# Modularity, component outsourcing, and inter-firm learning


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**Modularization of product architectures is a strategy for managing complex design activities and production systems, and associated supply chain issues. It has wide-reaching implications, from design engineering to business strategy. With standardized interface specifications, component outsourcing is possible, both with respect to the division of tasks in functional specification and detailed engineering of a product architecture. However, failure at the system level could still take place if interface compatibility issues of the outsourced component with the rest of the system are not understood. Outsourcing creates a certain degree of supplier-buyer interdependence and possibilities for inter-firm learning. A study of Chrysler Jeeps WIPERs suggested that learning-by-failure from one product architecture cultivated closer cooperation between the supplier and Chrysler to solve technical problems as well as to be innovative in searching for the best technological solutions for future product architecture designs.**


## 1. Introduction

There is increasing evidence that makers of complex systems, such as automobile assemblers, are delegating more product development responsibilities to the suppliers (Baldwin and Clark, 1997; Clark, 1989; Clark and Fujimoto, 1991). The growing number of new technologies (e.g., intelligent transportation systems, electronic engine management systems, fuel cells, etc.) is giving some automotive suppliers more responsibility in designing not only discrete parts but also whole systems (Womack *et al.*, 1990). This coincides with the trend of multinational high-tech firms to reduce the number of suppliers in order to facilitate more effective purchasing and supplier management. For instance, in the early 1980s Xerox reduced its supply base from 5,000 to 400 suppliers, a 92% reduction. Chrysler, too, reduced its supplier base from 2,500 in the late 1980s to a lean, long-term nucleus of 300 (Dobler and Burt, 1996, p. 214). This drastic reduction of supplier base means that the assemblers have to find innovative ways to cooperate with suppliers, and to carefully devise product architecture strategies.

Firms are taking the relationship they share with their suppliers seriously (Mudambi and Helper, 1998; Sako and Helper, 1998). Some firms form partnerships and alliances with suppliers as a strategy for competitive advantage (Chiesa and Manzini, 1998; Gulati, 1998; Baily *et al.*, 1998; Parker and Hartley, 1997; Kamath and Liker, 1994; Dyer and Ouchi, 1993; Contractor and Lorange, 1988), while others tackle this challenge by involving their suppliers early in the product development phase (Baldwin and Clark, 1997; Bozdogan *et al.*, 1998; Dowlatshahi, 1998; Clark and Fujimoto, 1991; Clark, 1989; Dobler and Burt, 1996; Hsuan, 1999). A growing number of high-tech firms (such as consumer electronics, automotive electronics, and elevator manufacturing firms) have embraced new approaches, such as postponement and mass customization (Feitzinger and Lee, 1997; Pine, 1993; Duray *et al.*, 2000), to the management of their new product development (NPD), manufacturing, and supply chain management activities. In order to shorten NPD lead time, to introduce multiple product models quickly with new product variants at reduced costs, and to introduce many successive versions of the same product line with increased performance levels, these firms are pursuing modular design strategies.

In modular product design, the standardized interfaces between components are specified to allow for a range of variations in components to be substituted into a product architecture (Sanchez and Mahoney, 1996). The goal is to create a design that can serve as the basis for a number of product variations with different performance and cost characteristics (Sanchez, 1995). Modular product designs enable firms to increase specialization (Langlois, 2000), encouraging them to pursue specialized learning curves and increasing their differentiation from competitors (Schilling, 2000). When interfaces shared among components of a system become well specified, outsourcing decisions can be made accordingly with respect to a firm's long-term strategic planning. Deciding whether to outsource or to produce a component in-house has direct consequences in supplier management strategies. If outsourcing delegates more responsibility towards suppliers, how do firms enhance learning, not only within its own organization but also with its suppliers? How does outsourcing decisions impact the degree of supplier-buyer interdependence?

The literature reveals the increasing number of outsourcing practices by manufacturers (Quinn, 2000; Quinn and Hilmer, 1994) and how it influences the boundary of the firms (Veloso and Fixon, 2001; Monteverde and Teece, 1982; Bello *et al.*, 1999; Masten, 1984; Cox, 1996) and the degree of supplier-buyer interdependence (Sobrero and Roberts, 2002; Bozdogan *et al.*, 1998; Wasti and Liker, 1997; Mudambi and Helper, 1998; Sako and Helper, 1998; Dyer, 1997; Cox, 1996). One of the main purposes of outsourcing is to have the supplier assume certain classes of investments and risks, such as demand variability. Due to greater complexity, higher specialization, and new technological capabilities, outside suppliers can perform many activities at lower cost and with higher value added than a fully integrated company can. New production technologies have also moved manufacturing economies of scale toward the supplier (Quinn and Hilmer, 1994). On the other hand, outsourcing is also an important cause for the continuing loss of international competitiveness by Western firms (Bettis *et al.*, 1992). In order to cope with risks associated with outsourcing many firms have engaged in strategic partnerships and alliances with other firms as a strategy for competitive advantage (Chiesa and Manzini, 1998; Gulati, 1998; Baily *et al.*, 1998; Parker and Hartley, 1997; Kamath and Liker, 1994; Dyer and Ouchi, 1993). Firms form alliances in order to gain production efficiencies, to expedite access to technology, markets and customers, to promote organizational learning, to expand strategic competencies, and so on. It has been estimated that the annual growth rate in the number of alliances is around 25%, and yet approximately 60–70% of all alliances fail (Bruner and Spekman, 1998; Duysters *et al.*, 1998; Savona, 1992; Harrigan, 1988; Levine and Byrne, 1986).

The literature also emphasizes the importance of early supplier involvement in NPD as means to reduce the risks of outsourcing (Trent and Monczka, 1998; Bidault *et al.*, 1998; Wasti and Liker, 1997; Dowlatshahi, 1998). There are many advantages why a firm may involve suppliers in its NPD activities. For instance, supplier participation in NPD reduces project development lead times (Gupta and Souder, 1998; Clark 1989) and project costs (Kessler, 2000; Clark, 1989), improved perceived product quality (McGinnis and Vallopra, 1999; Ragatz *et al.*, 1997), and better manufacturability (Wasti and Liker, 1997; Swink, 1999). The early supplier involvement in NPD brings the supplier and the firm closer in sharing not only knowledge and learning, but technological risks as well. This allows the firm to reduce its supply base, and allocate more NPD responsibilities to the supplier.

