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Developing Complex, Business-to-Business Products: Issues and Implications

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Developing complex, business-to-business products: issues and implications

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Abstract

Purpose – The purpose of this paper is to identify issues that are critical to developing complex, business-to-business products and discuss implications for vendor firms.

Design/methodology/approach – This paper employs the critical review approach to current complex product literature and draws from relevant literature streams in engineering, management, and marketing to propose a conceptual framework.

Findings – The critical review of the complex products research reveals the following as critical issues for research and practice in the development of complex products: definition, internal and external complexity, product and process complexity, standardized to customized complex products continuum, component and process modularity, and operant resources.

Research limitations/implications – This paper identifies six specific operant resources that are critical to the development of complex products and proposes a conceptual framework. Clearly, more needs to be done in terms of theoretical and empirical research with reference to the development of complex, business-to-business products. For example, researchers could empirically test the proposed framework; identify other relevant operant resources; and critique the proposed framework and develop a new, more comprehensive framework.

Practical implications – Firms that develop complex products could focus on developing the six operant resources that can help them become competent in developing complex products; and developing organizational structures and policies and providing an organizational environment that is conducive to developing robust internal and external social capital.

Originality/value – The proposed conceptual framework provides a theoretical foundation for practitioners and researchers to build on.

Keywords Product development, Product management, Resources, Critical thinking, Business-to-business marketing

Paper type Conceptual paper

Introduction

In business-to-business markets, some market offerings (products, services, or combinations of products and services) are considered to be highly complex. Accordingly, in this article, we use market offerings and products interchangeably. Examples of business-to-business firms dealing with such products include those who market industrial machinery, electronics, transportation equipment, engineering services, and consulting services (Ghosh *et al.*, 2006; Kratochvil and Carson, 2005). For client firms, complex products have the potential to improve performance through increased efficiency and/or effectiveness. Specifically, complex products like business information networks, mainframe computers, super-server networks, telecommunication network management systems can provide client firms with competitive advantages. For supplier firms, such highly complex products can have great profit potential and, therefore, constantly require

them to look for potential sources of competitive advantage. Consequently, firms that are better able to develop complex products according to the specific needs of their client organizations have a competitive advantage in the marketplace.

However, what kinds of products are considered to be complex? The word "complex" is derived from Latin, wherein *plexus* means braided or entwined, from which *complexus*, meaning braided or entwined together, is derived (Mittleton-Kelly, 2003). Therefore, a complex market offering is conceptualized as a market offering that requires the entwinement of several components and, for development, involves a coordinated effort on the part of the firm's employees. Over the years, researchers in the field of marketing, management, and engineering have attempted to investigate issues that are relevant to developing complex products. However, there is a great disconnect among the efforts of the three research silos.

In marketing, except for the works of a few researchers who focused on complexity of products (e.g. Brossard, 1998; Fisher, 1976; Ghosh *et al.*, 2006; Lilien and Wong, 1984; Puri and Sashi, 1994; Shaw *et al.*, 1989; Webster, 1978; Wuyts *et al.*, 2004), research on complex market offerings remains relatively unexplored. Also, most research seems to approach complexity of products from the buying firms' perspective. However, there has been a fair amount of research on complex market offerings in other fields like engineering (e.g. Gann and Salter, 2000; Gil, 2007; Grote *et al.*, 2007; Hobday, 1998, 2000; Hofer and Halman, 2005; Wang and Zhang, 2008) and management (e.g. Braha and Bar-Yam, 2007; Danilovic and Browning, 2007; Ethiraj, 2007; Marshall and Brady, 2001; Mitchell and Singh, 1996; Novak and Eppinger, 2001; Oshri, Newell, and Pan, 2007; Paajanen, 2001; Singh 1997) that focuses on complex market offerings from the suppliers' perspective.

Furthermore, although there are certain communalities between management and engineering research streams, they remain in their silos and address product development from their respective perspectives. That is, where as most engineering research focuses on technical knowledge, subcomponents of complex products, and process tools for engineering design, management research focuses on managing the product development, organizational structure, policies, processes, and managerial decision tools. Therefore, the purpose of this article is to integrate these three research streams through a critical review to explore why some supplier firms are better than others in developing complex market offerings for client firms. In doing so, this article develops a conceptual framework and proposes several empirically testable research propositions.

The remainder of the article is organized as follows. First, we critically review the engineering, management, and marketing literature streams on complex products and identify and discuss issues that are fundamental to complex product development. Second, drawing from and integrating the three research streams, we propose a new conceptual framework that provides rationale for why some firms are better than others at developing complex products. Third, we conclude with the discussion of our article's implications for theory and practice.

Critical review of research on complex products in engineering, management, and marketing

The purpose of a critical review is to conduct an extensive review, identify lacunae, identify important themes and issues, synthesize concepts, revise relevant concepts, develop new concepts and conceptual frameworks, and/or develop a robust research agenda (Madhavaram, 2009). Lane *et al.* (2006) provide an example for using critical review to advance theory development. They conduct a detailed analysis of 289 papers on absorptive capacity from 14 journals to assess how the construct is utilized, identify

five critical assumptions that drive absorptive capacity research, and propose a model of absorptive capacity processes, antecedents, and outcomes. In this paper, we conduct a critical review for similar purposes, that is, we conduct thematic analyses to identify significant issues and propose a conceptual framework with empirically testable research propositions.

In conducting the critical review, we focused on literature that is relevant to complex product development and followed the following steps. First, using *EBSCOhost Research Databases* (both Academic Source Complete and Business Source Complete), we searched for articles with complex products in their titles. Second, we searched for articles using different combinations of keywords "complex products," "product development," and "customization." Third, we critically reviewed the resulting articles for issues that are important to developing complex products. During the critical review, we followed a chronological approach. That is, if two or more articles tackle the same issue, we discarded the later article(s) from our article database. In addition, any article that did not address either significant issues with reference to complex products or the development of complex products was discarded from the article database. Fourth, drawing from and researching further, some of the issues that were identified in our critical review, we developed a conceptual framework that addresses why some firms are better than others in developing complex products.

