfelt, 1984). Resources are assets that are owned or controlled by a firm, whereas capabilities are the ability to exploit and combine resources, through organizational routines, in order to accomplish its targets (Amit and Schoemaker, 1993). Sundarakani *et al.* (2019) found Industry 4.0 is an emerging technology that equips businesses with intangible, resource-based capability by creating flexibility and efficiency in the supply chain network, which adds value to ensure customer satisfaction. Collis (1994) described capabilities as the socially complex procedures that determine the efficiency with which organizations are able to transform inputs into outputs. Strategically, a capability can be turned into a source of competitive advantage (Moingeon and Edmondson, 1996). Hamel and Prahalad (1990) use the term "core competencies" – collective organizational learning – to describe these central strategic capabilities. Although the concept of capability has been articulated in the literature, it has not been linked with Industry 4.0 supplier performance in manufacturing, and empirical testing has so far been sparse. This represents a good opportunity to conduct such research, in the manufacturing supply chain setting, to analyze supplier performance in the context of Industry 4.0.

2.1 Manufacturing strategies and Industry 4.0 supplier performance

Industry 4.0 encompasses a variety of technologies that enables the value chain to reduce manufacturing lead times, and improve product quality and organizational performance (Kamble *et al.*, 2018). This set of performance enablers is intangible resources that can be considered core competencies of a supply chain that might offer strategic advantage. Over time, firms follow strategies to exploit the opportunities provided by the market environment within the constraints that result from their accumulated asset base, organizational structure, ownership and other firm-specific factors (Barney, 1991; McGee and Thomas, 1986). Managers make strategic choices, but their options may be limited by the established framework of available resources.

de Sousa *et al.* (2018) argues that Industry 4.0 and its associated technologies have the potential to deliver sustainable competitive manufacturing practices. The ability to combine technology-driven resources provides firms with competitive advantage that is valuable and difficult to imitate. Grant (1991) argued that the firm's most important resources and capabilities are those that are durable, difficult to identify and understand, imperfectly transferable, not easily replicated, and of which the firms possess clear ownership and control. Hence, sustainable competitive advantage for a business unit results from building core capabilities or competencies. Skinner (1969) is considered to be the first to define manufacturing strategy, and defined manufacturing objectives of cost, quality, delivery and flexibility and the trade-offs between them. Trade-off decisions are required in a number of key areas in order to support the manufacturing objectives. There are five decision areas: plant and equipment; production planning and control; labor and staffing; product design engineering; and organization and management. A manufacturing strategy is defined by a pattern of decisions, both structural and infrastructural, which determine the capability of a manufacturing system and specify how it will operate to meet a set of manufacturing objectives which are consistent with overall business objectives. Industry 4.0 includes smart manufacturing systems which are highly flexible and responsive to changes (Öberg and Graham, 2016). These systems, by enhancing flexibility, enable quick and cost-efficient responses to changing customer and production requirements and lead to improved performance (Dubey *et al.*, 2017). Industry 4.0 supplier performance plays a critical role in manufacturing efficiency, determined by cost, quality, delivery and flexibility. Each of these defining factors are discussed in further detail.

Barney (1986) argued that strategic factor markets are imperfectly competitive, because of different expectations, information asymmetries and even luck, regarding the future value of a strategic resource. Should factor markets be perfectly competitive, then the cost of acquiring strategic resources would equal their economic value in implementing a strategy, and hence no firm could sustain its competitive advantage. Based on Barney's perspective, it can be inferred that the adoption of Industry 4.0 related technologies has the potential to deliver far-reaching industrial value creation (Müller *et al.*, 2018). Barney (1991) further suggested that a given strategy will generate sustainable performance differential if and only if the resources used to conceive and implement it are valuable, rare, non-imitable and non-substitutable. Müller *et al.* (2018) found that strategic, operational, environmental and social opportunities are the drivers of Industry 4.0 related technological adoption, which should deliver a differential competitive advantage to the firms. Based on the literature, the RBV is the cornerstone of the relationship between firm performance and competitive advantage. The central thrust of the RBV is that the more firm-specific resources (FSRs) the firm has, the more valuable they are. These valuable resources will create a sustainable competitive advantage for a firm that will later lead to better performance. Resource-based theory focuses on unique FSRs, rather than industry structure, and addresses both competitive advantage and the strategies intended to exploit such advantage (Priem and Swink, 2012). The resource-based model of business strategy focuses on how sustained competitive advantage is generated by the unique bundle of resources that are at the core of the firm (Barney, 1991; Grant, 1991; Wernerfelt, 1984).

