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The Complementary Effect of Manufacturing Process Modularity and IS Flexibility on Agility in Manufacturing

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ABSTRACT

In the situation of shortened product life cycles, modular product design enables organizations to adapt to unanticipated changes in their environments. This study extends modular systems theory to manufacturing process design and posits that: (i) firms can design their manufacturing processes for the same product into either an integrated or modularized structure, thereby being agile in dynamic environments, and (ii) the effect of manufacturing process modularity on agility is complemented by information systems (IS) flexibility. Conceptually, this study explains how important the congruence between the IS and manufacturing processes is to achieving agility in manufacturing and seeks to demonstrate how an IS adapts to shape agility. For practice, this study suggests that firms should focus their efforts on both IS flexibility and manufacturing process modularity, as well as their harmonization, in addition to modular product design.

Keywords (Required)

Modularity, IS flexibility, Agility.

INTRODUCTION

Contemporary organizations face a more dynamic environment than ever before. To cope with continuously changing customer demands, unanticipated supply chain turbulence, and shortened product lifetime cycles, organizations must be able to adapt to such changing environments faster than competitors. Modular product design has been suggested as one effective strategy to be highly responsive (Baldwin et al. 1997; Mikkola et al. 2003; Sanchez et al. 1996; Schilling 2000). Through "mixing and matching" or replacing modular components, firms can innovate the product while minimizing product redesign costs. Also, the firm can ramp up production volume or reduce manufacturing cost by replacing its contract manufacturers/suppliers of modular components, without incurring painful switching costs.

However, modular product design is not a sufficient practice by itself for a firm dealing with environmental turbulence. Consider the all-in-one PC industry as an example. All-in-one PCs refer to one specific kind of desktop computer that has its main computer components integrated with the display. Generally, all-in-one PCs have customization options such as display size, processor, memory, hard drive, and graphics card, etc. In combination, there exist hundreds of possible customization configurations, which impose several challenges to the manufacturing process and the supply chain despite the modular product design.

First, the complex and numerous configuration options make demand unpredictable. Due to the difficulty of demand prediction, the only feasible manufacturing approach for companies in this industry is to manufacture after receiving orders. This strategy leads to the second challenge: the all-in-one PCs must be customized and delivered to customers within 2-3 days. Third, the manufacturing capacity must be able to ramp up in a very short time frame. The demand of all-in-one PCs fluctuates across the product life cycle and peaks at an amazingly high volume during the new product announcement period and holiday promotion events. Computer firms must be able to dramatically ramp up manufacturing capacity just weeks before the burst in demand, therefore being able to maintain minimum material and final-product inventory levels. The company that fails to ramp up its capacity will miss sale opportunities. Fourth, computer firms must be able to minimize the influence of supply chain turbulence on manufacturing. An all-in-one PC consists of hundreds of parts that come from dozens of suppliers. Inevitably, there will be occasional part shortage that threatens production, especially when some critical parts, such as the CPU, the memory, or the hard drive, are manufactured by one or few suppliers. Part shortages will result in production bottlenecks or, in the worst case, halted production lines. When facing such challenges, implementing modular product design is not enough. Instead, the company's supply chain should be agile enough to rapidly change over between different product assemblies in order to produce different product configurations.

Agility refers to the ability to detect and seize opportunities by assembling requisite assets, knowledge, and relationships with speed and surprise (Goldman et al. 1995; Sambamurthy et al. 2003). Research has continued to focus on how a company can design its manufacturing processes to achieve agility. Studies have focused on a manufacturing practice/tool perspective, such as various practices and tools to support design of manufacturing process, dynamic process planning, responsive production scheduling, material handling and storage, and facility layout (e.g., Zhang et al. 2007). However, these studies have not provided a holistic principle/rule that guides the design of manufacturing processes. In addition, although modular manufacturing processes have been argued to have influence on mass customization (Feitzinger et al. 1997) and strategic flexibility (Sanchez 1997), there has been little focus on its effect on manufacturing processes' adaptability to changing environments. This leads to the first research question that this study seeks to answer: *How does manufacturing process modularity enable agility in manufacturing?* To address this gap in literature, we introduce modular system theory and propose that manufacturing process modularity is the principle that a manufacturing process should be designed based on, and explain how it enables agility in manufacturing, which in turn influences operational performance.