Our critical review of complex product research in engineering, management, and marketing literature streams reveals the following issues as being critical to the development and management of complex products: definition, internal and external complexity, product and process complexity, standardized to customized complex products continuum, component and process modularity, and operant resources. We summarize exemplars of significant research on complex products in engineering, management, and marketing research in Tables I-III.

Definition

Often, the definition of a concept provides foundation for subsequent conceptualization, theory development, and empirical testing. Therefore, the way researchers define complex products can significantly influence their research. There are multiple definitions of complex market offerings that are available in the literature. Drawing from the works of Weaver (1947), Simon (1969), Perrow (1984), and Scurcini (1988), the works of Mitchell and Singh (1996, p. 170) and Singh (1997, p. 340) define a complex product as "an applied system whose components have multiple interactions and constitute a nondecomposable whole." Singh (1997) further adds that three characteristics that are each necessary but insufficient can be extracted from the definition: complex products are systemic, have multiple interactions, and are nondecomposable. Singh (1997) elaborates on all three characteristics:

(1) the systemic characteristic means that a complex product comprises elemental units or components, usually organized in hierarchies of subsystems;

(2) the hierarchical structure causes the performance of each subsystem to be dependent on the performance of its components, while itself influencing and being dependent on the performance of higher-order systems, leading to multiple interactions; and

(3) the network of interactions leads to the nondecomposability characteristic of complex products, as a complex product cannot be separated into its components without seriously degrading its capabilities or performance.

Source	Nature of research	Context	Specific contributions
Webster (1978)	Conceptual	Macro	Discussion of product complexity, functional interdependence, buyer-seller interdependence, and buying process complexity Application of management science techniques to business-to-business marketing
Shaw *et al.* (1989)	Empirical	Main-frame computer products	Results indicate that buyers of complex, technical products value intangible attributes more highly than functional product features Discussion of the preferences of client firms
Puri and Sashi (1994)	Conceptual	Computer integrated manufacturing	Discussion on understanding buyer behavior of complex products Discussion on facilitating buyer-seller interaction
Brossard (1998)	Empirical	Macro (nonprobablistic sample of 197 companies set up in Belgium, France, Ireland, and Switzerland)	Information sources used by firms in making decision about buying complex products Discussion on implications for supplier firms' promotion strategies
Wuyts *et al.* (2004)	Empirical	Vendors of integrated computer networks and manufacturers of hardware and software in the computer network market	Importance of relationships among buyers, intermediary vendors, and suppliers of complex products Strong ties facilitate the mobilization of support and the transfer of complex knowledge and weak ties facilitate the gathering of intelligence and the monitoring of new developments
Ghosh *et al.* (2006)	Empirical	Industrial machinery and equipment, electrical and electronic equipment, transportation equipment, and instruments and related products	Importance of customization to composing complex products Customization when the modularity is low and technological complexity is high Conclusion that the extent of vendor control over customization is a strategic choice

Table I.
Research exemplars in marketing on complex products

Source: Madhavaram (2009)

In the context of engineering, Hobday (1998):

- draws from research on military systems (Walker, Graham, and Harbor, 1988), the measurement of complexity of systems (Kline, 1990), large technical systems (Hughes, 1983), project management (Shenhar, 1994), and industrial organization (Woodward, 1958); and
- defines complex products under the rubric of "Complex Products and Systems" as high cost, engineering-intensive products, systems, networks, and constructs.

Source	Nature of research	Context	Specific contributions
Mitchell and Singh (1996)	Empirical	Hospital software systems	Definition of complex products Interfirm development-oriented and marketing oriented collaborative relationships are useful for businesses producing complex products
Singh (1997)	Empirical	Hospital software systems	Firms require multiple competencies in commercializing complex products Alliances moderate failure risks in commercializing complex products
Novak and Eppinger (2001)	Empirical	Firms in auto industry in Japan, Europe, and the USA	Product complexity and vertical integration of supply chain provide complimentary benefits to firms Facilitation of buyer-seller interaction
Paajanen (2001)	Conceptual	Macro	Defining complex products in terms of internal and external complexity Discussion of the importance of competence and knowledge management for developing complex products
Braha and Bar-Yam (2007)	Empirical	Large-scale firms in the USA and England	The importance of organizational network structures for complex product development The importance of organizational network in providing insight into improving strategic and operational decision making
Ethiraj (2007)	Empirical	Personal computer component industry	Interactions between components in a product systems condition the R&D incentives of firms Conclusion that modular design architectures, while contributing to accelerating the pace of technical change, also tend to limit the economic benefits of firm's component R&D efforts

Source: Madhavaram (2009)

Table II.
Research exemplars in management on complex products

Hobday (1998) notes that there are at least three significant differences between complex products and mass produced goods:

(1) complex products are comprised of many customized, interconnected elements that are organized in a hierarchical manner and tailored for specific customers and/or markets;

(2) complex products exhibit emergent properties during production, as unpredictable and unexpected events and interactions often occur during design and engineering; and

(3) complex products tend to be produced in projects or in smaller batches to allow for a high degree of direct user involvement.