The following sections focus cost, delivery speed, flexibility in response to demand variation, quality and product connectivity, which are key to supplier performance (Dalenogare *et al.*, 2018).

2.2 Cost performance

Dalenogare *et al.* (2018) found that Industry 4.0 and its related technologies are cost efficient. The multi-layer IoT system can be targeted to reach an optimal balance of efficiency and flexibility that help reduce cost and increase customization. For example, a cement production company applied IoT technology with advanced machine learning algorithms to estimate energy consumption trends. The application optimized the company's energy consumption level and reduced energy consumption by 10 percent. Cloud computing is another area that offers high performance and low cost (Zheng *et al.*, 2014; Mitra *et al.*, 2017). Industry 4.0 applies CPS to realize smart factories (Kusiak, 2017). This provides significant real-time, resource and cost advantages in comparison with classic production systems (GTAI, 2014). Hayes and Wheelwright (1979) argued that manufacturing's role is to provide low cost in order to maintain or improve available margins necessary to support business investment and create opportunity for the future. In the automobile industry, cognitive technologies and cognitive planning tools are enabling automotive manufacturers to reduce operating costs and capital investment. For example, an automobile manufacturer used cognitive planning tools to optimize its use of available plant capacity to bring a new model into production. The application enabled the manufacturer to reduce operating costs and capital investment by about 10 percent (Xu *et al.*, 2018). Carr and Ittner (1992) explained that Total Cost of Ownership (TCO) is a structured approach for determining the total costs associated with acquisition and subsequent use of a given product or service from a given supplier. Ellram (1995) noted that this approach recognizes that the purchase price represents only a portion of the total cost of acquiring an item. Vendor performance also affects the cost of ordering, expediting, receiving and inspecting. Many firms hide these costs by burying them in overheads or general expenses. Companies use TCO as a means for measuring and evaluating their suppliers. Buyers can evaluate vendors based on the costs associated with the number of product returns, under shipments, non-conformance or late shipments. Companies incorporating these factors into their ownership analysis can better determine which suppliers offer the best overall value.

Harding (1998) stated that the total cost approach used the quoted price from each supplier. Then the process begins by first determining factors important to the organization, and each factor is translated into a cost component that is added into a formula. And finally, to each supplier's quoted price is added a debit (credit) for each factor that is appropriate to the supplier's performance. Hill (1994) explained that when profit margins are low, price is an "order-winner," and low-cost manufacturing is the priority. Kathuria (2000) showed that manufacturing companies pursuing low-cost focus on error reduction and standardized processes, and tend to use economies of scale that arise from continuous process technologies. Ward and Duray (2000) argued that low costs can be achieved by reducing production costs, reducing inventory, increasing equipment utilization and increasing capacity utilization. Thus, the first hypothesis of this study is:

H1. When cost performance decreases, Industry 4.0 supplier performance increases.

2.3 Delivery performance

One core capability of Industry 4.0 is the faster and cost efficient delivery of goods and services (Dalenogare *et al.*, 2018). Stalk and Hout (1990) defined a fast response time as getting things done quicker and is most readily observed in speedier cycles, including the order cycle, production time, new product design and product upgrades. Belev (1993) defined reliable delivery as delivering the right product, right quality, right quantity, at the right time, in the right place, from the right source, with the right service and finally at the right price. RFID technology is viewed as one of most important tools that enable the IoT network. RFID allows microchips to transmit the identification information to a reader through wireless communication (Xu *et al.*, 2014; Alyahya *et al.*, 2016). Using RFID readers, users are able to distinguish, track and monitor any object tagged with an RFID tag automatically (Jia *et al.*, 2012). RFID has been extensively applied across many different industries, such as transportation, package delivery, healthcare, transit systems, security, materials management, retailing, defence and warehousing.

Delivery implies dependable delivery as well as fast deliveries. Hill (1994) argued that the delivery speed or delivery reliability is an issue only if the existing order backlog plus the processing time to complete the order is greater than the delivery time required by the customer. Kazan *et al.* (2006) argued that a company that makes products to stock, using the line or continuous process technologies, is best equipped to compete on delivery by meeting orders from goods in stock. Hence, a second hypothesis of this study is:

H2. When delivery performance increases, the Industry 4.0 supplier performance increases.

