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ABSTRACT

The elusive relationship between information technology (IT) and business value continues to challenge academics and researchers. Recently, it has been suggested that a process-level framework that accounts for intermediate organizational factors is likely to allow us to better understand the antecedents of the business value of IT. This paper develops a model examining the impact of distinct IT usages on new product development (NPD) process performance. The mediating roles of two distinct integration types are examined: process integration and knowledge integration. These two integration types are conceptualized and distinguished from each other in an effort to provide a deeper understanding as to how they are influenced by IT and how they influence NPD performance. The model contributes to research by elucidating the role of IT in the NPD process and by extending the extant theory on integration and NPD performance and incorporating the distinct effects of the two integration types.

Keywords

IT usage; process integration; knowledge integration; NPD performance; process-level.

INTRODUCTION

Information systems (IS) researchers have been puzzled with identifying information technology (IT) business value. Empirical results at the firm-level ranged from positive (Brynjolfsson and Hitt, 1996), to non-significant (Gonzalez-Benito, 2007), to negative (Ataay, 2006). However, IT investments are made mostly at the process-level, and there are intermediate organizational factors enabled by IT that ultimately influence performance (Wade and Hulland, 2004). It is therefore appropriate to assess IT impact relative to its first-order process effects. In this paper we adopt such a process-level approach, which provides a finer lens with more data points to reveal the underlying impacts of IT (Brynjolfsson and Hitt, 1998), and to reduce confounding- and cross-level appropriation effects (Barua, Kriebel and Mukhopadhyay, 1995). Specifically, we examine IT impacts on the new product development (NPD) process while accounting for mediating organizational factors. NPD, being a key source of competitive advantage (Pavlou and El Sawy, 2006), provides a fertile context to examine the impact of IT on process-level performance.

From the limited literature on IT impact on NPD and from the wider literature on NPD performance, *integration* stands out as a complementary organizational factor that mediates the impact of IT on NPD performance. Nevertheless, inconsistencies still exist, which we attribute to the omission of integration as a mediator, and the ill-definition of the integration concept. In essence, the literature has focused mostly on *process integration* (PI), which comprises *structural* and *behavioral* dimensions. However, this must be distinguished from *knowledge integration* (KI), which reflects a *cognitive* dimension. NPD is naturally a knowledge-intensive process (Pavlou and El Sawy, 2006) which requires assessing how dispersed knowledge of NPD workers is combined and applied to enhance performance. We propose that NPD performance is in fact influenced by both integration types (PI and KI). A key contribution of this paper is to develop precise conceptualization of both types of integration, in addition to embedding these constructs in a theoretical network, in order to provide a more accurate picture of how IT affects NPD performance. We present the following research questions:

1. What are the characteristics of the two integration types and how are they related?
2. How do they impact NPD performance?
3. How do different IT usages support the distinct integration types and how is IT related to NPD performance?

IT AND NPD PERFORMANCE: THEORETICAL DEVELOPMENT

NPD Process

NPD involves a wide range of activities. First, the NPD team generates ideas to leverage market opportunities until converging to a suitable product concept, contingent on successful marketing/financial/technical analyses. The product is then developed and tested before engaging in full-scale production and market launch. While these activities were once considered sequential, it is now recognized that close overlapping and synchronization are needed to improve process efficiency and product effectiveness (Clark and Fujimoto, 1991). For example, product and process engineers synchronize the timing of their tasks to reduce development time. We refer to this as an example of the structural dimension of PI. Additionally, these activities require close collaboration and involvement. We refer to this as the behavioral dimension of PI. Finally, NPD requires the integration of disparate knowledge inputs from entities with different backgrounds, including R&D scientists, designers, engineers, and marketers to jointly develop/launch new products (Pavlou and El Sawy, 2006). This is referred to as the cognitive dimension of KI[1]. Prior research has focused mostly on PI at the expense of KI, or did not adequately distinguish between the two; a gap which this paper addresses. This allows us to better understand the impact of distinct IT usages on NPD performance.

IT and NPD Performance

IT supports NPD in multiple ways, including NPD worker-collaboration, accessing each other's knowledge stored in IT-based knowledge repositories, creating online knowledge communities on product-related issues, enabling customer participation in product co-creation, using blogs initiated by NPD workers or customers, implementing CAD/CAM systems for product design, and employing IT-based market intelligence techniques. Potential benefits of IT include enhancing the quantity, quality, and variety of NPD information flows (Brown and Eisenhardt, 1995). This diffusion of IT into NPD begs an increased attention to research that examines the linking mechanisms between IT and NPD performance. However, the extant literature is very limited (Banker, Bardhan and Asdemir, 2006), while still confirming that IT influences NPD mainly via integration mechanisms. We conducted a review of empirical studies examining the impact of IT on NPD performance. In specifying the domain of our search, we examined articles that focused on internal NPD. To better understand the mechanisms by which IT contributes to NPD performance, we included studies with direct-, mediating-, and moderating effects (see Appendix 1).