Source	Nature of research	Context	Specific contributions
Hobday (1998)	Conceptual	Macro	Definition of complex products Discussion of dimensions of product complexity involving number of components, the degree of customization of both system and components, the number of design choices, elaborateness of system architectures, the range, and depth of knowledge and skill inputs required, and the variety of materials and information inputs
Hobday (2000)	Case study	Industrial equipment	Discussion on the strengths and weaknesses of project-based organization (PBO) and functional matrix organization
Gann and Salter (2000)	Case studies	Design, engineering, and construction firms	Discussion on the importance of knowledge of customer organizations, competences in specialized technical areas, and cross-sectional learning Discussion on how the integration of project and business processes makes firms more effective in developing complex products
Hofer and Halman (2005)	Case studies	Technology-driven firms	Recommendation that the employment of layout platforms, through the imposition of a dominant design on a product family, can lead to substantial complexity reduction and resultant competitive advantages
Sosa *et al.* (2007a)	Empirical	Aircraft engineering	The importance of coordination of technical interdependencies for the successful development of complex products The finding that component modularity and communication network structure are critical to the capabilities of teams developing complex products
Gil (2007)	Case studies	Airport terminal construction	Discussion on the importance and of project safeguards for highly modular, complex products

Source: Madhavaram (2009)

Table III.
Research exemplars in engineering on complex products

Although Hobday's (1998) conceptualization of complex product is similar to that of Singh's (1997), Hobday (1998) explicitly introduces the notion of customization into his conceptualization. The notion of customization can provide fresh perspectives to firms that look for potential sources of competitive advantages in developing complex products. Drawing from:

- the roots of the word complex (Mittleton-Kelly, 2003);
- the complex product literature; and
- the conceptualization of market offering (Hunt, 2000).

We define a complex market offering as a "hierarchical, nondecomposable set of highly entwined entities that are composed of complex bundles of attributes, which may be tangible and/or intangible, objective and/or subjective, and which may be viewed by customer(s) or client organization(s) as a want-satisfier."

Internal and external complexity

Recently, Paajanen (2001) noted that complex products often have two aspects to them: internal complexity and external complexity. While internal complexity refers to several interconnected systems that functionally depend on each other, external complexity refers to various configurable entities that provide options for customization. In the context of business-to-consumer complex products, given that there are huge gaps between knowledge levels of suppliers and consumers, firms could focus on external configurability in terms of simplification and customization as a strategy. That is, firms can simplify the external complexity and provide customization options. For example, the iPhone is a business-to-consumer complex product that is internally complex with fewer external, customizable options like color, cover, and accessories.

In the context of business-to-business complex products, client firms are often as knowledgeable as the supplier firms, if not more. For example, consider a firm that is involved in selling network solutions to software development firms. In this case, given that the knowledge levels of such suppliers and their vendors are similar, suppliers will have to focus equally on internal and external complexities and on customization. As Paajanen (2001) notes, as number of customers with reference to single, complex product, go from high to low, suppliers of business-to-business complex products will have to focus more and more on customization capabilities. That is, from a supplier's perspective, as the client firms' requirements become specific, suppliers should focus on pure customization and pay equal attention to internal and external complexities.

Product and process complexity

The complexity in the context of development is not limited to the product. It also involves the processes that are required for the development of complex products. The product itself is complex because, as Singh (1997) notes, complex product comprises elemental units or components, usually organized in hierarchies of subsystems and the hierarchical structure causes the performance of each subsystem to be dependent on the performance of its components, while itself influencing and being dependent on the performance of higher-order systems, leading to multiple interactions. The processes involved in the development of complex products are also complex because, as Hobday (1998) notes, complex products are comprised of many customized, interconnected elements that are tailored for specific customers and/or markets and complex products exhibit emergent properties during production, as unpredictable and unexpected events and interactions often occur during design and engineering. Therefore, firms focusing on reducing process complexity in developing complex products can potentially develop competitive advantages.

Standardized to customized complex product continuum

Not all complex market offerings in business-to-business markets need customization. For example, products such as high capacity computers, software packages such as SAS, though are complex, can be and are sold in a standardized form. However, there are certain business-to-business, complex market offerings that need customization because of the unique needs of buying firms. In the business-to-business marketplace, there are a number of complex market offerings that require customization. For example, business information networks, mainframe computers, super-server networks, telecommunication network management systems, business consulting services, custom marketing research, advertising campaigns, and so on. These market offerings are complex because of critical dimensions of the market offering, breadth of knowledge and skills required, and the degree of new knowledge involved in production. From the client's perspective, these market offerings might be important for a variety of reasons. By aiding in production and process requirement of client firms, strategic decisions, providing competitive analysis, or improving effectiveness, these market offerings may lead to clients' competitive advantages in the marketplace. Lampel and Mintzberg (1996) suggest that standardization and (pure)customization are not two alternative models of strategic action but, rather, are two ends of a continuum of strategies with segmented standardization, customized standardization, and tailored customization in the middle. Therefore, depending on where on the continuum the offerings of the suppliers fall, suppliers need to develop appropriate capabilities for developing complex products.

Component and process modularity

The concept of modularity is now informing complex products research (e.g. Kratochvil and Carson, 2005; Persson and Ahlstrom, 2006; Sosa *et al.*, 2004). For Sanchez (1999), an organization's knowledge architecture includes four essential and distinct kinds of knowledge:

(1) knowledge of how a given functionality may be decomposed into specific product and process functions;

(2) knowledge of how product and process components function;

(3) knowledge of how its product and process components interact in product and process architectures; and

(4) knowledge of how each component in its product architecture interacts with each process component in its process architecture as the organization creates and realizes products.

Sanchez (1999) claims that:

- modular architecture can be used as a flexible platform for leveraging a potentially large number of variations on a product concept; and
- mixing and matching modular components to leverage product variations also is used in processes for mass customization of products.

That is, modular architectures for products suggest the decomposability of products so that various combinations can be put together according to the needs and preferences of various customers. Further, modular architectures can support the configuration of customized combinations of component variations for individual customers, though not necessarily the customization of individual components for individual customers.

In sum, it is being suggested that developing process and product modularities can help firms in developing complex, business-to-business products. In fact, Sosa *et al.* (2004) show how process modularity can impact interdependencies across organizational and functional boundaries in the context of complex product development. However, as Ghosh *et al.* (2006) note, developing complex, customized products when modularity is low is difficult and resource intensive. That is, when the constituent subparts (components) of the product are not standardized and/or cannot be easily configured, it is difficult to develop such products modularly. In such cases, process modularity takes precedence over product modularity.