2.4 Flexibility performance

Industry 4.0 creates a cyber-physical manufacturing environment that enables communication and interaction among all the players in the value chain. Service-oriented architectures are an emerging paradigm for enterprises to coordinate seamlessly in the environment of heterogeneous information systems, enabling the timely sharing of information and enhancing integration. One advantage of service-oriented infrastructure is flexibility (Petrasch and Hentschke, 2016). Industry 4.0 offers a wide range of technologies that enables flexibility in the manufacturing environment. Barad and Sipper (1988) described flexibility is the ability of a manufacturing system to cope with environmental uncertainties. Flexibility reflects an organization's ability to adapt or respond to changes that add value in the customers' eyes (Upton, 1995). Gatignon and Anderson (1988) define flexibility as the ability to change system and methods quickly and at low cost. Toni and Tonchia (1998) described flexibility in flexible manufacturing systems, where flexibility allows the system to react to changes, whether predicted or not. There are two categories of flexibility: machine flexibility covers the system's ability to be changed to produce new product types, and the ability to change the order of operations executed on a part, while routing flexibility consists of the ability to use multiple machines to perform the same operation on a part, as well as the system's ability to absorb large-scale changes in volume, capacity or capability.

Industry 4.0 enables flexibility through business process management (BPM). The purpose of BPM is to analyze, measure, model, automate, optimize and improve manufacturing processes. In an Industry 4.0 ecosystem, BPM supports an organization's strategic goals, aligning resources within a company, between companies, or even across an entire supply chain. Hence, it contributes to the improvement of overall performance, efficiency, effectiveness and flexibility of supply chain operations (Rossini *et al.*, 2019; Li *et al.*, 2014). The third hypothesis of this study is:

H3. When flexibility performance increases, the Industry 4.0 supplier performance increases.

2.5 Quality performance

Increasing the quality of Industry 4.0 can be accomplished with proper integration of the existing and/or new technologies (Xu *et al.*, 2018). The most revolutionary driving forces of Industry 4.0 are improved product and process quality (Gunasekaran *et al.*, 2019). Dalenogare *et al.* (2018) argued that greater connectivity through adoption of Industry 4.0 can help companies to achieve better industrial performance. Quality is the conformance to manufacturing process requirements (Garvin, 1987). Juran (1985) stated that quality is the product performance which results in customer satisfaction and freedom from product deficiencies, and avoids customer dissatisfaction. Feigenbaum (1986) found that quality is the total composite product and service characteristic of marketing, engineering, manufacture and maintenance through which the product in use will meet the expectations of the customer. Garvin (1987) summarized the eight dimensions of quality: Aesthetics: the product appearance, feel, taste; Perceived quality: reputation; Performance: main operating characteristics; Conformance: extent to which product characteristics fall within design specifications; Features: characteristics that enhance basic functioning of product – the added touches or secondary characteristics; Serviceability: speed, courtesy, competence and ease of repair or servicing; Reliability: probability that product fails within specified time period; Durability: amount of use one gets from a product before it breaks down and replacement is preferable to continued repair. Reeves and Bednar (1994) explained that quality is defined as excellence, value, conformance to specifications and meeting or exceeding customers' expectations. Hence, the fourth research hypothesis of this study is:

H4. When quality performance improves, the Industry 4.0 supplier performance increases.

In the Industry 4.0 context, based on the RBV and the related theoretical background discussed in the above sections, manufacturing strategies have a significant influence on Industry 4.0 supplier performance depending on type of strategy adopted by the manufacturers. The conceptual model based on the extant literature for this research is shown in Figure 1.

3. Research methodology

This study examines the relationship between independent variables (cost, delivery, flexibility and quality) and a dependent variable (Industry 4.0 supplier performance). The researcher used a survey approach in order to collect primary data from respondents. Tull and Hawkins (1993) state that survey research is the systematic collection of data from respondents for the purpose of understanding and predicting the aspect of behavior of the population under study. Survey techniques also provide a relatively low cost, quick and accurate means of assessing information about the population. The researcher used a survey to obtain the information from managers responsible for sourcing decisions in manufacturing firms. The sample companies were selected from the Purchasing Association of Thailand (PAT) Directory of registered firms.