Appendix 1 reveals that integration mediates the link between IT and NPD performance. Four out of the six identified articles had as mediating effects constructs that reflect some form of integration; e.g., collaboration (Banker et al., 2006), concurrent engineering (Koufteros and Marcoulides, 2006), coordination capabilities, collective mind and cross-functional integration (Pavlou and El Sawy, 2006), and cross-functional team interaction (Chen, 2007). Whereas studies that included integration as a mediating factor between IT and NPD performance found a positive link, those that did not include this mediating effect exhibited mostly mixed or inconclusive results (see Appendix 1).

Therefore, our contention of integration as a complementary organizational factor (Wade and Hulland, 2004: complementarity view) mediating the IT-NPD performance link seems to be supported empirically. However, these studies focused mostly on PI at the expense of KI (see Appendix 1). Whereas some may have discussed the integration of knowledge in an anecdotal manner, in fact their operational definitions either entirely reflected PI (Chen, 2007; Koufteros and Marcoulides, 2006), had a mix of elements of PI and KI (Banker et al., 2006), or had a mix of elements of PI and other, non-integration elements in their measurement scales (e.g., Pavlou and El Sawy, 2006). Hence, much less is known about the role of KI in the IT-to-NPD performance chain, and a conceptual distinction between PI and KI is warranted. Also, rather than treating IT as a black box, we maintain that distinct IT usages may have differential effects on PI and KI. With the exception of Pavlou and El Sawy (2006), all studies lumped together all possible usages and technologies under a single IT construct.

In summary, we posit that (1) integration is likely to be an important mediator between IT and NPD performance, (2) no prior IS studies examined PI and KI simultaneously, (3) the integration concept has been ill-defined, and (4) we need to identify specific IT usages that impact integration and NPD performance. In the next section we attempt to provide a deeper understanding of the two integration types to unveil the relationship between IT and integration and the ultimate effect on NPD performance.

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[1] We will define these three dimensions of integration and the two integration types below.

PROCESS INTEGRATION, KNOWLEDGE INTEGRATION, AND NPD PERFORMANCE

Process Integration

The *process integration* concept originates from organizational information processing theory (Galbraith, 1977), which holds that organizations strive to reduce uncertainties (Tushman and Nadler, 1978), arising from technological/market sources (Tatikonda and Montoya-Weiss, 2001). One way to do so is by enhancing the firm's information processing structures (Tushman and Nadler, 1978), by drawing on structural integrative mechanisms that bring work units together to communicate and coordinate their activities. As an example in NPD, PI may occur where NPD workers from different functions (e.g., marketing and product design) coordinate and synchronize their activities to reduce customer uncertainty about the product.

To conceptualize PI, we conducted a literature review to identify areas that tap its different aspects (Churchill, 1979). Our search revealed that PI is a second-order formative construct with seven underlying first-order constructs, each having its own set of measurement indicators (see Appendix 2). It is formative to the extent that it is caused by these first-order constructs, each of which tapping a different aspect of PI. Moreover, had it been a reflective construct then perceived variations in the concept of "integration" would cause *all* of the underlying seven constructs to reflect this change (Petter et al., 2007), which is not the case seeing that the seven constructs are not necessarily highly correlated. Moreover, Kahn (1996) also posited integration as a *composite* construct comprising a structural dimension and a behavioral dimension, which is in line with our formative conceptualization. In our case, changes in each of the seven first-order constructs of PI causes a change in the higher-order PI construct[2]. We further mapped these seven constructs to the two dimensions identified earlier: the structural and behavioral dimensions (see Appendix 2). The structural dimension embodies the following five first-order constructs: (1) coordination and task interdependency, (2) synchronization and overlapping of activities, (3) close interaction and communication, (4) role flexibility, and (5) a project manager that oversees NPD tasks. Moreover, the behavioral dimension includes the following two first-order constructs: (6) involvement and participative decision-making, and (7) collaboration and information sharing/exchange. In our NPD context, the structural dimension represents configurational elements such as timely coordination of NPD tasks, managing dependencies, and synchronizing/overlapping activities (Iansiti, 1995). The behavioral dimension of PI deals with collaboration and mutual involvement of disparate NPD workers. Whereas the structural element may be more formal and transactional, the behavioral element may be more informal and cooperative (Ramesh and Tiwana, 1999). Appendix 2 also presents the conceptual definitions and measurement scales for each of the underlying constructs of PI.

While some studies in the NPD literature defined PI in terms of a single construct/dimension such as communication/structural (Griffin and Hauser, 1992) or collaboration/behavioral (Kahn and Mentzer, 1998), other, more recent studies treated PI as a composite construct involving both structural and behavioral dimensions (Tan and Tracey, 2007). It is true that these two dimensions of PI have been somewhat recognized in the literature (e.g., Gomes, de Weerd-Nederhof, Pearson and Cunha, 2003), but the same cannot be said of KI with its cognitive dimension, to which we now turn.

