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# Effects of product lifecycle management systems on new product development performance

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## ABSTRACT

To examine the effects of product life cycle management (PLM) systems on new product development (NPD) performance, the study developed a conceptual model linking firms' ability to diffuse and routinize PLM systems in NPD processes (called "PLM system capability") with process management, coordination, and absorptive capabilities. The study assumed that the selected management capabilities mediate the effects of PLM system capability on NPD performance. The empirical results supported the theorized relationships, indicating that PLM system capability shapes firms' capabilities for NPD process management, partner coordination, and knowledge absorption, which subsequently affect NPD performance. Therefore, in order to improve NPD performance, managers must create conditions conducive for implementing PLM systems to enhance NPD-required management capabilities.

## 1. Introduction

Challenges such as shrinking product life cycles and heterogeneous customer preferences have compelled manufacturing firms to recognize that outperforming their competitors requires improving the development of new products (Thomas, 2013; Kettunen et al., 2015). New product development (NPD) involves various complex and interdependent activities such as generating and assessing new product opportunities and ideas, incorporating product requirements into final design specifications, and launching products on the market (Hilletofth and Eriksson, 2011; Acur et al., 2012). Firms must effectively collaborate with external partners to achieve excellent NPD performance. Such collaboration involves intense interorganizational processes requiring coordination mechanisms to not only cultivate mutual understanding between firms and their NPD partners but also align partner activities with firm objectives (Mishra and Shah, 2009; Ma et al., 2012). Such intensive interorganizational interactions create an increased demand for information processing, the success of which depends heavily on a firm's ability to implement appropriate information technology (IT) solutions.

Product lifecycle management (PLM) is a strategic solution for the integrated management of product-related information throughout a product's life cycle (Ameri and Dutta, 2005; Schuh et al., 2008; Stark, 2015). PLM is possible because of recent advances in information and communication technologies. The information systems designed to support PLM, generally called "PLM systems" enable firms to integrate information and knowledge despite functional and organizational boundaries in NPD contexts (Ding et al., 2011; Cantamessa et al., 2012; Merminod and Rowe, 2012). The advent of PLM systems provides a dynamic, interorganizational, and integrative Internet-based information sharing platform to facilitate the creation, modification, and exchange of product information throughout a product's entire life cycle (Pol et al., 2008; Stark, 2015). PLM systems enable firms to manage product portfolios and product development project information by supporting the definition and standardization of the workflows and informational objects created during product development (Vezzetti et al., 2011; Merminod and Rowe, 2012). To improve NPD performance, numerous firms have developed PLM-related IT solutions to streamline NPD management processes, enhance NPD participant

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management, and improve NPD participant interactions. Companies such as Boeing, General Electric, and Honda have implemented PLM systems to facilitate collaboration with NPD partners (Fielding et al., 2014; Stark, 2015).

Previous studies on PLM have described various benefits of implementing PLM systems for product development. Ameri and Dutta (2005) stated that PLM systems enable firms to streamline the flow of information about products and effectively manage knowledge-intensive processes throughout their life cycle. Alemanni et al. (2008) proposed that the benefits of PLM systems can be divided into long-term benefits and short-term benefits. Schuh et al. (2008) suggested that the goal of PLM systems is to realize the benefits of reducing the time to market of products, improving product functionality, and enhancing customization. Cantamessa et al. (2012) suggested that the performance effects of PLM systems can be divided into individual operative effects such as the reduction of design mistakes, past design information reuse, and reduction of time invested for research; organizational process effects such as the reduction of data redundancy, higher design quality, and lower influence of product changes on the development process; and strategic effects such as higher levels of product innovation and product cost and process cost reductions. Hadaya and Marchildon (2012) suggested that firms can derive numerous benefits from adopting PLM systems, such as accelerating the delivery of innovative products, improving the success rate of newly introduced products, and establishing effective collaborative relationships with supply chain partners.

The increased awareness of PLM system support of NPD has encouraged firms to invest in PLM systems. However, industry-level studies have reported conflicting results regarding the effects of PLM systems on NPD performance (Cantamessa et al., 2012; Raap, 2013; Stark, 2015). This study suggests that this is because of a widespread belief that the relevance of PLM systems is not based a detailed understanding of the mechanisms through which they influence performance. The specific factors that mediate the effects of PLM systems on NPD performance have seldom been studied. Recent studies have questioned the direct effects of IT systems on firm performance by asserting that such effects are mediated by a firm's management capabilities (Mithas et al., 2011; DeGroote and Marx, 2013; Liu et al., 2013; Peng et al., 2016). Therefore, this study investigated the mechanisms underlying the influence of PLM system use. A firm's ability to diffuse and routinize PLM systems in NPD processes (called “PLM system capability”) was conceptualized as the fundamental capability shaping the three critical management capabilities in NPD contexts (i.e., process management capability, coordination capability, and absorptive capability), which in turn affect NPD performance.

This study assumed that the ability to control and improve NPD processes (i.e., process management capability), coordinate NPD partners' resources (i.e., coordination capability), and identify and leverage valuable knowledge received from external sources (i.e., absorptive capability) are critical and direct sources of superior NPD performance. PLM systems provide firms with a platform to streamline NPD processes, align NPD activities, and govern knowledge production and dissemination in NPD contexts. PLM system capability represents a firm's ability to embed PLM system applications in NPD processes (Vezzetti et al., 2011; Merminod and Rowe, 2012; Fielding et al., 2014). Hence, this paper proposes that PLM system capability affects the development of process management, coordination, and absorptive capabilities, thereby influencing NPD performance.

The rest of the paper is organized as follows. First, the conceptual background of the study and hypothesis development are presented. Second, this paper describes the research methodology, including the data collection procedure, construct operationalization and measurement, and the results of hypothesis testing. Finally, the paper concludes with a discussion of the research findings, their theoretical and practical implications, and suggestions for future research.

## 2. Conceptual background and research model

### 2.1. PLM systems

PLM systems form the backbone of product information for firms and their NPD partners (Pol et al., 2008; Cantamessa et al., 2012; Stark, 2015), thereby assisting the firms in managing the creation, modification, and exchange of product information during the product development process. PLM systems comprise tightly integrated information systems that include numerous industrial application systems such as visualization, CAx integration, computer-integrated manufacturing, product data management, and configuration management systems (Gecevska et al., 2010; Segonds et al., 2015). PLM systems integrate product development information into a single logical database to support the definition and standardization of the workflows and informational objects created and used during product development (Merminod and Rowe, 2012; Bruun et al., 2015). Furthermore, PLM systems are designed to fulfill certain business requirements such as the efficient management of abundant information and knowledge, information and knowledge sharing, and standard database operations such as transaction management and concurrent control and recovery (Fielding et al., 2014; Segonds et al., 2015). PLM systems enable firms to effectively manage their product portfolios and product development project information, and collaborate with product development partners.

PLM systems support collaborative work in product development processes for the efficient integration of development participants and all associated information (Cantamessa et al., 2012; Hadaya and Marchildon, 2012; D'Amico et al., 2013). How PLM system capability is integrated into NPD processes determines whether the objective of PLM systems is ultimately achieved. This study conceptualized PLM system capability as a firm's ability to embed PLM system applications in NPD processes. This conceptualization paralleled that of “IT usage” and “IT assimilation,” which are common in studies on information systems (Mithas et al., 2011; Liu et al., 2013). This study investigated how PLM system capability influences NPD performance. Although the advantages of using PLM systems in NPD contexts have previously been recognized, there is little evidence regarding the role of PLM system capability in fostering management capabilities that are crucial for achieving excellent NPD performance. Therefore, this study proposed and tested a model wherein the effects of PLM system capability on NPD performance are mediated by the three aforementioned critical management capabilities.

### 2.2. Research model and hypotheses

NPD involves various complex and interdependent activities that can be categorized into discovery, which involves generating and assessing new product opportunities and ideas; development, which involves incorporating product requirements into final design specifications; and commercialization, which involves implementing marketing plans to launch products on the market (Pavlou and El Sawy, 2006; Hilletofth and Eriksson, 2011). Each of these activities has distinctive process design objectives and requires coordination with NPD partners. NPD success is determined by how NPD processes are streamlined and how NPD partner resources are integrated and deployed (Mishra and Shah, 2009; Thomas, 2013). Streamlining business processes requires firms to continually improve and optimize process execution and control (Cantamessa et al., 2012; Stark, 2015). A strong process management capability enables firms to increase task processing reliability and resource utilization (Ma et al., 2012; Hsu et al., 2014). Integrating and deploying partners' resources involves intense interorganizational processes that require comprehensive communication and interaction between firms and partners (Johnson and Filippini, 2013; Gao and Tian, 2014). Robust coordination capability enables firms to facilitate mutual understanding with partners and align partners' activities with their business strategies (Tavani et al., 2013; He et al., 2014).