The literature, however, does not help us understand the relationship between the complexity of the technology being outsourced and the degree of supplier-buyer interdependence at different levels of supply chain. Outsourcing can only be realized when a system can be decomposed in such a way that interfaces of the components are well specified and standardized, which is a central focus on modularization strategies. How a firm decides to decompose its system is dependent on the technological complexity of the system and its NPD capabilities as well as on the suppliers capabilities in developing the component at lower cost and faster lead times than by the firm itself. Product design and implementation of complex systems, such as automobiles, must be tightly coordinated (Monteverde and Teece, 1982). Product modularity strategies are influenced not only by a firm's idiosyncratic capabilities but also by other parties in the supply chain (e.g., suppliers, competitors, and customers), hence technological changes in components introduced by one supplier would certainly affect the performance of the system as a whole. Given the trend of increasing outsourcing activities by many high-tech firms, and increasing demand for product variety and customization, the supplier and the buyer have inevitably become more interdependent of one another.

The focus of this paper is to explore qualitatively the role of modularity in product architecture designs and how it impacts outsourcing decisions with respect to division of tasks in functional specification and detailed engineering. Taxonomy of types of components used in automotive industry (i.e., detailed-controlled, supplier-proprietary, and black-box parts) is applied to illustrate the relationship between modularity and component outsourcing as well as, to some extent, how it influences the degree of supplier-buyer interdependence and hence the amount of inter-firm learning. A case study on the development of a black box part, front-intermittent windshield wipers controller (WIPER), by a first-tier supplier for the first generation of Chrysler Grand Cherokee Jeeps is presented. The paper is organized as follows. First, a literature on modularity and product architecture is reviewed, followed by a discussion on component outsourcing. Second, the extent of inter-firm learning and supplier-buyer interdependence created from product architecture designs is elaborated. Next, the Chrysler Jeeps WIPER case is presented. Finally, the paper concludes with discussions and future research.

## 2. Modularity

In broadest terms, modularity is an approach for organizing efficiently the design and production of complex products and processes (Baldwin and Clark, 1997). Complex tasks are decomposed into simpler elements so that they can be managed independently and yet operate together as a whole. A motivation behind decomposition of a complex system into more manageable parts is to gain flexibility and cost savings through economies of scale. Modularity in terms of maximizing economies of scale through standardization of components was already practiced in the early 1900s. For instance, inspired by Taylor's idea of using standard components, in 1913 the Ford model T reduced assembly time from 12 to 1.5 hours (Hsieh *et al.*, 1997), hence creating the concept of mass production.

In addition to cost advantages, modularity also has positive impacts on a firm's specialization (Langlois, 2000; Fine, 1998), product variety (Sanchez and Mahoney, 1996; Schilling, 2000; Pine, 1993), new product development flexibility (Henderson and Clark, 1990; Sanchez, 1995; Muffatto, 1999; Christensen and Rosenbloom, 1995; Schilling, 2000; Baldwin and Clark, 1997; Sanderson and Uzumeri, 1997; Ulrich and Eppinger, 1995), and the number of compatible suppliers (Langlois, 1992, 2000; Langlois and Robertson, 1992; Morris and Ferguson, 1993; Tassey, 2000; Reed, 1996), to name a few. But, what kinds of sacrifices must a firm make in order to benefit from the advantages of modularization? How do firms translate modularity decisions into their product architecture designs?

From a system's perspective, modularity can be perceived as a continuum outlining the degree to which a system's components can be decomposed and recombined as well as the tightness of coupling between components and the degree to which the 'rules' of the system architecture enable (or prohibit) the mixing-and-matching of components (Schilling, 2000). Modularity permits components to be produced separately, or 'loosely coupled' (Orton and Weick, 1990; Sanchez and Mahoney, 1996), and used interchangeably in different configurations without compromising system integrity (Flamm, 1988; Garud and Kumaraswamy, 1993, 1995; Garud and Kotha, 1994). Modularity has been extensively applied in the organization of software and programming for managing complex systems (Vignone, 1980; Parnas *et al.*, 1985; Stone, 1985; Meyer and Lehnerd, 1997; Cusumano, 1997), but less well understood in the management of product architecture designs, and the role of component designs in outsourcing and related inter-firm learning. In this paper, modularity refers to a NPD strategy in which interfaces shared among components in a given product architecture become standardized and specified to allow for greater substitutability of components across product families (Mikkola, 2003).

## 2.1. Product architecture

Product architecture is the arrangement of the functional elements of a product into several physical building blocks, including the mapping from functional elements to physical components, and the specification of the interfaces among interacting physical components. Its purpose is to define the basic physical building blocks of the product in terms of both what they do and what their interfaces are with the rest of the device (Ulrich, 1995; Ulrich and Eppinger, 1995). Product architectures can vary from integral to modular. In integral product architectures, one-to-one mapping between functional elements and physical components of a product is non-existent, and interfaces shared between the components are coupled (Ulrich, 1995). Changes to one component cannot be made without making changes to other components. Integral architecture designs enhance knowledge sharing and interactive learning as team members rely on each other's expertise in designing the architecture. With integral product architectures, firms may be able to customize their products to satisfy each customer's particular needs. Costs of customized components tend to be high because improvement in functional performance of the system cannot be achieved without making changes to other components. As the interfaces of the customized components become standardized, alterations to product architecture can be localized and made without incurring costly changes to other components, making outsourcing possible. Conversely, modular product architectures are used as flexible platforms for leveraging a large number of product variations (Gilmore and Pine, 1997; Meyer *et al*., 1997; Robertson and Ulrich, 1998; Sanchez and Mahoney, 1996), enabling a firm to gain cost savings through economies of scale from component commonality, inventory, logistics, as well as to introduce technologically improved products more rapidly. Some of the reasons for product change include upgrade, add-ons, adaptation, wear, consumption, flexibility in use, and reuse (Ulrich and Eppinger, 1995). Modular architectures enable firms to minimize the physical changes required to achieve a functional change. Hence, outsourcing decisions are usually made concurrently with the design of modular product architectures, where specialization of knowledge is gained through division of labor.