Social capital

As noted earlier, the nature of complex products requires the employees of the firm to work together in order to successfully develop complex products. As Ulrich and Eppinger (2008) and Clark and Fujimoto (1991) note, as products become more complex, the number of employees required for product development increases and relationships among employees become critical. In engineering literature, researchers (e.g. Hobday, 2000; Sosa *et al.*, 2007a, b) focus on the importance of relationships among the employees developing complex products. That is, internal social capital is critical to complex product development. Furthermore, according to Levitt (1981, 1983), relationships become critical when products are complex and are specific to customer needs. Ruyter *et al.* (2001) claim that the level of complexity with high technology products demands buyer-seller relationships based on long-term commitment and trust. Levitt (1983) also suggests that communication and ongoing relationship are essential in the context of technologically complex products. In fact, Maier *et al.* (2008) explored concurrent engineering in five empirical studies in the aerospace, automotive, and IT industries and concluded that coordination among many participants is critical to designing complex products.

In marketing literature on complex products, researchers (e.g. Puri and Sashi, 1994; Webster, 1978) have focused on external relations, that is, relationships between the firms developing complex products and external entities like buyers. In management literature, researchers (e.g. Mitchell and Singh, 1996; Singh, 1997) note that external relationships, with reference to suppliers and other alliance partners, are beneficial to firms developing complex products. Therefore, consistent with the premise that social capital can result in positive outcomes for firms (e.g. Szeto *et al.*, 2006), both internal and external social capital can contribute to the successful development of complex products.

Operant resources

In a recent, seminal article in marketing, Vargo and Lusch (2004) differentiated between *operand* resources (those on which an act or operation is performed) and *operant* resources (those that act on other resources), and recommended that firms should focus on specialized skills and knowledge as operant resources that provide competitive advantages. This view has its parallels in management's intellectual capital concept (e.g. Nahapiet and Ghoshal, 1998; Subramanium and Youndt, 2005). For Nahapiet and Ghoshal (1998), intellectual capital refers to the knowledge and knowing capability of a social collectivity, such as an organization, intellectual community, or professional practice, and represents a capability for action based in knowledge and knowing. Consistent with this view, several researchers in complex product literature (e.g. Hobday, 1998; Gann and Salter, 2000; Hofer and Halman, 2005; Paajanen, 2001; Singh,

1997) discuss the importance of knowledge, capabilities, and competences. Because of how Constantin and Lusch (1994) initially conceptualized operant resources, concepts such as competences, capabilities, and dynamic capabilities can be viewed as *operant* resources. Overall, given that operant resources can give potential competitive advantages, firms should actively seek, develop, and manage their operant resources. Therefore, it is important to identify operant resources that are relevant to the development of complex products.

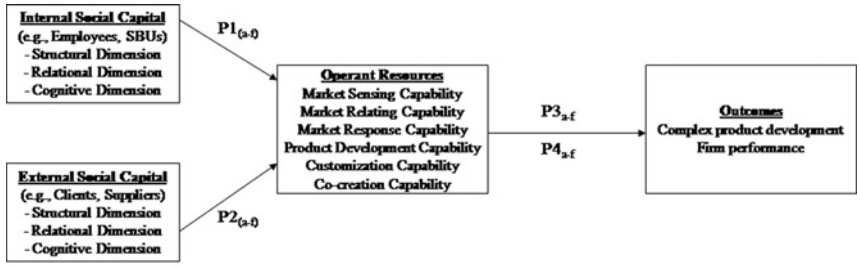
A conceptual framework for developing complex, business-to-business products

In this section, we integrate the complex product research streams in engineering, management, and marketing and draw from research on social capital, intellectual capital, and operant resources to develop a conceptual framework for developing complex, business-to-business market offerings. Research suggests that complex market offerings require collaboration efforts (Hobday, 1998; Moretti, 2003). In the context of developing complex market offerings, collaboration involves complex internal exchanges within the organization and complex external exchanges with entities external to the firm. Complex exchanges refer to a system of mutual relationships among at least three entities and the entire system may be organized by an interconnective web of relationships (Bagozzi, 1975; Lusch *et al.*, 1992). Hence, for collaboration, and therefore effective development of complex market offerings to take place in a firm, a firm needs a set of social resources embedded in internal relations (i.e. internal social capital) and external relations (i.e. external social capital). The conceptual framework (see Figure 1) is based on two premises:

(1) intellectual capital as captured in operant resources positively influences complex product development and firm performance; and

(2) internal social capital and external social capital positively influence firm's intellectual capital (operant resources).

In management literature, social capital has mostly been conceptualized as a multidimensional construct. The works of Nahapiet and Ghoshal (1998) and Tsai and Ghoshal (1998) conceptualize social capital as a multidimensional construct that can facilitate the development of intellectual capital. In the context of exploring the role of social capital in the creation of intellectual capital as having three facets: the structural, the relational, and the cognitive dimensions. Hence, it is proposed that social capital, as conceptualized by its three dimensions, is an antecedent to intellectual capital.



Source: Madhavaram (2009)

Figure 1.
A conceptual framework for developing complex, business-to-business products

Structural dimension

Drawing on Granovetter's (1992) discussion of structural and relational embeddedness, Nahapiet and Ghoshal (1998) note that structural embeddedness concerns the properties of the social system and of the whole network of relations. For Nahapiet and Ghoshal (1998), the structural dimension of social capital refers to the overall pattern of connections among actors. The structural dimension of social capital involves examination of the extent to which individuals in an organization are connected, description of the patterns of connections among employees, and the examination of the usefulness of such connections.

Relational dimension

For Nahapiet and Ghoshal (1998), the term "relational embeddedness" describes the kind of relationships people have developed with each other through a history of interactions (Granovetter, 1992). Therefore, the long-term relationships that people have with each other may prove beneficial as resources can be created and leveraged through relationships (Nahapiet and Ghoshal, 1998).