Knowledge Integration

Drawing on Grant (1996), we define knowledge integration (KI) as *the access and utilization of dispersed knowledge of NPD work unit specialists such that individual knowledge and aggregate level of pooled and new knowledge are applied towards a system-wide product solution*. KI emanates from the knowledge-based view (KBV), maintaining that knowledge is the most valuable resource for the firm, and hence – if applied effectively – a source of sustained competitive advantage (Grant, 1996).

NPD, being a broad-scoped and knowledge-intensive process (Pavlou and El Sawy, 2006), requires the integration of the dispersed knowledge of a large base of individuals with different backgrounds and mental models, which allows for the cross-fertilization of ideas as to enhance the NPD process (Malhorta, Majchrzak, Carman and Lott, 2001). Despite these differences, NPD work units are also characterized by knowledge dependencies (Carlile, 2002).

Compared to conceptualizing PI, tapping the domain of KI is difficult as a result of the scarcity of conceptual/operational measures, mostly due to the abstrusity of observing knowledge management phenomena (Alavi and Leidner, 2001). This is further blurred by the embeddedness and tacitness of knowledge (Levina and Vaast, 2005). As a starting point to assess KI, we adopt the notion of boundary spanning and boundary objects (Carlile, 2002). In NPD, knowledge is integrated across boundaries as each group of experts (e.g., marketing; engineering; production; design) may have their distinct sources and contexts of knowledge schemas. Boundary spanners integrate knowledge by sharing common boundary objects that are a result of negotiating the differences and dependencies between NPD workers. Hence, KI is assessed via boundary objects, which provide a shared context that helps integrate domain-specific knowledge dispersed across NPD workers (Carlile,

[2] The same reasoning applies to KI, which is a formative construct with three underlying first-order constructs.

2002). Appendix 2 illustrates the three first-order constructs that tap the second-order formative KI construct, represented by three boundary objects at three boundary levels, along with conceptual and operational definitions. Whereas the PI constructs reflected the structural and behavioral dimensions, KI reflects the cognitive dimension, since it involves integrating individuals' mental models, beliefs, and viewpoints about NPD-related tasks.

Distinction between PI and KI, and their Impacts on NPD Performance

As evident from the domains of PI and KI established above, these concepts are distinct. For example, an organization can configure an NPD process to be well coordinated with formal communication occurring between NPD workers (PI), yet this does not guarantee that they will combine their disparate knowledge (KI) as to improve the decision quality and/or speed up the NPD process. Also, NPD workers may collaborate on a certain task (PI), but this does not necessarily mean that there is a change in the cognitive disposition of the collaborators (KI). These distinctions are also supported in the literature, albeit mostly in an anecdotal and/or implicit manner. For example, Brown and Eisenhardt (1995) distinguish internal/external communication, manifested in both task coordination of technical and design issues to secure valuable NPD resources (PI), from knowledge combination and sharing between NPD workers in an interactive and iterative fashion (KI). Despite these anecdotal distinctions, concepts characterizing PI and KI have been applied loosely, making it difficult to draw precise conclusions on their meanings, mechanisms, and effects. Overall, the literature has not tapped the different integration types and dimensions in a single NPD study, which limits our ability to explain NPD-related phenomena.

In fact, we argue that the ill-conceptualization of PI and KI and the lack of distinction between them may contribute to inconsistencies in relating integration to NPD performance. Although there is overall evidence of a positive impact of integration, results become less conclusive when exploding integration into PI and KI, and looking at distinct NPD performance outcomes (e.g., Souder, Sherman and Davies-Cooper, 1998; Swink and Song, 2007). For example, some studies with mixed results did not conceptualize integration (e.g., Song, Thieme and Xie, 1998) or did not operationalize integration in a comprehensive way (Swink and Song, 2007).

In sum, while prior research has advanced our knowledge by focusing on structural-PI and behavioral-PI dimensions, we maintain that including cognitive-KI and clearly defining and distinguishing the different integration concepts deepens our understanding of how NPD workers integrate their respective efforts to improve NPD performance, aided by IT usages that support each integration type. The research model is shown in Figure 1 below.

RESEARCH MODEL

The research model incorporates three types of IT usages: *IT use for project/process management*, *IT use for collaboration*, and *IT use for knowledge management*. Each of these positively impacts one or more integration types, which in turn influence NPD performance. In addition to the full mediation effect of the two integration types, there is a partial mediation effect of KI on the link between PI and NPD performance (quality and cycle time). NPD performance is measured in terms of process efficiency (development cost and cycle time) and product effectiveness (quality).

