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Structural equation modelling on knowledge creation in Six Sigma DMAIC project and its impact on organizational performance

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ABSTRACT

Six Sigma is a business strategy that helps organizations to improve organizational efficiencies and customer satisfaction; it decreases operating costs and increases profits. Numerous practitioner studies claim that Six Sigma improves organizational performance. However, empirical research in this area is limited. No detailed investigation exists on how Six Sigma leads to improvement of organizational performance. This study suggests that the link between Six Sigma and organizational performance can be explained and developed by integrating organizational knowledge creation processes. A theoretical research model is developed based on the literature. This study investigates the existence of a relationship among organizational knowledge creation processes (socialization, externalization, combination, and internalization) in Six Sigma DMAIC project, knowledge, Six Sigma project success, and organizational performance by using structural equation modeling. The survey study results show general support for the theoretical research model. Findings reveal that organizational knowledge creation processes positively affect knowledge. In turn, knowledge positively affects Six Sigma project success, and Six Sigma project success leads to improved organizational performance.

1. Introduction

The Six Sigma concept was developed by Motorola in the 1980s and boosted by the efforts of General Electric (GE), AlliedSignal, and others in the late 1990s (Braunscheidel et al., 2011). Today, Six Sigma is one of the primary quality initiatives that have been billed as a critical business tool in the 21st century (Pepper and Spedding, 2010; Mader, 2008). Six Sigma not only helps industries improve organizational efficiencies and customer satisfaction, but also reduces operating costs and increases profits (Laureani et al., 2013; Harry et al., 2010; Ho and Chuang, 2006; Gowen and Tallon, 2005; Mahanti and Antony, 2005; McAdam and Lafferty, 2004).

Success stories of large corporations that have adopted Six Sigma, such as Motorola, GE, and AlliedSignal/Honeywell, have been reported in various papers, which claim that Six Sigma implementation results in high financial savings (Gijo et al., 2011; Hendricks and Kelbaugh, 1998). For instance, in the decade between Six Sigma's beginning in 1987 and 1997, the achievements of Motorola included a fivefold growth in sales, with profits climbing nearly 20%, cumulative savings based on Six Sigma pegged at $14 billion, and Motorola stock price gains compounded to an annual rate of 21.3% (Pande et al., 2000). In 1997, GE invested $400 million in Six Sigma, which resulted in reported savings of $700 million (Pande and Holpp, 2002). In 1999, GE spent $700 million and saved over $2 billion (Watson, 2003). AlliedSignal reduced costs by $1.4 billion from 1992 through 1997 (Brue and Howes, 2006). Considering these reports, the academia doubts whether such claim savings are truly attributed to Six Sigma. Sousa and Voss (2002) highlighted the necessity for empirical justification of assertions of all types in quality management literature.

Many Six Sigma publications, such as articles and books, are available. Current concepts in the field of Six Sigma are largely descriptive and based upon the prescription of leading “gurus” who worked in major companies, such as GE, Motorola, and Honeywell, that use Six Sigma (Zu et al., 2008). For example, Pyzdek and Keller's (2009) *The Six Sigma Handbook* was written based on the authors' experiences in companies, such as GE and Motorola, which successfully used Six Sigma. The book provides details about Six Sigma concepts, methodology, tools and techniques, and implementation strategy. Kubiak and Benbow's (2009) *The Certified Six Sigma Black Belt Handbook* and Breyfogle et al.'s (2003) *Implementing Six Sigma* also provide similar Six Sigma

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framework. The practitioner literature primarily provides prescriptive guidelines and procedures that are necessary for Six Sigma implementation. Theory development is seldom discussed. Nonthaleerak and Hendry (2006) commented that, in general, numerous studies have focused on the descriptions of practice rather than on theory development that is useful to managers and scholars. Linderman et al. (2003) remarked that Six Sigma has significantly influenced the industry, but the theory about Six Sigma is lacking. Antony (2004a, 2004b) agreed and noted that despite the significant influence of Six Sigma on the industry, the academic community lags behind in understanding Six Sigma. Schroeder et al. (2008) further argued that systematic and rigorous research is necessary to determine the effect of Six Sigma on organizational performance.

In Malaysia, empirical studies that investigate even the mere existence of Six Sigma initiatives in the country are lacking. With the exception of Jayaraman et al. (2012) study, no other study empirically investigates the extent of the existence of Six Sigma initiatives in the general Southeast Asian region. However, Jayaraman et al. (2012) study only investigated the Lean Six Sigma initiatives based on the perceptions of the practitioners. A few empirical studies also investigated the relationship between Six Sigma and organizational performance, but the results are mixed. The majority of the studies found that Six Sigma has positive effects on organizational performance (Lee, 2002; Flora, 2003; Zu et al., 2008; and Ang et al., 2010). Other studies (Goh et al., 2003; Gutie´rrez et al., 2009) found no significant relationship with organizational performance. Studies that found that Six Sigma has positive effects on organizational performance focused on the direct relationship between Six Sigma and organizational performance. Meanwhile, Arumugam et al. (2013) investigated the effects of two antecedents, namely, resources and team psychological safety, on learning and knowledge creation in Six Sigma project teams that promote knowledge creation and in turn affect project performance.

However, no detailed discussion is available on the phenomenon of how Six Sigma leads to organizational performance. The link between Six Sigma and organizational performance has not been clearly explained and fully developed. A variety of components make up these links, and understanding their interaction is important. A holistic view is useful (Linderman et al., 2004). Linderman et al. (2004) commented that theory about Six Sigma is lacking and that no basis for research exists other than best practice studies. Therefore, the starting point in conducting research on Six Sigma must be the formulation and identification of useful theories that are related to the Six Sigma phenomenon.

Given this situation, the relationship between Six Sigma and organizational performance is an interesting issue. This study proposes that the knowledge-based theory of the firm and Nonaka (1994) organizational knowledge creation theory are useful approaches in explaining the phenomenon that Six Sigma leads to organizational performance. Based on the knowledge-based theory of the firm, knowledge is a strategic resource that the firm uses to develop sustained competitive capability (Davenport and Prusak, 1998; Grant, 1996; Kogut and Zander, 1996; Spender, 1996) and the firm's practices that toward the generation of knowledge can have substantial effects on organizational performance. Based on Nonaka (1994) organizational knowledge creation theory, the conversion between tacit and explicit knowledge allows knowledge to be created through socialization, externalization, combination, and internalization processes. From these two theoretical perspectives, if Six Sigma practices lead to knowledge creation, then the link between Six Sigma and firm performance can be explained. That is, Six Sigma becomes a source of knowledge creation that results in a competitive advantage that leads to improved organizational performance.

This study minimizes the gaps found in the literature by reporting an empirical investigation and understanding of the effect of socialization, externalization, combination, and internalization processes of the knowledge on the success of Six Sigma projects, which in turn leads to organizational performance. Thus, this study empirically supports the earlier research of Linderman et al. (2010) and Lloréns-Montes and Molina (2006) and extends the research conducted by Choo et al. (2007). The rest of the paper is organized as follows: Section 2 introduces Six Sigma, knowledge management, and performance and the development of theoretical models and hypotheses. Section 3 presents the research methods, including data collection and development of measures. Section 4 presents the analysis and results. Section 5 includes a discussion about theoretical and managerial implications, opportunities for future research, and limitations of the research. Section 6 provides the conclusion.

2. Literature review

2.1. Six Sigma

Brue (2006) provided three meanings of Six Sigma depending on the context: (1) it is a level of quality (Pyzdek and Keller, 2009; Montgomery and Woodall, 2008), (2) it is a problem-solving methodology (Tjahjono et al., 2010; Antony and Banuelas, 2002), and (3) it is a management philosophy (Summers, 2010; Kwak and Anbari, 2006). *Sigma* refers to the Greek letter σ, which is used as a statistical measure of variation in a process (Omachonu and Ross, 2004). A stated sigma level is used to describe how well the process variation meets the customer's requirements (Pyzdek and Keller, 2009). Achieving a Six Sigma level (6σ) of quality means that processes are producing only 3.4 defects per million opportunities with 1.5σ allowable shift under the normal distribution, or practically it corresponds to 99.999770% yield (Raisinghani et al., 2005; Antony (2004a, 2004b))

Six Sigma is a project-driven approach to process- and product-quality improvement (Ray and Das, 2010; Gitlow et al., 2006). Projects are the means by which Six Sigma converts quality improvements into bottom-line financial benefits (Gulcin and Demet, 2010; Kubiak and Benbow, 2009). Six Sigma projects are conducted by a group of improvement specialists, typically referred to as champions, master black belts, black belts, and green belts (Gitlow, 2009; Schroeder et al., 2008; Linderman et al., 2003). They receive intensive differentiated training that is designed to improve their knowledge and skills in statistical methods, project management, process design, problem solving techniques, leadership skills, and other managerial skills (Morgan and Brenig, 2012; Gitlow, 2009; Schroeder et al., 2008; Gowen and Tallon, 2005).