Product configurations are rooted in product architecture designs. Issues related to system decomposition as well as the integration of disparate components into new innovations vis-à-vis how these components are linked to the rest of the product architecture can not be taken for granted. In other words, the degree of modularity inherent in product architectures is sensitive and dependent upon the constituent components and respective interfaces in relation to the system as a whole. Another element of modularity is the extent of economies of substitution of components across product families. According to Garud and Kumaraswamy (1993, p. 365) 'economies of substitution occur due to preservation

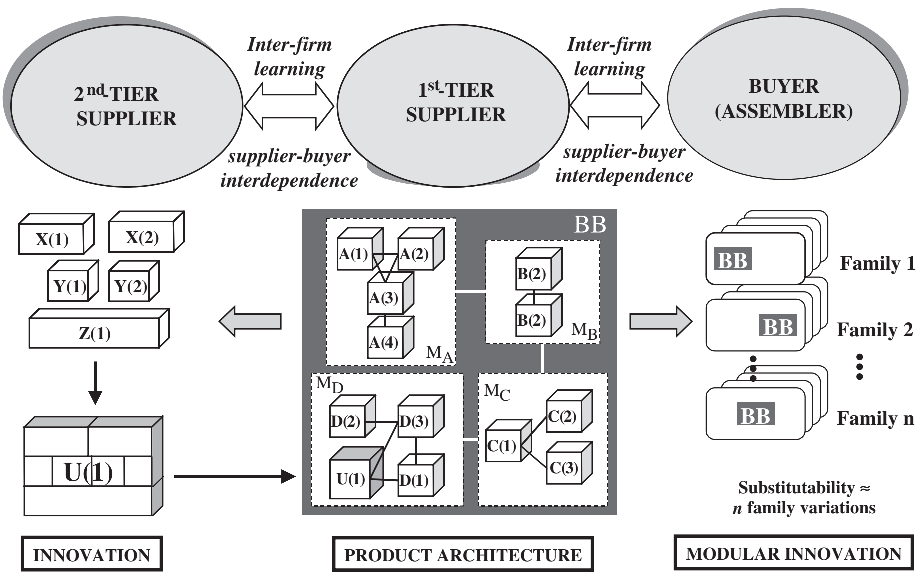


Figure 1. Product architecture's influence on innovation and supply chain.

 

and enhancement of existing knowledge through the use of standardized interface specifications and technological platforms with wide degrees of freedom'. We can interpret product architecture's influence on innovation and supply chain as follows (Figure 1). Suppose BB is a modular innovation, that is, an innovation that changes only the relationships between core design concepts of a technology without changing the product's architecture (Henderson and Clark, 1990; Christensen and Rosenbloom, 1995). BB is outsourced to a first-tier supplier, and can be decomposed into modules [$M_A$, $M_B$, $M_C$, and $M_D$] and components [A(n), B(n), C(n), D(n), and U(1)] connected via interfaces. These components can be developed in-house or outsourced. If outsourced, the second-tier supplier can decide the best combination of components [X(n), Y(n), and Z(n)] to produce the component(s) [e.g., U(n)]. For the buyer, the BB would be more valuable if it can be substituted and used across product families (*n*).

## 3. Component outsourcing

Outsourcing terminology means buying a part from another company rather than making it yourself (Womack *et al.*, 1990, p. 158). With outsourcing, a company enters into a contractual agreement with a supplier concerning supply of capacity that has previously been carried out in-house, hence shifting the ownership and decision rights of the outsourced function to the supplier (Momme *et al.*, 2000). When different components of a technological system require conceptually different kinds of knowledge, it makes sense to partition the system into modules that different members can manufacture in a distributed manner (von Hippel, 1994). As argued by Ernst and Kamrad (2000), the higher the level of modularization, the easier it is to outsource manufacturing or its constituent components.

Many firms are experiencing financial gains from outsourcing of non-core activities, as it holds down the unit costs and investment needed to produce products rapidly, and it frees companies to direct scarce capital to where they hold a competitive advantage. For example, in 1993 Dell Computers did not own plants but leased two small factories to assemble computers from outsourced parts. With savings in fixed costs, Dell takes in $35 per dollar of fixed assets, compared to $3 at Compaq (Tully, 1993). According to Garud and Kumaraswamy (1995), internalizing activities within a firm involves managerial and production costs. Managerial costs of coordination increase with the number of components produced in-house and with the number of stages required to produce a given component. Cognitive complexity faced by managers also increases, which at some point, becomes more costly for a firm to undertake any more activities in-house than it is to delegate them to others. In-house production costs increase when demand is low or uncertain, such as when the firm can not justify production facilities that operate at a minimum efficient scale for each component. In this view, managerial and production costs are key forces for the disaggregation of activities. Coincidently, many systemic industries are moving toward modular product architecture configurations with industry-wide standards, reducing asset specificity and small numbers bargaining (Garud and Kumaraswamy, 1995), hence progressively decreasing the transaction costs (Quinn, 1992). The combined effects of decreases in transaction costs, increases of managerial and production costs are prompting firms to focus on a set of conceptually related activities and outsourcing the rest (Demsetz, 1993; Langlois, 1992; Piore and Sabel, 1984; Richardson, 1972).

A firm should manage its business activities in relation to its capabilities and those of its potential partners (Barney, 1999), and such decisions are dependent upon how tasks are decomposed and specified. Furthermore, the efficiency of activity structure is contingent on the way the resources in the network are utilized. Available resources, residing both inside and outside the boundary of the firm, can be combined in new ways, thus introducing dynamics and innovation. Internal resources are part of a large resource constellation within the firm (Håkansson and Snehota, 1995) while external resources are spread over a number of suppliers and customers. Outsourcing and supplier involvement have made access to the resources of other firms as important as the resources acquired and deployed inside the firm (Gadde and Håkansson, 2001). Suppliers are considered as resource elements in the total supply structure of the buying company. There are four issues associated with this argument (Gadde and Håkansson, 2001):

1. Fitting supplier resources elements with the company's internal resources;
2. Division of labor among the parties and the design of the production facilities within the

company in relation to the complementary facilities of the supplier;
3. Mapping of products and services used and produced within the company, in which the most important interfaces must be identified and assessed in terms of potential development opportunities;
4. Matching relationships with other firms.