Our unit of analysis is the NPD work unit, which includes disparate specialists coming together from various departments, such as marketing, R&D, operations, and so forth, for the purpose of developing a new product and undertaking all tasks related to this project (cf. Pavlou and El Sawy, 2006). Although the unit of measurement draws on individual perceptions (e.g., usage of IT; integration; NPD performance), the unit of analysis is in fact the NPD work unit, averaging across responses of individuals in various NPD activities, and yielding the lowest level of independent observations (Kenny, 1996). This unit of analysis is also appropriate since we want to generalize about NPD work units – a unit that is more closely bounded to the NPD process as our phenomenon of interest and which can be observable and subject to empirical testing - rather than individuals within these work units or the organization at large. Finally, adopting the NPD work unit as the unit of analysis allows us to adequately measure the constructs of interest and reconcile the level of theory with the level of observation (see Appendices 2 and 3).

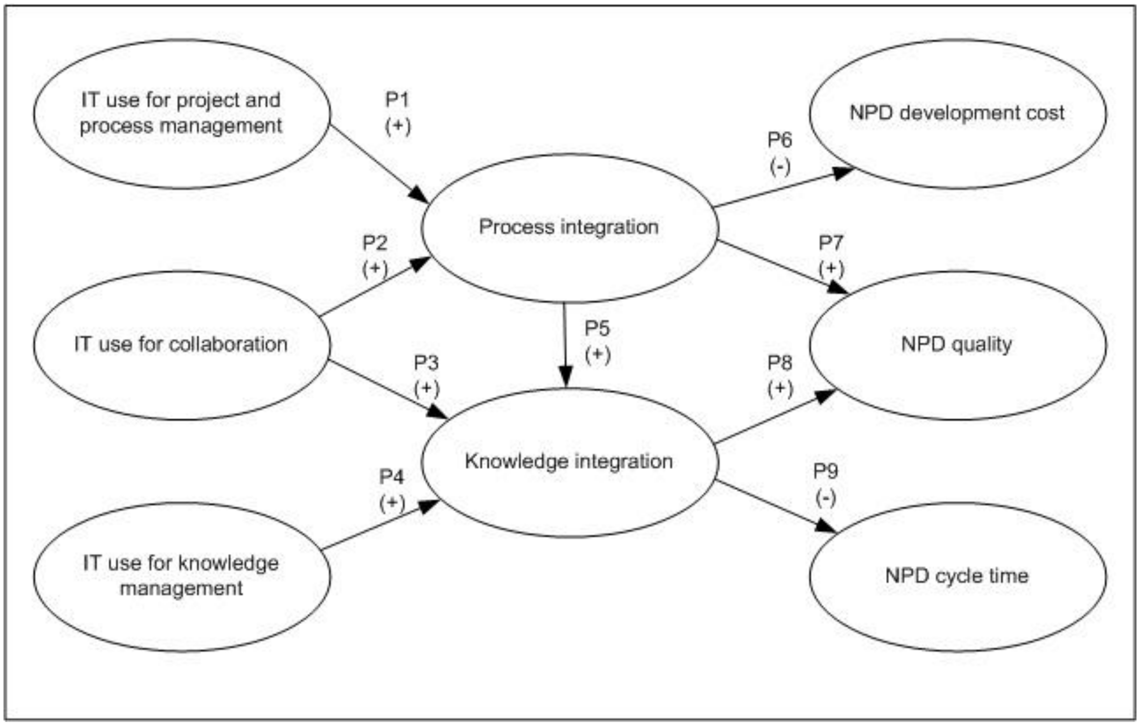

Figure 1. Research Model

IT Usage

In their seminal paper, Rangaswamy and Lilien (1997) introduced two types of IT: (1) systems that support NPD decision making, and (2) systems that support NPD process. The first denotes systems that aid decisions such as selecting product names, generating ideas, brainstorming, and product evaluation. The second type represents systems that support the NPD process itself, such as project management systems (e.g., MS Project), groupware for collaboration (e.g., Lotus Notes), workflow systems, and so forth. In this paper, we follow Pavlou and El Sawy (2006), and define the following: (1) IT use for project/process management, (2) IT use for collaboration, and (3) IT use for knowledge management (KM). Operationally, these measures of IT usage are aggregations of individual perceptions of different IT usages at the NPD work unit level, to be consistent with our unit of analysis. Appendix 3 shows the conceptual and operational definitions of the different IT usages.

IT Use for Project/Process Management

Using IT for project/process management involves scheduling, prioritizing, managing, and coordinating NPD tasks. With such systems, NPD workers can plan NPD projects, assign resources where they are needed, forecast and control project issues, and continuously monitor project progress while providing real-time information.

IT Use for Collaboration

Due to the complexity and wide scope of the NPD process, getting dispersed people to collaborate and co-develop products is greatly enabled by IT use for collaboration. This concept involves effective use of groupware enabling group communication across time and space, and employing three functionalities: conveyance of product configurations, presentation of models, and convergence of ideas (Pavlou and El Sawy, 2006).