Six Sigma process improvement projects are conducted by using the DMAIC methodology. The DMAIC methodology consists of five phases: Define, Measure, Analyze, Improve, and Control. These phases are designed to take a team through a step-by-step process improvement project, from inception to completion (Wheeler, 2010; Satolo et al., 2009). Kubiak and Benbow (2009) stated that the purpose of the Define phase is to determine the project focus, such as project charter and customer critical to quality. In the Measure phase, project teams collect actual data to estimate the capability of the current process in meeting customer requirement (Gijo et al., 2011; Evans and Lindsay, 2010; Omachonu and Ross, 2004). Arthur (2010) explained that in the Analyze phase, project teams identify, organize, and validate potential root causes. In the Improve phase, project teams identify a solution to the problem that the project aims to address (Keller, 2010; Kubiak and Benbow, 2009). Pyzdek and Keller (2009) stated that in the

Control phase, project teams document procedures, train all employees for new processes, and create monitoring and reaction plans for new processes.

2.2. Knowledge management

2.2.1. Knowledge

Knowledge is growing in importance as a key to a sustainable competitive advantage for all successful organizations (Davenport and Prusak, 1998; Nonaka and Takeuchi, 1995). The capability to create and utilize knowledge into business processes and products/services enables organizations to achieve superior performance (Nonaka and Takeuchi, 1995). Knowledge has been defined as "justified true belief" that increases an organization's capacity for effective action (Nonaka, 1994; Nonaka and Takeuchi, 1995). Knowledge can be essentially divided into two forms: tacit and explicit (Polanyi, 1966; Nonaka and Takeuchi, 1995; Chou, 2005; Frappaolo, 2006). Knowledge that includes individual experiences, know-how, skills, beliefs, perspectives, insights, intuitions, hunches, instincts, values, understanding of a future state, and creative processes can be considered tacit (Dyck et al., 2005; Sabherwal and Sabherwal, 2007). Explicit knowledge, also called codified or visualized knowledge, is that which can be transmitted in the form of formal and systematic language (Nonaka, 1994; Huang, 2004; Weiss and Prusak, 2005).

2.2.2. Knowledge-based theory of the firm

The knowledge-based theory of the firm emerged from the resource-based theory of the firm by focusing on intangible resources rather than on physical assets. In this perspective, knowledge is the most important resource. The knowledge-based theory of the firm views knowledge as a key resource of the firm and a source of competitive advantage that improves firm performance (Davenport and Prusak, 1998; Grant, 1996; Kogut and Zander, 1996; Spender, 1996). In this theoretical perspective, firms are viewed as distributed repositories of tacit and explicit knowledge whose heterogeneous knowledge bases are the key determinants of sustained competitive advantage (Kogut and Zander, 1996; Spender, 1996). Thus, capabilities to manage and create knowledge can provide sustainable competitive advantage (Argyris, 1999; De Geus, 1988; Prahalad and Hamel, 1990; Hatch and Dyer, 2004; Hayes et al., 1988).

2.2.3. Theory of knowledge creation

Nonaka and Takeuchi (1995) developed a theory of organizational knowledge creation. Based on this theory, an organization can create new knowledge through a continuous dynamic process of interaction between tacit and explicit knowledge that it is raised from the individual level to the interorganizational level. Four modes of knowledge-creation process are created when tacit and explicit knowledge interact. These modes are socialization, combination, externalization, and internalization. Socialization is the process of creating tacit knowledge through shared experience. Externalization is the conversion of tacit knowledge into explicit knowledge. Combination involves the use of social processes to combine different pieces of explicit knowledge held by individuals or information systems. Internalization is the conversion of explicit knowledge into tacit knowledge.

2.3. Six Sigma and organizational performance

A number of empirical studies have investigated the effects of Six Sigma on organizational performance, but the results are mixed. The empirical research conducted by Lee (2002) addressed the effect of Six Sigma implementation on operational performance, which includes operating performance, customer satisfaction, and quality cultural change. The survey study results indicate that Six Sigma has positive effects on operational performance. Ayeni (2003) studied the effect of Six Sigma on financial performance, which was defined as net income, return on assets, and stock price. The result indicates that financial performance is significantly and positively affected by the use of Six Sigma. The effect of Six Sigma on financial performance is greater than that of toal quality management (TQM). Goh et al. (2003) examined the effect of Six Sigma implementation on stock performance. They found hints of short-lived abnormal returns but no significant evidence of short- or long-term returns.

Lee and Choi (2006) investigated the effect of four Six Sigma management activities on process innovation, quality improvement, and corporate competitiveness improvement. The results of the study indicate that all four management activities have a positive effect on process innovation. The results also indicate that process innovation significantly affects quality improvement, which in turn affects corporate competitiveness. Foster (2007) examined the financial and operational effects of implementing Six Sigma, and the results are mixed. Significant main effects are found for free cash flow; earnings before interest, taxes, depreciation, and amortization; and asset turnover. However, Six Sigma does not appear to affect sales return on assets, return on investment, or firm growth. Zu et al. (2008) investigated the criticism that Six Sigma is just a reformulation of TQM and the integration of Six Sigma practices to traditional quality management practices to affect quality performance and business performance. The test results reveal that the Six Sigma practices (role structures, methodology, and focus on metric) are distinct from traditional quality management practices and that they complement the traditional quality management practices in improving quality and business performance.

Gutie´rrez et al. (2009) investigated the effects of Six Sigma teamwork and statistical process control (SPC) on organizational shared vision and the effect of organizational shared vision to organizational performance (sales, market share, and profits). They concluded that although teamwork and SPC positively affected organizational shared vision, no significant link existed between shared vision and organizational performance. Braunscheidel et al. (2011) studied the effect of Six Sigma adoption and implementation on organizational performance, which consists of Six Sigma project savings, process improvements, improvement of on-time deliveries, and reduction of inventories and setup times. They concluded that Six Sigma adoption and implementation leads to the improvement of organizational performance.

2.4. Six Sigma and knowledge creation

Six Sigma project teams are cross-functional teams that receive intensive differentiated training that is tailored for their ranks and is designed to improve their knowledge and skills in statistical methods, project management, process design, problem solving techniques, leadership skills, and other managerial skills (Gulcin and Demet, 2010; Kubiak and Benbow, 2009). They work closely with one another to determine the root cause of a problem and generate solutions (Ray and John, 2011; Satolo et al., 2009). Each project team member has knowledge and experience on subject matters. Interactions among Six Sigma project team members with multidisciplinary knowledge and experience can create knowledge more efficiently and effectively (Ang et al., 2010; Linderman et al., 2004; Sabherwal and Becerra-Fernandez, 2003; Anand et al., 2010). The empirical research conducted by Anand et al. (2010) and Ang et al. (2010) found that Six Sigma process improvement practices facilitate the creation of organizational knowledge.

2.5. Six Sigma project and organizational performance

Six Sigma projects must be linked with business strategy, meet the requirements of the customer, and provide maximum financial benefits to the organization (Abe et al., 2007; Breyfogle, 2010; Jung and Lim, 2007; Kumar et al., 2008; Ray and Das, 2010; Russell and Tippett, 2008; Coronado and Antony, 2002). Six Sigma can enhance the quality of product or service and organization's competitive capability (Banuelas et al., 2005; Goh, 2002). Six Sigma projects will unlikely be supported if they do not simultaneously provide significant customer satisfaction and make progress toward achieving the organization's strategic goals (Jacobsen, 2008; Hopen, 2007; Huehn-Brown, 2006). Six Sigma projects are required to be regularly reviewed by top management to ensure that projects stay focused on obtaining expected results and provide access to leaders who can remove any barriers to progress (Banuelas et al., 2006; George, 2003; Kendrick and Saaty, 2007).

2.6. Research model

A theoretical research model (Fig. 1) based on the literature review was developed for hypotheses testing to achieve the research objective. The knowledge-based view of the firm can provide an excellent explanation of the phenomenon that Six Sigma improves organizational performance. It is suitable as a theoretical foundation of empirical research in the study of Six Sigma and organizational performance. However, the knowledge-based view of the firm does not explain the knowledge creation process in an organization. This result indicates that knowledge-based view of the firm alone cannot completely explain the phenomenon of how Six Sigma practices lead to knowledge creation. The knowledge-based view of the firm has to be complemented by other theories or views of the firm if the objective is to understand how Six Sigma practices can create knowledge in an organization.

Although many theories exist in the field of knowledge management, few explicitly consider the process of creating knowledge. Nonaka (1994) organizational knowledge creation theory is one of the most widely known and accepted theories that comprehensively explains the process of knowledge creation in an organization. Nonaka's theory considers both the epistemological and ontological dimensions of knowledge. This theory describes the transformations between tacit and explicit knowledge through socialization, externalization, combination, and internalization; the movement from individual to organizational knowledge results in these transformations. Nonaka's foundational work should provide a useful theoretical lens to understand how Six Sigma DMAIC projects result in creating knowledge, which in turn improves organizational performance.