Cognitive dimension

According to Nahapiet and Ghoshal's (1998) conceptualization, the cognitive dimension of social capital refers to those resources providing shared representations, interpretations, and systems of meaning among parties (Cicourel, 1973). Noting that mainstream social capital literature has not yet addressed the cognitive dimension, Nahapiet and Ghoshal (1998) claim that the cognitive dimension is particularly important in the context of the creation of intellectual capital. Furthermore, for Nahapiet and Ghoshal (1998), mutual understanding among employees is achieved through the existence of a shared language. Therefore, the cognitive dimension of social capital concerns the degree to which employees possess a common language and share narratives.

Social capital theory suggests social capital to be a precursor to intellectual capital (e.g. Atuahene-Gima, 2002; Nahapiet and Ghoshal, 1998; Tsai and Ghoshal, 1998). Nahapiet and Ghoshal (1998, p. 245) use the term "intellectual capital" to refer to the knowledge and knowing capability of a social collectivity, such as an organization, an intellectual community, or a professional practice. Specifically, Tsai and Ghoshal (1998) suggest that social capital is a precursor to resource combinations (i.e. intellectual capital). As noted earlier, the intellectual capital view is similar to the operant resources concept. Therefore, internal social capital and external social capital that facilitate such resource combinations may help organizations develop operant resources that may in turn lead to competitive advantages. For example, Atuahene-Gima (2002) discusses firm's internal and external social capital as precursors to inter-firm market learning capability. For Atuahene-Gima (2002, p. 7), inter-firm market learning capability reflects a set of organizational routines or processes for acquiring, integrating, and exploiting inter-firm market knowledge. Atuahene-Gima's (2002) inter-firm market learning capability seems to be a specific form of intellectual capital (operant resource) that involves the ability of a social collectivity. As Hafeez and Essmail (2007) note, firms should focus on developing operant resources (competences) in order to achieve competitive advantages through innovative solutions. However, what specific operant resources are relevant to developing complex products? Our critical review revealed the following operant resources as being crucial to the development of complex products.

Market sensing capability

The first of the capabilities addressed is the firm's market sensing capability, the knowledge and skills associated with systematically gathering, interpreting, and using market information quicker and more effectively than competitors (Day, 1994). In the context of complex products development, most complex products combine components that draw from different knowledge bases. Gann and Salter (2000) note that complex products often require detailed knowledge about customer firms. In addition, firms also need knowledge of suppliers, competitors, and technological advances from the market (Wuyts *et al.*, 2004). Building on the internal social capital and external social capital issues discussed above, the most important influencer of market sensing capability is networking.

Market relating capability

Day (1999) identifies orientation, knowledge and skills, and integration and alignment of processes as the three elements of a market-relating capability. These three elements interact and reinforce each other. Therefore, firms can relate to the market better, if:

(1) a relationship orientation pervades the mindset, values, and norms of the organization;

(2) a firm continually deepens its knowledge of the customers and puts it to work throughout the organization; and

(3) the key processes are internally integrated and externally aligned with the corresponding processes of the firm's customers.

As Shaw *et al.* (1989) suggest, firms should be able to relate to the needs and preferences of client firms in order to be successful in the development of complex products. For Mitchell and Singh (1996), social capital reflected in collaborative relationships is paramount for suppliers to be product development-oriented and marketing-oriented with reference to client firms.

Market response capability

In the context of developing complex products, one particularly important operant resource is the firm's ability to respond to what they find in the market, such as the development of new market offerings by competitor firms, or a shift in the positioning of competitor firms, or a change in the competitor firms' market communications strategies. Furthermore, developing technical expertise and better understanding of the clients helps to add value to the development of complex market offerings. In responding to the competitors' actions, changing customer preferences, and new technological developments, firms can initiate the development of new capabilities and new marketing strategies. For example, if buyers of complex, technical products value intangible attributes more highly than functional product features (Shaw *et al.*, 1989), firms can use this knowledge and respond to the client firms through specific marketing strategies. In fact, as Low *et al.* (2007) suggest, responding to the market can prove synergistic with reference to firm's innovation activities.

Product development capability

Product development is at the heart of the firms that offer complex market offerings, their raison d'être. Drawing from Danneels (2002), product development capability requires the firm to have capabilities relating to technology and relating to customers.

While customer capability gives the firm the ability to serve certain customers, technological capability gives the firm the ability to design and manufacture complex market offerings. As complex product development is a process of linking firm's technology and customers, it requires bringing together the capabilities related to technology and customers. Furthermore, as noted earlier, firms focusing on reducing process complexity in developing complex products can potentially develop competitive advantages. Consequently, firms developing complex products should start focusing on modularizing design architectures (Ethiraj, 2007), developing appropriate organizational network structures (Braha and Bar-Yam, 2007), using project-based organization (Hobday, 2000), and developing the capabilities of relevant teams involved complex product development.

Customization capability

For Hobday (1998) the term "complex" is used to reflect the number of *customized* components, the breadth of knowledge and skills required, the degree of new knowledge involved, and the manner in which components are integrated together. Indeed, complex products are comprised of many *customized*, interconnected elements that are organized in a hierarchical manner and tailored for specific customers and/or markets. With reference to complex engineering products, Hayes and Wheelwright (1984) and Mowery and Rosenberg (1982) suggest that complex market offerings often need to be customized for specific customers. Accordingly, as Bayraktar *et al.* (2007) note, embracing customization as an organization-wide philosophy may prove beneficial. As Ghosh *et al.* (2006) note, customization becomes critical and complex when the modularity of complex products is low and technological complexity is high. Therefore, firms should start focusing on developing customization capabilities that make them more efficient and/or effective in customizing their complex market offerings.