IT Use for KM

IT enables KM via (1) knowledge coding/sharing, (2) IT-based knowledge directories, and (3) IT-based knowledge networks (Alavi and Leidner, 2001; Pavlou and El Sawy, 2006). Examples of corresponding IT applications include generalized software such as EMC Documentum's eRoom, or specialized solutions such as Dassault's ENOVIA.

Note that our choice of these three IT usages addresses four important modeling issues: (1) disaggregating the IT construct to unveil the impact of distinct IT usages, (2) actual IT usage versus IT availability in order to capture real- as opposed to potential effects, (3) IT usage at the process level, and (4) IT usage from the user side, measured at the level of NPD work units rather than IT units (cf. Pavlou and El Sawy, 2006).

Relationships between IT and Integration

We posit that distinct IT usages affect PI and KI differently, which in turn have different impacts on NPD performance outcomes. For example, the project/process management functionalities of IT provide real-time information to synchronize activities and address changes early on (PI) without significantly affecting development costs and/or cycle time. Moreover, collaborative functionalities such as groupware technologies provide a common base for dispersed individuals to work remotely and a common platform through which they can communicate (PI), collaborate (PI), and integrate their knowledge (KI). Finally, IT use for KM helps codify knowledge and create IT-based knowledge directories and networks allowing NPD workers to access, combine, leverage, reuse, integrate, and apply their NPD-related knowledge (KI).

IT-Process Integration

We found both conceptual and empirical support for the link between IT and PI. Hameri and Nihtila's (1997) case study suggests that IT supports NPD by enhancing communication [PI-3][3] and dissemination of information [PI-7]. Empirically, Chen (2007) found that IT (via its collaboration and project/process management functionalities) supports coordination and communication mechanisms for NPD workers. Also, IT use for collaboration allowed NPD workers to synchronize their communication [PI-4] and collaborate more effectively [PI-7] (Banker et al., 2006). Hence, we propose:

P1: IT use for project/process management will be positively correlated to PI.

P2: IT use for collaboration will be positively correlated to PI.

IT-Knowledge Integration

IT enhances knowledge integration by providing a platform among expertise holders through which they can create a wide breadth and depth of knowledge flows (Alavi and Leidner, 2001). It increases weak ties among them, allowing for the combination of new, dispersed sources of expertise that enhance knowledge sharing and integration (Alavi and Leidner, 2001). Since knowledge integration involves combining dispersed sources of individual specialists' knowledge (Grant, 1996), extending the base of this dispersed knowledge is likely to enhance knowledge integration.

Several studies implied and/or confirmed a link between IT and KI[4]. In his conceptual piece, Nambisan (2003) argued that IT use for KM may support distributed knowledge creation and management. Pavlou and El Sawy (2006) found that IT use for KM positively affects the NPD work units' ability to acquire, assimilate, transform, and utilize knowledge (absorptive capacity). Additionally, IT use for collaboration enhances KI, for example by supporting customer co-innovation in virtual environments (Nambisan, 2003). Hence:

P3: IT use for collaboration will be positively correlated to KI.

P4: IT use for KM will be positively correlated to KI.

Relationship between PI and KI

To further establish the distinction between PI and KI, we posit that PI is in fact an antecedent to KI. In essence, PI enables a tighter coupling of the NPD processes and tasks, paving the way for NPD workers to build on each other's perspectives and integrate their disparate knowledge. We find theoretical support for the link between PI and KI, although mostly conceptual, and sometimes derived implicitly. For instance, Souder and Moenart (1992) argue that communication and information sharing (PI) allow knowledge to be accessible to other NPD workers (KI). Empirically, Okhuysen and Eisenhardt (2002) found in an experimental study that information sharing (PI) and knowledge integration (KI) are two distinct constructs. Another study found that formal/informal integrative practices (PI) led to KI which in turn enhanced development performance (Patnayakuni, Rai and Tiwana, 2007). Hence:

P5: PI will be positively correlated to KI.

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[3] [PI-3] is the third first-order construct of PI (cf. Appendix 2).

[4]However, the terminology describing KI sometimes differed.

Relationships between Integration and NPD Performance

IT-enabled integration can enhance NPD performance. Integration may reduce redundancies and errors, and minimize delays between NPD stages, leading to decreases in cycle time and development costs. Also, since the expertise of many dispersed individuals with different backgrounds is leveraged, this can have a positive impact on product quality.

PI-NPD Performance

We posit that PI has a positive impact on NPD performance, leading to less rework since different NPD functions will perform their work while being aware of the various interdependences between their objects, processes, and tasks. This translates to development cost reductions. Further, PI may reduce NPD cycle time as it allows for overlapping and seamless transition between activities, thus overcoming the inefficiencies of the stage-gate approach. However, we argue below that there is no direct link between PI and cycle time since cycle time reduction requires that knowledge first be integrated between NPD workers. Finally, PI enhances quality of the developed product since the various integrated entities develop the product with a holistic view rather than a narrow viewpoint that focuses on separate components (Clark and Fujimoto, 1991).