Agility in manufacturing emphasizes multi-enablers' harmonization rather than their respective optimization (Yusuf et al. 1999). This harmonization requires a coevolutionary adaptation process between IT capability and other critical resources (Sambamurthy et al. 2003). To achieve agility, the technology underlying the manufacturing process should be flexible enough to change synchronously (Gunasekaran et al. 2002). If both manufacturing process modularity and IS flexibility have something to do with manufacturing process adaptability, how should these two be related to create synergy? This leads to the second research question that this study seeks to answer: *How does manufacturing process modularity and IS flexibility complement and contribute to agility in manufacturing?* To address this gap, we will draw on IS flexibility literature to argue that IS flexibility complements the effect of manufacturing process modularity on agility in manufacturing, which in turn strengthens operational performance.

THE CONCEPTUAL MODEL

Figure 1 presents the conceptual model. The key propositions are that (i) agility in manufacturing mediates the positive influence of manufacturing process modularity on operational performance; and (ii) IS flexibility enhances operational performance by strengthening the positive influence of manufacturing process modularity on agility in manufacturing. The definitions are summarized in Table 1.

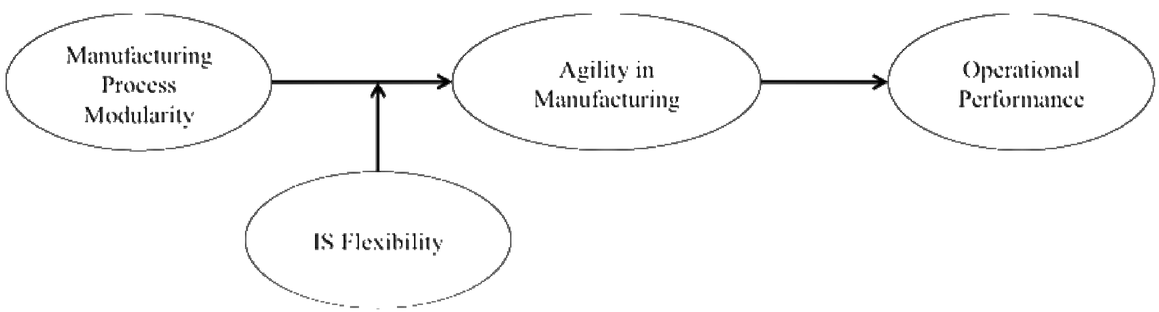

Figure 1: The Conceptual Model

Constructs	Definitions	Key References
Operational Performance	The extent to which the operations of the focal firm are superior relative to its direct competitors.	(Rai et al. 2006)
Agility in Manufacturing	The capability to reconfigure a manufacturing process to react quickly to unanticipated supply chain turbulence, while being highly responsive to changing customer demand.	(Gunasekaran et al. 2002; Sambamurthy et al. 2003; Zhang et al. 2007)
Manufacturing Process Modularity	The extent to which the focal firm's manufacturing processes can be decomposed into loosely coupled sub-processes that communicate through standardized interfaces.	(Tanriverdi et al. 2007)
IS Flexibility	The ability to quickly and economically adapt the IS applications to support changes in manufacturing processes.	(Kumar 2004; Nelson et al. 1998; Saraf et al. 2007)

Table 1: Definitions of Constructs

The rest of this paper proceeds as follows: In the next section, we introduce the concept of agility in manufacturing. Next, we introduce modular system theory and apply it to manufacturing process design, explaining how manufacturing process modularity enables agility in manufacturing. Then, IS flexibility is defined and its effect on the relationship between manufacturing process modularity and agility in manufacturing is proposed. The final part of this paper discusses this study's potential contributions and provides directions for future research. The key objective is to develop propositions and arguments that support the conceptual model in this study.