In a handful of literature, modularity is portrayed in light of strategic sourcing (Momme *et al.*, 2000), supplier-buyer co-involvement in NPD (Baldwin and Clark, 1997; Hsuan, 1999; Bozdogan *et al.*, 1998), and selling of modules and systems (Henke, 2000). Momme *et al.* (2000), for instance, discuss the concept of modular product architecture and strategic sourcing as a means to facilitate the integration of system suppliers in the supply chain. They argue that modularization can bring a firm's R&D activities closer to its supplier network due to shared knowledge contributions of technical and commercial innovations, and a modular product architecture may help to optimize and manage the supply chain. Furthermore, Baldwin and Clark (1997) argue that modularity shifts the responsibility to suppliers, hence promoting competition among module suppliers. For instance, many big car manufacturers involve their suppliers in the design of modules or the entire system. Concurrently, many automotive original equipment manufacturers (OEMs) are also moving towards the acquisition of integrated systems from their suppliers. This trend puts an enormous challenge on the suppliers of the OEMs to sell integrated modules or systems to the OEM strategically. Bozdogan *et al.* (1998) discuss this in their analysis of the dynamics of architectural innovation in product development over the supplier network. According to them, seamless information flows linking the customer with its suppliers, within the larger context of integrated product teams involving early supplier participation, facilitates innovation in product development. Henke (2000), furthermore, discusses some potential benefits and impediments to module/system acquisition by OEMs, and subsequent implications for developing a supplier sales strategy for selling modules and systems.

Many scholars predict that we are entering a new age of customization, in which new technologies, increased competition, and more assertive customers are leading firms toward customization of their products and services (Pine *et al.*, 1993; Gilmore and Pine, 1997; Kotha, 1995; Coates, 1995; Yovovich, 1993). Today, buyers want customized products in enormous quantities, and to get them as quickly as possible as standardized products (Gooley, 1998). This drive for gaining economies of scale concurrently with economies of scope has direct implications for technology choices embedded in product architecture designs and respective degrees of modularization. In the late 1980s, the three US automobile manufacturers outsourced many of their small models. About 38% of their mini-compact and sub-compact cars were outsourced (for Chrysler the number is almost 50%). By 1990 Chrysler and Ford directly produced only about 30% and 50% of the value of all their cars respectively, and General Motors bought about 50% of its total engineering and design services (Bettis *et al.*, 1992). These figures reflect on the total value of outsourcing activities, but they do not reveal how components vary in importance in relation to a firm's NPD strategies vis-à-vis suppliers' capabilities.

Decisions regarding to component outsourcing are derived from product architecture modularity, which in turn impacts the degree of supplier-buyer interdependence and subsequent amount of inter-firm learning. Supplier-buyer interdependence denotes the degree of supplier involvement in product development leading to capabilities benchmarking, trust development, and creation of inter-firm knowledge (Hsuan, 1999). Outsourcing decisions are made concurrently with the design of modular product architectures in which specialization of knowledge is gained through division of labor. Integral architecture designs, on the other hand, inhibit decomposition as knowledge sharing and interactive learning take place as team members rely on each other's expertise in designing the architecture. Next, a typology of outsourcing parts and their impact on the degree of supplier-buyer interdependence and inter-firm learning is provided.

### *3.1. Types of outsourcing components*

When the design team has given the 'green light' to start the development of a new component, the associated NPD activities and processes can be analyzed in three stages: planning, design, and production. The planning phase activities refers to the *functional specification* of the new product such as general product definition, lead time requirements, definition of interface specifications, platform/architecture design specifications,

 

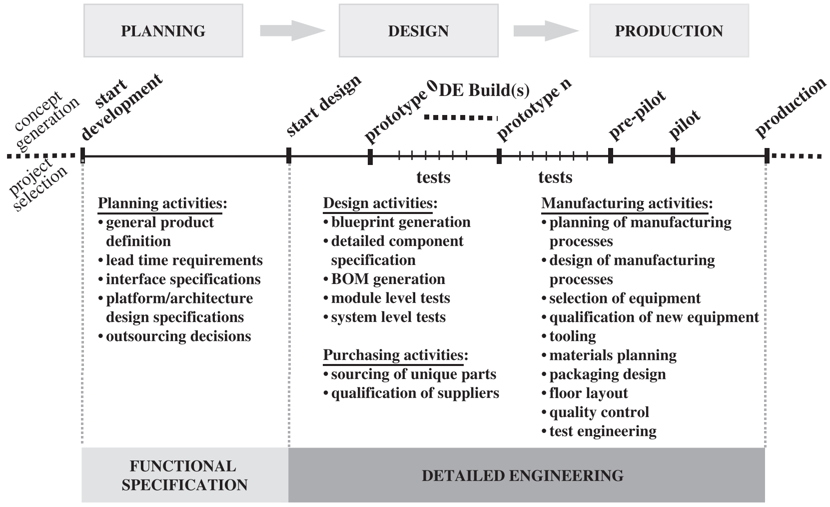


Figure 2. New product development activities.

and outsourcing decisions. The design and production stages are often referred to as the *detailed engineering* phase where bill of materials (BOM) and blue prints are generated, prototypes are built and tested, manufacturing processes and equipment are selected and qualified, and so on, as shown in Figure 2. Functional specification and detailed engineering are terminologies primarily used in the automotive industry (Clark and Fujimoto, 1991; Clark, 1989; Lamming, 1993; Womack *et al*., 1990).