Empirical support includes Pavlou and El Sawy (2006), who found that cross-functional integration – reflecting the quality of interaction among NPD workers – was significantly related to NPD process efficiency, which reflected development cost and quality, among others. Additionally, Tatikonda and Montoya-Weiss (2001) established significant links between process concurrency and development cost reduction/quality improvements. Hence:

P6: PI will be negatively correlated to development cost.

P7: PI will be positively correlated to product quality.

As for PI and cycle time, we argue that this link is not direct but rather mediated via KI. As an argument supporting a direct link, merging NPD tasks and processes and managing the dependencies between entities may reduce cycle time due to less time spent working on mismatches between various functions and NPD workers (Rusinko, 1997). However, as a counterargument, different backgrounds and cultures of NPD workers may actually increase the time it takes to agree on relevant NPD decisions, which increases cycle time (Tatikonda and Montoya-Weiss, 2001). Simply attempting to manage dependencies and merge activities of NPD workers does not guarantee that they will actually work together to reduce NPD cycle time. To achieve this, NPD work units must actively integrate their knowledge and create a pool of new and existing knowledge which can then be applied to rapidly resolve NPD-related problems/conflicts, which in turn leads to cycle time reduction. We therefore propose that the link between PI and cycle time is an indirect one mediated by KI.

Empirical results substantiate these contradictions. Whereas some studies found a negative link between PI and cycle time (e.g., Chen, 2007; Pavlou and El Sawy, 2006), others found a non-significant link (e.g., Souder et al., 1998), mixed results (Gomes et al., 2003; Swink and Song, 2007), or even a positive link[5] (Swink and Song, 2007). Hence:

P9a: KI fully mediates the influence of PI on cycle time.

P6a7a: PI fully mediates the influence of IT (IT use for project/process management and collaboration) on NPD performance (cost and quality).

KI-NPD Performance

A central thesis of this paper is that in addition to PI, KI also improves NPD performance. KI leverages the dispersed knowledge and unique advantages of NPD workers as to enhance product development advantage. We argue that KI is likely to improve NPD product quality and reduce cycle time. Since investments in boundary objects used to integrate knowledge may offset savings in development costs, we posit no direct link between KI and development cost.

In contrast to the link between PI and NPD performance, empirical studies examining the link between KI and NPD performance are scant, and correspondingly there is less empirical support to ground our propositions. Concerning the link between KI and quality, Tan and Tracey (2007) established a significant positive link where supplier involvement, - which involved suppliers integrating their expertise with the focal firm - increased NPD product quality. Hence:

P8: KI will be positively correlated to product quality.

P8a: KI partially mediates the influence of PI on product quality.

[5] Note that a positive link refers to an increase in cycle time and works against the hypothesized direction if the goal is to reduce cycle time. A negative link refers to the opposite.

With regards to KI and cycle time, Iansiti (1995) introduced the technology integration construct (integration of novel technical approaches into complex new product systems by merging new and existing knowledge), which was negatively associated with cycle time. Similarly, Mitchell (2006) found that knowledge access/integration reduced IT project delays. Hence:

P9: KI will be negatively correlated to cycle time.

P8a-9a: KI fully mediates the influence of IT (IT use for collaboration and knowledge management) on NPD performance (quality and cycle time).

In summary, we posit that IT enhances NPD performance via a full mediation effect by two integration types: PI (structural and behavioral) and KI (cognitive). This is in agreement with the complementarity view of IT that holds that IT resources achieve business value when they are complemented by organizational resources (Melville, Kraemer and Gurbaxani, 2004; Wade and Hulland, 2004). KI also partially mediates the impact of PI on NPD performance. Additionally, each of the two integration types is supported by distinct usages: IT use for project/process management, IT use for collaboration, and IT use for KM. Therefore, PI and KI are enabled through different IT usages and they also have different effects on NPD performance. While IT use for project/process management and IT use for collaboration may be more suitable for PI, IT use for collaboration and IT use for KM are better for KI. Moreover, PI is likely to reduce NPD development cost and improve quality while KI is likely to improve quality and reduce cycle time.

LIMITATIONS, IMPLICATIONS, AND CONCLUSION

Limitations of this paper include the lack of distinction between stable and dynamic environments. It may be that in stable environments communication patterns prevail (Carlile, 2002), rendering PI more salient, while in dynamic environments (e.g., changing technological and market demands) tensions may increase within NPD work units where different groups attempt to push their own knowledge and perspectives, rendering KI more important. Several studies found that dynamic environments moderated effects on NPD outcomes (Pavlou and El Sawy, 2006; Song and Montoya-Weiss, 2001; Souder et al., 1998). We forwent the inclusion of this factor in the interest of parsimony and to maintain our focus on the two integration types, as well as on how they are enabled by IT and how they enhance NPD performance. Moreover, we constrained our analysis to internal NPD, but this was done to provide a focused, fertile context to develop our conceptualization of PI and KI, and to establish the links between them and how they are differently supported by distinct IT usages. Future research can extend our analysis and examine the antecedents and consequences of PI and KI in external NPD.