Co-creation capability

Vargo and Lusch (2004) introduce the notion that firms are beginning to compete in an environment where the customer is always considered a co-creator. Therefore, if a firm is truly market oriented, then, it should develop a co-creation capability. In the context of developing complex products, given the issues with product complexity, functional interdependence, buyer-seller interdependence, and buying process complexity (Webster, 1978), developing co-creation capabilities could be a potential strategic option. As Hobday (1998) notes, user involvement in complex product innovation is high and suppliers and clients work together in developing complex products. Furthermore, as complex products are often costly, have the potential to increase the profitability and competitive advantages of client firms, specific to the needs and preferences of client firms, require resource intensive efforts from suppliers, co-creation could potentially reduce the burden of suppliers and clients and make the process of developing complex products more efficient and/or effective. Also, this potentially can help supplier firms in their innovation efforts. Consistent with this view, recently firms such as GE HealthCare have even encouraged users to alter their products so that they can be made better (Kroll, 2006).

In conclusion, our conceptual framework rests on two foundational premises:

(1) firm's intellectual capital (operant resources) can make it better than competitors in developing complex market offerings; and

(2) internal social capital and external social capital are precursors to the firms' intellectual capital.

First, specifically, for Hunt (2000), a firm's comparative advantage in resources enables it to achieve superior performance through a position of competitive advantage in some market segment(s). That is, firms that have comparative advantages in intellectual capital (operant resources) such as market sensing capability, market relating capability, market response capability, product development capability, customization capability, and co-creation capability, can outperform competitors in developing complex market offerings in terms of well-developed complex products and overall, firm performance. Second, as Tsai and Ghoshal (1998) note, social capital, as captured in the structural, relational, and cognitive dimensions, is a precursor to intellectual capital. Also, our critical review establishes the importance of internal social capital and external social capital, for the development of complex products. Therefore, following our conceptual framework (see Figure 1), we formally present the following propositions.

$P1_{a\text{-}f}$. There is a positive relationship between the firm's internal social capital as captured in the structural, relational, and cognitive dimensions and its operant resources as characterized in market sensing capability, market relating capability, market response capability, product development capability, customization capability, and co-creation capability.

$P2_{a\text{-}f}$. There is a positive relationship between the firm's external social capital as captured in the structural, relational, and cognitive dimensions and its operant resources as characterized in market sensing capability, market relating capability, market response capability, product development capability, customization capability, and co-creation capability.

$P3_{a\text{-}f}$. There is a positive relationship between the firm's operant resources as characterized in market sensing capability, market relating capability, market response capability, product development capability, customization capability, and co-creation capability and complex product development.

$P4_{a\text{-}f}$. There is a positive relationship between the firm's operant resources as characterized in market sensing capability, market relating capability, market response capability, product development capability, customization capability, and co-creation capability and firm performance.

Discussion

This paper critically reviewed the complex products literature streams in engineering, management, and marketing; identified and analyzed definition, internal and external complexity, product and process complexity, standardized to customized complex products continuum, component and process modularity, and operant resources as important issues for the development of complex products; identified and discussed market sensing capability, market relating capability, market response capability, product development capability, customization capability, and co-creation capability as essential intellectual capital (operant resources) for developing complex products; and integrated the complex product research streams in engineering, management, and marketing and drew from research on social capital, intellectual capital, and operant resources to develop a conceptual framework. The proposed conceptual framework rests on the foundational premises that:

- intellectual capital (operant resources) can contribute to the development of complex products and firm performance; and

- internal and external social capital are precursors to intellectual capital (operant resources).

Implications for research

As the competition in the context of complex, business-to-business products evolves, firms should focus on specialized skills and knowledge as operant resources that can provide competitive advantages. Therefore, reflecting this evolution, research in complex products should also focus on operant resources. To some extent, there is evidence in the works of, for example, Hobday (1998), Gann and Salter (2000), Hofer and Halman (2005), Paajanen (2001), and Singh (1997), that complex product research is moving in the right direction. However, as noted earlier, often, research silos results in literature confounding the development of theory. This paper attempts to resolve this issue through a critical review and the integration of three different research streams. Also, the conceptual framework proposed in this paper can provide theoretical foundation for further research in this area. In addition, this paper identifies six specific operant resources that are critical to the development of complex products. Clearly, more needs to be done in terms of theoretical and empirical research with reference to the development of complex, business-to-business products. For example, researchers could:

- empirically test the proposed framework;
- identify other relevant operant resources; and
- critique the proposed framework and develop a new, more comprehensive framework.

Potential implications for practice

As this paper is conceptual in nature, to the extent that the framework can stand empirical scrutiny, there can be implications for practice. Therefore, here, we discuss some potential implications of the proposed framework for practitioners. As our framework details that:

- intellectual capital (operant resources) influences the development of complex products and firm performance; and
- internal social capital and external social capital are precursors to intellectual capital (operant resources).

Firms that develop complex products could focus on:

- developing the six operant resources that can help them become competent in developing complex products; and
- developing organizational structures and policies and providing an organizational environment that is conducive to developing robust internal and external social capital.

In summary, this paper provides a foundation for

- future researchers to investigate the development of complex, business-to-business products; and
- practitioners to approach the development of complex, business-to-business products from the perspectives of social capital and intellectual capital (operant resources).

References

Atuahene-Gima, K. (2002), "The social capital of the top marketing team, inter-firm market learning capability, and business performance: a test of a mediating model", MSI working paper series, Marketing Science Institute, Cambridge, MA.

Bagozzi, R.P. (1975), "Marketing as exchange", *Journal of Marketing*, Vol. 39 October, pp. 32-9.

Bayraktar, E., Jothishankar, M.C., Tatoglu, E. and Wu, T. (2007), "Evolution of operations management", *Management Research News*, Vol. 30 No. 11, pp. 843-71.

Braha, D. and Bar-Yam, Y. (2007), "The statistical mechanics of complex product development: empirical and analytical results", *Management Science*, Vol. 35 No. 7, pp. 1127-45.