Successful NPD requires firms to not only assimilate new knowledge obtained from external sources (e.g., NPD partners) but also apply this knowledge to understand market tendencies and exploit market opportunities (Escribano et al., 2009; Bellamy et al., 2014). A highly developed absorptive capability enables firms to learn about technological developments or business trends and integrate external knowledge into their NPD activities (Roberts et al., 2012; Liu et al., 2013; M & kinen and Vilkko, 2014). Therefore, this study proposes that to achieve excellent NPD performance, firms must develop absorptive capability in addition to their process management capability and coordination capability.

#### 2.2.1. Effects of management capabilities on NPD performance

Process management capability refers to a firm's ability to control and improve NPD management processes (Bendoly et al., 2012; Kettunen et al., 2015). To effectively control and improve NPD processes, firms must develop strong process efficiency capability and process optimization capability. Process efficiency capability refers to a firm's ability to streamline NPD processes to regulate the duration and cost of NPD (Mishra and Shah, 2009; Bendoly et al., 2012; Cantamessa et al., 2012). Firms with strong process efficiency capability can not only reduce NPD cycle times and project costs but also increase the reliability of processing tasks. Process optimization capability refers to a firm's ability to optimize NPD processes to reduce waste generation and increase resource utilization (Ma et al., 2012; Hsu et al., 2014). Firms with strong process optimization capability can identify and exclude nonvalue-added activities from projects and efficiently allocate resources for tasks.

This paper proposes that process management capability is a major source of NPD performance. Firms with strong process management capability means that the firms have the ability to control and improve NPD management processes, thereby enabling them to benefit from time and cost savings. A robust ability to streamline and optimize NPD processes enables firms to adaptively allocate resources for various NPD tasks and increase the reliability of processing such tasks (Cantamessa et al., 2012; Hsu et al., 2014). In other words, the capability to effectively and efficiently manage NPD processes can yield enhanced NPD performance. Hence, this study proposed the first hypothesis (H1):

*H1. Process management capability is positively related to NPD performance.*

Coordination capability is defined as a firm's ability to coordinate partners' resources to achieve its own strategic objectives (Tavani et al., 2013; He et al., 2014). NPD involves complex and interdependent interorganizational activities that require firms to engage in information sharing and partner alignment for effective coordination with their NPD partners. Information sharing capability refers to a firm's ability to develop mechanisms that promote the exchange of accurate information among NPD participants (Hilletofth and Eriksson 2011; Ma et al., 2012; He et al., 2014). Firms with robust information sharing capability can establish information sharing mechanisms to enable NPD participants to make appropriate decisions. Partner alignment capability refers to a firm's ability to develop mechanisms for aligning NPD partners' production strategies with its own NPD strategies (Acur et al., 2012; Tavani et al., 2013; Schilke, 2014). Firms with a strong partner alignment capability can synchronize the output of their NPD partners' production activities with their own NPD plans, thereby enabling the implementation of effective NPD strategies.

This paper proposes that coordination capability is a critical source of NPD performance. Firms with strong coordination capability means that the firms have the ability to establish interorganizational coordination mechanisms to manage their partners' resources and actions. The establishment of robust interorganizational coordination mechanisms enables firms to react promptly and appropriately to market conditions (Acur et al., 2012; Kettunen et al., 2015). In addition, such mechanisms empower firms to effectively employ partners' capabilities to achieve NPD goals. In other words, the capability to effectively and efficiently coordinate with NPD partners can yield enhanced NPD performance. Hence, this study proposed the second hypothesis (H2):

*H2. Coordination capability is positively related to NPD performance.*

Absorptive capability refers to a firm's ability to identify and leverage valuable knowledge received from external sources (Flatten et al., 2011; Roberts et al., 2012; M & kinen and Vilkko, 2014). Integrating knowledge received from NPD partners into the development of new products is a valuable method of creating competitive advantages in turbulent market environments (Liu et al., 2013; Thomas, 2013). Firms with robust absorptive capability have a sufficiently developed knowledge base to facilitate the recognition and utilization of new knowledge received from NPD partners and other organizations (Roberts et al., 2012; Bellamy et al., 2014). However, firms must develop their potential and realized absorptive capabilities to effectively recognize and exploit such knowledge. Potential absorptive capability refers to a firm's ability to acquire and integrate valuable knowledge received from external sources (Fabrizio, 2009; Bapuji et al., 2011; Bellamy et al., 2014). Firms with strong potential absorptive capability can identify the valuable knowledge received from external sources and analyze, interpret, and understand such acquired knowledge. Realized absorptive capability refers to a firm's ability to modify and exploit valuable knowledge received from external sources (Zahra and George, 2011; Roberts et al., 2012; Tavani et al., 2014). Firms with strong realized absorptive capability can leverage valuable knowledge received from external sources to enhance NPD.

This paper proposes that absorptive capability is a crucial source of NPD performance. More specifically, a greater absorptive capability enables firms to accurately assess and assimilate new knowledge acquired from external sources (e.g., NPD partners) and effectively apply this knowledge to identify business opportunities in the market (Fosfuri and Tribó, 2008; Bapuji et al., 2011). For example, firms with absorptive capability can effectively acquire new external knowledge regarding customer preferences, technology development, and market trends. Such acquisition enhances the firms' understanding of market tendencies, which are critical to achieving success in NPD. Furthermore, absorptive capability affects a firm's ability to effectively convert new external knowledge into expertise (Zahra and George, 2011; Tavani et al., 2014). Firms with absorptive capability can learn to apply new knowledge to achieve product improvement. Thus, such firms are more able to assimilate new knowledge acquired from external sources, resulting in superior NPD performance. Hence, the third hypothesis (H3) was proposed:

*H3. Absorptive capability is positively related to NPD performance.*

#### 2.2.2. Linking PLM system capability with management capabilities

Implementing PLM systems enables firms to effectively control and manage NPD processes (Fielding et al., 2014; Segonds et al., 2015). Firms with strong PLM system capability can use PLM systems to streamline NPD processes, thereby reducing the time and cost of developing new products (i.e., improving process efficiency capability). PLM systems provide a virtual product design platform that enables firms to expedite feasibility analysis and reduce the costs of product testing and validation (Gecevska et al., 2010; Hadaya and Marchildon, 2012). Moreover, firms with strong PLM system capability can use PLM systems to continually optimize NPD processes (i.e., improving process optimization capability). PLM systems involve maintaining a product information database for design reuse and this reduces partial redundancy, providing resource configuration management functions for adaptively allocating resources to various NPD tasks (Merminod and Rowe, 2012; Bruun et al., 2015). Accordingly, the fourth hypothesis (H4) was proposed:

*H4. PLM system capability is positively related to process management capability.*

PLM systems act as coordination platforms that facilitate interactions between firms and their NPD partners (Pol et al., 2008; Stark, 2015). These platforms enable firms to share updated product information among their NPD partners and align NPD partners' product development activities. Firms with strong PLM system capability can use PLM systems to exchange product information with NPD partners at different levels of their respective organizational hierarchies, from the strategic to operational levels. Because PLM systems are designed to fulfill the requirements of managing large quantities of information and knowledge and exchanging information and knowledge among product development participants (Fielding et al., 2014; Segonds et al., 2015). Moreover, firms with robust PLM system capability can use PLM systems to align the plans of NPD partners with their own NPD plans. PLM systems support collaborative work in product development processes to enable the efficient integration of product development participants and all associated information (Cantamessa et al., 2012; D'Amico et al., 2013). Implementing interorganizational coordination with PLM systems facilitates knowledge-driven decision support and product information sharing throughout the product development life cycle, thereby providing the information and knowledge required for prompt and accurate decision-making and adjustments (D'Amico et al., 2013; Fielding et al., 2014). According to the preceding arguments, the fifth hypothesis (H5) was proposed:

*H5. PLM system capability is positively related to coordination capability.*

Implementing PLM systems facilitates the improvement of absorptive capability by enhancing the depth and reach of a firm's knowledge. PLM systems use object-based storage, workflows, and coherent data structures, thereby enabling firms to effectively manage NPD knowledge in interorganizational contexts (Vezzetti et al., 2011; Merminod and Rowe, 2012). In particular, firms with strong PLM system capability can use PLM systems to define and standardize workflows, information, and knowledge objects as they are produced and used by multiple NPD participants, thereby facilitating the integration of various knowledge sources. The integrated knowledge management functionalities provided by PLM systems enable firms to effectively manage knowledge sharing with their NPD partners, thereby expanding a firm's knowledge reach (Gecevska et al., 2010; Cantamessa et al., 2012). Moreover, PLM systems provide a real-time collaboration platform for transferring and recombining knowledge across organizational boundaries (Hadaya and Marchildon, 2012; Segonds et al., 2015). Firms with robust PLM system capability can use PLM systems to enable NPD participants to share explicit product development knowledge and exchange implicit knowledge through multimedia objects, thereby increasing the scope of their knowledge. Hence, this study proposed the sixth hypothesis (H6):

*H6. PLM system capability is positively related to absorptive capability.*

#### 2.2.3. Mediating role of management capabilities

The rationale for hypothesizing a mediating effect is that the forms of management capability considered in this study represent complex, higher order capabilities that can be improved through the antecedent construct of PLM system capability. In other words, it is unlikely that firms that merely deploy sophisticated PLM systems experience the expected contribution to NPD performance. Instead, the antecedent construct shapes the firms' ability to improve management capabilities critical to NPD performance.