3.1 Sample size and data collection

The sample was largely composed of purchasing and supply chain managers. Respondents were asked to indicate how different manufacturing strategies affect Industry 4.0 supplier performance. The Thai companies are already in the adoption stage of Industry 4.0 technologies, as in 2012 the government led an initiative known as "Industry 4.0 in Thailand 4.0" which supports Thailand's transition to the fourth industrial revolution. During the survey, one of the screening questions was, "Does your company use at least one smart manufacturing technology (Industry 4.0 technology) such as artificial intelligence, sensor technologies, robotics or industrial automation?" Only if they answered, "Yes," were they included in the survey. The respondent firms all use some of these technologies and are early adopters of Industry 4.0 based smart and intelligent manufacturing technologies (Jones and Pimdee, 2017). Many of these companies are

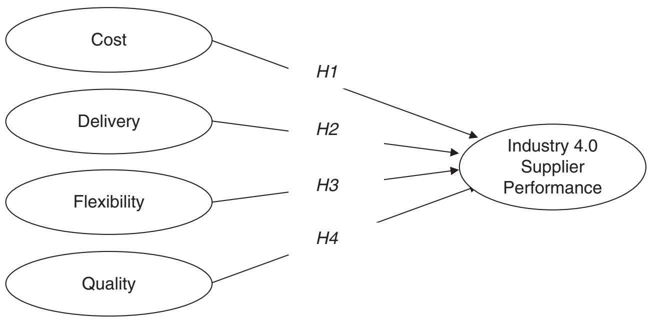

Figure 1. Determinants of Industry 4.0 supplier performance

industrial leaders, operating as partners of leading foreign multinational companies and exposed to cutting edge manufacturing technologies. In the survey, 200 companies were targeted and eventually 80 usable responses were returned. The resultant response rate of the survey was 40 percent. The respondent firms are drawn from the listed companies in the PAT Directory, 2017. The sample size in this study is determined according to the recommendation of Hair *et al.* (2012) who argue that it requires at least 20 respondents for each parameter. The survey data were collected over a period of two months from February to March 2018. The data collection process involved two phases. At the end of initial phase of one month, 56 responses had been received. Subsequently, a reminder was sent by post, after which an additional 24 responses were received. At the end of the two-month period, the data collection process was closed. The sample responses were received in two waves based on return time, which consisted of 56 from the first wave of responses and 24 responses from the second wave. The mean scores of the response groups were compared using *t*-tests. The results yield no differences among the questionnaire items, which strengthens the validity of this study (Tan, 2001).

Data cleaning in this study was done in two stages. First, there was a screening process after the questionnaires received were checked for completeness and consistency. Completeness was tested based on whether all the questions had been answered. If any questionnaire had too many missing responses, it was removed from further analysis. Consistency was checked by looking at response patterns. If responses showed extremity bias, the questionnaire was removed. This also includes ambiguous or double responses to any question. Second, outliers were detected and removed. After completing these procedures, the statistical analysis was carried out.

3.2 Research instruments/questionnaire

The scale items for all the variables in the questionnaire are adapted from previous studies which are found to be valid and reliable. The scales items for measuring cost were adopted from the study by Nowak and Washburn (1998). The measurement scales for delivery were adopted from Morash (2001). The scales items for measuring flexibility were adopted from the study by Taechathayanon (2006) and Morash (2001). The measurement scales for quality were adopted from Taechathayanon (2006), Nittin *et al.* (2006) and Victor and Alice (2006). Finally, the scale items for measuring Industry 4.0 supplier performance were adopted from the study by Sonny *et al.* (2002) and Gianfranco *et al.* (2006). The Industry 4.0 supplier performance items were measured using Likert-scales which consist of five-points from very low performance to very high performance.

The scale items were initially developed in English and then translated into Thai, using a back-translation method. The back-translation technique has been reported as a technique frequently applied by management researchers (Matsumoto, 1994; Hwang *et al.*, 1996). The study then pre-tested the survey with both academics and practitioners to assess face validity, and questions were either reworded or eliminated if they were ambiguous or did not relate to the construct of interest. The final survey was sent to a random sample of 200 (out of a population of 3,000) purchasing managers and executives in consumer-products manufacturing industries, following Dillman's (2000) prescriptions for formatting and mailing surveys.