THEORETICAL DEVELOPMENT

Agility in Manufacturing

Agility has been recognized as conceptually distinct from flexibility. While flexibility has been studied as an internally focused competence, agility has been conceptualized as an externally focused capability (Braunscheidel et al. 2009; Swafford et al. 2006). As an external capability, agility emphasizes speed or responsiveness (Swafford et al. 2006), which is an outcome of organizational capabilities.

A number of definitions of agility have been given and the concept of agility has been modified for different study contexts. Nevertheless, as 'agile' implies, all those different definitions have a common focus on being able to thrive within an unanticipated and continuously changing environment, as well as being highly responsive to changes in customer demand by rearranging requisite resources (Goldman et al. 1995; Sambamurthy et al. 2003). Definitions of agility found in the literature range very broadly and imply that organizational agility involves several aspects of an organization.

The context of this study focuses on an organization's agility that emerges from its manufacturing process. Specifically, the purpose of this study is to investigate how an organization can be more agile by rearranging its manufacturing process in the presence of unanticipated supply chain and customer dynamics. Thus, in this study, *agility in manufacturing is defined as the capability to reconfigure a manufacturing process to react quickly to unanticipated supply chain turbulence, while being highly responsive to changing customer demands*. This definition shares some properties with the definitions in literature (Gunasekaran et al. 2002; Sambamurthy et al. 2003; Zhang et al. 2007) and has two key characteristics.

First, it addresses how an organization's manufacturing process for a specific product is designed and arranged to make the organization agile. Second, this definition makes it clear that turbulence arises from two sources: unanticipated supply chain problems and changing customer demand. This dynamic and turbulent environmental requires the ability to reconfigure manufacturing processes for short-lived opportunities and not just for product design modularity.

Modular Systems Theory

The concept of modularity is grounded in Simon's system perspective (1962) that every complex system (e.g., an organization, a product, or a process) can be decomposed into a hierarchy of subsystems that interrelate with each other. Here "hierarchical subsystems" mean that each system, or its components, can be decomposed into subsystems, which in turn consist of interrelated subsystems until the very basic unit is reached. Modularity is used to describe a specific interrelated structure among subsystems. *Modularity refers the degree to which a system can be decomposed into loosely coupled components with standardized interfaces* (Baldwin et al. 1997; Salvador 2007; Sanchez et al. 1996).

Two attributes describe the degree of modularity: interface standardization and loose coupling. Interfaces describe the relationships between components, specifying the materials and information for input and output, as well as how components interact. A standardized interface refers to an interface that is not permitted to change when modifying or substituting a component until new standard is established (Baldwin et al. 1997; Sanchez et al. 1996). A modular system architecture consists of a complete set of component interfaces, which essentially specifies what components are included in the system, their roles in the system, and how they interact to operate aggregately as an integrated whole (Baldwin et al. 1997; Sanchez et al. 1996).

Interface standardization is a necessary but insufficient condition to achieve modularity (Sanchez et al. 1996; Tanriverdi et al. 2007). In addition to standardized interfaces, another condition key to modularity is loose coupling among components. Loose coupling refers to the degree to which a change in one component requires compensating changes in another component (Sanchez et al. 1996). A perfectly loosely coupled structure exists when each component in the system is designed to be highly internally cohesive, meaning functionally complete and operationally independent, so that all the components within the system are loosely coupled with each other (Baldwin et al. 1997; Ethiraj et al. 2004; Mikkola et al. 2003; Salvador 2007; Sanchez et al. 1996).

Modular systems are thought to be highly flexible in changing environments (Baldwin et al. 1997; Sanchez et al. 1996; Schilling 2000). Modularity maintains this advantage in two ways. First, by maintaining the standardized interface, the hidden operating logic within a component can be freely modified without having disruptive effects on other components of the same system. Since the interface is the only requirement for a component to interact with other components, there is much freedom when designing the operation logic of the component (Salvador 2007). In other words, by keeping a standardized interface unchanged, a component's operation logic can be modified to any extent and the component can still seamlessly interact with other components. In essence, using a standard interface guarantees that modified components can collaborate with other components without loss of functionality.