By combining H1 and H4 it can be inferred that process management capability mediates the relationship between PLM system capability and NPD performance. High levels of process management capability can be achieved when firms successfully implement PLM systems in NPD. With robust PLM system capability, firms can employ such systems to empower themselves to effectively control and improve NPD processes, thereby facilitating the development of process efficiency and process optimization capabilities. Robust process efficiency capability and process optimization capability provide opportunities for firms to achieve high NPD performance. Therefore, this study conceptualized process management capability as a mediator between PLM system capability and NPD performance. In other words, PLM system capability influences NPD performance through process management capability. Hence, the seventh hypothesis (H7) was proposed:

*H7. Process management capability mediates the effects of PLM system capability on NPD performance.*

Combining H2 and H5 leads to the inference that coordination capability operates as an intermediary in the relationship between PLM system capability and NPD performance. With strong PLM system capability, firms can employ such systems to not only develop efficient and accurate information flow between themselves and their NPD partners but also synchronize their NPD partners' product development resources and capacities with their own strategic plans. Robust information sharing capability and partner alignment capability provide opportunities for firms to achieve high NPD performance. Therefore, coordination capability was conceptualized as a mediator between PLM system capability and NPD performance. In other words, PLM system capability influences NPD performance through coordination capability. Hence, this study's eighth hypothesis (H8) was proposed:

*H8. Coordination capability mediates the effects of PLM system capability on NPD performance.*

By combining H3 and H6 it can be inferred that absorptive capability mediates the relationship between PLM system capability and NPD performance. Strong PLM system capability enables a firm to employ PLM systems to define and standardize workflows and information objects created during product development, thereby facilitating the development of potential and realized absorptive capabilities. High levels of absorptive capability provide opportunities for firms to achieve strong NPD performance. Therefore, absorptive capability was conceptualizedas a mediator between PLM system capability and NPD performance. In other words, PLM system capability influences NPD performance through absorptive capability. Hence, the ninth hypothesis (H9) of this study was proposed:

*H9. Absorptive capability mediates the effects of PLM system capability on NPD performance.*

On the basis of the proposed hypotheses, this study developed a research model (Fig. 1) and evaluated it empirically in NPD contexts. The model emphasizes the mediating role of process management capability, coordination capability, and absorptive capability in the relationship between PLM system capability and NPD performance. In addition, PLM system capability was regarded as a crucial factor in enhancing the three management capabilities required for NPD, which subsequently influence NPD performance. Moreover, firm size was a control variable, controlling for the possible spurious effects in the research model. Firm size was specified as a control variable for NPD performance because large firms generally have substantial resources for improving product development, manufacturing processes, and product sales. Such firms benefit from certain economies of scale that might not be accessible to smaller firms. Therefore, firm size was controlled and measured as a natural logarithm value of the number of employees in a firm.

## 3. Research methodology

Having discussed the hypotheses and theoretical research model of this study, this section describes the operational domain. We first describe the data collection procedure, and subsequently proceed to present the operationalization and measurement of the research constructs.

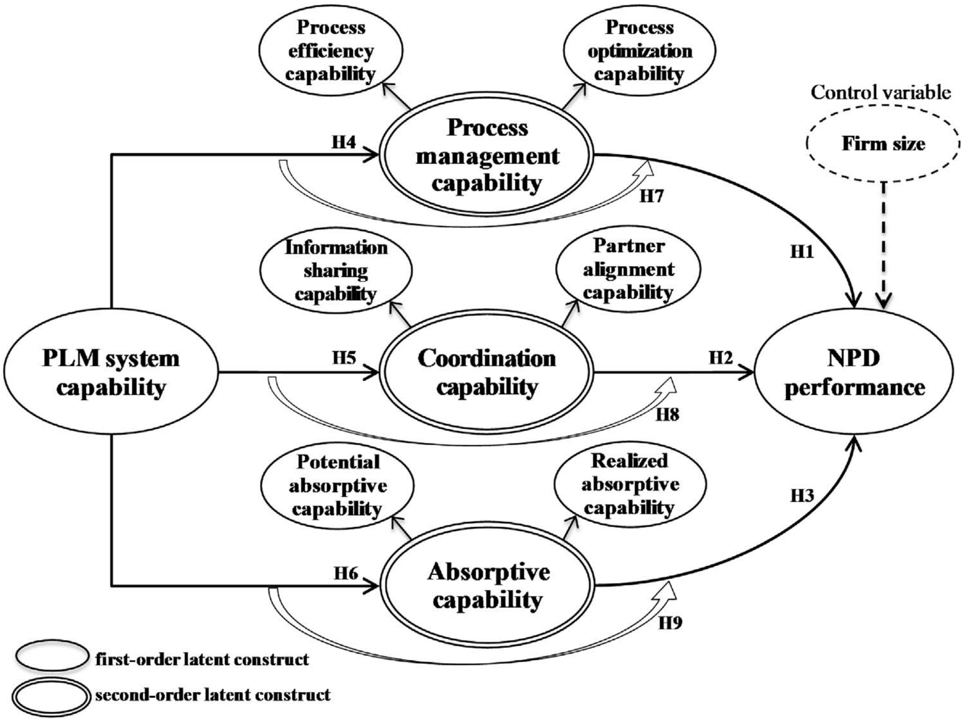


**Fig. 1.** Research model.

### 3.1. Data collection

The questionnaire was mailed to a purposive sample of 491 manufacturing firms listed in the top 1000 manufacturers in Taiwan complied by the CommonWealth Magazine (CommonWealth Magazine Editor Board, 2012). This study selected the firms that have participated in government-subsidized electronic business (e-business) development projects. To assist domestic companies in building a robust information technology infrastructure, the government in Taiwan subsidized the projects of many leading domestic companies. These e-business projects facilitate the creation of information technology and management capabilities. Hence, we can ensure that the sample companies have ability to implement information systems to support business functions.

The key informant methodology was used, and only firms' product development executives were requested to respond to the survey. The major determinant of respondent selection was the respondents' positions within their organization; respondents knowledgeable about interorganizational coordination for developing new products and interacting with NPD partners were preferred. Moreover, the IT-based constructs (i.e., PLM system capability) addressed the use of PLM systems in NPD contexts, not the technical details of the systems.

A postcard describing the study was sent to 491 respondents. After a week, a letter was mailed to the potential respondents that explained the purpose of the study; a copy of the questionnaire and a return envelope were also provided. Moreover, the letter stated that if their companies had not implemented PLM systems, they could ignore this survey. After nearly 3 weeks, a reminder postcard was mailed. Approximately 8–10 weeks after the initial survey was sent, an e-mail reminder was sent to all who had not responded. The data collection period began on February 23, 2015 and ended on June 23, 2015. The survey was available for 17 weeks and generated 189 responses. After incomplete responses and missing values were excluded, a sample of 137 valid responses was obtained (27.9% valid response rate).

Table 1 presents the characteristics of the responding firms; of the total sample, 75.18% of the firms were from the semi-conductors, electronic, and computer peripheral equipment industries, whereas 24.82% of firms were from the chemical, fabricated metal, optoelectronic, and vehicles industries. The sample primarily comprised medium-sized firms. The average work (i.e., product development management) experience of the respondents was 6.73 years in their current position, indicating adequate informant knowledge.