Brossard, H.L. (1998), "Information sources used by an organization during a complex decision process", *Industrial Marketing Management*, Vol. 27, pp. 41-50.

Cicourel, A.V. (1973), *Cognitive Sociology*, Penguin Books, Harmondsworth.

Clark, K.B. and Fujimoto, T. (1991), "Heavyweight product managers", *The McKinsey Quarterly*, Vol. 1, pp. 42-60.

Constantin, J.A. and Lusch, R.F. (1994), *Understanding Resource Management*, The Planning Forum, Oxford, OH.

Danilovic, M. and Browning, T.R. (2007), "Managing complex product development projects with design structure matrices and domain mapping matrices", *International Journal of Project Management*, Vol. 25, pp. 300-14.

Danneels, E. (2002), "The dynamics of product innovation and firm competences", *Strategic Management Journal*, Vol. 23, pp. 1095-121.

Day, G.S. (1994), "The capabilities of market-driven organizations", *Journal of Marketing*, Vol. 58 October, pp. 37-52.

Day, G.S. (1999), "Managing market relationships", *Journal of the Academy of Marketing Science*, Vol. 28 No. 1, pp. 24-30.

Ethiraj, S.K. (2007), "Allocation of inventive effort in complex product systems", *Strategic Management Journal*, Vol. 28, pp. 563-84.

Fisher, L. (1976), *Industrial Marketing: An Analytical Approach to Planning and Execution*, Business Books, London.

Gann, D.M. and Salter, A.J. (2000), "Innovation in project-based, service enhanced firms: the construction of complex products and systems", *Research Policy*, Vol. 29, pp. 955-72.

Ghosh, M., Dutta, S. and Stremersch, S. (2006), "Customizing complex products: when should the vendor take control?", *Journal of Marketing Research*, Vol. 43 November, pp. 664-79.

Gil, N. (2007), "On the value of project safeguards: embedding real options in complex products and systems", *Research Policy*, Vol. 36, pp. 980-99.

Granovetter, M.S. (1992), "Problems of explanation in economic sociology", in Nohria, N. and Eccles, R. (Eds), *Networks and Organizations: Structure, Form and Action*, Harvard Business School Press, Boston, MA, pp. 25-56.

Grote, C.A., Jones, R.M., Blount, G.N., Goodyer, J. and Shayler, M. (2007), "An approach to the EuP directive and the application of the economic eco-design for complex products", *International Journal of Production Research*, Vol. 45 Nos 18/19, pp. 4099-117.

Hafeez, K. and Essmail, E.A. (2007), "Evaluating organization core competences and associated personal competencies using analytical hierarchy process", *Management Research News*, Vol. 30 No. 8, pp. 530-47.

Hayes, R.H. and Wheelwright, S.C. (1984), *Restoring Our Competitive Edge: Competing Through Manufacturing*, John Wiley, New York, NY.

Hobday, M. (1998), "Product complexity, innovation and industrial organization", *Research Policy*, Vol. 26, pp. 689-710.

Hobday, M. (2000), "The project-based organization: an ideal form for managing complex products and systems?", *Research Policy*, Vol. 29, pp. 871-93.

Hofer, A.P. and Halman, J.I.M. (2005), "The potential of layout platforms for modular complex products and systems", *Journal of Engineering Design*, Vol. 16 No. 2, pp. 237-58.

Hughes, T.P. (1983), *Networks of Power: Electrification in Western Society*, Johns Hopkins University Press, London, pp. 1880-930.

Hunt, S.D. (2000), *A General Theory of Competition: Resources, Competences, Productivity, Economic Growth*, Sage Publications, Thousand Oaks, CA.

Kline, S.J. (1990), "A numerical measure for the complexity of systems: the concept and some applications", Report INN-5, Thermosciences Division, Department of Mechanical Engineering, Stanford University, Stanford, CA.

Kratochvil, M. and Carson, C. (2005), *Growing Modular: Mass Customization of Complex Products, Services, and Software*, Springer, Berlin.

Kroll, K.M. (2006), "Customer made", *American Way*, available at: http://americanwaymag.com

Lampel, J. and Mintzberg, H. (1996), "Customizing customization", *Sloan Management Review*, Vol. 38 No. 1, pp. 21-30.

Lane, P.J., Koka, B.R. and Pathak, S. (2006), "The reification of absorptive capacity: a critical review and rejuvenation of the construct", *Academy of Management Review*, Vol. 31 No. 4, pp. 833-63.

Levitt, T. (1981), "Marketing intangible products and product intangibles", *Harvard Business Review*, Vol. 59 No. 3, pp. 94-102.

Levitt, T. (1983), "After the sale is over", *Harvard Business Review*, Vol. 61 No. 5, pp. 87-93.

Lilien, G. and Wong, M.A. (1984), "An exploratory investigation of the structure of the buying center in the metal working industry", *Journal of Marketing Research*, Vol. 21 February, pp. 1-11.

Low, D.R., Chapman, R.L. and Sloan, T.R. (2007), "Inter-relationships between innovation and market orientation in SMEs", *Management Research News*, Vol. 30 No. 12, pp. 878-91.

Lusch, R.L., Brown, S.W. and Brunswick, G.J. (1992), "A general framework for explaining internal vs external exchange", *The Journal of Academy of Marketing Science*, Vol. 20 No. 2, pp. 119-34.

Madhavaram, S. (2009), "A critical review of complex product research: theoretical foundations, conceptual framework, and research agenda", working paper, Cleveland State University, Cleveland, OH.

Maier, A.M., Kreimeyer, M., Hepperle, C., Eckert, C.M., Lindeman, U. and Clarkson, P.J. (2008), "Exploration of correlations between factors influencing communication in complex product development", *Concurrent Engineering: Research and Applications*, Vol. 16 No. 1, pp. 37-59.