Second, a modular system can maintain its flexibility by "mixing and matching" part of its components to perform different functions. Since a component interacts with other components through its pre-defined interface, the component can work as usual with any component as long as it obeys the specifications of the interface. Therefore, a modular system could have more variations and thus be more adaptable to environmental changes by "mixing and matching" existing components (e.g., substituting some specific components that better fit the new environment) to form a new system without redesigning all components in the system (Sanchez et al. 1996; Schilling 2000).

Manufacturing Process Modularity, Agile Manufacturing, and Operational Performance

Tanriverdi et al. (2007) conceptualized business process modularity and studied its impact on firms' sourcing choices. For this study which investigates the effect of modular design in manufacturing processes, we modified Tanriverdi et al.'s definition of *manufacturing process modularity as the extent to which the focal firms manufacturing process can be decomposed into loosely coupled sub-processes that communicate through standardized interfaces.* Manufacturing process modularity enables the reconfigurability of a manufacturing process (Gunasekaran et al. 2002; Yusuf et al. 1999), or in other words, agility in manufacturing, through four mechanisms.

First, if manufacturing process is modularly designed to be loosely coupled with other processes, meaning that the number of other processes needed for the process to be executed is minimized, the process can be executed independently without needing to exchange feedback from too many other processes (Sanchez et al. 1996). In this manner, the environmental disturbances (such as part shortage) or changing requirements (such as specification improvements) can be localized within specific processes (Sanchez et al. 1996). A temporary breakdown of one process will not cause the whole manufacturing process to fail – other loosely coupled processes can continue to operate concurrently therefore increasing agility in manufacturing.

Second, standardized process interfaces and a loosely coupled process architecture allow a process to be improved autonomously within the process. Because the standardized interface specifies all the information needed for interactions and the range of variations of inputs and outputs, process innovation can be carried out autonomously (without involving other processes) through individual process experiments (Sanchez 1997). Manufacturing process modularity can therefore improve agility by adapting to new requirements and incorporating new technologies in continuous and concurrent process improvement.

Third, since a modular architecture allows the "mixing and matching" of modules to provide different functionalities (Sanchez et al. 1996; Schilling 2000), modular manufacturing processes can be reconfigured as a response to supply chain turbulence or changing requirements. For example, a modularized manufacturing process that is designated to be loosely coupled can minimize the impacts of part shortage. Because the number of linkages required for operation is minimized, the process can be re-organized to be carried out concurrently (Sanchez 1997). In the scenario where customer requirements change continuously, modular manufacturing processes can be reordered and postponed to provide new customized products (Feitzinger & Lee, 1997). In this way, existing processes and facilities can be reused, operators do not need to be retrained, and manufacturing speed need not be rebuilt from zero.

Finally, a modularized manufacturing process can be delegated to other agents to reengineer the entire supply chain. Because the information and quality needed for agents to work is fully specified and standardized, and the interaction parameters are minimized because of loosely coupled architecture design, manufacturing processes can be delegated to other organizations for flexibility and lower costs (Baldwin et al. 1997). Likewise, the final assembly processes for customization can be postponed and extended into a near-market distribution center resulting in a more responsive manufacturing network (Tu et al. 2004).

Operational performance refers to the extent to which the operations of the firm are superior relative to its direct competitors (Rai et al. 2006). If an organization is agile enough in its manufacturing processes when facing supply chain turbulence, the organization can rearrange its manufacturing processes to operate concurrently, minimizing idle equipment and avoiding wasting capacity. In dealing with changing requirements, the agile organization can seize opportunities faster than its competitors by implementing new technology or bursting up capacity. Therefore, agility in manufacturing enables the organization to achieve higher operational performance.

Based on these arguments, our first proposition is as follows.