3.3 Key informant issue

To ensure the integrity of the data collection process, the researchers took two measures to ensure that survey respondents were knowledgeable (Campbell, 1955) and relevant. First, they addressed the survey to purchasing managers and executives, as the results of the pre-test and pilot test indicated that personnel at the managerial level or higher were capable of answering the study's questions (John and Reve, 1982). Additionally, the survey included questions which addressed the respondents' knowledge and capacity in answering the scale items that measured the study's constructs (Kumar *et al.*, 1993). These questions included the number of years that the respondents had been involved with the purchasing function and their degree of involvement on a four-point Likert scale, in which 1 signified only somewhat involved and 4 signified very involved. Prior to conducting data analysis, data cleaning was performed.

4. Analysis and findings

The researchers used a reliability test, a validity test and regression analysis to analyze the relationship between dependent and independent variables. In descriptive analysis, the data were presented in form of frequency and percentages to describe the characteristics of the sample. Also, the data were examined in the form of mean and standard deviation in order to describe scores for each independent variable associated with responses. Data showing the characteristics of the sample are presented in Table I. A total of 37.5 percent of the respondents had been working with their current supplier less than five years. The major supplier of respondents (40 percent) is in the packaging industry. In total, 30 percent of respondents' companies employed between 151 and 200 persons. A total 34 percent of the respondents are in manufacturing business.

Characteristics of the sample	Frequency ($n=80$)	Percentage
Years in business		
Less than 5 years	30	37.5
6–10 years	27	33.8
11–15 years	2	2.5
Over 15 years	21	26.3
Supplier industry		
Beverage	6	7.5
Automobile	6	7.5
Food	7	8.8
Telecommunication	3	3.8
Packaging	32	40.0
Office supplies	10	12.5
Engineering	4	5.0
Others	12	15.0
No. of people employed		
Less than 50	9	11.3
51–100	9	11.3
101–150	12	15.0
151–200	17	21.3
201–250	3	3.8
Over 300	30	37.5
Main business		
Manufacturing	34	42.5
Marketing	6	7.5
Trading: wholesale, retail	15	18.8
Servicing	7	8.8
Manufacturing and distribution	1	1.3
Manufacturing and trading	17	21.3

Table I. Sample profile

4.1 Descriptive analysis

The mean, standard deviations and Cronbach's α for all the variables are presented in Table II. Cronbach's α of all the constructs are found to be greater than 0.70. As shown in Table II, all constructs were found to be reliable and ranged between 0.794 and 0.892. These results are in line with the generally accepted threshold in the literature. Nunnally (1978) suggested that, Cronbach's α values for the key constructs should be greater than 0.70.

The correlations among all the variables are presented in Table III. A comparison of Cronbach's α values and the correlations among the variables revealed that Cronbach's α values are greater than the variables' correlations. Hence, there is decomposition validity of the scales (Gaski, 1984). When the results of correlation between the variables are taken into account, both between the predictor variables and with Industry 4.0 supplier performance, there is a positive value at the $p < 0.01$ level. These results may therefore be considered significant in statistical terms.

4.2 Hypothesis testing

Regression analysis was conducted for hypothesis testing. The analysis consisted of four main steps: to check whether or not the regression assumptions are met, to investigate multicollinearity, to detect outliers, and, finally, to conduct the appropriate statistical tests. Three regression assumptions: normality of residuals, homoscadisticity

Construct	Operational variables	Mean	SD	Cronbach's α
Industry 4.0 supplier performance	Supplier's quality performance relevant to your requirements	3.5563	0.59030	0.892
	Supplier's cost performance relevant to your requirements			
	Supplier's delivery performance relevant to your requirements			
	Supplier's after sales service relevant to your requirements			
	Supplier's technical competence relevant to your requirements			
	Supplier's flexibility in respond to needs and wants relevant to your requirements			
	In your opinion, your supplier is respectable and trustworthy			
	On the whole, you are satisfied with the current supplier			
Cost performance	Investment we have to make	3.4825	0.61269	0.794
	Human effort we have to put			
	Time commitment we have to make			
	Final price we have to pay (value for money)			
	Their ability to save your company money			
Delivery performance	On-time delivery	3.4950	0.74288	0.844
	Speed delivery			
	Overall reliability			
	Time flexibility			
	Reduced lead time			
Flexibility performance	Ability to make rapid design changes	3.2950	0.73466	0.864
	Ability to make rapid production changes			
	Ability to make rapid volume changes			
	Ability to provide desired quantities on a consistent basis			
	Ability to produce a range of products			
Quality performance	Offer consistent, reliable quality	3.5050	0.64747	0.797
	Improve conformance to the product specification			
	Willingness to work toward continuous improvement			
	Having sufficient design and technical capabilities to ensure quality			
	Number of claims and damaged			