**Table 1**
Characteristics of the responding firms.

| Characteristic | Number | Percentage (%) |
|---|---|---|
| Title/position | | |
| Factory chief | 3 | 2.19 |
| Factory sub-chief | 9 | 6.57 |
| Product development director | 13 | 9.49 |
| Product development project manager | 41 | 29.93 |
| Production assistant manager | 28 | 20.43 |
| Production section manager | 15 | 10.95 |
| Special assistant of president | 23 | 16.79 |
| Other | 5 | 3.65 |
| Number of working years in current position | | |
| Less than 3 | 2 | 1.46 |
| 3–4.9 | 25 | 18.25 |
| 5–6.9 | 52 | 37.96 |
| 7–8.9 | 39 | 28.47 |
| 9–10.9 | 16 | 11.68 |
| Over 10.9 | 3 | 2.18 |
| Industry type | | |
| Chemical industry | 6 | 4.38 |
| Computer peripheral equipment | 25 | 18.25 |
| Electronic industry | 49 | 35.76 |
| Fabricated industry | 7 | 5.11 |
| Optoelectronic industry | 16 | 11.68 |
| Semi-conductors industry | 29 | 21.17 |
| Vehicles industry | 5 | 3.65 |
| Number of employees | | |
| Less than 200 | 3 | 2.19 |
| 201–500 | 5 | 3.65 |
| 501–1000 | 47 | 34.31 |
| 1001–2000 | 49 | 35.76 |
| 2001–3000 | 26 | 18.98 |
| Over 3000 | 7 | 5.11 |

**Table 2**
Operational definition of the latent constructs.

1. NPD performance: The extent to which the success of firms' NPD efforts.
2. Process management capability: A firm's ability to control and improve NPD management processes.
   - Process efficiency capability: A firm's ability to streamline NPD processes to regulate the duration and cost of NPD.
   - Process optimization capability: A firm's ability to optimize NPD processes to reduce waste generation and increase resource utilization.
3. Coordination capability: A firm's ability to coordinate partners' resources to achieve strategic objectives.
   - Information sharing capability: A firm's ability to develop mechanisms that promote the exchange of accurate information among NPD participants.
   - Partner alignment capability: A firm's ability to develop mechanisms for aligning NPD partners' production strategies with its own NPD strategies.
4. Absorptive capability: A firm's ability to identify and leverage valuable knowledge received from external sources.
   - Potential absorptive capability: A firm's ability to acquire and integrate valuable knowledge received from external sources.
   - Realized absorptive capability: A firm's ability to modify and exploit valuable knowledge received from external sources.
5. PLM system capability: A firm's ability to embed PLM system applications in NPD processes.

### 3.2. Measures

Table 2 presents a summary of the operational definitions of the latent constructs in the research model. A structured questionnaire was developed for measuring the first-order latent constructs (refer to Appendix A). All construct items were evaluated using 7-point Likert-type scales, with anchors ranging from 1 (strongly disagree) to 7 (strongly agree).

To measure NPD performance, four reflective items were adapted from the literature on NPD and operations management (e.g., Hilletofth and Eriksson, 2011; Bendoly et al., 2012; Thomas, 2013; Gao and Tian, 2014; Stark, 2015). The construct of NPD performance was operationalized using items that indicated the extent to which firms can achieve their goals for new products' (a) time to market, (b) innovativeness, (c) market performance, and (d) customer satisfaction. Respondents were asked to assess the performance indicators of new products launched in the previous three years. PLM system capability was measured by four reflective items adapted from the literature on PLM systems (e.g., Gecevska et al., 2010; Marchetta et al., 2011; Hadaya and Marchildon, 2012; Merminod and Rowe, 2012). The construct of PLM system capability was operationalized using items that indicated the extent to which firms use PLM systems to (a) manage NPD-related information across organizational boundaries, (b) retrieve previous product development cases, (c) schedule tasks during the product development cycle, and (d) communicate with NPD partners.

Process management capability was defined as a reflective second-order onstruct with two first-order dimensions: process efficiency capability and process optimization capability. It was measured by six reflective items (with three items each for process efficiency capability and process optimization capability) adapted from the literature on product development management (e.g., Mishra and Shah, 2009; Bendoly et al., 2012; Cantamessa et al., 2012; Ma et al., 2012; Hsu et al., 2014). Specifically, process efficiency capability was operationalized using items that indicated the extent to which firms (a) complete NPD projects within the given time frame, (b) efficiently regulate NPD project costs, and (c) maintain an efficient NPD process overall. Process optimization capability was operationalized using items that indicated the extent to which firms (a) reduce waste generation in NPD projects, (b) increase resource utilization during NPD, and (c) exclude non-value-added activities from NPD projects.

Coordination capability was defined as a reflective second-order construct with two first-order dimensions: information sharing capability and partner alignment capability. It was measured by six reflective items (with three items each for information sharing and partner alignment capabilities) adapted from the literature on supply chain management and interorganizational coordination (e.g., Hilletofth and Eriksson 2011; Acur et al., 2012; Ma et al., 2012; Tavani et al., 2013; Thomas, 2013; He et al., 2014; Schilke, 2014). Specifically, information sharing capability was operationalized using items that indicated the extent to which firms and their NPD partners (a) inform each other of changing needs in advance, (b) exchange information in a timely manner, and (c) exchange information about events that may affect the other party. Partner alignment capability was operationalized using items that indicated the extent to which (a) NPD partners are willing to adjust their manufacturing process and capacity to correspond with focal firms' strategic plans, (b) the shared work tasks between focal firms and NPD partners are synchronized, and (c) NPD partners' production activities are aligned with focal firms' NPD plans.

Absorptive capability was defined as a reflective second-order construct with two first-order dimensions: potential absorptive and realized absorptive capabilities. It was measured by six reflective items (with three items each for potential and realized absorptive capabilities) adapted from the literature on knowledge management and organizational learning (e.g., Fabrizio, 2009; Bapuji et al., 2011; Zahra and George, 2011; Roberts et al., 2012; Liu et al., 2013; Bellamy et al., 2014; Tavani et al., 2014). Specifically, potential absorptive capability was operationalized using items that indicated the extent to which firms (a) learn by tracking new market trends, (b) identify changing market demands, and (c) adequately train their employees to assimilate external knowledge. Realized absorptive capability was operationalized using items that indicating the extent to which firms (a) recognize the utility of new external knowledge, (b) capitalize on the opportunities created by the new external knowledge, and (c) understand how to efficiently exploit their knowledge.

Finally, to ensure the content validity of the scales, the selected items must accurately represent the concept about which generalizations are to be made. Therefore, a content validity panel was convened to reconsider the items collected from previous studies to determine the applicability and semantics of each item. The panel members in this study consisted of four managers from manufacturing firms in Taiwan and one professor whose research focuses on supply chain management and information management. The adoption criterion depended on the content validity ratio (CVR). Following the suggestion by Lawshe (1975) that the CVR of each item must exceed or equal 0.99. Useful comments were incorporated to measure the eight research constructs.

## 4. Data analysis and results

We performed statistical analysis on the collected data using AMOS (version 21.0). In addition, AMOS was used to evaluate the measurement model, examine the second-order model, test the structural model, and evaluate the mediating effects of management capabilities.

### *4.1. Common method bias*

This study adopts a single-informant approach to collect survey data and therefore the possibility of common method bias should be assessed (Podsakoff et al., 2003). Harman's one-factor test is employed to assess the extent to which common method bias may be a problem (Harman, 1976). The result yields eight factors with eigenvalues greater than 1.0, which accounted for 79.740 percent of the total variance. The first factor captured 28.398 percent of the variance in the data. No single factor accounted for a majority of the covariance.

### *4.2. Evaluating the measurement model*

This study employed confirmatory factor analysis (CFA) to assess the validity of the scales. The CFA results indicated that the fit between the measurement model and the dataset was satisfactory (CMIN = 427.509; DF = 302; CMIN/DF = 1.416; NFI = 0.926; CFI = 0.951; IFI = 0.953; RMSEA = 0.055). Table 3 exhibits that the loadings of all items are higher than the suggested benchmark of 0.707 (ranging from 0.771 to 0.897), indicating that more than half of the variance is captured by the constructs (i.e., individual item reliability). Table 3 also reports the Cronbach's alpha (ranging from 0.795 to 0.879) and composite reliability values (ranging from 0.852 to 0.917) for each construct. All indicators are above the recommended level of 0.70, indicating adequate internal consistency.

The model fit was quite acceptable as all fit indices met respective criteria. However, looking at the correlations of the management capability constructs in Table 4, the multicollinearity problem emerges. In this context, in which there are high correlations between some constructs (i.e., ISC and PALC, PAC and RAC, POC and PEC), discriminant validity may be difficult to establish and the second-order construct can address the problem (Koufteros et al., 2009; Agostini et al., 2016).