Socialization is the process of creating tacit knowledge through shared experience (Nonaka and Takeuchi, 1995). Linderman et al. (2004) stated that this mode of knowledge conversion requires individuals to interact with one another and, in doing so, to create tacit knowledge, such as shared mental models and technical skills. In Six Sigma DMAIC project activities, project teams should share technical knowledge and experiences. Project teams bring together a wide variety of skills, knowledge, experiences, and abilities (Linderman et al., 2004; Pyzdek and Keller, 2009; Anand et al., 2010) and are provided a context for socialization. Experiences and mental modes primarily emerge through these DMAIC activity discussions and sharing that require team collaboration. Team-oriented reflective discussions in these activities provide the project team numerous opportunities to share divergent worldviews, opinions, and experiences, which lead everyone to a greater understanding of subject matters and make decisions based on a growing common understanding. Thus, the following hypothesis is developed:

2.6.1. H1a: socialization has a positive effect on knowledge in Six Sigma DMAIC project.

The externalization process aims to encourage project teams to articulate or express tacit knowledge into explicit concepts (Nonaka and Takeuchi, 1995), and it involves the application of Six Sigma tools and techniques that help to express team members' ideas or translating the tacit knowledge of team members, customers, suppliers, and experts or processes into understandable forms (Linderman et al., 2004; Anand et al., 2010; Keller, 2010). Each of the DMAIC phases is important, and each phase consists of a set of tools and techniques that provide a common, structured approach to solving a problem (Summers, 2006; Keller, 2010). Throughout the Six Sigma DMAIC project life cycle, the project team applies multiple Six Sigma tools and techniques to capture the tacit knowledge of team members, customers, suppliers, and experts and the tacit knowledge embedded in business processes into understandable forms so that the team can work on business process improvement (Allen, 2011; Linderman et al., 2004). Thus, the following hypothesis is developed:

2.6.2. H1b: externalization has a positive effect on knowledge in Six Sigma DMAIC project.

The combination process involves reconfiguration of different discrete elements of explicit knowledge into a more complex and systematic explicit knowledge (Nonaka and Takeuchi, 1995). In the Six Sigma DMAIC project life cycle, project teams are required to perform re-configuration (sorting, adding, combining, exchanging, and synthesizing) of multiple sources of information to define the problem, assess the process baseline performance, identify the root cause, and generate solutions (Henderson, 2011; Mundo et al., 2008; Jordan, 2012). Project teams collect and synthesize business information, such as customer complaint, product/process failure, and survey or interview data. The data are then analyzed, charted, and illustrated in tables, bar charts, Pareto diagrams, and flow

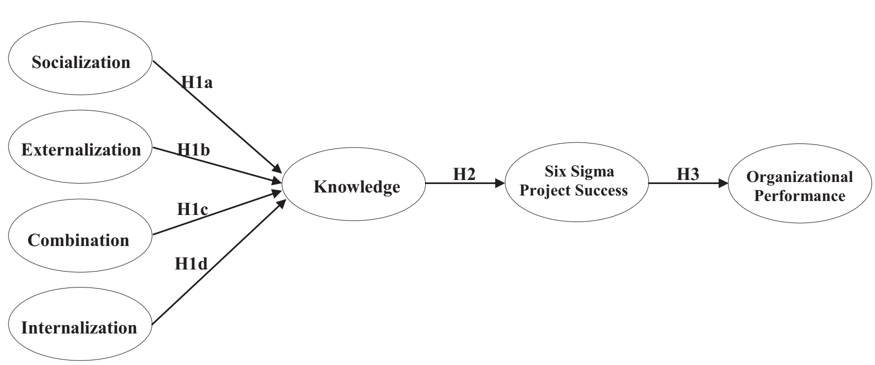

Fig. 1. Research model.

diagrams to gain insight about process data and behavior. Project teams apply Six Sigma tools and techniques, such as design of experiment and hypothesis analysis, to validate each potential root cause identified (Ginn and Varner, 2011; Harry and Schroeder, 2005). During discussions and sharing, project teams collect, integrate, and structure team members' ideas into different topics or categories to generate potential solutions. Reconfiguration of different bodies of explicit knowledge previously resulted in new knowledge synthesized from multiple sources of information (Nonaka and Konno, 1998; Eliufoo, 2008). Thus, the following hypothesis is developed:

2.6.3. *H1c: combination has a positive effect on knowledge in Six Sigma DMAIC project.*

The internalization process aims to encourage project teams to transform explicit knowledge into individual tacit knowledge based (Nonaka and Takeuchi, 1995) on learning by discussions and sharing. In the Six Sigma DMAIC project life cycle, project team members internalize the explicit or new knowledge to make it part of their own expanded repertoire of tacit knowledge bases in the form of shared mental models or technical know-how (Nonaka and Takeuchi, 1995). This process is performed by learning through team discussions and sharing in the course of DMAIC phases. During project team discussions, team members share knowledge about a product and process by using diagrams, graphs, documents, and manuals. Through project team discussions and sharing of the team, each member elicits knowledge from different sources, including subject matter discussions or sharing and team professional experience to cultivate new knowledge. Team members internalize new layers of understanding that can be characterized as developing a deep understanding of subject matters. This ongoing process not only helps the project team to make decisions, but also highlights their learning experience. Thus, the following hypothesis is developed:

2.6.4. *H1d: internalization has a positive effect on knowledge in Six Sigma DMAIC project.*

Six Sigma project teams are cross-functional teams that are equipped with a wide variety of skills, knowledge, experiences, and abilities (Linderman et al., 2004; Pyzdek and Keller, 2009; Anand et al., 2010). They work closely with one another to determine the root cause of a problem and generate solutions (Ray and John, 2011; Satolo et al., 2009). Each project team member has knowledge and experience on subject matters. Interactions among Six Sigma project team members with multidisciplinary knowledge and experience can create knowledge more efficiently and effectively (Ang et al., 2010; Linderman et al., 2004; Sabherwal and Becerra-Fernandez, 2003; Anand et al., 2010). Creating new knowledge about processes and products has contributed to Six Sigma project success (Zu et al., 2008). Anand et al. (2010) found that Six Sigma process improvement practices facilitate the creation of organizational knowledge, which can then influence Six Sigma project success. Koskinen (2000) emphasized that project teams that generate knowledge can have a noticeable effect on the success of a project, whereas project teams that lack knowledge creation may result in a poorly performing project. Thus, the following hypothesis is developed:

2.7. *H2: knowledge creations in Six Sigma DMAIC phases have a positive effect on Six Sigma project success.*

Six Sigma is regarded as a well-structured methodology for improving the quality of processes and products. It helps achieve the company's strategic goals through the effective use of project-driven approaches. Six Sigma projects must be linked with business strategies and should meet the requirements of customers. Given that Six Sigma is a project-driven methodology, prioritizing projects that provide maximum financial benefits to the organization is essential (Coronado and Antony, 2002). Empirical studies (Banuelas et al., 2005; Goh, 2002; Linderman et al., 2003) indicate that Six Sigma can increase an organization's competitive capability and enhance the quality of products or services by conducting projects. Snee (2002) argued that Six Sigma project performance has an effect on organizational performance because Six Sigma projects must possess some characteristics that are connected to business priorities and have major importance to the organization. Similarly, Gijo and Rao (2005) commented that Six Sigma projects must be selected in line with the organization's core strategies. They should relate to the organization's core processes, address issues that customers view as critical to quality, enable revenue growth, and enable cost and time reductions. Notably, Six Sigma has an effect on organizational performance. Not only application of the well-structured DMAIC methodology but also project selection, which is aligned with the organization's strategic goals, are important. Thus, the following hypothesis is developed:

H3: Six Sigma project success has a positive effect on organizational performance.

3. Research methodology

The data for this study were collected through a survey method. The instrument for the survey was a questionnaire. The firm as a whole was considered as the research analysis unit. The target population of the survey study was manufacturing firms that have implemented the Six Sigma program. The respondents were Six Sigma black belts. The measurement instrument was created through an extensive review of the literature. Validated multi-item measures from the literature were used in operationalizing the constructs in the theoretical framework (Sekaran and Bougie, 2010; Zikmund et al, 2010). A 1–5 Likert scale was used for the measure item. Most measures were adapted and modified to make them more suitable for this research setting.

The initial instrument was reviewed by an expert panel to verify its content validity. A pilot study was conducted to test the reliability of the study instrument before data collection. The reliability scores and Cronbach's alpha, which range from 0.821 to 0.912, above the acceptable level of 0.70, indicated that the measurement items are satisfactory in measuring the constructs of interest. The survey data were analyzed by using a two-step structural equation modeling technique. The first step assessed the measurement model validity by using confirmatory factor analysis (Hair et al., 2009). The second step assessed the structural relationships among the research variables in the hypothesized model (Kline, 2011). The SPSS AMOS 16.0 software was used to test the hypothesized model.

4. Analysis results

4.1. *Descriptive analysis*

4.1.1. *Response rate*

Out of the 364 total possible survey participants, 231 (63.5%) surveys were returned and received. Six (1.6%) firms were excluded from data analysis because they did not participate in the study or the surveys were returned incomplete. The study obtained a sample size of 225, which indicates a response rate of 61.8%.

Table 1
Business Characteristics of Survey Respondents.

Business characteristics	Frequency	Percentage
Primary business	225	100%
Electrical and electronic	225	100.0%
Chemical and chemical products	0	0.0%
Paper and paper products	0	0.0%
IT and Networking Products	0	0.0%
Software applications	0	0.0%
Food Products and Beverages	0	0.0%
Textiles and wearing apparels	0	0.0%
Rubbers and plastic products	0	0.0%
Industrial type	225	100%
Manufacturing	225	100.0%
Service	0	0.0%
Health care	0	0.0%
Sales and marketing	0	0.0%
Education	0	0.0%
Government	0	0.0%
Number of Employees	225	100%
Less than 100	0	0.0%
100–250	0	0.0%
251–500	11	4.9%
501–1000	18	8.0%
More than 1000	196	87.1%
Year of Business Operation	225	100%
$\leq$5 years	0	0.0%
6–10 years	2	0.9%
11–15 years	5	2.2%
$>$15 years	218	96.9%

Table 2
Six Sigma experiences.