A system producer basically faces three alternatives to manage the development of new components: in-house sourcing, outsourcing, or co-development. In co-development the supplier and buyer join forces (e.g., through mergers or consortia) to set industry standards or create new innovations. Co-development is justified when technologies are so expensive that individual firms cannot afford to develop them alone. In many cases firms join forces to create the technological synergy necessary for innovation. In developing an innovation the degree of interdependence depends on the proprietary sensitivity of the innovation as well as supplier management practices, which in turn, determines how responsibilities for functional specification and detailed engineering are split between the supplier and the buyer. In US automotive terminology, outsourced components can be classified as supplier proprietary parts, detail-controlled parts, or black-box parts. In Japan detail-controlled and black-box parts are called 'design-supplied' and 'design-approved' parts respectively (Asanuma, 1985).

*Supplier proprietary parts* are parts that are developed entirely by parts supplier including functional specification and detailed engineering (Clark, 1989). These parts are taken by the supplier from concept to production, and sold to assemblers through catalogue (Clark and Fujimoto, 1991). Often the assembler becomes dependent on supplier for availability, upgrades, and system integration. The supplier of these parts often shows dominance over the technological path of innovation in question, such as evidenced by Intel's and Microsoft's dominance in the PC market. These components often have well-specified and standardized interfaces, and supplier performance can be contracted *ex ante*. There is minimal investment in inter-firm knowledge sharing routines, suggesting low degree of supplier-buyer interdependence.

*Detail-controlled parts* are parts that are developed entirely by assemblers including functional specification and detailed engineering (Clark, 1989). Specialized suppliers are selected through inquiries and bids to take the responsibility for process engineering and production based on blueprints provided by the assemblers. Detailed-controlled parts are advantageous when an assembler wants to preserve detailed technological capabilities in a particular component area, tightly control component design quality, and preserve bargaining power with respect to supplier parts prices. However, detail work for numerous components can distract in-house engineering organization from its total system focus, not mentioning the assembler's risks of losing competitiveness relative to supplier engineering units that are more focused on specific component technologies (Clark and Fujimoto, 1991). With detail-controlled components, the assembler is dependent on the supplier to deliver the part built to the exact specifications. After supplier selection from the bidding process, the assembler gets involved with supplier's manufacturing, purchasing, and distribution practices. Typically an engineer (from the supplier) is assigned to handle design-for-manufacturability, prototyping, and testing issues. This way the supplier learns about the assembler's product development process and technological advancements. The engineer serves as a liaison between supplier and assembler, creating certain amount of interdependence.

*Black-box parts* are those parts whose functional specification is done by assemblers while detailed engineering is carried out by parts suppliers (Clark, 1989). The development work of black-box parts is split between the assembler and the supplier. Typically, assembler's responsibilities include generating costs/performance requirements, exterior shapes, interface details, and other basic design information based on the total vehicle planning and layout. Black-box parts enable assemblers to utilize supplier's engineering expertise and manpower while maintaining control of basic design and total system integrity. To the supplier, the accumulation of engineering expertise becomes its competitive edge. Prototypes and production parts exchange is a source for facilitating knowledge exchange between the supplier and the assembler (Clark and Fujimoto, 1991). Added value can be attained when supplier and assembler are willing to collaborate in solving technical problems, especially in resolving interface compatibility issues when new technological solutions are created and patents attained. The higher the technical complexity of a black box part, the more necessary it is for the supplier to become involved in the assembler's engineering activities. This is especially crucial when supplier and buyer's product and process technologies become more interdependent. This supplier-buyer interdependence leads to inter-firm learning as both parties rely on each other's expertise to ensure successful introduction of the innovation into the market.

A comparative assessment of supplier involvement in automotive design with respect to supplier-proprietary parts, detailed-controlled parts, and black-box parts portrays a striking difference in component outsourcing practices and degree of supplier buyer interdependence in Japan, America, and Europe, as shown in Table 1

Table 1. Supplier involvement in automotive design.

| | Japan | America | Europe |
|---|---|---|---|
| Supplier proprietary parts (%) | 8 | 3 | 7 |
| Detail-controlled parts (%) | 30 | 81 | 54 |
| Black box parts (%) | 62 | 16 | 39 |

(adapted from Clark and Fujimoto (1994, p. 145), Womack *et al.* (1990, p. 157), and Lamming (1993)). The North American suppliers rely on detail-controlled parts as a means for supplier involvement in product development. The Japanese, on the other hand, delegate more development responsibility to the suppliers in the form of black-box parts.

Typical information flows with parts suppliers are illustrated in Figure 3, adapted from Clark and Fujimoto (1991, p. 141). Platform and architecture planning takes place at the vehicle concept stage. Although Clark and Fujimoto's model focus on car manufacturers' relationship with first-tier suppliers, the same model can also be used to describe the information flows between the first-tier manufacturers with their suppliers.

## 4. Inter-firm learning

Learning is triggered by problem solving strategies stimulated by gaps between potential and effective performance (von Hippel and Tyre, 1994), and it is originated from the activities undertaken by people (Leonard-Barton, 1995) in conditions of uncertainty, complexity, and conflict (Amit and Shoemaker, 1993) and requires social interaction for the continuous conversion of tacit and explicit knowledge (Nonaka, 1994). Learning is a process that takes place continuously in a highly adaptive and interactive manner (Imai *et al.*, 1985). While, intra-firm learning is concerned with learning dynamics internal to the firm (e.g., cross-functional activities, job rotation, training, etc.), inter-firm learning deals with learning gained between the firm and other firms within the supply chain (e.g., customers and suppliers). As Imai *et al.* (1985, p. 351) so clearly state that 'the loose coupling of [project] phases also makes division of labor, in the strict sense of the word, ineffective. Division of labor works well in a [decoupled] system where the tasks to be accomplished in each phase are clearly delineated and defined. ... Under a loosely couple system,

 