> ***Proposition 1***. *Agility in manufacturing mediates the positive influence of manufacturing process modularity on operational performance.*

For example, in the all-in-one PC industry firms generally implement two distinct manufacturing practices simultaneously: integrated manufacturing and network manufacturing. The former is a tightly coupled, integrated process; the latter is a loosely coupled, modularized process. Both approaches have their respective advantages. The integrated manufacturing approach is designated to maximize manufacturing capacity while fulfilling dramatically increased demands with low inventory levels. Alternatively, the network manufacturing approach is designed to lower costs. In addition, the network manufacturing approach allows firms to response to markets rapidly and to be more resilient during part shortages. Indeed, firms harness these two approaches with different portfolios. The production of all-in-one PCs can easily switch between these two approaches. Specifically, whereas the integrated manufacturing approach is mainly utilized to cope with peaking demand during the product announcement period or promotion events, the network manufacturing approach is utilized throughout the ramp phase and the sustaining phase for lowering costs, reducing response times, and mitigating the negative effect of supply chain turbulence.

The integrated manufacturing approach is a tightly coupled manufacturing process even though the product is modular in design. The assembly line of all-in-one PCs can be divided into two categories: the process for common components and the process for customization. The process for common components assembles shared components, such as the LCD panel, the power-supply unit, the optical drive, etc. Alternatively, the customization process assembles optional components, like the hard drive, the motherboard, or the graphics card. The integrated manufacturing approach integrates the customization process along with the common component assembly processes in order to maximize capacity. Specifically, the sub-processes of these two processes are intermixed with one another in the most efficient order to maximize manufacturing capacity.

On the other hand, the network manufacturing approach demonstrates a system of loosely coupled sub-processes connected with standard process interfaces. This approach postpones the customization process and delegates it to its near-market local distribution centers rather than its main factory. In essence, the main factory that assembles the common components into the semi-product, and local distribution centers that customize the semi-product, manufacture collaboratively. The local distribution centers receives the customized components and *after* sales actually take place differentiates the products based on the semi-product builds. The main drawback of this approach is that the capacity drops to approximately one-half to two-thirds of the integrated manufacturing approach.

Although the demand fluctuates along the product life cycle, maybe peaking to four or five times the sustained demand within one week, with the integrated manufacturing approach the requisite capacity can be increased to catch the peaking demand just several days to one week ahead, thereby minimizing the final-product inventory level. Since the demand of the base configurations (without customized options) is relatively stable and predictable, most of them are manufactured *before* sales actually take place to replenish final-product warehouses.

However, the network manufacturing approach has several advantages over the integrated manufacturing approach. First, though the production cost of the network manufacturing approach is slightly higher than the integrated one, its lower shipping cost makes its total manufacturing cost lower than the other approach. Second, since the customization process takes place at local distribution centers, response time to market demands becomes quicker and more economic. Third, the negative impacts of part shortages can be mitigated. The integrated manufacturing approach, which intermixes the assembly of common and customization components, operates under the assumption that part supplies are stable and sufficient. In contrast, the network manufacturing approach distributes the risk to several assembly sites. If a part shortage occurs with the customization components, the main factory can attenuate the line-down threat by producing the semi-product. Alternatively, if a part shortage happens with the common components, though the main factory may halt its production line, the local distribution centers can keep on building based on semi-product inventory and continue to fulfill market demands.

IS Flexibility

In general, flexibility connotes the capability to incur relative small penalties when departing from one configuration to another (Carlsson 1989). In this paper, we draw from the literature and define *IS flexibility as the ability to quickly and* *economically adapt IS applications to changes in the manufacturing process* (Kumar 2004; Nelson et al. 1998; Saraf et al. 2007).

Gosain et al. (2004) showed that the cost of switching business partners can be lowered because when the IS is flexible enough to facilitate switching business partners quickly. In effect, IS flexibility can be regarded as the ideally flexible infrastructure that would support the continuous redesign of business processes (Duncan 1995). In the context of a manufacturing process, the IS must be able to be reconfigured in a very short time for new products or new assembly approaches which impose new information needs (Gunasekaran 1999). Specifically, to achieve agility in manufacturing, the IS should be reconfigurable for future unique customized requirements (Coronado et al. 2002).