Marshall, N. and Brady, T. (2001), "Knowledge management and the politics of knowledge: illustrations from complex products and systems", *European Journal of Information Systems*, Vol. 10, pp. 99-112.

Mitchell, W. and Singh, K. (1996), "Survival of business using collaborative relationships to commercialize complex goods", *Strategic Management Journal*, Vol. 17, pp. 169-95.

Mittleton-Kelly, E. (Ed.) (2003), "Ten principles of complexity and enabling infrastructures", in *Complex Systems and Evolutionary Perspectives on Organizations – The Application of Complexity Theory to Organizations*, Elsevier Science, Oxford.

Moretti, G. (2003), "It takes many heads to design a product", *EDN*, Vol. 48 No. 7, pp. 56-62.

Mowery, D. and Rosenberg, N. (1982), "The commercial aircraft industry", in Nelson, R. (Ed.), *Government and Technical Progress: A Cross-Industry Analysis*, Pergamon, New York, NY.

Nahapiet, J. and Ghoshal, S. (1998), "Social capital, intellectual capital, and the organizational advantage", *Academy of Management Review*, Vol. 23 No. 2, pp. 242-66.

Novak, S. and Eppinger, S.D. (2001), "Sourcing by design: product complexity and the supply chain", *Management Science*, Vol. 47 No. 1, pp. 189-204.

Oshri, I., Newell, S. and Pan, S.L. (2007), "Implementing component reuse strategy in complex product environments", *Communications of the ACM*, Vol. 50 No. 12, pp. 63-7.

Paajanen, J. (2001), "Commercializing complex products", seminar study, Helsinki.

Perrow, C. (1984), *Normal Accidents: Living with High-Risk Technologies*, Basic Books, New York, NY.

Persson, M. and Ahlstrom, P. (2006), "Managing issues in modularising complex products", *Technovation*, Vol. 26, pp. 1201-9.

Puri, S.J. and Sashi, C.M. (1994), "Anatomy of a complex computer purchase", *Industrial Marketing Management*, Vol. 23, pp. 17-27.

Ruyter, K.D., Moorman, L. and Lemmink, J. (2001), "Antecedents of commitment and trust in customer-supplier relationships in high technology markets", *Industrial Marketing Management*, Vol. 30 No. 3, pp. 305-22.

Sanchez, R. (1999), "Modular architectures in the marketing process", *Journal of Marketing*, Vol. 63 special issue, pp. 92-111.

Scurcini, G.B. (1988), "Complexity in large technological systems", in Peliti, L. and Vulapni, A. (Eds), *Measures of Complexity*, Springer-Verlag, New York, NY, pp. 83-101.

Shaw, J., Giglierano, J. and Kallis, J. (1989), "Marketing complex technical products: the importance of intangible attributes", *Industrial Marketing Management*, Vol. 18, pp. 45-53.

Shenhar, A.J. (1994), "A new conceptual framework for modern project management", in Khalil, T.M. and Bayraktar, B.A. (Eds), *Management of Technology, IV*, Institute of Industrial Engineers, Orlando, FL.

Simon, H.A. (1969), *The Sciences of the Artificial*, MIT Press, Cambridge, MA.

Singh, K. (1997), "The impact of technological complexity and interfirm cooperation on business survival", *Academy of Management Journal*, Vol. 40 No. 2, pp. 339-67.

Sosa, M.E., Eppinger, S.D. and Rowles, C.M. (2004), "The misalignment of product architecture and organizational structure in complex product development", *Management Science*, Vol. 50 No. 12, pp. 1674-89.

Sosa, M.E., Eppinger, S.D. and Rowles, C.M. (2007a), "A network approach to define modularity of components in complex products", *ASME Journal of Mechanical Design*, Vol. 129 No. 11, pp. 1118-29.

Sosa, M.E., Eppinger, S.D. and Rowles, C.M. (2007b), "Are your engineers talking to one another when they should?", *Harvard Business Review*, November, pp. 133-42.

Subramanium, M. and Youndt, M.A. (2005), "The influence of intellectual capital on the types of innovative capabilities", *Academy of Management Journal*, Vol. 48 No. 3, pp. 450-63.

Szeto, R., Wright, P.C. and Cheng, E. (2006), "Business networking in the Chinese context: its role in formation of guanxi, social capital, and ethical considerations", *Management Research News*, Vol. 29 No. 3, pp. 425-38.

Tsai, W. and Ghoshal, S. (1998), "Social capital and value creation: the role of intrafirm networks", *Academy of Management Journal*, Vol. 41 No. 4, pp. 464-76.

Ulrich, K.T. and Eppinger, S.D. (2008), *Product Design and Development: A Resource for Students and Professionals in the Field of Product Design and Development*, 4th ed., McGraw Hill, New York, NY.

Vargo, S.L. and Lusch, R.F. (2004), "Evolving to a new dominant logic for marketing", *Journal of Marketing*, Vol. 68 No. 1, pp. 1-18.

Walker, W., Graham, M. and Harbor, B. (1988), "From components to integrated systems: technological diversity and integration between the military and civilian sectors", in Gummett, P. and Reppy, J. (Eds), *The Relations Between Defense and Civil Technologies*, Kluwer Academic, London.

Wang, H.W. and Zhang, H.M. (2008), "An integrated and collaborative approach for complex product development in distributed heterogeneous environment", *International Journal of Production Research*, Vol. 46 No. 9, pp. 2345-61.

Weaver, W. (1947), *The Scientists Speak*, Boni & Gaer, New York, NY.

Webster, F.E. (1978), "Management science in industrial marketing", *Journal of Marketing*, January, pp. 21-7.

Woodward, J. (1958), *Management and Technology*, Her Majesty's Stationery Office, London.

Wuyts, S., Stremersch, S., Van Den Bulte, C. and Hans Franses, P. (2004), "Vertical marketing systems for complex products: a triadic perspective", *Journal of Marketing Research*, Vol. 41 November, pp. 479-87.