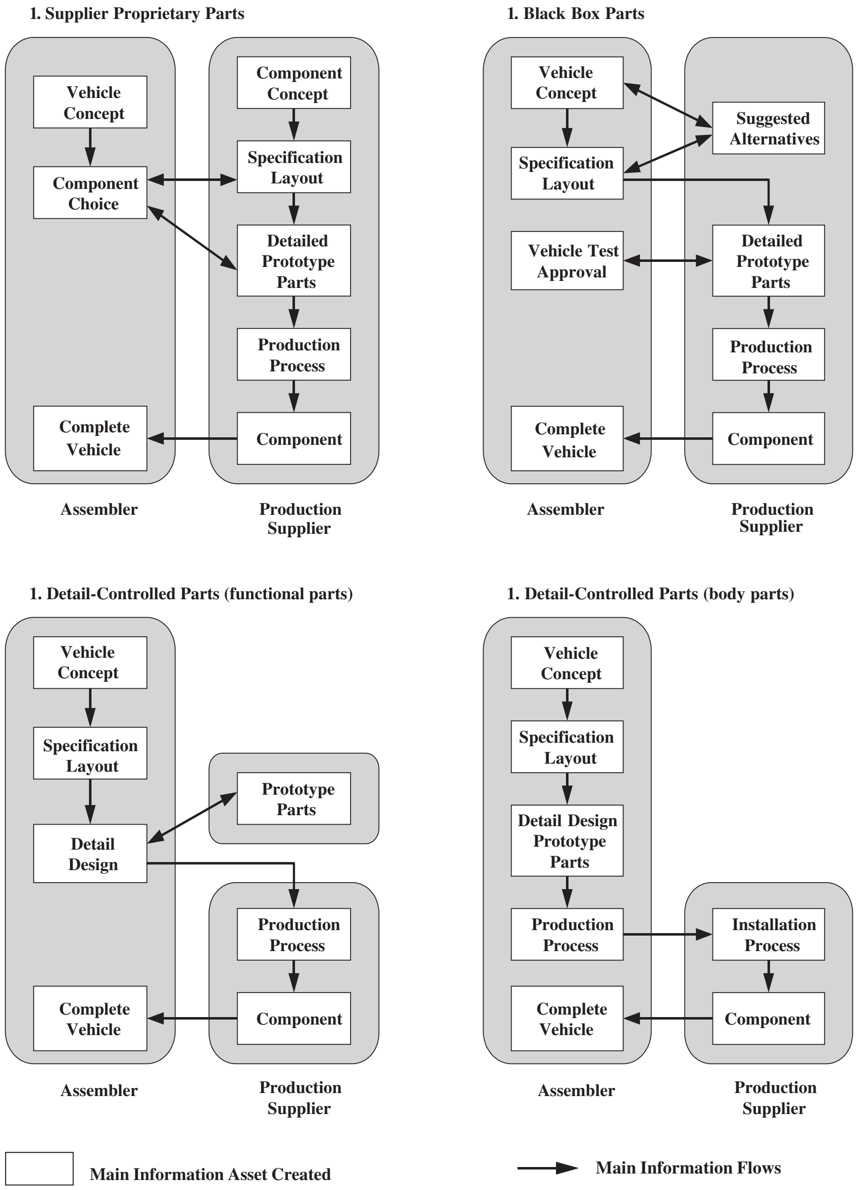


Figure 3. Typical information flows with parts suppliers.

then, the tasks can only accomplished through … "shared division of labor" … [which] takes place not only within the company but also with outside suppliers.'

The modular product architecture approach has direct implications for task partitioning (von Hippel, 1990) and self-organization (Imai *et al.*, 1985), consequently altering outsourcing strategies and the extent of learning harvested between firms. Modular product architectures require that interfaces shared amongst components to be loosely coupled, hence promoting competition among suppliers, as they possess specialized expertise to innovate independently and deliver the best technological solutions to enhance performance of the system. This division of tasks between the firm and its suppliers creates certain degree of supplier-buyer interdependence, hence influencing the degree of inter-firm learning. The degree of inter-firm learning varies with the degree of component modularity. The higher the component modularity the less the inter-firm learning is expected to take place between suppliers and buyers. For example, commodity parts can be bought from numerous suppliers where specifications are well defined and specified. Commodity parts are off-the-shelf parts providing limited value to the overall product

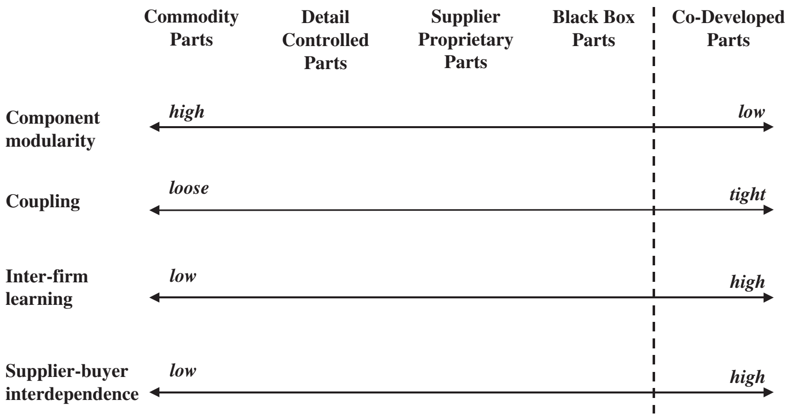


Figure 4. Characteristics of component outsourcing.

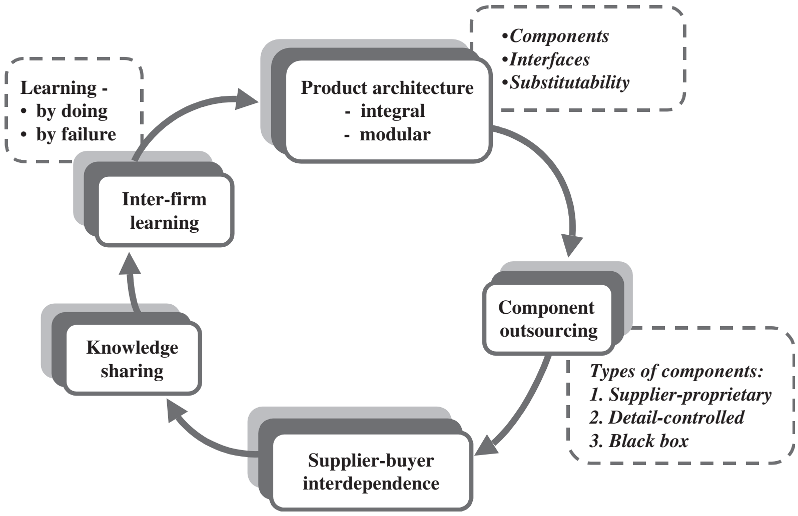


Figure 5. Modularization, outsourcing, and inter-firm learning.