**Table 3**
Factor loadings and reliability estimates.

| Construct | Item | Factor loading | Cronbach's Alpha | Composite Reliability |
|---|---|---|---|---|
| (NPD) NPD performance | NPD1 | 0.881 | 0.879 | 0.917 |
| | NPD2 | 0.859 | | |
| | NPD3 | 0.897 | | |
| | NPD4 | 0.786 | | |
| (PEC) Process efficiency capability | PEC1 | 0.843 | 0.836 | 0.888 |
| | PEC2 | 0.794 | | |
| | PEC3 | 0.861 | | |
| (POC) Process optimization capability | POC1 | 0.864 | 0.848 | 0.899 |
| | POC2 | 0.821 | | |
| | POC3 | 0.811 | | |
| (ISC) Information sharing capability | ISC1 | 0.840 | 0.859 | 0.910 |
| | ISC2 | 0.831 | | |
| | ISC3 | 0.824 | | |
| (PALC) Partner alignment capability | PALC1 | 0.890 | 0.810 | 0.865 |
| | PALC2 | 0.802 | | |
| | PALC3 | 0.784 | | |
| (PAC) Potential absorptive capability | PAC1 | 0.824 | 0.795 | 0.852 |
| | PAC2 | 0.851 | | |
| | PAC3 | 0.813 | | |
| (RAC) Realized absorptive capability | RAC1 | 0.830 | 0.824 | 0.877 |
| | RAC2 | 0.823 | | |
| | RAC3 | 0.831 | | |
| (PLM) PLM system capability | PLM1 | 0.855 | 0.874 | 0.910 |
| | PLM2 | 0.863 | | |
| | PLM3 | 0.771 | | |
| | PLM4 | 0.883 | | |

*Note*: CMIN = 427.509; DF = 302; CMIN/DF = 1.416; NFI = 0.926; CFI = 0.951; IFI = 0.953; RMSEA = 0.055.

**Table 4**
Correlations of the management capability constructs.

| Construct | Mean | SD | ISC | PAC | PALC | POC | PEC | RAC |
|---|---|---|---|---|---|---|---|---|
| ISC | 4.443 | 0.865 | - | | | | | |
| PAC | 4.644 | 0.908 | 0.339 | - | | | | |
| PALC | 5.008 | 1.023 | 0.516 | 0.371 | - | | | |
| POC | 4.892 | 0.893 | 0.257 | 0.241 | 0.239 | - | | |
| PEC | 4.490 | 0.858 | 0.352 | 0.354 | 0.233 | 0.568 | - | |
| RAC | 4.882 | 0.928 | 0.284 | 0.491 | 0.288 | 0.336 | 0.338 | - |

### *4.3. Examining the second-order model*

Following a hierarchical approach well-grounded in the relevant literature (e.g., Lai, 2006; Koufteros et al., 2009; Agostini et al., 2016), this study examined the hypothesized reflective second-order model of process management capability by estimating four alternative models. Model 1 contains one first-order latent construct with six observed variables, Model 2 containsed two first-order latent constructs and their observed variables, Model 3 hypothesizes correlation factors among the two first-order latent constructs, and Model 4 contains a second-order latent construct with the two first-order latent constructs. In Model 4, it is hypothesized that the second-order latent construct (i.e., process management capability) accounts for the covariance among the two first-order latent constructs (i.e., process efficiency capability and process optimization capability). The four models were compared based on their fit indices. Fig. 2 shows the four alternative models.

Table 5 shows that Models 1 and 2 have significant chi-square statistics indicating poor model fit, whereas Models 3 and 4 fit the data well. Considering the deficiency (e.g., discriminant validity, issues of multicollinearity) of Model 3 and that the theoretical construct of process management capability was regarded as a second-order latent construct in this study, Model 4 appeared to be the most suitable choice. In Model 4, the standardized path coefficients connecting the second-order latent construct to the first-order latent constructs are 0.81 ($p < 0.01$) and 0.80 ($p < 0.01$). Moreover, the target coefficient index (ratio of the chi-square of the first-order model to that of the second-order model) was employed to assess the fit of the second-order factor model relative to that of the first-order factor model (Marsh and Hocevar, 1985). A value of 1.0 was obtained, indicating that the second-order factor model could completely explain the relationships among the first-order factors. Furthermore, the fit statistics for the second-order model indicated an acceptable fit.

Following the procedure applied to test the hypothesized reflective second-order model of process management capability, this study found that the constructs of coordination capability and absorptive capability can be regarded as reflective second-order constructs. Figs. 3 and 4 show the alternative measurement models for coordination capabaility and absorptive capability, respectively. Tables 6 and 7 show the fit indices of the models.

### *4.4. Testing the structural model*

Fig. 5 presents the results of the structural model. The results showed a good fit between the model and the dataset (CMIN = 501.022; DF = 315; CMIN/DF = 1.591; NFI = 0.899; CFI = 0.927; IFI = 0.925; RMSEA = 0.068). As exhibited in Fig. 5,

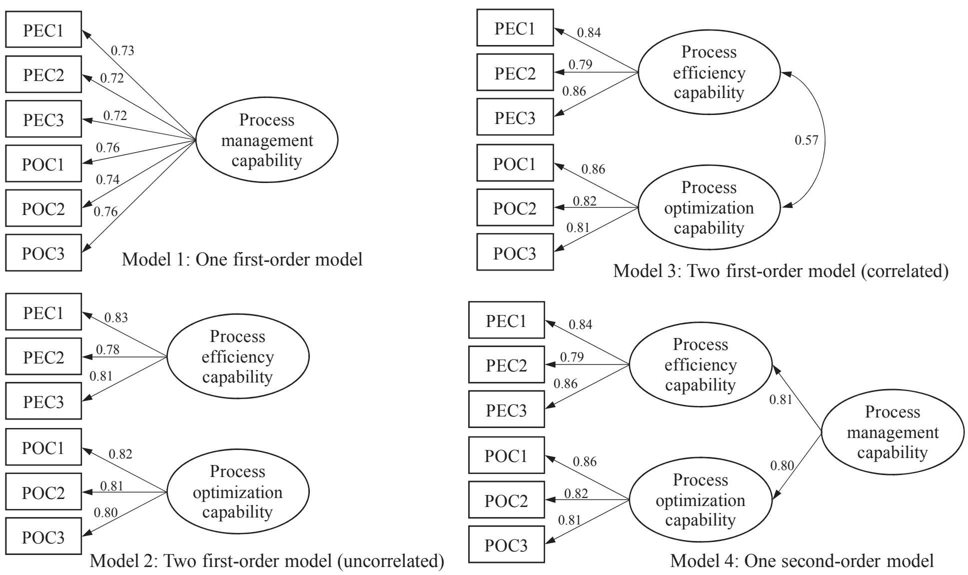


**Fig. 2.** Alternative models of process management capability.

**Table 5**
Results of alternative models of process management capability.

| Goodness of fit index | Measurement model | | | |
|---|---|---|---|---|
| | Model 1: One first-order model | Model 2: Two first-order model *uncorrelated* | Model 3: Two first-order model *correlated* | Model 4: One second-order model |
| CMIN (chi-square value) | 106.533 | 61.601 | 10.812 | 10.812 |
| CMIN/DF | 11.837 | 6.844 | 1.352 | 1.352 |
| Normed fit index (NFI) | 0.769 | 0.867 | 0.977 | 0.977 |
| Incremental fit index (IFI) | 0.785 | 0.884 | 0.994 | 0.994 |
| Comparative fit index (CFI) | 0.782 | 0.882 | 0.994 | 0.994 |
| RMSEA | 0.282 | 0.207 | 0.046 | 0.046 |

hypothesis 1 to 6 are supported. Moreover, the results indicate that the control variable (i.e., firm size) does not significantly influence NPD performance (path coefficient = 0.108, p-value > 0.05). This may be attributed to the fact that this study measured NPD performance by asking respondents to evaluate the extent to which their goals are realized. Finally, the combination of process management capability, coordination capability, absorptive capabilities, and firm size explains 42.6% of variance in NPD performance.

First, H1 addressed the effects of process management capability on NPD performance. The results indicate that firms with superior process management capability will achieve higher NPD performance goals (path coefficient = 0.219, p-value < 0.05). Second, H2 focused on the influence of coordination capability on NPD performance. The results indicate that firms with superior coordination capability will feel greater NPD performance results can be obtained (path coefficient = 0.303, p-value < 0.01). Third, H3 examined the effects of absorptive capability on NPD performance. The results indicate that firms with superior absorptive capability will achieve higher NPD performance goals (path coefficient = 0.285, p-value < 0.05). Therefore, based on the empirical results, this study argues that if firms have strong capabilities for NPD process management, partner coordination, and knowledge absorption, the firms' NPD performance can be enhanced.