For example, a manufacturing process with a modular design can innovate one of its modularized process for new customer requirements or concurrently operate several processes that are loosely coupled to each other for handling unanticipated shortages resulting from turbulence in the supply chain. Although the modular design of processes minimizes the making modifications to other processes, the new functionalities or improved performance from such local innovation or “mixing and matching” strategy would result in new information processing needs for planning and control purposes. These changes in the manufacturing process would alter the information needs for manufacturing planning and control purposes, such as the information needs for: controlling work-in-progress inventory, monitoring real-time production progress, managing resources for new process and capacity, and planning new production and corresponding shipment/supply schedule. Without the adapted IS, the new manufacturing process will be less efficient. We therefore expect that without a flexible IS can adapt to new processes quickly (by fulfilling new information needs), manufacturing process modularity can generate no value by reconfiguring new process in response to changes in the environment. This leads to the second proposition.

> ***Proposition 2***. *IS flexibility enhances operational performance by strengthening the positive influence of manufacturing process modularity on agility in manufacturing.*

DISCUSSION

This study seeks to explain how an organization’s manufacturing processes can be designed to be agile in a dynamic environment. A conceptual framework is proposed to describe the relationship between manufacturing process modularity and IS flexibility, and their effects on agility in manufacturing and operational performance. Rooted in modular systems theory, we illustrate how a manufacturing process with a modular design architecture is able to rapidly and efficiently adapt between different product assemblies thus enabling the manufacturing process to prosper in a turbulent environment. We also show how the flexibility of the underlying IS can complement the effect of a modular process structure on manufacturing agility. This research has several important contributions.

First, this study demonstrates that agility in manufacturing can be achieved through modular design in manufacturing processes. Research related to agility in manufacturing has mainly adopted a tool/practice view and ignored the effect of the design structure of manufacturing processes on agility.

Second, by emphasizing the modularity of processes, this study also contributes to the literature on modularity. By studying an organization’s strategic flexibility, research has shown that modular system theory explains the benefits of product design modularity. However, many studies seem to assume that a modular product architecture equates to a modular manufacturing process structure in terms of its effects on strategic flexibility. This study seeks to show how these two differ. Indeed, the manufacturing process for modularized products can be tightly coupled and integrated to maximize capacity when part supply is steady and customer requirements do not deviate from predictions. Alternatively, the manufacturing process can be loosely coupled so that it can operate concurrently to utilize capacity when part supply is unpredictable and unstable. Such modular process structures also allow the manufacturing process to response quickly to customer demands that require modifications in manufacturing processes.

Third, research has provided a list of resources critical to agility in manufacturing. However, those studies have not explained how the resources should be coordinated and harmonized to form a synergic effect on agility in manufacturing. Since contemporary manufacturing processes intermixed with the IS, this study proposes to investigate how the manufacturing process and the supporting IS should fit together to complement each other’s effect. Specifically, only if the IS that underlies the manufacturing process is flexible enough to support the reconfigured ‘mixed and matched’ process, can the organization benefit from its modular manufacturing process architecture.

CONCLUSION

When coping with dynamic environments, organizations should consider designing their manufacturing processes modularly. As a result, manufacturing process modularity can enable the organization’s agility in manufacturing, hence contributing to operational performance. This effect is complemented by IS flexibility. Therefore, in addition to modular product design, firms should focus their efforts on both IS flexibility and manufacturing process modularity, as well as their harmonization.