architecture. These components are widely available in the market, with price as the most sensitive mechanisms for competition. There is almost no supplier-buyer interdependence as assemblers can easily find substitutes for these parts. Conversely, co-developed parts involve active and interactive participation in NPD from both the supplier and the customer. This type of component is most prominent with Japanese approach to NPD management process (Dyer and Ouchi, 1993; Dyer *et al*., 1998; Sobek *et al*., 1998). The characteristics of outsourced components with respect to component modularity, coupling, inter-firm learning, and supplier-buyer interdependence are summarized in Figure 4.

The modularity management of product architectures has an enormous impact on supplier selection, on how a firm should organize its knowledge stock, and on how investment and resource allocation should be dealt with. In fact, inter-firm learning and outsourcing decisions with respect to product architecture design decisions are a never-ending process, as shown in Figure 5.

The degree of modularization embedded in product architectures (that can range from integral to modular depending on the constituent components, interfaces and substitutability) defines the types of components to be outsourced (i.e., supplier-proprietary, detail-controlled, or black-box). These outsourced components trigger some degree of supplier-buyer interdependence that encourages suppliers and buyers to cooperate in solving technical problems during development and manufacturing phases of the process. Knowledge is shared between the parties during this process. Over time inter-firm learning takes place either through learning-by-doing as well as learning-by-failure, and the lessons learned are fed back to the product architecture designs, either to improve the current product architecture or to devise the next generation product architecture.

## 5. The story of Chrysler Jeep's windshield wipers controller

Since late 1980s, Chrysler has replaced its adversarial bidding system with one in which the company designates suppliers for a component and then uses target costing to determine with suppliers the component prices and how to achieve them. Target costing is a technique for managing a company's future profits by determining the life cycle costs at which a company must produce a proposed product with specified functionality and quality if the product is to be profitable at its anticipated selling price (Cooper and Slagmulder, 1999). Jeep Grand Cherokee was first introduced in the USA in 1993 as a high-end utility vehicle. The commercial success of this new family of Jeeps was uncertain, as it had numerous new concepts and innovations that were not present in former Jeeps. Moreover, a great portion of the development responsibilities of these innovations was outsourced. As in this case, the wipers controller module (WIPER) was outsourced as a black-box part to a Fortune-100 world class OEM (a first-tier supplier), resulting in two technological solutions: solid-state and silent-relay. The data is collected between 1991 and 1993, from the start of the development date to the start of the full production date. Primary data (i.e. author's direct involvement in product design, pre-production, and sourcing) as well as secondary data (such as engineering logbooks, schematic drawings, bill of materials, and other proprietary engineering data) were examined. Although the case analysis is based on a situation that took place a decade ago, nevertheless it illustrates the significance of product architecture modularity and its implications for outsourcing and inter-firm learning.

The controller used by older Jeep families applied relay-based technology which made 'clicking sound' when switching from ON to OFF, an annoying feature that Chrysler wanted to eliminate. The OEM was asked to develop a 'quiet' WIPER controller. One plausible technical solution was to create a solid-state module, using only transistors and other electrical components. Because the application of solid-state technology

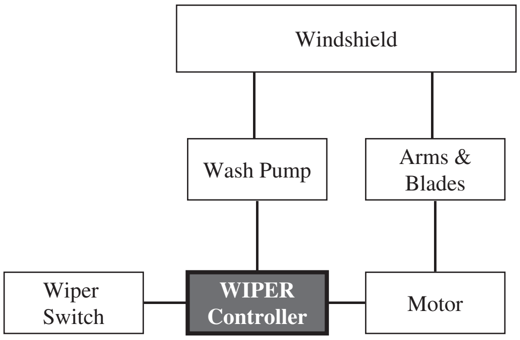


Figure 6. Block diagram of Jeep's windshield wiper system.

was common knowledge among the OEM's electrical engineers and there were no radical innovations involved in the process, the development of solid-state WIPER was carried out independently of Chrysler's involvement. A block diagram of Jeeps windshield wiper system is illustrated in Figure 6.

Tight budget, limited development and manufacturing lead times in addition to working with Chrysler for the first time, the OEM's design team faced many development challenges. For instance, test runs on the first prototypes proved to be almost catastrophic. Careless assumption about some specifications of the system was one of the mistakes. Although all the modules of the wiper system (i.e. motor, wiper arms, blades, wiper switch, and WIPER) had pre-determined interface specifications set by Chrysler, how they would function as an integrated wiper system in relation to the rest of the vehicle was not known. This uncertainty was accentuated, especially when innovations were concurrently being developed for the new Jeeps. At one stage, solid-state WIPERs would catch fire when tested under certain conditions in the real Grand Cherokees, even though the modules worked well in lab simulations and tests. Eventually, the development of solid-state WIPER was halted. Triggered by the failure, interface specifications and compatibility issues had to be re-examined. As a consequence, the design team went back to the drawing board, and started the redesign of WIPER from scratch. Even though the solid-state-WIPER was abandoned after several different architecture designs, it provided both the OEM and Chrysler with an unforgettable and valuable learning experience. A much better understanding of the windshield wipers system as a whole in terms of its functionality and interfaces with other elements of the vehicle was gained. Most importantly, a great deal of WIPER's specifications for the Grand Cherokee Jeep had to be redefined. This step was possible through an increased OEM and Chrysler involvement in NPD at solving technical and interface specification problems. Face-to-face meetings, joint problem solving, daily phone calls, etc. became a habit. Throughout this second round of development effort, the team was able to focus on the design and other concurrent processes with more confidence and determination.