Note: All the scales are five-point, with "Very low performance" and "Very high performance" as the anchors

Table II. Mean, SD and Cronbach's α reliabilities of the measures

		Cost	Delivery	Flexibility	Quality	Industry 4.0 supplier performance
Spearman's ρ	Cost performance	1.000	0.611**	0.676**	0.691**	0.675**
	Delivery performance		1.000	0.601**	0.740**	0.667**
	Flexibility performance			1.000	0.717**	0.659**
	Quality performance				1.000	0.702**
	Industry 4.0 supplier performance					1.000

Note: **Correlation is significant at the 0.01 level (two-tailed)

Table III. Correlations of the measures

(equality of variance) of error terms and zero mean of error terms, were investigated using residual plots available in the SPSS software, Version 23.

First, the results from a normal probability (P-P) plot and a histogram of studentized residuals suggested that the errors were normally distributed (Norusis, 1985). Second, the plot of the studentized residuals against the predicted values for the data showed a random scatter pattern. Third, the plot of residuals against the predicted values for the overall firm performance data indicated the random distribution of residuals/error above and below zero. This suggested that the mean of the error term was likely to be zero. Diagnostic method/criteria were used to examine whether or not multicollinearity occurred, which included the variance inflation factor (VIF). VIF is defined as the reciprocal of $1 - R^2$ for a variable with respect to all other regressor variables in the model. It follows that a high VIF value indicates multicollinearity in the explanatory variables. Wetherill (1986) suggested that VIF should not be larger than ten. This cut-off point is far above the highest VIF value (i.e. 3.675 for Quality) found in the analysis. Thus, according to the VIF criterion, multicollinearity among the explanatory variables is not a problem.

To detect the outliers, studentized residuals (R-Student) obtained from the REG procedure in SAS (SAS Institute, 1985) is used as indicator. A case with a very large value of positive or negative residual is an outlier. No outliers were found in the data due to the fact that R-Student values do not exceed 2 in magnitude (Myers, 1986). The coefficients of all the predictor variables are positive. That is to say, an increase in each of these predictors will lead to an increase in overall firm performance. Finally, a multiple regression analysis was performed to test the hypothesized model in Figure 1. Following equation represents the regression model of the hypothesized model:

$$\text{SP} = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4,$$

where SP is the Industry 4.0 supplier performance; X_1 the cost; X_2 the delivery; X_3 the flexibility; and X_4 the quality.

This model tested the influence of the manufacturing strategies on the Industry 4.0 supplier performance with multiple analysis of cost, delivery, flexibility and quality. Tables IV–VI show the results from the regression analysis.

In Table IV, R^2 (an indicator of total variance explained by the model) is a very good predictor of the fitness of the data to the model. In this study, the adjusted R^2 is 0.641 (see Table IV) which means, the total amount of variance explained by the regression model is 64.1 percent, which is an acceptable amount. Bagozzi (1994) argued that "the closer the coefficient of determination (R^2) to 1, the better the model fits the data."

In the regression model, the dependent variable was Industry 4.0 supplier performance and the independent variables were cost, delivery, flexibility and quality. The model was found to be statistically significant at the 5 percent level. The findings from the regression analysis for the model showed that the results for each hypothesis are as follows:

The first hypothesis asserts that when costs decrease, the Industry 4.0 supplier performance increases. According to the results shown in Table VI, this hypothesis was not supported ($\beta = 0.157$, $t = 1.466$, $p = 0.147$). This indicates that there was no significant effect of cost on Industry 4.0 supplier performance. The second hypothesis states that when delivery performance increases, the Industry 4.0 supplier performance increases. It was found that this hypothesis was not supported ($\beta = 0.155$, $t = 1.478$, $p = 0.144$). This indicates that there was no significant effect of delivery performance on the Industry 4.0 supplier performance. The third hypothesis states that when flexibility increases, the Industry 4.0 supplier performance increases. It was found that this hypothesis was statistically significant ($\beta = 0.329$, $t = 2.937$, $p = 0.004$), thus providing strong evidence that flexibility increases the Industry 4.0 supplier performance. The last hypothesis states that when quality increases, the Industry 4.0 supplier performance increases. It was found that this hypothesis was statistically significant ($\beta = 0.270$, $t = 2.089$, $p = 0.040$), thus providing strong evidence that quality increases the Industry 4.0 supplier performance. Table VII summarizes the results of hypothesis testing.