Fourth, H4 focused on the effects of PLM system capability on process management capability. The results indicate that the level of NPD system capability has a positive impact on process management capability (path coefficient = 0.625, p-value < 0.001). Fifth, H5 examined the influence of PLM system capability on coordination capability. The results indicate that the level of NPD system capability has a positive impact on coordination capability (path coefficient = 0.631, p-value < 0.001). Sixth, H6 dealt with the effects of NPD system capability on absorptive capability. The results indicate that the level of NPD system capability has a positive effect on absorptive capability (path coefficient = 0.657, p-value < 0.001). Therefore, based on the empirical results, this study argues that if firms have strong ability to diffuse and routinize PLM systems in NPD processes (i.e., srong PLM system capability), the firms' capabilities for NPD process management, partner coordination, and knowledge absorption can be enhanced.

### *4.5. Evaluating the mediating role of management capabilities*

To confirm H7, H8, and H9, this study employed two approaches to test the mediating effects of process management capability,

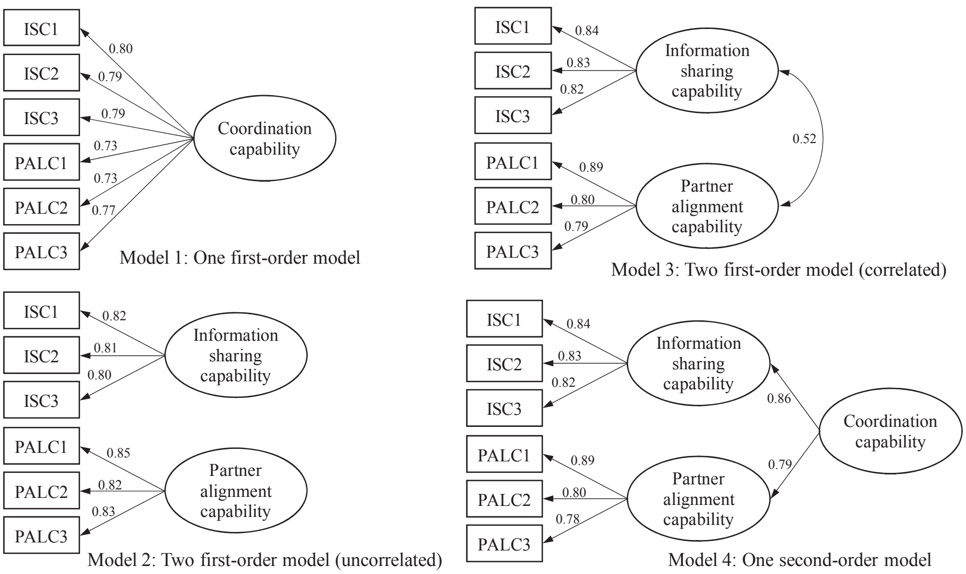


**Fig. 3.** Alternative models of coordination capability.

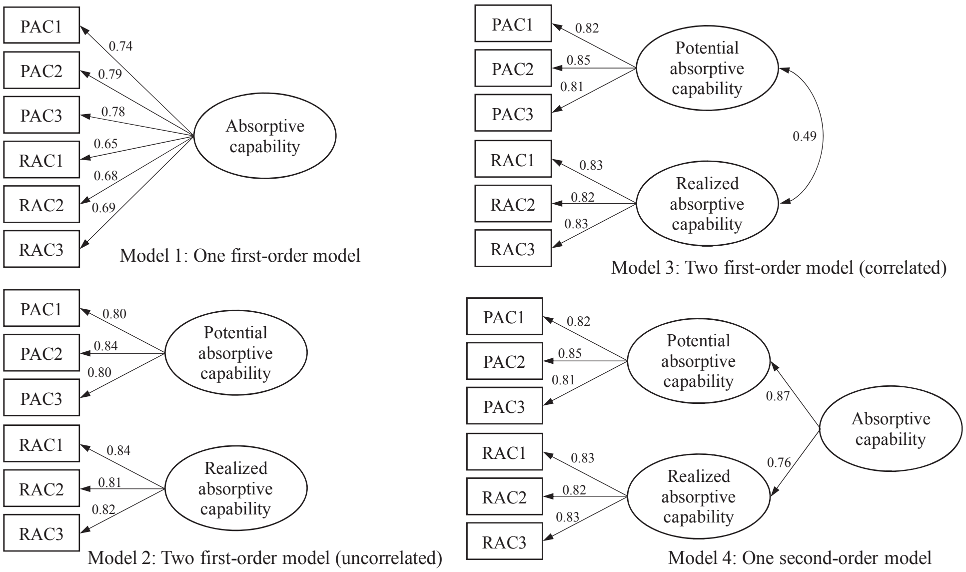


**Fig. 4.** Alternative models of absorptive capability.

coordination capability, and absorptive capability. First, as recommended by MacKinnon (2008), this study used an extension of the simple mediation model to analyze the mediating effects of our model. A comparison between Model 1 (Fig. 6), Model 2 (Fig. 7), and Model 3 (Fig. 8) was conducted (like the method proposed by Baron and Kenny (1986)). In Model 1, this study established that PLM system capability has a significant effect on NPD performance (path coefficient = 0.456, p-value < 0.001) (see Fig. 6). In Model 2, this study established that PLM system capability has significant effects on the three proposed mediators – process management capability, coordination capability, and absorptive capability (path coefficient = 0.622, p-value < 0.001; path coefficient = 0.631, p-value < 0.001; path coefficient = 0.655, p-value < 0.001) (see Fig. 7). In Model 3, this study established that each of the three proposed mediators has a significant effect on NPD performance (path coefficient = 0.202, p-value < 0.05; path coefficient = 0.296, p-value < 0.01; path coefficient = 0.278, p-value < 0.05) while controlling for PLM system capability (path coefficient = 0.116, p-value > 0.05) (see Fig. 8). This means that process management, coordination, and absorptive capabilities fully mediate the relationship between PLM system capability and NPD performance.

Second, this study conducted a complimentary test by using AMOS (version 21.0) with bootstrapping to obtain estimates of the indirect effects and test their significance by using 95% bias-corrected confidence intervals (Preacher and Hayes, 2008; Preacher et al., 2011). Because our model contained more than one mediating effect, separating the indirect effects and testing the significance of the mediating effects was necessary. However, AMOS does not provide bootstrapping for specific indirect effects in the presence of multiple mediators. To circumvent this limitation, this study used the phantom model approach (Macho and Ledermann, 2011) to calculate each specific indirect effect of our model.

Table 8 shows the mediating effects of process management capability, coordination capability, and absorptive capability on the relationship between PLM system capability and NPD performance. In the first phantom model, a positive significant indirect effect of process management capability was found (point estimate = 0.160, p-value < 0.05). The bias-corrected lower and upper confidence intervals are 0.045 and 0.298, respectively, indicating no zero in-between. Therefore, process management capability mediates the relationship between PLM system capability and NPD performance. In the second phantom model, a positive significant indirect effect of coordination capability was found (point estimate = 0.232, p-value < 0.01). The bias-corrected lower and upper confidence intervals are 0.112 and 0.426, respectively, indicating no zero in-between. Therefore, coordination capability mediates the relationship between PLM system capability and NPD performance. In the third phantom model, a positive significant indirect

**Table 6**
Results of alternative models of coordination capability.

| Goodness of fit index | Measurement model | | | |
|---|---|---|---|---|
| | Model 1: One first-order model | Model 2: Two first-order model *uncorrelated* | Model 3: Two first-order model *correlated* | Model 4: One second-order model |
| CMIN (chi-square value) | 124.165 | 42.812 | 8.319 | 8.319 |
| CMIN/DF | 13.796 | 4.757 | 1.040 | 1.040 |
| Normed fit index (NFI) | 0.716 | 0.902 | 0.978 | 0.978 |
| Incremental fit index (IFI) | 0.731 | 0.921 | 0.992 | 0.992 |
| Comparative fit index (CFI) | 0.727 | 0.920 | 0.991 | 0.991 |
| RMSEA | 0.307 | 0.166 | 0.030 | 0.030 |