Six Sigma experiences	Frequency	Percentage
Years of Six Sigma implementation	225	100%
More than 8 years	15	6.6%
5–8 years	67	29.8%
3–5 years	112	49.8%
2–3 years	31	13.8%
Six Sigma methodology applied	225	100%
DMAIC	223	99.1%
DFSS	0	0.0%
DMAIC and DFSS	2	0.9%
Average annual cost savings per project	225	100%
Less than $ 50,000	4	1.8%
$ 50,000–$ 100,000	11	4.9%
$ 100,000–$ 150,000	34	15.1%
$ 150,000–$ 200,000	100	44.4%
More than $ 200,000	76	33.8%
Six Sigma position title	225	100%
Black Belt	225	100.0%
Master Black Belt	0	0.0%
Champion	0	0.0%
Six Sigma executive	0	0.0%
Number of years in the Six Sigma position title	225	100%
More than 8 years	15	6.6%
5–8 years	67	29.8%
3–5 years	112	49.8%
2–3 years	31	13.8%

4.1.2. Business characteristics

The characteristics of the survey respondents' businesses were assessed to provide a better understanding of their basic nature. The questions included primary business, industrial type, number of employees, year of business operation, and firm ownership. Table 1 shows the characteristics of the firms that participated in the study survey.

First, the primary business of the firm was asked to understand the types of business/products that were handled by the study participants. Among the respondents, 225 (100%) reported that their major business was related to electricity and electronics. These statistics suggested most of the Six Sigma initiatives were implemented by electrical and electronic companies. Second, the large proportion of the respondents (100%) represented the manufacturing industry, which is understandable given that Six Sigma started in manufacturing, and it is strongly embraced by this sector.

Third, the number of employees was requested to obtain an overview of the participant's firm size. Out of 225 respondents, 196 (87.1%) employed more than 1000, 18 (8.0%) employed 501–1000, and 11 (4.9%) employed less than 500. This finding suggested that a significant portion of Six Sigma firms would be classified as large business operations and that Six Sigma program implementation was mostly interesting to large rather than small businesses. Fourth, the responses on the years of the firm's operations revealed that over 96.9% of the participants had more than 15 years of operations, 2.2% between 11 and 15 years of operations, and 0.9% less than 10 years of operations.

4.1.3. Six Sigma experiences

The characteristics of Six Sigma operations were manifested through various survey questions, including the years of Six Sigma implementation, Six Sigma methodologies applied, average annual cost savings, and position title. Table 2 summarizes the detailed information on the Six Sigma experiences of the respondents. The length of time an organization has been implementing Six Sigma is shown in Table 2. These results were expected given that Six Sigma is a relatively new concept. This situation is proven by the fact that over 75% of the organizations in the survey have been working with Six Sigma for eight years or less. Out of 225 respondents, 223 (99.1%) reported that they used the DMAIC methodology and 2 (0.9%) employed the DMAIC and DFSS methodologies. These statistics suggested most of the Six Sigma initiatives of firms focus on existing business process improvement, and minor focus is placed on product/business process design/redesign.

Six Sigma emphasizes the financial results of a project. The firms' annual cost savings per project were assessed. Out of 225 respondents, 100 (44.4%) reported that their annual cost savings per project were between $150K and $200K, 76 (33.8%) more than $200K, 34 (15.1%) between $100K and $150K, 11 (4.9%) between $50K and $100K, and only 1.8% less than $50K. Therefore, cost saving is one of the indices used to determine the success or failure of Six Sigma initiatives. Finally, the title of the participant's Six Sigma position and number of years in the Six Sigma position title within the firm were determined to ensure that the participant was qualified to respond to the survey questions as intended in the study design. Among the respondents, 225 (100.0%) were black belts. The respondents' black belt year of experience is the same as the year of Six Sigma implementation in the firms. These results confirmed that the survey respondents were qualified to provide their firms' Six Sigma DMAIC project execution information required in the study.

4.2. Measurement model analysis results

An overall measurement model fit was examined with multiple goodness-of-fit measures. The chi-square value of the measurement model was 635.136 and p-Value >0.05, which indicates the good fit of the model to the data. RMSEA showed a value of 0.061, which is lower than the 0.08 required for acceptable fit. The GFI value of 0.915 exceeded the 0.90 required for good fit. NFI showed a value of 0.927, and the CFI value was 0.948, which indicates an excellent fit of the overall model. Table 3 shows the results of the study's measurement model analysis, including the construct names, observed variables, standardized factor loadings, composite reliability, and average variance extracted (AVE).

The reliability measures and composite reliability of all variables ranged from 0.837 to 0.924, all exceeding the acceptable threshold level of 0.70 (Hair et al., 2009). Convergent validity was assessed by examining the magnitude and sign of the factor loadings of observed variables. Table 3 shows all observed variables were statistically significant, given that all critical ratio (CR) values of the factor loadings from unstandardized estimates were higher than 1.96, which indicates statistical significance at a 95% confidence level. All factor loadings showed positive signs, which suggests positive relationships between the observed variables and their respective constructs. Discriminant validity was examined by comparing the squared correlations between constructs and AVE for a construct (Hair et al., 2009). The analysis results showed that the square correlations for each construct is less than the AVE by the indicators that measure that construct, as shown in Table 4, which indicates that the measure has adequate discriminant validity.

4.3. Results of structural model analysis

An overall structural model fit was examined with multiple goodness-of-fit measures. The chi-square value of the structural model was 864.928 and p-Value > 0.05, which indicates the good fit of the model to the data. RMSEA showed a value of 0.064, which is lower than the 0.08 required for acceptable fit. The GFI value of 0.921 exceeded the 0.90 required for good fit. In addition, among incremental fit indices, NFI showed a value of 0.921, and the CFI value was 0.929, which indicates an excellent fit of the overall model. Table 5 and Fig. 2 show the results of the study's structural model, including standardized parameter estimates, CR values from unstandardized solutions, significance levels for the structural paths, and overall goodness-of-fit indices. Model path analysis and hypothesis testing results indicated that all hypotheses are supported. Table 6 shows the results of the testing hypotheses.

4.4. Post-hoc model modification

An alternative structural model was examined based on the theory and the analysis results from the original research model to explain potential misfit in the structural model. A path from knowledge to organizational performance was added to the alternative structural model to explore the possibility of any direct effect of knowledge on organizational performance. Fig. 3 shows the alternative structural model. Table 7 shows the analysis results of the alternative structural model. The overall fit of this model was slightly improved (chi-square value = 845.471, p-Value > 0.05, RMSEA = 0.006, GFI = 0.922, NFI = 0.922, and CFI = 0.929). However,

Table 3
Measurement model analysis result.

Independent variables				**Mediating variable**				**Dependent variables**			
Construct/item	*Std loadings*	*Composite reliability*	*AVE*	*Construct/ item*	*Std loadings*	*Composite reliability*	*AVE*	*Construct/ Item*	*Std loadings*	*Composite reliability*	*AVE*
Socialization				Knowledge				Six Sigma project success			
SOC1	0.781	0.862	0.677	KNO1	0.793	0.877	0.641	SSP1	0.745	0.861	0.608
SOC2	0.823			KNO2	0.824			SSP2	0.752		
SOC3	0.862			KNO3	0.751			SSP3	0.809		
				KNO4	0.832			SSP4	0.810		
Externalization											
EXT1	0.773	0.844	0.643					Organizational Performance			
EXT2	0.794							ORP1	0.871	0.924	
EXT3	0.838							ORP2	0.792		0.670
Combination								ORP3	0.803		
COM1	0.796	0.868	0.686					ORP4	0.821		
COM2	0.828							ORP5	0.844		
COM3	0.860							ORP6	0.775		
Internalization											
INT1	0.837	0.837	0.632								
INT2	0.792										
INT3	0.753										

All critical ration values are statistically significant at $p < 0.05$, $N = 225$.Goodness-of-fit statistics.
$\chi^2 = 635.13$, $p > 0.05$.
CFI = 0.948.
NFI = 0.927.
RMSEA = 0.061.
GFI = 0.915.

Table 4
Discriminant validity analysis for measurement model.

Construct	[1]	[2]	[3]	[4]	[5]	[6]	[7]
[1] Socialization	**0.677**						
[2] Externalization	0.203	**0.643**					
[3] Combination	0.178	0.219	**0.686**				
[4] Internalization	0.221	0.180	0.161	**0.632**			
[5] Knowledge	0.133	0.224	0.223	0.174	**0.641**		
[6] Six Sigma project success	0.137	0.128	0.151	0.207	0.238	**0.608**	
[7] Organizational performance	0.114	0.143	0.212	0.154	0.144	0.155	**0.670**

Table 5
structural model 1 analysis result.