Table IV.
Regression model summary

					Change statistics					
Model	R	R^2	Adjusted R^2	SE of the estimate	R^2 change	F change	df1	df2	Sig. F change	Durbin–Watson
1	0.812[a]	0.659	0.641	0.35370	0.659	36.261	4	75	0.000	1.919

Notes: [a]Predictors: (Constant), quality, cost, delivery, flexibility; Dependent variable: Industry 4.0 supplier performance

Table V.
ANOVA model

Model		Sum of squares	df	Mean squares	F	Sig.
1	Regression	18.145	4	4.536	36.261	0.000[a]
	Residual	9.383	75	0.125		
	Total	27.528	79			

Notes: [a]Predictors: (Constant), quality, cost, delivery, flexibility; Dependent variable: Industry 4.0 supplier performance

Table VI.
Regression coefficients

		Unstandardized coefficients		Standardized coefficients			Correlations			Collinearity statistics	
Model		B	SE	β	T	Sig.	Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	0.866	0.243		3.569	0.001					
	Cost	0.151	0.103	0.157	1.466	0.147	0.687	0.167	0.099	0.396	2.524
	Delivery	0.123	0.083	0.155	1.478	0.144	0.667	0.168	0.100	0.414	2.418
	Flexibility	0.264	0.090	0.329	2.937	0.004	0.746	0.321	0.198	0.363	2.754
	Quality	0.246	0.118	0.270	2.089	0.040	0.751	0.235	0.141	0.272	3.675

Note: Dependent variable: Industry 4.0 Supplier Performance

5. Discussion, conclusions and implications

This paper contributes to a growing number of research studies into the diffusion of Industry 4.0 in supply chains. Specifically, it provides an understanding of Industry 4.0 supplier performance in the Asian context. Perhaps a wider dissemination of the Industry 4.0 concept will develop an understanding of issues and challenges in implementation and how the decisions to implement constitute a competitive advantage. The effect of manufacturing strategies based on cost performance, delivery performance, flexibility performance and quality performance on the Industry 4.0 supplier performance was empirically investigated and analyzed. The findings of this study are in line with previous literature related to Industry 4.0, but, interestingly, it was found that cost and delivery performance does not have any significant relationship with Industry 4.0 supplier performance. Based on the study findings, it was found that both the flexibility and quality dimensions had significant positive relationships with Industry 4.0 supplier performance. There may be several reasons for this counter-intuitive result. Xu *et al.* (2018) investigated the impact of cost on firm size. They found that the quality, cost and flexibility positively impact performance but delivery does not have any impact on performance. This finding is in line with the results of the present study that both flexibility and quality positively affects Industry 4.0 supplier performance. However, neither cost reduction nor delivery performance affect Industry 4.0 supplier performance. This is probably because the respondents represent businesses that consider other factors to be more important than cost and delivery. For example, due to the emergence of Industry 4.0, many firms are focusing on innovation and partnership or alliance formation. They are focusing on long-term strategic goals which outperform cost and delivery. Anecdotal evidence from the data collection interviews indicates that many of these firms look at cost and delivery as operational goals not strategic goals, so for them having a long term strategic and trusted relationship with a supplier who will bring opportunities in the form of new products and processes, which is more important than short-term operational gain. Some of the respondent firms have not completely transitioned to Industry 4.0 manufacturing technologies, so it might not be clear to them how cost and delivery performance could affect Industry 4.0 supplier performance.

A related study by Xu (2011) found that integration, consolidation and coordinated applications have been identified as critical issues in Industry 4.0. This is also reflected in the current study, as flexibility is one of the key factors that was found to have a significant relationship with Industry 4.0 supplier performance (Lin *et al.*, 2018). To achieve integration and coordination, the enterprise systems must be flexible and support unexpected changes from either upstream or downstream in the supply chain. Eventually the boundaries of individual factories may disappear. Manufacturing plants will be interconnected or integrated on a real-time basis across industrial sectors and geographical locations. Xu *et al.* (2017) also found that due to the wave of fourth industrial revolution, as manufacturing technologies become smarter, their efficiency and performance has improved greatly. They have become powerful, versatile and intelligent enough to deal