**Table 7**
Results of alternative models of absorptive capability.

| Goodness of fit index | Measurement model | | | |
|---|---|---|---|---|
| | Model 1: One first-order model | Model 2: Two first-order model *uncorrelated* | Model 3: Two first-order model *correlated* | Model 4: One second-order model |
| CMIN (chi-square value) | 148.932 | 40.871 | 11.311 | 11.311 |
| CMIN/DF | 16.548 | 4.541 | 1.414 | 1.414 |
| Normed fit index (NFI) | 0.643 | 0.902 | 0.968 | 0.968 |
| Incremental fit index (IFI) | 0.657 | 0.922 | 0.987 | 0.987 |
| Comparative fit index (CFI) | 0.652 | 0.921 | 0.987 | 0.987 |
| RMSEA | 0.338 | 0.161 | 0.051 | 0.051 |

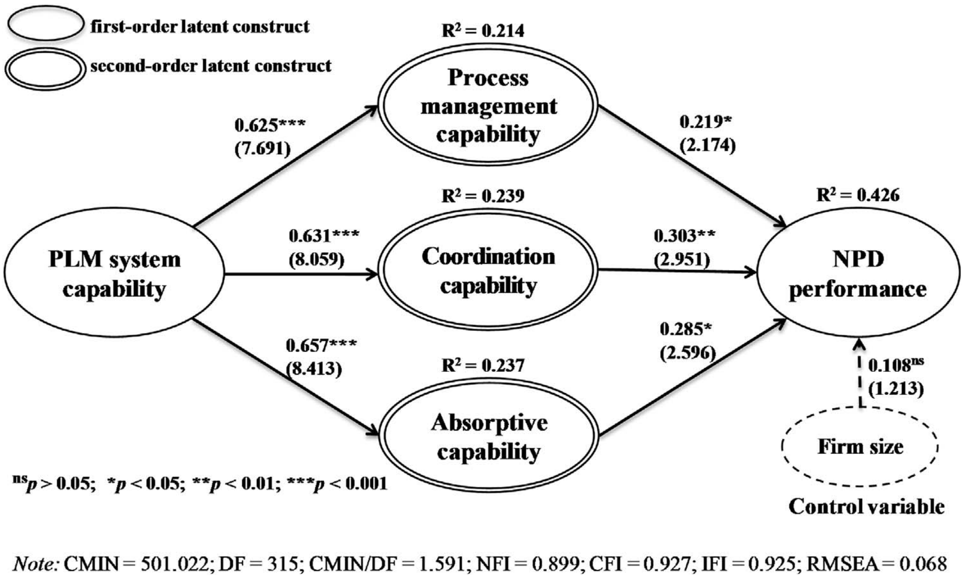


**Fig. 5.** Structual model.

effect of absorptive capability was found (point estimate = 0.181, p-value < 0.05). The bias-corrected lower and upper confidence intervals are 0.059 and 0.317, respectively, indicating no zero in-between. Therefore, absorptive capability mediates the relationship between PLM system capability and NPD performance.

## 5. Conclusion

### *5.1. Discussion*

This study examined how PLM systems affect NPD performance. An empirical analysis of 137 manufacturing firms revealed that firms can achieve excellent NPD performance through effective process management capability, coordination capability, and absorptive capability. The implementation of PLM systems to support NPD activities represents a method for improving NPD

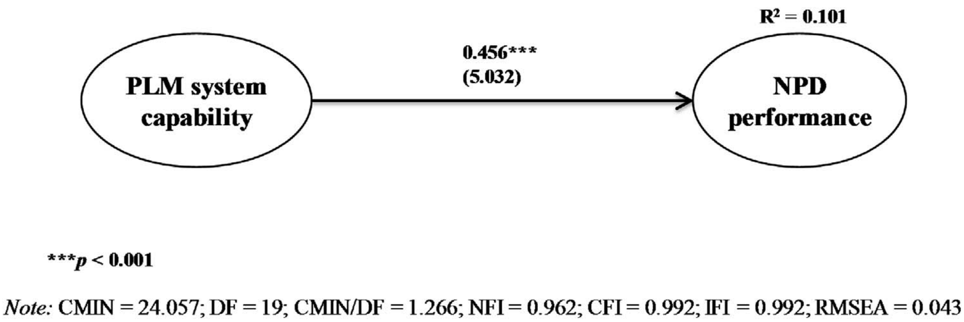


**Fig. 6.** Model 1 of testing mediating effects.

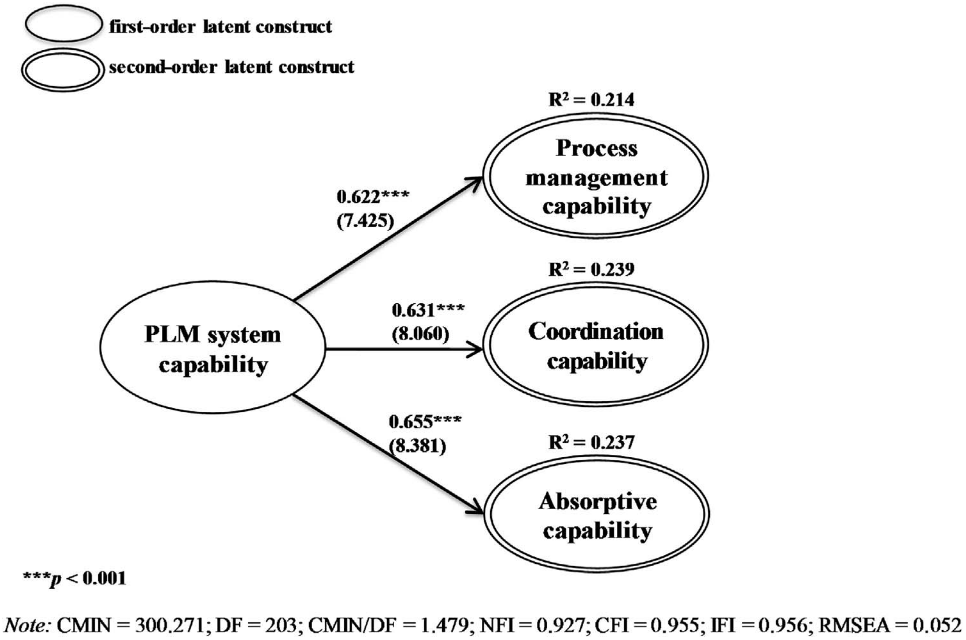


**Fig. 7.** Model 2 of testing mediating effects.

performance that can be leveraged to develop firms' process management capability, coordination capability, and absorptive capability. These capabilities can serve as a foundation for increasing firms' NPD performance.

Our results revealed that when PLM system capability was the sole independent variable, its correlation with NPD performance was positive and significant (Fig. 6). When we introduced process management capability, coordination capability, and absorptive capability into the model, this correlation ceased (Fig. 7). Our findings suggest that PLM systems can create value for firms only through the coherent integration of PLM system capability into management capabilities, thereby improving NPD management. This finding is partially consistent with the argument advanced in IT business value studies (Mithas et al., 2011; DeGroote and Marx, 2013; Liu et al., 2013; Peng et al., 2016), namely that management capabilities mediate the impact of IT systems on firm performance. The question of how to streamline NPD processes, improve the ability to absorb external knowledge, and synchronize the activities of NPD

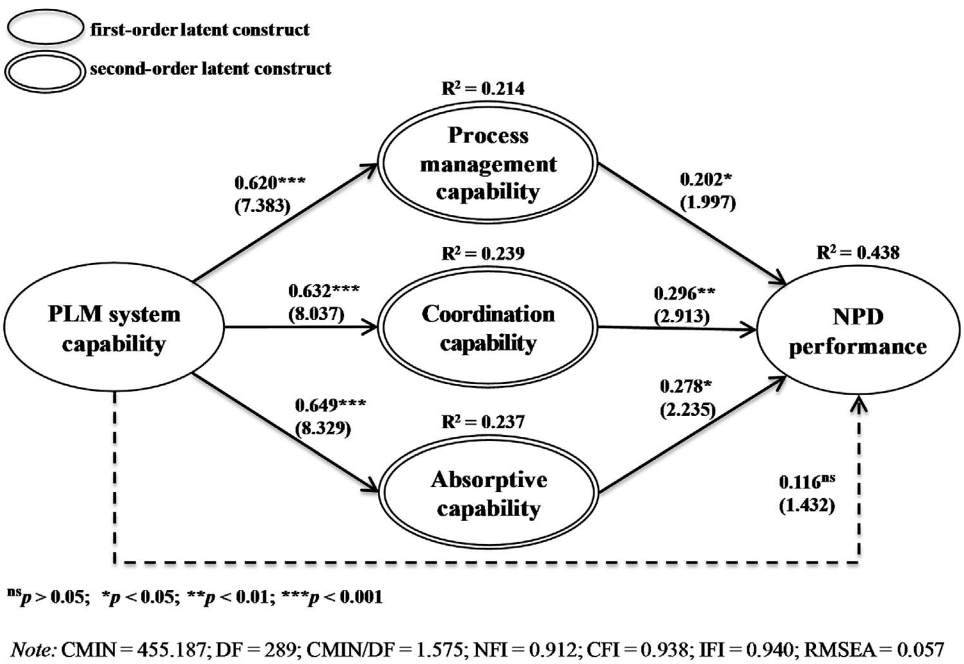


**Fig. 8.** Model 3 of testing mediating effects.

**Table 8**
Summary of mediating effects and confidence intervals.

| Parameter | Point Estimate | P-Value | Bias corrected 95% confidence interval | |
|---|---|---|---|---|
| | | | Lower | Upper |
| PLM → PMC → NPD | 0.160 | 0.029 | 0.045 | 0.298 |
| PLM → CC → NPD | 0.232 | 0.002 | 0.112 | 0.426 |
| PLM → AC → NPD | 0.181 | 0.017 | 0.059 | 0.317 |