During this stage of the development, the design team came up with a solution to substitute a portion of the architecture with a 'silent relay.' One of the advantages of relay-based technology for this application was that it would increase the robustness of the WIPER. Such 'silent relay' would have the properties of standard off-the-shelf relays, but would be significantly more 'quiet'. The only problem was that all the relays sold at the market, at the time, were considered too 'noisy.' Thanks to an efficient sourcing team and close coordination with the design team, major relay suppliers in the world got to know about the new relay's technical requirements, and started to compete and innovate to deliver first-run prototypes that would meet the specifications of the 'silent relay.' Within a period of less than one year, some 15 prototypes were tested and evaluated. At the end, a Japanese firm was chosen as the sole supplier because it was able to offer the best performing 'silent relay' with the most competitive price. The 'silent relay' proved to be the key factor for allowing economies of substitution to take place. With it, not only Jeep Grand Cherokee's WIPER became 'quiet,' it could also be used with other Jeep families (i.e. Jeep Cherokee and Jeep Wrangler families). This meant that one common WIPER could be mounted on any Jeep family without degradation in functionality and performance. The silent-relay WIPER entitled the OEM to deliver a 'quiet' module that was appreciated by Chrysler, not to mention the savings gained from availability and economies of scale of components, universal tooling, and common assembly and manufacturing processes.

## 6. Discussion and future research

This paper discussed modularity of product architectures and how it impacts outsourcing decisions and inter-firm learning. The underlying assumption is that modular product architecture allows the decomposition of a complex system or process into smaller sub-systems. Based on product architecture strategies, an outsourced component can be categorized as a supplier proprietary part, a detail-controlled part, or a black-box part. Outsourcing creates a certain degree of supplier-buyer interdependence and possibilities for inter-firm learning depending on the division of tasks in functional specification and detailed engineering of product architectures. Commodity components, for instance, can be bought from numerous suppliers. Generally, supplier-buyer interdependence for these types of components is of arm's-length type. Co-developed components, on the other hand, involve co-specialized investments which increases the transactors' interdependence and, consistent with theory, serves as an economic rationale for cooperative, long-term relationships (Dyer, 1997). Supplier-buyer interdependence can be analyzed in terms of investments in relation-specific assets vis-à-vis transaction costs. In a study of the automotive industry, Dyer (1997) found that the level of relation specific investments made by the suppliers is strongly influenced by the automaker's strategy with regard to supplier management and governance. He proposes a model of inter-firm collaboration that maximizes transaction value, which suggests that the credibility of a firm's promise to behave cooperatively increases as transactors: (1) demonstrate through behavior a commitment to future interaction; (2) increase the amount of information sharing; and (3) employ self-enforcing safeguards to govern the relationship. Dyer further argues that an increase in trustworthiness within the trading relationship reduces transaction costs and increases the likelihood that transactors will invest in relation-specific assets, hence maximizes the transaction value or the joint performance of the transactors.

Another issue related to the degree o supplier-buyer interdependence is the degree of supplier involvement in product development activities. The increasing trend on early supplier involvement in the NPD process has led to changes in the management of supplier-buyer relationships, with a tendency towards the partnership form (Twigg, 1998). According to Lamming (1993), this poses greater responsibilities to the suppliers, in the form of black boxes, as operating uncertainties are resulted through joint discussions, reciprocal dialogue of information, and long-term cost knowledge. Bidault *et al.* (1998) also highlight the importance of black box part in industrial transactions, as it lies at the heart of the early supplier involvement concept since the supplier assumes some level of design responsibility and therefore need to be involved in project discussion early in the development process.

As the case of WIPERs revealed, different product architecture designs lead to different modularity outcomes. The eventual success of the silent-relay WIPER was attributed to lessons learned from the failure of the solid-state WIPER in addition to the willingness of both Chrysler and the supplier to collaborate to solve technical problems related to the windshield wiper system as a whole. The failure of solid-state WIPER was the impetus for the subsequent creation of the modular product architecture of silent-relay WIPER. Some of the outcomes of this cooperation included the increased number of product variants per Jeep family, performance superiority, a better understanding of the windshield system, cost savings, stronger supplier-buyer interdependence, and inter-firm learning. The case showed that black-box parts enable assemblers to utilize supplier's engineering expertise and manpower while maintaining control of basic design and total system integrity. To the OEM, the accumulation of engineering expertise becomes its competitive edge. Prototypes and production parts exchange is a source for facilitating knowledge exchange between the supplier and the assembler (Clark and Fujimoto, 1991). Added value can be attained when supplier and assembler are willing to collaborate in solving technical problems, especially in resolving interface compatibility constraint issues, which tend to strength the appropriability regime of the innovation, especially when new technological solutions are created and patents attained. The higher the technical complexity of a black box part, the more necessary it is for the supplier to become involved in the assembler's engineering activities. This is especially crucial when supplier and buyer's product and process technologies become more interdependent. This supplier-buyer interdependence leads to inter-firm learning as both parties rely on each other's expertise to ensure successful introduction of the innovation into the market.

The importance of taking a supply chain view in analyzing product architecture modularity was also emphasized. Even with outsourcing, firms need to cooperate with suppliers, customers and even rivals to ensure they have complementary resources, skills, knowledge, and components for long-term survival. Because the components or the modules delivered by the supplier must have perfect fit with the system dictated by the assembler, it is crucial for the supplier to have in-depth understanding about the system as a whole and its constraints. It has been suggested that organizational design and supply chain management issues should be evaluated hand-in-hand with more formal analysis of modularization (Mikkola, 2003). The effects and value of modularity management should also be extended to include managerial implications such as cost and benefit compromises, coordination and information management among suppliers, etc. What kinds of tools should be developed in order for managers and academics to gain a better understanding of modularization, not only in new product development, but also in organizational design, marketing strategies, and supply chain management? Research suggestions to increase our understanding of modularity with respect to supply chain management, for example, to study the relationship between product design policies, purchasing policies, outsourcing policies and the degree of supplier-buyer interdependence. Furthermore, some intangible factors such as culture, traits, and communication skills of the managers are difficult to measure, but they play an important role in orchestrating the supplier-buyer relationships. As companies increase their outsourcing activities, the role of strategic partnership in R&D in devising product architecture designs and supply chain management will be indispensable.

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