Hypothesis	Regression model β	t-value
H1: when cost performance decreases, the Industry 4.0 supplier performance increases	0.157	1.466
H2: when delivery performance increases, the Industry 4.0 supplier performance increases	0.155	1.478
H3: when flexibility performance increases, the Industry 4.0 supplier performance increases	0.329	2.937
H4: when quality performance improves, the Industry 4.0 supplier performance increases	0.270	2.089

Table VII. Summary of hypothesis testing with changes and complexity. For the networked system, simple devices without superior computation capability can be integrated, and information can be acquired for real-time decision making. Finally, the primary objective of this study was to identify the key determinants of Industry 4.0 supplier performance. Based on the study findings, Industry 4.0 has tremendous potential for innovative producers and system suppliers to improve their operational flexibility, speed, cost reduction and quality of the production process by adopting new business models, production processes and other innovations. As more industrial producers invest in Industry 4.0 technologies, they will enter a new level of mass market customization for industrial offerings.

6. Managerial implications

The findings of this study have important implications for industry practitioners. One finding emerged in this study in the light of Industry 4.0, which is counter-intuitive. Study findings indicate that only flexibility and quality had a significant impact on Industry 4.0 supplier performance in Thai businesses, while traditional businesses sense considers cost and delivery to be strategic factors. This might be the case for businesses across the region but this should be the subject of further investigation based on the data from other economies in the Association of South East Asian Nations (ASEAN) region. However, the findings of this study differ from those reported in the literature, e.g. Salam (2011, 2017). From a practitioner's standpoint, the findings of this study reveal that there is a paradigm shift from cost and delivery to flexibility and quality that will determine suppliers' performance in the Industry 4.0 driven business environment. To some extent this shift is noticeable in the fact that the fourth industrial revolution is characterized by cyber-physical systems, i.e. connectivity, intelligence and flexible automation, that have upended traditional manufacturing. Forward-thinking companies have demonstrated how investment in these technologies can create a better, cleaner world, through new levels of efficiency in manufacturing. Hence, these implications are vital for managerial and entrepreneurial decision making. Supply chain partners must be aware of this paradigm shift, as it is critical for the BPM and is likely to have a significant impact on future supply chains. At the macro level, there will be constant change driven by the evolution of new technological developments which will support quality and flexibility in the manufacturing supply chains.

Finally, it is important for firms to understand the influential factors that help improve Industry 4.0 supplier performance, so that the companies can monitor these factors in managing their suppliers strategically. The business landscape is now characterized by rapid change with shortening product life cycles. There are the impacts of globalization and technological development which are necessary for companies to reach the economies of scale and reduce costs. Creating the strategic partnerships is a key element in the evolving Industry 4.0 environment. To ensure efficient and effective Industry 4.0 supplier performance, firms must continuously innovate, to improve the quality of outputs at reasonable cost with faster and flexible delivery systems. The key to a firm's survival in this competitive environment is to learn from emerging manufacturing technologies. This research focuses on four enablers that have influence in shaping Industry 4.0 supplier performance. The current study can be used by practitioners to increase their awareness of the roles of manufacturing strategies in Industry 4.0 supplier performance and direct their resources and capabilities accordingly to create a sustainable competitive advantage.

7. Limitations and directions for future research

There are a number of limitations of this study. First, the current study was conducted in an Asian setting, and the sample drawn from a single country. Hence, the findings cannot be generalized across other economies and industries. Second, the respondents were limited to the members of the PAT in the fast-moving consumer goods industry, potentially limiting the applicability of the findings to unrelated sectors. Further empirical analysis across purchasing managers from outside PAT, and in other industries, as well as in other parts of Asia, are necessary. Additional empirical research is needed to extend the results of the current study to a broader spectrum of firms and to other functional areas involved in the management of supply chains. A related issue concerns the use of a cross-sectional design. Stronger causal inferences could be drawn through the use of longitudinal studies, and this is another area in need of further research. This study focuses on the impact of manufacturing strategy on Industry 4.0 supplier performance. Potentially, there are other factors those could also be considered, such as innovation, technology and satisfaction, each of which could be the focus of further study. The suppliers in the study are all manufacturing firms. Suppliers in service industries could be studied in the future. Finally, future studies could include an examination of how Industry 4.0 supplier performance might affect cross-functional relationships within the firm, and, ultimately, an organization's bottom line. Additional empirical research is also needed to examine the barriers and challenges to Industry 4.0 implementation.

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