PLM: PLM system capability; NPD: NPD performance PMC: process management capability; CC: coordination capability; AC: absorptive capability.

participants is a complex issue. In such situations, PLM systems can exert an effect. PLM systems provide effective tools for managing NPD. Consequently, the integration of management capabilities and PLM system capability is a positive and significant driver for improving NPD performance.

### *5.2. Implications for research*

The current investigation provides avenues for further research regarding the PLM systems and NPD performance nexus. First, this study contributes to the literature concerning the business value of PLM systems by revealing three vital management capabilities that have seldom received attention in PLM studies. The study demonstrated how these management capabilities leverage IT capability (i.e., PLM system capability) and convert it into business value (i.e., NPD performance). Second, this study combined individual studies on PLM systems, management capabilities in interorganizational contexts, and NPD performance, and examined the relationships among these components in NPD contexts. The results partially elucidate the contribution of PLM systems to NPD performance, demonstrating that process management capability, coordination capability, and absorptive capability fully mediate the effects of PLM system capability on NPD performance.

Third, by adopting a perspective involving a hierarchy of capabilities, this study developed a conceptual model wherein PLM system capability (a lower-order capability) influences NPD performance through three management capabilities (higher-order capabilities). The empirical results revealed that implementing PLM systems to support NPD is a valuable strategy for achieving excellent NPD performance that can be leveraged to develop process management capability, coordination capability, and absorptive capability, which can subsequently serve as a foundation for increasing NPD performance. This observation reinforces the hierarchy of capabilities perspective, which proposes that lower-order capabilities facilitate the development of higher-order capabilities within a firm. This perspective is consistent with those of previous studies (e.g., Kraaijenbrink et al., 2010; Mithas et al., 2011; Lindgreen et al., 2013; Liu et al., 2013) that have posited that the effects of IT capability (a lower-order capability) on firm performance are mediated by management capabilities (higher-order capabilities).

### *5.3. Implications for practice*

The findings of the present study have crucial practical implications. Firms invest substantial time, effort, and resources into implementing PLM systems to achieve superior NPD performance. However, such investment may not contribute to NPD performance if the implemented PLM systems cannot be leveraged to develop the improved management capabilities required in NPD contexts. Managers should be aware of the relationships between PLM system capability, management capabilities, and NPD performance. Furthermore, this study provides the necessary guidance and knowledge to facilitate managers in identifying the management capabilities required in the NPD contexts of their own firms and whether their implemented PLM systems can reinforce such management capabilities.

On the basis of our research results, we suggest that firms must consider whether their PLM system solutions enable them to develop rigorous NPD processes, streamline interactions among NPD participants, and improve knowledge absorption mechanisms. The development of rigorous NPD processes entails increasing process management capability, wherein PLM system solutions are applied to enhance NPD task processing reliability and resource utilization. The streamlining of interactions among NPD participants involves strengthening coordination capability, wherein PLM system solutions are used to establish information sharing and partner alignment mechanisms. The improvement of comprehensive knowledge absorption mechanisms entails strengthening absorptive capability by using PLM system solutions to enhance the ability to identify and leverage valuable knowledge received from NPD partners.

### *5.4. Limitations and future research*

This study has several limitations. First, its focus was restricted to three specific management capabilities, the combination of which explains only 42.6% of the variance in NPD performance. Therefore, other management capabilities might influence NPD performance. Further research could incorporate other management capabilities that may be required in NPD contexts. Second, the NPD performance measure is subjective because it is based on the responses of product development executives measured using a Likert scale. A more objective method would be to obtain and analyze firms' performance data (such as financial and other quantitative performance data) to measure NPD performance.

Third, because the production values of the semi-conductors, electronic, and computer peripheral equipment industries contributes to approximately 50% of Taiwan's gross domestic product (Industrial development bureau, 2012), most of the respondents in our study were from these three industries (Table 1), which are inherently dynamic. Customer preferences are heterogeneous and change frequently; thus, the technologies and competitive structure of these three industries are dynamic. Such market dynamism creates several challenges for firms regarding the management of collaborative NPD, such as the potential for significant changes among technically suitable and tactically available NPD partners. In such dynamic environments, firms must closely coordinate with their NPD partners to ensure the adequate fulfillment of firm requirements. In this study, the environmental characteristics of the three aforementioned industries may have been a major factor influencing the effects of coordination capability on NPD performance. Market dynamism might moderate the effects of coordination capability on NPD performance, indicating that the effects of coordination capability on NPD performance might increase with market dynamism. Therefore, future studies should further consider the moderating role of market dynamism in the relationship between coordination capability and NPD performance.

**Appendix A. Measurement items for survey questionnaires**

| Construct | Item | Reference |
|---|---|---|
| NPD performance | The extent to which your firm can achieve goals for<br>• The time to market of new products.<br>• The innovativeness of new products.<br>• The customer satisfaction of new products.<br>• The market performance of new products. | Hilletofth and Eriksson, 2011; Bendoly et al., 2012; Thomas, 2013; Gao and Tian, 2014; Stark, 2015 |
| Process efficiency capability | The extent to which your firm<br>• Completes NPD projects within a given time frame.<br>• Efficiently regulates NPD project costs.<br>• Maintains an efficient NPD process overall. | Mishra and Shah, 2009; Bendoly et al., 2012; Cantamessa et al., 2012; Ma et al., 2012; Hsu et al., 2014 |
| Process optimization capability | The extent to which your firm<br>• Reduces waste generation in NPD projects.<br>• Increases resource utilization during NPD.<br>• Excludes non-value-added activities from NPD projects. | |
| Information sharing capability | The extent to which your firm and NPD partners<br>• Inform each other of changing needs in advance.<br>• Exchange information in a timely manner.<br>• Exchange information about events that may affect the other party. | Hilletofth and Eriksson, 2011; Acur et al., 2012; Ma et al., 2012; Tavani et al., 2013; Thomas, 2013; He et al., 2014; Schilke, 2014 |
| Partner alignment capability | The extent to which<br>• NPD partners are willing to adjust their manufacturing process and capacity to correspond with your firm's strategic plans.<br>• The shared work tasks between your firm and NPD partners are synchronized.<br>• NPD partners' production activities can be aligned with your firm's NPD plans. | |
| Potential absorptive capability | The extent to which your firm<br>• Learns by tracking new market trends.<br>• Recognizes changing market demands.<br>• Adequately trains employees to assimilate external knowledge. | Fabrizio, 2009; Bapuji et al., 2011; Zahra and George, 2011; Roberts et al., 2012; Liu et al., 2013; Bellamy et al., 2014; Tavani et al., 2014 |
| Realized absorptive capability | The extent to which your firm<br>• Recognizes the utility of new external knowledge.<br>• Capitalizes on the opportunities created by the new external knowledge. | |

| | | |
|---|---|---|
| | • Understands how to efficiently exploit its own knowledge. | |
| PLM system capability | The extent to which your firm uses PLM systems to<br>• Manage NPD-related information across organizational boundaries.<br>• Retrieve previous product development cases.<br>• Schedule tasks during the product development cycle.<br>• Communicate with NPD partners. | Pol et al., 2008; Gecevska et al., 2010; Hadaya and Marchildon, 2012; Merminod and Rowe, 2012; D'Amico et al., 2013; Fielding et al., 2014; Stark, 2015 |

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