Notwithstanding these limitations, several contributions are recognized. We have developed a model of IT business value at the process level, while accounting for complementary organizational factors that mediate the effects of IT on NPD performance. Also, IT is treated not as a black box but rather as a collection of distinct functionalities that support specific NPD processes. Our model also highlights that it is the actual usage of IT rather than its mere availability which contributes to NPD performance.

For integration/NPD performance literature, this paper contributes by enriching the conceptualization of integration and elucidating how integration (with its two types and three dimensions) is supported by IT and how it contributes to NPD performance. Prior literature has dealt mostly with PI and how it enhances performance. Our model complements and extends prior research, and we develop a more comprehensive view of integration which considers both PI and KI, as well as their antecedents and consequences.

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Appendix 1: IT and NPD Performance: Summary of Empirical Results

Source	Type of integration (PI/KI)	Independent variable	Mediating (Me) / moderating (Mo) variable	Outcome variable	Results
Banker et al. (2006)	Mixed	IT use for collaboration	Collaboration (Me)	Cycle time	(-)
Banker et al. (2006)	Mixed	IT use for collaboration	Collaboration (Me)	Development cost	(-)
Banker et al. (2006)	Mixed	IT use for collaboration	Collaboration (Me)	Product quality	(+)
Durmusoglu et al. (2006)	N/a	IT infrastructure support of NPD	N/a	Development cost	(+) (Counter)
Durmusoglu et al. (2006)	N/a	IT infrastructure support of NPD	N/a	Time-to-market	ns
Durmusoglu et al. (2006)	N/a	IT infrastructure support of NPD	N/a	Product quality	ns
Koufteros and Marcoulides (2006)	PI	IT use	Concurrent engineering (Me)	Product innovation	(+)
Koufteros and Marcoulides (2006)	PI	IT use	Concurrent engineering (Me)	Product quality	(+)
Pavlou and El-Sawy (2006)	Mixed	IT use for collaboration/KM/ project management	Dynamic capabilities (Me)	Product quality	(+)
Pavlou and El-Sawy (2006)	Mixed	IT use for collaboration/KM/ project management	Dynamic capabilities (Me)	Cycle time; development cost	(-)
Barczak et al. (2007)	N/a	IT use	N/a	Cycle time	ns
Barczak et al. (2007)	N/a	IT use	N/a	Product success	(+)
Chen (2007)	PI	IT investment/ training	Cross-functional team interaction (Me)	NPD performance	(+)

Appendix 2. Conceptual and Operational Definitions of PI and KI

Second-order construct / dimension	First-order construct	Conceptual definition	Measurement scale
Process integration / structural	Coordination and task interdependency [PI-1]	Enabling the NPD work unit to manage task interdependence when working towards a common goal (Hauptman and Hijri, 1999)	Scale used by Pavlou and El Sawy (2006): - NPD tasks fit together very well; group is well coordinated; appropriate allocation/sharing of resources; etc.
Process integration / structural	Synchronization/overlapping of activities [PI-2]	Real-time intervention and dynamic scheduling of tasks such as to allow mutual adjustments of various NPD activities in time and space (Hauptman and Hijri, 1999)	- Project activities were overlapped (Swink 2000) - Concurrent workflows (Koufteros et al., 2005) - Overlapping product and process engineering (Iansiti and Clark, 1995)
Process integration / structural	Close interaction and communication [PI-3]	An interactive process between NPD workers involving communication activities such as meetings, teleconferencing, conference calls, memoranda, exchange of standard documentation, and other forms of information flows (Kahn and Mentzer, 1998)	- Communication between departments (Montoya-Weiss and Calantone, 1994) - Degree of interaction (Montoya-Weiss and Calantone, 1994) - Frequency of meetings (Kahn and Mentzer, 1998) - Level of contact (Souder et al., 1998) - Frequency of contact (Souder and Jenssen, 1999)
Process integration / structural	Role flexibility [PI-4]	Flexibility in assuming organizational roles and tasks, reflecting the extent to which organizational members move their jobs across functions (Leenders and Wierenga, 2002), or the degree of extrafunctional tasks a project member assumes in the course of a project (Moenart et al., 1994)	- Frequency of job rotations or years of experience at various function (Hauptman and Hijri, 1999) - Proportion of NPD workers with cross-functional job rotation experience (Leenders and Wierenga, 2002) - Job rotation and movement between design and manufacturing (Ettlie and Reza, 1992) - Relocation at source of uncertainty (Iansiti, 1995)
Process integration / structural	Project manager oversees tasks [PI-5]	Existence of a project manager (PM) who performs specific NPD tasks, influences NPD entities, has direct contact with entities, and champions NPD activities	- Relative influence of PM (Hauptman and Hijri, 1999) - PM are given real authority over personnel (Koufteros and Marcoulides, 2006) - PM has enough influence to make things happen (Koufteros and Marcoulides, 2006)
Process integration / behavioral	Involvement and participative decision-making [PI-6]	Becoming involved in each other's activities from the early staged of the project and attempting to understand each other via discussions (Gupta et al., 1986) and shared decision making (Patnayakuni et al., 2007)	- Participative decision making broadly used in NPD projects (Patnayakuni et al., 2007) - Decision-making authority rests with managers as opposed to NPD workers (reverse coded) (Patnayakuni et al., 2007)