Paths in the structural model	Standardized estimates	Critical ratio	Probability ≤
Socialization → Knowledge	0.579	17.590	0.000
Externalization → Knowledge	0.573	18.229	0.000
Combination → Knowledge	0.580	15.537	0.000
Internalization → Knowledge	0.561	15.524	0.000
Knowledge → Six Sigma project success	0.446	13.884	0.000
Six Sigma project success → Organizational performance	0.484	15.500	0.000
	Goodness-of-fit Iindices		
	χ^2 = 864.928, $p > 0.05$		
	CFI = 0.929		
	NFI = 0.921		
	RMSEA = 0.064		
	GFI = 0.921		

Critical Ratio values are from unstandardized solutions. Probability values from two-tail *t*-test.

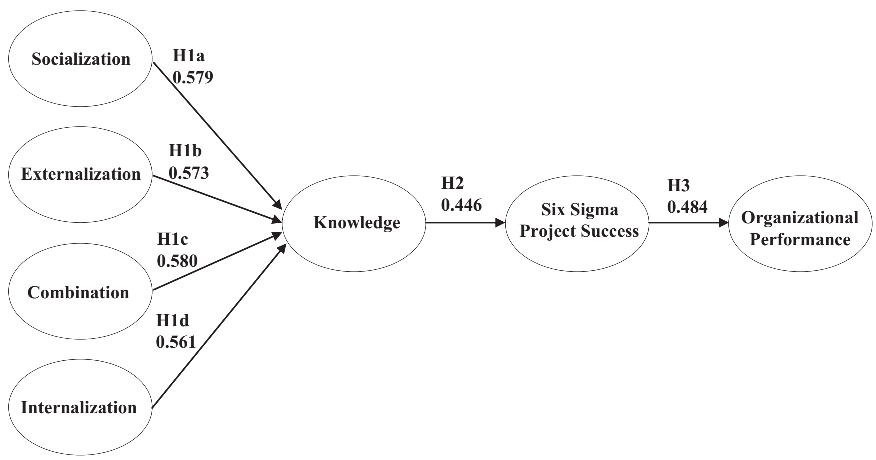

Fig. 2. Path diagram structural model.

the path coefficients were not statistically significant even at *p*0.05. This result suggested that knowledge showed no statistically significant direct effect on organizational performance.

In sum, the results of post-hoc modification suggested that the original structural model was more appropriate for explaining the topic of this study. Particularly, this study was an exploratory attempt to gain an understanding of the relationships among organizational knowledge creation processes, knowledge, Six Sigma project success, and organizational performance. Thus, the original model was deemed to produce sufficient and meaningful knowledge of Six Sigma and organizational performance.

5. Discussion

The results of structural model analysis revealed that all the research hypotheses were supported. The results of hypothesis testing for H1a through H1d indicated that the knowledge-creation process of socialization, externalization, combination, and internalization has a positive effect on knowledge. These findings are consistent with earlier conceptual arguments and related empirical research (Nonaka and Takeuchi, 1995; Nonaka and Konno, 1998; Linderman et al., 2004; Sabherwal and Becerra-Fernandez, 2003; Anand et al., 2010; Ang et al., 2010; Eliufoo, 2008).

The significant relationship between socialization and knowledge in Six Sigma DMAIC project is consistent with studies conducted by Arthur (2010), who claimed that sharing ideas, experiences, and mental model among project team members is required in the Six Sigma DMAIC project lift cycle. Bringing together team members with different knowledge and experiences and providing an opportunity for socialization are necessary conditions for knowledge conversion and creation (Linderman et al., 2004; Pyzdek and Keller, 2009; Anand et al., 2010). The finding of the present study confirms that knowledge creation lies in the mobilization and conversion of tacit knowledge, and both types of tacit knowledge (technical and cognitive) are important for Six Sigma project success and developing organizational core capabilities.

Externalization is also significantly related to the knowledge in Six Sigma DMAIC project. In each of the DMAIC phases, project teams consist of multiple functional members who discuss the issue; offer their views, comments, and suggestions; generate ideas for process improvement or product design; discuss the alternatives; and contribute to the decision making of the team (Kubiak and Benbow, 2009). Application of the Six Sigma tools and techniques (e.g., brainstorming, cause-and-effect diagram, and why–why analysis) in these processes enables the project teams to convert the tacit knowledge from individual team members to explicit concepts, ideals, or reasoning (Linderman et al., 2004; Anand et al., 2010). Brainstorming is one of the techniques used by project teams to generate ideas (Maisel and Maisel, 2010). A cause-and-effect diagram is used to organize teams' ideas into different categories of root causes (Connie, 2008). Teams can establish theories about the cause-and-effect relationships between defects and process characteristics and factors by using a technique called why–why analysis, in which “why” is asked a few times (Latino et al., 2011).

The results also showed that combination has a significant effect on knowledge in Six Sigma DMAIC project. Reconfiguration

Table 6
Summary of hypotheses testing results.

Hypotheses		Result
H1a	Socialization has a positive effect on knowledge in Six Sigma DMAIC project.	Supported
H1b	Externalization has a positive effect on knowledge in Six Sigma DMAIC project.	Supported
H1c	Combination has a positive effect on knowledge in Six Sigma DMAIC project.	Supported
H1d	Internalization has a positive effect on knowledge in Six Sigma DMAIC project.	Supported
H2	Knowledge creations in Six Sigma DMAIC have positive effect on Six Sigma project success.	Supported
H3	Six Sigma project success have an effect on organizational performance.	Supported

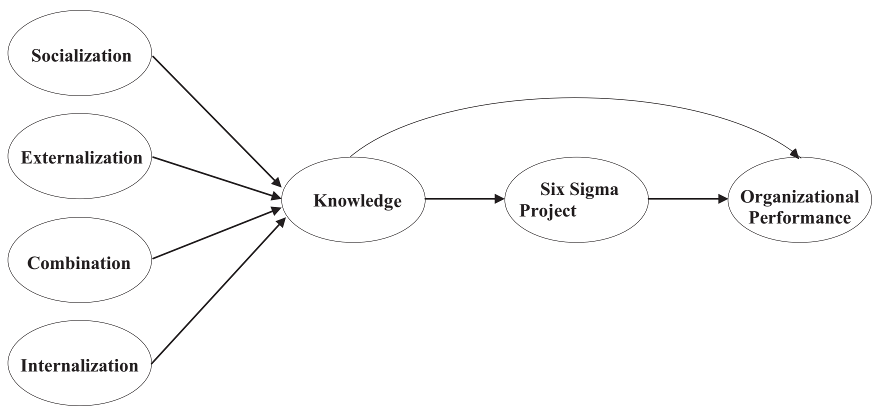

Fig. 3. Alternative structural model.

of multiple sources of information is necessary in defining the problem, assessing process baseline performance, identifying root causes, and generating solutions to resolve the problem (Henderson, 2011; Jordan, 2012). To achieve this goal, project teams collect and synthesize business information; analyze the data, and chart and illustrate them by using tables, charts, or diagrams; and apply Six Sigma tools and techniques to validate the identified root causes (Ginn and Varner, 2011; Harry and Schroeder, 2005). Potential solutions are generated by project teams during discussions and sharing through collecting, integrating, and structuring team members' ideas into different topics or categories. In a previous study, reconfiguration of different bodies of explicit knowledge produced new knowledge that was integrated from multiple information sources (Nonaka and Konno, 1998; Eliufoo, 2008).

The present study highlighted the effect of internalization on knowledge in Six Sigma DMAIC project. Explicit or new knowledge is internalized to expand the team members' repertoire of tacit knowledge bases in the form of shared mental model or technical know-how (Anand et al., 2010). This goal is achieved through learning by discussion, knowledge sharing, questions, and answers made by the team (Linderman et al., 2004; Anand et al., 2010). Every team member absorbs team knowledge and reflects on new understanding. This process can be considered as developing a deep understanding of subject matters (Nonaka and Takeuchi, 1995; Anand et al., 2010). It not only helps the project team enhance their learning experience but also assists them in making decisions throughout the DMAIC phases.

Comparison of the direct path coefficients (from standardized estimates) of socialization, externalization, combination, and internalization to knowledge shows that all of these knowledge creation processes appear to have similar effects (path coefficients: socialization [0.579], externalization [0.573], combination [0.580], and internalization [0.561]) on knowledge. This result could suggest that for organizations that use the Six Sigma DMAIC methodology for process improvement, all the knowledge creation processes (socialization, externalization, combination, and internalization) are important for knowledge creation. Relying solely on practices that create explicit knowledge is insufficient. Practices that create tacit knowledge or personalize the knowledge by making it tacit are also critical. This result is consistent with Anand et al.'s (2010) study, where socialization, externalization, combination, and internalization significantly affected knowledge creation, and is consistent with the assertions made by Nonaka and Takeuchi (1995) that organizations must not neglect the creation of tacit knowledge.

The results of this study also showed the importance of knowledge creation on Six Sigma project success, which is consistent with the findings of Anand et al. (2010), who stated that knowledge creation influences the success of process improvement projects. The results also supported Koskinen (2000), who emphasized that lack of knowledge creation in project teams may result in poor project performance. Each project team member has different knowledge and experiences, and interaction among them can create knowledge efficiently and effectively (Ang et al., 2010; Lindermanet al., 2004). New knowledge about products and processes helps project team members find the root cause of a problem and generate solutions, consequently contributing to Six Sigma project success.