REFERENCES

1. Baldwin, C. Y., & Clark, K. B. (1997) Managing in an age of modularity, *Harvard Business Review*, 75, 5, 84-93.
2. Braunscheidel, M. J., & Suresh, N. C. (2009) The organizational antecedents of a firm's supply chain agility for risk mitigation and response, *Journal of Operations Management*, 27, 2, 119-140.
3. Carlsson, B. (1989) Flexibility and the theory of the firm, *International Journal of Industrial Organization*, 7, 2, 179-203.
4. Coronado, A. E., Sarhadi, M., & Millar, C. (2002) Defining a framework for information systems requirements for agile manufacturing, *International Journal of Production Economics*, 75, 1-2, 57-68.
5. Duncan, N. B. (1995) Capturing flexibility of information technology infrastructure: A study of resource characteristics and their measure, *Journal of Management Information Systems*, 12, 2, 37-57.
6. Ethiraj, S. K., & Levinthal, D. (2004) Modularity and innovation in complex systems, *Management Science*, 50, 2, 159-173.
7. Feitzinger, E., & Lee, H. L. (1997) Mass customization at Hewlett-Packard: The power of postponement, *Harvard Business Review*, 75, 1, 116-121.
8. Goldman, S. L., Nagel, R. N., & Preiss, K. (1995) Agile competitors and virtual organizations: Strategies for enriching the customer, Van Nostrand Reinhold, New York.
9. Gosain, S., Malhotra, A., & El Sawy, O. A. (2004) Coordinating for flexibility in e-business supply chains, *Journal of Management Information Systems*, 21, 3, 7-45.
10. Gunasekaran, A. (1999) Agile manufacturing: A framework for research and development, *International Journal of Production Economics*, 62, 1-2, 87-105.
11. Gunasekaran, A., & Yusuf, Y. Y. (2002) Agile manufacturing: a taxonomy of strategic and technological imperatives, *International Journal of Production Research*, 40, 6, 1357-1385.
12. Kumar, R. L. (2004) A framework for assessing the business value of information technology infrastructures, *Journal of Management Information Systems*, 21, 2, 11-32.
13. Mikkola, J. H., & Gassmann, O. (2003) Managing modularity of product architectures: toward an integrated theory, *IEEE Transactions on Engineering Management*, 50, 2, 204-218.
14. Nelson, K. M., & Ghods, M. (1998) Measuring technology flexibility, *European Journal of Information Systems*, 7, 4, 232-240.
15. Rai, A., Patnayakuni, R., & Seth, N. (2006). Firm performance impacts of digitally enabled supply chain integration capabilities, *MIS Quarterly*, 30, 2, 225-246.
16. Salvador, F. (2007) Toward a Product System Modularity Construct: Literature Review and Reconceptualization, *IEEE Transactions on Engineering Management*, 54, 2, 219-240.
17. Sambamurthy, V., Bharadwaj, A., & Grover, V. (2003) Shaping agility through digital options: Reconceptualizing the role of information technology in contemporary firms, *MIS Quarterly*, 27, 2, 237-263.
18. Sanchez, R. (1997) Preparing for an uncertain future: Managing organizations for strategic flexibility, *International Studies of Management & Organization*, 27, 2, 71.
19. Sanchez, R., & Mahoney, J. T. (1996) Modularity, flexibility, and knowledge management in product and organization design, *Strategic Management Journal*, 17, special issue, 63-76.
20. Saraf, N., Langdon, C. S., & Gosain, S. (2007) IS application capabilities and relational value in interfirm partnerships, *Information Systems Research*, 18, 3, 320-339.
21. Schilling, M. A. (2000) Toward a general modular systems theory and its application to interfirm product modularity, *Academy of Management Review*, 25, 2, 312-334.
22. Simon, H. A. (1962) The architecture of complexity, *Proceedings of the American Philosophical Society*, 106, 6, 467-482.

23. Swafford, P. M., Ghosh, S., & Murthy, N. (2006) The antecedents of supply chain agility of a firm: Scale development and model testing, *Journal of Operations Management*, 24, 2, 170-188.
24. Tanriverdi, H., Konana, P., & Ge, L. (2007) The choice of sourcing mechanisms for business processes, *Information Systems Research*, 18, 3, 280-299.
25. Tu, Q., Vonderembse, M. A., Ragu-Nathan, T. S., & Ragu-Nathan, B. (2004) Measuring modularity-based manufacturing practices and their impact on mass customization capability: A customer-driven perspective, *Decision Sciences*, 35, 2, 147-168.
26. Yusuf, Y. Y., Sarhadi, M., & Gunasekaran, A. (1999) Agile manufacturing: The drivers, concepts and attributes, *International Journal of Production Economics*, 62, 1-2, 33-43.
27. Zhang, Z. W., & Sharifi, H. (2007) Towards theory building in agile manufacturing strategy - A taxonomical approach, *IEEE Transactions on Engineering Management*, 54, 2, 351-370.