			- Joint decision-making made by managers and NPD workers (Patnayakuni et al., 2007) - Manufacturing sign-off for design (Ettlie and Reza, 1992) - Marketing involved with R&D in setting new product development goals and priorities (Song and Parry, 1992)
Process integration/ behavioral	Collaboration and information/knowledge sharing/exchange [PI-7]	A higher form of information processing and exchanging (Yassine et al., 2004) that involves various departmental members working closely together towards a common goal (Kahn, 1996)	- Frequency of collaborative interactions related to NPD (Banker et al., 2006) - Extent of detailed design information exchanged during collaborative interactions (Banker et al., 2006) - Degree of cooperation between design and manufacturing (Ettlie, 1995)
Knowledge integration/ cognitive	Boundary objects for knowledge transfer [KI-1]	Boundary objects that enable accounting for common knowledge via accessing and transferring knowledge at the syntactic boundary level (Carlile, 2002)	- Data generated during a particular task/phase of NPD is easily accessed by related tasks/phases (Patnayakuni et al., 2007) - Modifications made to development information in a particular task/phase are communicated to related tasks/phases (Patnayakuni et al., 2007) - Other boundary objects assessing knowledge integration through the use of repositories
Knowledge integration/ cognitive	Boundary objects for knowledge translation [KI-2]	Boundary objects that enable accounting for common meanings of knowledge by learning about differences and dependencies and translating knowledge at the semantic boundary level (Carlile, 2002)	- Logical models remain consistent across different development tasks/phases (Patnayakuni et al., 2007) - No semantic information is lost in moving from one task/phase of development to another (Patnayakuni et al., 2007) - Other boundary objects assessing knowledge integration through the use of standardized forms and methodologies
Knowledge integration/ cognitive	Boundary objects for knowledge transformation [KI-3]	Boundary objects that enable accounting for different interests by jointly transforming old knowledge to new one at the pragmatic boundary level (Carlile, 2002)	- Other boundary objects assessing knowledge integration through the use of maps

Appendix 3. Conceptual and Operational Definitions of IT Usage and NPD Performance

Construct	Conceptual definition	Measurement scale
IT use for project and process management	Use of IT tools for scheduling, prioritizing, managing, and coordinating NPD tasks (Pavlou and El Sawy, 2006)	Scale from Pavlou and El Sawy (2006): - Effectively tracking rapidly changing information to update project deliverables in real time - Accurately providing real-time information on resource availability, usage, and cost - Quickly prioritizing tasks and keeping deliverables on track to ensure realistic schedules
IT use for collaboration	Use of groupware enabling group communication across time and space, and employing three functionalities: conveyance of product configurations, presentation of models, and convergence of ideas (Pavlou and El Sawy, 2006)	Scale from Pavlou and El Sawy (2006): - Adequate use of IT tools to manipulate the format of contributions - Adequate use of IT tools to simultaneously work together in real-time - Effective use of IT tools for seamless virtual product design reviews
IT use for knowledge management	Use of IT tools to code/share knowledge, locate expertise via knowledge directories, and engage in online knowledge communities (Pavlou and El Sawy, 2006)	Scale from Pavlou and El Sawy (2006): - Effective use of IT tools for capturing, compiling, and coding relevant information - Project history readily accessible for reuse - Creating online knowledge communities focused on new ideas and products - Using IT tools to locate relevant expertise
NPD cycle time	Time taken to complete NPD projects	- Degree to which NPD project was completed on time (Swink. 2000) - Degree to which product development time was reduced (Swink, 2000)
NPD quality	Quality of developed new products	- Degree to which product was manufacturable (Swink, 2000) - Degree to which product met quality targets (Swink, 2000) - Degree to which product met specific customer needs (Swink, 2000) - Frequency of manufacturing problems encountered during development (Swink, 2000)
NPD development cost	Cost of developed new products	- Overall development costs (Pavlou and El Sawy, 2006) - Overall efficiencies of NPD process (Pavlou and El Sawy, 2006)