The results also showed that Six Sigma project success has a significant effect on organizational performance. This finding is consistent with earlier conceptual arguments and related empirical research (Banuelas et al., 2005; Goh, 2002; Linderman et al., 2003) that indicated that Six Sigma is capable of increasing the competitive capability of an organization and enhancing the quality of products or services through Six Sigma projects. The results of the present study also supported Snee (2002) findings that indicated that Six Sigma project performance has a positive effect on organizational performance. Six Sigma helps a company to achieve its strategic goals and consequently improve its organizational performance. The Six Sigma project must be aligned with the organization's goals and objectives and address the issues that are critical in the main customers' point of view.

In post-hoc modification analysis, a path from knowledge to organizational performance was added to explore the possibility of any direct effect of knowledge on organizational performance.

Table 7
Alternative structural model analysis result.

Paths in the structural model	Standardized estimates	Critical ratio	Probability ≤
Socialization → knowledge	0.577	18.000	0.000
Externalization → knowledge	0.572	17.162	0.000
Combination → knowledge	0.581	14.178	0.000
Internalization → knowledge	0.562	15.951	0.000
Knowledge → Six Sigma project success	0.448	14.119	0.000
Six Sigma project success → organizational performance	0.486	14.971	0.000
Knowledge → organizational performance	0.341	6.786	0.104
	Goodness-of-fit Indices		
	$\chi^2=845.471$, $p>0.05$		
	CFI = 0.929		
	NFI = 0.922		
	RMSEA = 0.063		
	GFI = 0.922		

Critical Ratio values are from unstandardized solutions. Probability values from two-tail *t*-test.

However, the path coefficient was not statistically significant. This result suggested that knowledge showed no statistically significant direct effect on organizational performance. However, knowledge has a positive indirect effect on organizational performance through Six Sigma project success. This finding is consistent with the knowledge-based theory of the firm. Based on the knowledge-based theory of the firm, knowledge is a strategic resource that the firm uses to develop sustained competitive capability that can lead to improve firm performance (Davenport and Prusak, 1998; Grant, 1996; Kogut and Zander, 1996; Spender, 1996). The new knowledge on processes and products created in Six Sigma projects contributes to the competitive advantage position of organizations (Zu et al., 2008), which leads to improved organizational performance.

6. Implications for theory

6.1. Knowledge-based theory of the firm

In this research, the knowledge-based theory of the firm was used to frame the study. The knowledge-based theory of the firm views knowledge as a key resource of the firm and a source of competitive advantage that improves firm performance (Davenport and Prusak, 1998; Grant, 1996; Kogut and Zander, 1996; Spender, 1996). From this theoretical perspective, firms are viewed as distributed repositories of tacit and explicit knowledge whose heterogeneous knowledge bases are the key determinants of sustained competitive advantage (Kogut and Zander, 1996; Spender, 1996). Thus, the ability of firms to create and manage knowledge can deliver a sustainable competitive advantage that has substantial effects on organizational performance (Argyris, 1999; De Geus, 1988; Prahalad and Hamel, 1990; Hatch and Dyer, 2004; Hayes et al., 1988).

Six Sigma is a customer-driven process improvement program that continuously improves organizational processes to achieve the strategic business goal of increasing bottom-line benefits and enhancing customer satisfaction through projects undertaken by experts trained in the Six Sigma methodologies (Pyzdek and Keller, 2009; Summers, 2010). This research investigated the knowledge-based theory of the firm assumption explicitly in the context of Six Sigma, and the findings empirically supported the knowledge-based theory of the firms. The research findings revealed that Six Sigma DMAIC practices lead to knowledge creation and that knowledge creation results in improved Six Sigma project success, and finally, Six Sigma project success influences organizational performance.

6.2. Theory of organizational knowledge creation

The findings of this study empirically supported Nonaka and Takeuchi's (1995) organizational knowledge creation theory that was used to frame the study. This theory suggests that an organization can create new knowledge through a continuous dynamic process of interaction along *epistemological* and *ontological* dimensions of knowledge. Explicit and tacit knowledge represent the epistemological dimensions of knowledge. The ontological dimension of knowledge begins with individual knowledge and then moves to higher levels, including group, organizational, and interorganizational. Knowledge creation occurs through a spiral interaction between the epistemological and ontological dimensions of knowledge. This process involves four different patterns of interaction between explicit and tacit knowledge: socialization (tacit to tacit), externalization (tacit to explicit), combination (explicit to explicit), and internalization (explicit to tacit). These patterns of interaction represent ways that existing knowledge is transformed into new knowledge. The study results reveal that Six Sigma DMAIC practices allow knowledge to be created through the interactive spiral processes of socialization, externalization, combination, and internalization. These processes will connect and convert tacit and explicit knowledge. The dynamic SECI model enables Six Sigma project teams to create new knowledge or combine existing knowledge to form new insights and become valuable knowledge assets that can be used in projects. Six Sigma can amplify the mobilization of knowledge and trigger new spirals of knowledge creation continuously to transform a strategy into better business value and performance.

6.3. Relationship between knowledge and quality

The research findings explain the relationship between knowledge and quality. The quality management field increasingly searches for new ways to improve organizational performance. Most quality improvement activities require the creation of new knowledge for the organization. This perspective suggests that knowledge plays a critical role in the early development of quality management. Yet the link between quality management and knowledge has not been fully developed in concrete terms. Studies that connect organizational knowledge and quality management are limited. For example, Ahire et al. (1995) and Sousa and Voss (2002) provided comprehensive literature reviews of the quality management literature but did not identify any studies that relate quality management to knowledge. The empirical research findings provide a basis for understanding the connection between quality and knowledge, and from a knowledge perspective develop insights into how effective deployment of quality management practices leads to improved performance.

Academic literature on knowledge and quality has primarily focused on explicit knowledge, which tends to be easily shared and imitated. However, Dooley (2000) noted that "Since the ultimate value of the firm depends on knowledge that cannot be imitated, it is reasonable to assume that knowledge which is tacit and not easily imitated, as opposed to explicit knowledge, will grow in importance. For this reason we might expect quality management systems will increasingly focus on tacit knowledge." Others considered individual knowledge, whereas some highlighted organizational knowledge. As a result, quality management has dealt with concepts related to knowledge in a haphazard manner. This situation suggests a formalized integrative view of knowledge is required to effectively link knowledge to quality management. Such a view should consider not only tacit and explicit knowledge, but also individual and organizational knowledge. Thus, knowledge-based view of the firm and Nonaka's theory of knowledge creation were used to frame this study. The research findings provide useful empirical support that links knowledge to quality, and it considers not only tacit and explicit knowledge but also individual and organizational knowledge.

6.4. Limitations

The study is cross-sectional in nature, where all the data for each organization were collected at approximately the same time. Given that the relationship between Six Sigma, knowledge creation, and organizational performance is complex, it is never complete; it shifts and changes over time and across circumstances. It would not substantially add to our understanding of how Six Sigma DMAIC practices can be used systematically to develop and reinforce knowledge creation capability and firm performance over time. Therefore, caution is important when interpreting the results. One method to address this problem would be to collect longitudinal data to test the predictive validity of the independent, dependent, and mediating variables.

Given that this research focused on knowledge creation in organizations, manufacturing firms, especially electrical and electronic firms in Malaysia, were selected as samples because these firms are characterized by rapid technological changes and tend to have a significant intensity of knowledge because of their emphasis on innovation, which they consider their key source of competitive advantage (Balkin et al., 2000). However, considering that the data set for this study is limited to electrical and electronic manufacturing firms, the issue on the application of the results to other industries should be considered. Therefore, the results of the study should be treated with caution when applied to non-manufacturing firms or countries other than Malaysia.

6.5. Conclusion

This study mainly aimed to identify the relationship between knowledge creation processes (socialization, externalization, combination, and internalization) and knowledge in a Six Sigma DMAIC project. This study found that a positive relationship exists between knowledge creation processes and knowledge. The results supported the conclusion that process improvement in organizations that use the Six Sigma DMAIC methodology involves knowledge creation. The underlying basis for knowledge creation practices employed in the Six Sigma DMAIC methodology allows knowledge to be created through the transformation of knowledge from tacit to explicit and vice versa, and through the transfer of both types of knowledge from individuals to teams.

Knowledge created through the Six Sigma DMAIC methodology has a positive effect on Six Sigma project success. This finding signifies that project teams that generate knowledge can expect a noticeable effect on the success of a project. Project teams must propagate their experience and knowledge throughout the team members who are working on a project. Teams must collectively learn facts and situations to solve the myriad problems encountered in projects. Experience and knowledge will allow project teams to complete an initiative within the estimates of schedule, cost, scope, and goal. Success stories of many companies that adopted Six Sigma have been reported in various papers, which claim that Six Sigma implementation results in high financial savings without empirical justification. This study provides empirical evidence that Six Sigma project success has a positive effect on organizational performance. Therefore, organizations are encouraged to select Six Sigma projects that align with their core strategies, relate to their core processes, address issues that customers view as critical to quality, enable revenue growth, and enable cost and time reductions.

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References

Abe, N., Akkiraju, R., Buckley, S., Ettl, M., Huang, P., Subramanian, D., Tipu, F., 2007. On optimizing the selection of business transformation projects. IBM Syst. J. 46 (4), 777–795.
Ahire, S.L., Landeros, R., Golhar, D., 1995. Total quality management: a literature review and an agenda for future research. Prod. Oper. Manag. 4 (3), 277–303.
Allen, T.T., 2011. Introduction to Engineering Statistics and Lean Sigma: Statistical Quality Control and Design of Experiments and Systems. Springer, Columbus, Ohio.
Anand, G., Ward, P.T., Tatikonda, M.V., 2010. Role of explicit and tacit knowledge in Six Sigma projects: An empirical examination of differential project success. J. Oper. Manag. 28 (4), 303–315.
Ang, B.S., Zailani, S., Ramayah, T., 2010. Six Sigma and Organizational performance: a knowledge creation perspective. Int. J. Product. Qual. Manag. 6 (2), 182–212.
Antony, J., 2004a. Some pros and cons of Six Sigma: an academic perspective. TQM Mag. 16 (4), 303–306.
Antony, J., 2004b. Six sigma in the UK service organisations: results from a pilot survey. Manag. Audit. J. 19 (8), 1006–1013.
Antony, J., Banuelas, R., 2002. Key ingredients for the effective implementation of Six Sigma programmes. Meas. Bus. Excell. 6 (4), 20–28.
Arumugam, V., Antony, J., Kumar, M., 2013. Linking learning and knowledge creation to project success in SixSigma projects: an empirical investigation. Int. J. Prod. Econ. 141, 388–402.
Argyris, C., 1999. On organizational learning. Blackwell, Malden, Massachusetts.
Arthur, J., 2010. Lean Six Sigma Demystified, Second ed.. McGraw-Hill, New York.
Ayeni, F.O., 2003. An empirical Study of The Impact Of Six Sigma Methodology on Organization Financial Performance in the United States. Regent University, Virginia Beach, VA.
Balkin, D.B., Markman, G.D., Gomez-Mejia, L.R., 2000. Is CEO pay in high-technology firms related to innovation? Acad. Manag. J. 43 (6), 1118–1129.
Banuelas, R., Antony, J., Brace, M., 2005. An application of Six Sigma to reduce waste. Qual. Reliab. Eng. Int. 21, 553–570.
Banuelas, R., Tennant, C., Tuersley, I., Tang, S., 2006. Selection of Six Sigma projects in the UK. TQM Mag. 18 (5), 514–527.
Braunscheidel, M.J., Hamister, J.W., Suresh, N.C., Star, H., 2011. An institutional theory perspective on Six Sigma adoption. Int. J. Oper. Prod. Manag. 31 (4), 423–451.
Breyfogle III, F.W., 2003. Implementing six sigma: smarter solutions using statistical methods. John Wiley & Sons, Austin, Texas.
Breyfogle, F.W., 2010. Process improvement projects shortcomings and resolution. Int. J. Lean Six Sigma 1 (2), 92–98.
Brue, G., 2006. Six Sigma for Managers: 24 Lessons to Understand and Apply Six Sigma Principles in Any Organization. McGraw-Hill, New York.
Brue, G., Howes, R., 2006. Six Sigma: The Mcgraw-Hill 36 Hour Course. McGraw-Hill, New York.
Choo, A., Linderman, K., Schroeder, R., 2007. Method and context perspectives on learning and knowledge creation in quality improvement projects. Manag. Sci. 53 (3), 437–450.

Chou, S.W., 2005. Knowledge creation: Absorptive capacity, organizational mechanisms, and knowledge storage/retrieval capabilities. J. Inf. Sci. 31 (6), 453–465.
Connie, M.B., 2008. The Certified Quality Engineer Handbook, Third ed.. ASQ Quality Press, Milwaukee, WI.
Coronado, R.B., Antony, J., 2002. Critical success factors for the successful implementation of Six Sigma projects in organizations. TQM Mag. 14 (2), 92–99.
Davenport, T.H., Prusak, L., 1998. Working Knowledge: How Organizations Manage What They Know, Boston, MA. Harvard Business School Press.
De Geus, A.P., 1988. Planning as learning. Harvard Bus. Rev. 66 (2), 70–74.
Dooley, K.J., 2000. The paradigms of quality: evolution and revolution in the history of the discipline. Adv. Manag. Organ. Qual. 5, 1–28.
Dyck, B., Starke, F.A., Mischke, G.A., Mauws, M., 2005. Learning to build a car: an empirical investigation of oragnizational learning. J. Manag. Stud. 42 (2), 387–416.
Eliufoo, H.K., 2008. Knowledge Creation in Construction Organisations: A Case Approach. Learn. Organ. 15 (4), 309–325.
Evans, J.R., Lindsay, W.M., 2010. Managing for Quality and Performance Excellence. South-Western Cengage Learning, Mason, OH.
Flora, O.A., 2003. An Empirical Study of the Impact of Six Sigma Methodology on Organization Financial Performance in the US. (Ph.D. dissertation). Regent University, Virginia.
Foster Jr., S.T., 2007. Does Six Sigma improve performance? Qual. Manag. J. 14 (4), 7–20.
Frappaolo, C., 2006. Knowledge Management. Capstone Publishing Ltd., Souther Gate Chichester, West Sussex, England.
George, M.L., 2003. Lean Six Sigma for services. McGraw-Hill, New York.
Gijo, E.V., Rao, T.L., 2005. Six Sigma implementation hurdles and more hurdles. Total Qual. Manag. 16 (6), 721–725.
Gijo, E.V., Scaria, J., Antony, J., 2011. Application of Six Sigma methodology to reduce defects of a grinding process. Qual. Reliab. Eng. Int. 27 (8), 1221–1234.
Ginn, D., Varner, E., 2011. The Design for Six SIGMA Memory Jogger: Tools and Methods for Robust Processes and Products. Goal/QPC, Salem, NH.
Gitlow, H., Levine, D., Popovich, E., 2006. Design for Six Sigma for Green Belts and Champions.New Jersey. Prentice-Hall, Upper Saddle River.
Gitlow, H., 2009. A Guide to Lean Six Sigma Management Skills. Taylor & Francis Group, Boca Raton, FL.
Goh, T.N., 2002. A strategic assessment of Six Sigma. Qual. Reliab. Eng. Int. 18, 403–410.
Goh, T.N., Low, P.C., Tsui, K.L., Xie, M., 2003. Impact of Six implementation on stock price performance. Total Qual. Manag. Bus. Excell. 14 (7), 753–763.
Gowen, C.R., Tallon, W.J., 2005. Effect of technological intensity on the relationships among Six Sigma design, electronic-business, and competitive advantage: a dynamic capabilities model study. J. High Technol. Manag. Res. 16 (1), 59–87.
Grant, R.M., 1996. Toward a knowledge-based theory of the firm. Strateg. Manag. J. 17, 109–122.
Gulcin, B., Demet, O., 2010. An integrated analytic approach for Six Sigma project selection. Expert Syst. Appl. 37 (8), 5835–5847.
Gutie´rrez, L.J.G., Lloréns-Montes, F.J., Sa´nchez, Oscar F., Bustinza Sanchez, 2009. Six Sigma: from a goal-theoretic perspective to shared-vision development. Int. J. Oper. Prod. Manag. 29, 151–169.
Hair Jr., J.F., Black, W.C., Babin, B.J., Anderson, R.E., Tatham, R.L., 2009. Multivariate Data Analysis, 7th ed. Prentice Hall, Upper Saddle River, NJ.
Harry, M.J., Mann, P.S., De Hodgins, O.C., Hulbert, R.L., Lacke, C.J., 2010. Practitioner's Guide to Statistics and Lean Six Sigma for Process Improvements. John Wiley & Sons, New York.
Harry, M.J., Schroeder, R., 2005. Six Sigma: The Breakthrough Management Strategy Revolutionizing the World's Top Corporations. Doubleday, New York.
Hatch, N.W., Dyer, J.H., 2004. Human capital and learning as a source of sustainable competitive advantage. Strateg. Manag. J. 25 (12), 1155–1178.
Hayes, R.H., Wheelwright, S.C., Clark, K.B., 1988. Dynamic manufacturing: Creating the learning organization. Free Press, New York.
Henderson, R.G., 2011. Six Sigma Quality Improvement with Minitab. John Wiley & Sons, New York.
Hendricks, C.A., Kelbaugh, R., 1998. Implementing six sigma at GE. J. Qual. Particip. 21 (4), 48–53.
Ho, L., Chuang, C., 2006. A study of implementing Six Sigma quality management system in government agencies for raising service quality. J. Am. Acad. Bus. 10 (1), 167–173.
Hopen, D.,2007. Lean six sigma best practices forum: tales from the trenches. Paper presented at the American Strategic Management Institute Conference, Arlington, VA.
Huang, W., 2004. Adding Context-awareness to knowledge management in modern enterprises. In: Proceedings of the 2nd IEEE International Conference on Intelligent Systems, Varna, Bulgaria.
Huehn-Brown, W.J., 2006. An Analysis of Continuous Improvement in Lean Enterprise and Six Sigma Approaches. (Ph.D. dissertation). University of Missouri-Rolla, United States.
Jacobsen, J., 2008. Avoiding the mistakes of the past: Lessons learned on what makes or breaks quality initiatives. J. Qual. Particip. 31 (2), 4–8.
Jayaraman, K., Kee, T.L., Soh, K.L., 2012. The perceptions and perspectives of Lean Six Sigma (LSS) practitioners: an empirical study in Malaysia. TQM J. 24 (5), 433–446.
Jordan, M.S., 2012. The Effect Of Organizational Knowledge Creation On Firm Performance: An Operational Capabilities-Mediated Model. (Doctorate Dissertation). Georgia State University, Atlanta, Georgia.
Jung, J., Lim, S.G., 2007. Project categorization, prioritization, and execution based on Six Sigma concept: a case study of operational improvement project. Project Manag. J. 38 (1), 55–60.
Keller, P.A., 2010. Six Sigma Demystified, Second ed.. McGraw-Hill, New York.
Kendrick, J.D., Saaty, D., 2007. Use analytic hierarchy process for project selection. ASQ Six Sigma Forum 6 (4), 22–29.
Koskinen, K., 2000. Tacit knowledge as a promoter of project success. Eur. J. Purch. Supply Manag. 6, 41–47.
Kline, R.B., 2011. Principles and Practice of Structural Equation Modeling, 3rd ed.. Guilford Press, New York.
Kogut, B., Zander, U., 1996. What firms do? Coordination, identity, and learning. Organ. Sci. 7 (5), 502–518.
Kubiak, T.M., Benbow, D.W., 2009. The Certified Six Sigma Black Belt Handbook, 2nd ed.. ASQ Quality Press, Milwaukee, WI.
Kumar, M., Antony, J., Madu, C., Montgomery, D., Park, S., 2008. Common myths of Six Sigma demystified. Int. J. Qual. Reliab. Manag. 25 (8), 878–895.
Kwak, Y.H., Anbari, F.T., 2006. Benefits, obstacles and future of six sigma. Int. J. Technol. Innov. Entrep. Technol. Manag. 26 (5/6), 708–715.
Latino, R.J., Latino, K.C., Latino, M.A., 2011. Root Cause Analysis: Improving Performance for Bottom-Line Results, Fourth ed.. CRC Press, Boca Raton, FL.
Laureani, A., Brady, M., Antony, J., 2013. Applications of Lean Six Sigma in an Irish hospital. Leadersh. Health Serv. 26 (4), 322–337.
Lee, K.C., Choi, B., 2006. Six Sigma management activities and their influence on corporate competitiveness. Total Qual. Manag. 17 (7), 893–911.
Lee, K.L, 2002. Critical Success Factors of Six Sigma Implementation and the Impact on Operations Performance (Ph.D. Dissertation). Cleveland State University, United States.
Linderman, K., Schroeder, R.G., Zaheer, S., Choo, A.S., 2003. Six Sigma: a goal-theoretic perspective. J. Oper. Manag. 21 (2), 193–203.
Linderman, K., Schroeder, R.G., Sanders, J., 2010. A knowledge framework underlying process management. Decision Sciences 41 (4), 689–719.
Linderman, K., Schroeder, R.G., Zaheer, S., Liedtke, C., Choo, A.S., 2004. Integrating quality management practices with knowledge creation processes. J. Oper. Manag. 22 (6), 589–607.
Lloréns-Montes, F.J., Molina, L.M., 2006. Six Sigma and management theory: process, content and effectiveness. Total Quality Management and Business Excellence 17 (4), 485–506.
Mader, D.P., 2008. Lean Six Sigma's evolution. Qual. Prog. 41 (1), 40–48.
Mahanti, R., Antony, J., 2005. Confluence of Six Sigma, simulation and software development. Manag. Audit. J. 20 (7), 739–762.
Maisel, E., Maisel, A., 2010. Brainstorm: Harnessing the Power of Productive Obsessions. New World Library, Novato, California.
McAdam, R., Lafferty, B., 2004. A multilevel case study critique of Six Sigma: statistical control or strategic change? Int. J. Oper. Prod. Manag. 24 (5/6), 530–548.
Montgomery, D.C., Woodall, W.H., 2008. An overview of Six Sigma. Int. Stat. Rev. 76 (3), 329–346.
Morgan, J., Brenig, J.M., 2012. Lean Six Sigma For Dummies. Wiley Publishing, Indianapolis, IN.
Mundo, R.A., Mailo, M.J., Nawaz, M.B., Ramu, G., Zemiak, D.J., 2008. The Cmcertified Six Sigma Green Belt Handbook. ASQ Quality Press, Milwaukee, WI.
Nonaka, I., 1994. A dynamic theory of organizational knowledge creation. Organ. Sci. 5 (1), 14–37.
Nonaka, I., Takeuchi, H., 1995. The knowledge-Creating Company: How Japanese Companies Create The Dynamics of Innovation. Oxford University Press, New York.
Nonaka, I., Konno, N., 1998. The concept of "Ba": building a foundation for knowledge creation. Calif. Manag. Rev. 40 (3), 40–54.
Nonthaleerak, P., Hendry, L., 2006. Six Sigma: literature review and key research areas. Int. J. Six Sigma Compet. Advant. 2 (2), 105–161.
Omachonu, V.K., & Ross, J.E. (2004). Principles of Total Quality, 3rd ed., CRC Press LLC, Florida.
Pande, P.S., Neuman, R.P., Cavanagh, R.R., 2000. The Six Sigma way: how GE, Motorola, and Other Top Companies Are Honing Their Performance. McGraw-Hill, New York.
Pande, P.S., Holpp, L., 2002. What is Six Sigma. McGraw-Hill, Columbus, OH.
Pepper, M.P.J., Spedding, T.A., 2010. The evolution of Lean Six Sigma. Int. J. Qual. Reliab. Manag. 27 (2), 138–155.
Polanyi, M., 1966. The Tacit Dimension. Doubleday & Company, Inc, Garden City, NY.
Prahalad, C.K., Hamel, G., 1990. The core competence of the corporation. Harvard Bus. Rev. 68 (3), 79–91.
Pyzdek, T., Keller, P.A., 2009. The Six Sigma Handbook – A Complete Guide for Green Belts, Black Belts, and Managers at All Levels, 3rd ed.. McGraw-Hill, New York.
Raisinghani, M.S., Ette, H., Pierce, R., Cannon, G., Daripaly, P., 2005. Six Sigma concepts, tools and applications. Ind. Manag. Data Sys. 105, 491–505.
Ray, S., Das, P., 2010. Six Sigma project selection methodology. Int. J. Lean Six Sigma 1 (4), 293–309.
Ray, S., John, B., 2011. Lean Six-Sigma application in business process outsourced organization. Int. J. Lean Six Sigma 2 (4), 371–380.
Russell, R.K., Tippett, D.D., 2008. Critical success factors for the Fuzzy front end of innovation in the medical device industry. Eng. Manag. J. 20, 36–43.
Sabherwal, R., Becerra-Fernandez, I., 2003. An Empirical Study of the Effect of Knowledge Management Processes at Individual, Group, and Organizational Levels. Decision Sciences 34 (2), 225–260.

Sabherwal, R., Sabherwal, S., 2007. How do knowledge management announcements affect firm value? A study of firms pursuing different business strategies. IEEE Trans. Eng. Manag. 54 (3), 409–422.
Satolo, E.G., Andrietta, J.M., Miguel, P.A.C., Calarge, F.A., 2009. Analysis on the usage of techniques and tools from the Six-Sigma program on a survey-type assessment. Production 19, 400–416.
Schroeder, R.G., Linderman, K., Liedtke, C., Choo, A.S., 2008. Six Sigma: definition and underlying theory. J. Oper.Manag. 26, 536–554.
Sekaran, U., Bougie, R., 2010. Research Methods for Business: A Skill Building Approach. John Wiley & Sons, United Kingdom.
Snee, R.D., 2002. The project selection process. Qual.Prog. 35, 78–80.
Sousa, R., Voss, C.A., 2002. Quality management re-visited: a reflective review and agenda for future research. J. Oper. Manag. 20 (1), 91–109.
Spender, J.C., 1996. Making knowledge the basis of a dynamic theory of the firm. Strateg. Manag. J. 17, 45–62.
Summers, D.C., 2006. Six Sigma: Basic Tools and Techniques. Prentice-Hall, Upper Saddle River, NJ.
Summers, D.C., 2010. Lean Six Sigma. Prentice-Hall, Upper Saddle River, NJ.
Tjahjono, B., Ball, P., Vitanov, V.I., Scorzafave, C., Nogueira, J., Calleja, J., Minguet, M., et al., 2010. Six Sigma: a literature review. Int. J. lean Six Sigma 1 (3), 216–233.
Watson, G.H., 2003. Six sigma: an evolving stage in the maturity of quality. In: Conti, T., Kondo, Y., Watson, G.H. (Eds.), Quality into the 21st Century, IAQ. ASQ Quality Press, Milwaukee, WI.
Weiss, L., Prusak, L., 2005. Seeing knowledge plain: how to make knowledge visible. In: Desouza, K.C. (Ed.), New frontiers of knowledge management. Palgrave McMillan Ltd., New York, NY, pp. 36–50.
Wheeler, D.J., 2010. The Six Sigma Practitioner's Guide to Data Analysis. SPC Press, United States.
Zikmund, W.G., Babin, B.J., Carr, J.C., Griffin, M., 2010. Business Research Methods, 8th ed.. South-Western Cengage Learning, Mason, OH.
Zu, X., Fredendall, L.D., Douglas, T.J., 2008. The evolving theory of quality management: the role of Six Sigma. J. Oper. Manag. 26, 630–650.