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3C Framework of Modular Supply Network in Chinese Automotive Industry

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Abstract

Purpose – This paper aims to understand and identify the context, capability requirements and configurations of the modular supply network in the Chinese automotive industry.
Design/Methodology/Approach – In an attempt to specify the main elements of the modular supply network, a case study and 3C framework approach are used to analyze the different contexts of the network. The framework not only considers the capabilities of product design, production, inbound logistics and information sharing but also considers the configuration of role structure, process structure and information structure to achieve the above capabilities.
Findings – The paper analyzes two types of modular supply network, directly reflecting the degree of involvement in the modularity logic of the module supplier and the automaker, which largely depends on their corporate strategy regarding technology innovation. Within the fully integrated module supply network, the module supplier needs sufficient capability for upstream supply network integration as well as modularization, while in the partly integrated module supply network, a 3PL provider plays an important role regarding production capability.
Research limitations/implications – Four modules are investigated in this study. The practical tools for configuring the modular supply network will be specified in more detail in future research.
Practical implications – With the emerging M&A operations of the component supplier, modular supply has become dominate in the Chinese automotive industry. The modular supply network increasingly relies on the establishment of the capabilities of the key roles in the network configuration. The 3C framework suggests a method for practitioners to improve the performance of the modular supply network.
Originality/value – The 3C framework described in this paper contributes to theory in not only the field of supply chain management but also to modularity, and it assists in further expanding the theory of SCM as well.
Keywords Modular supply network, Modularity, Supply chain, Third party logistics, Automotive
Paper type Research paper

Introduction

Modularity has become one of the most prevalent means to support product variety (Baldwin and Clark, 1997; Duray, Ward et al., 2000; Fujita, 2002; Pil and Holweg, 2004) and to achieve mass customization (Duray, Ward et al., 2000; Mikkola, 2007). Recently, modularity has received increasing attention from researchers and industrial practitioners (Fixson, 2007; Salvador, 2007). The research topics cover not only modular product design (Sako, 2003; Kreng and Lee, 2004; Mikkola, 2006; Mikkola, 2007; Tseng, Chang et al., 2008) and service design (Pekkarinen and Ulkuniemi, 2008) but also modular production (Sturgeon, 2002; Brusoni and Prencipe, 2006; Kotabe, Parente et al., 2007).

Baldwin and Clark (1997) describe modularity as "building a complex product or process from smaller subsystems that can be designed independently yet functions together as a whole." Modularity is not a new concept. In 1910, the young American automobile industry initiated an extensive standardization program for the design of automotive part and related engineering practices in order to establish a high level of inter-company and inter-industry technical coordination within the automotive industry (Thompson, 1954). It was believed that modular architecture could make standardization possible (Ulrich, 1995). Furthermore, it was a strategy for designing and mixing sets of standard components to provide maximum variety to the customer (Evans, 1963; Starr, 1965). Since then, the modular logic has been applied in different industries, from hardware (Langlois and Robertson, 1992) to software (Baldwin and Clark, 1997; Kratochvil and Carson, 2005; Griswold, Shonle et al., 2006), from bicycles (Schilling, 2000) to automobiles (Cusumano and Nobeoka, 1992; Pires, 1998), even from financial services (Baldwin and Clark, 1997) to logistics services (Pekkarinen and Ulkuniemi, 2008). Modularity has been applied to the computer industry; early in 1964, IBM announced the first modular computer, the system/360, and DELL is among the most famous successful companies to employ modularity, regarding it as a strategy for mass customization and achieving product variety at lower cost (Pine II, 1993).

Like the many different industries that have applied the concept of modularity to their production functions, the automotive industry is also involved in using modularity to achieve competitive advantages from mass customization. Recently, one of the major trends of automakers has been moving from the procurement of discrete components to the procurement of modular systems (Doran, Hill et al., 2007). Recent studies on the automotive industry from different countries (including Brazil (Kotabe, Parente et al., 2007), France (Doran, Hill et al., 2007), U.K. (Doran, 2004) and the U.S. (Ro, Liker et al., 2007)) have proven that the automotive industry moving to modularity and modular supply will lead to risk sharing, cost reduction, speed of distribution and increased flexibility.

Volkswagen and Mercedes-Benz (Daimler Chrysler since 2000) were the first automakers to introduce modularity into the automotive industry in 1996 (plant in Resende, Brazil) and 1997 (plant in Hambach, France) (Roberto, Mauro et al., 1997; Ramalho and Santana, 2002; Takeishi and Fujimoto, 2003). In their plants, some of the individual components that had once been delivered to the final assembly line one by one were first sub-assembled on a separate line and then delivered to the main assembly line to be installed into the vehicle body as a module. The Blue Macaw plant opened by General Motors in Gravatai, Brazil, in 2000, follows the logic of modularity introduced by Volkswagen and Mercedes-Benz (Reichhart and Holweg, 2007).

One of the most famous cases of modularity is the “Smart” car project cooperatively launched by the joint venture of Mercedes-Benz and SMH (Swatch, the Swiss watchmakers) (Takeishi and Fujimoto, 2003). A typical automaker must conduct business with around two to three hundred suppliers, but the Smart car has only twenty five module suppliers (called “system partners”) that provide modules including complete dashboard systems, body structure, breaking control systems and seating modules (Doran, Hill et al., 2007).

Most recently, Audi has started a program called “The Audi modular longitudinal platform technology” on the A5/S5 coupe, switching to a modular architecture that will allow most of its product lines to share major components (Kurylko, 2007). Through the modular approach, Audi has developed modules for costlier components, including heating and ventilation and key components of the body, driver train and suspension. Employing sister company Audi’s new modular sharing strategies, Volkswagen AG (VW) will cut its development times by a year and expand its portfolio significantly. The largest modular assembly in the Hyundai plant in Montgomery is the cockpit, which is supplied by the Hyundai-owned module supplier Hyundai Mobis, and the right cockpit can be delivered to the right place at the right time and at the right level of quality (Wortham, 2007).

As automakers are moving to modular assembly, the rules and practices of the supply network are changing. Because of the complex product structure and supplier network, it is not easy to apply modularity and collaboration within the upstream supply chain. Actually, organizations are increasingly compelled to deal with more complexities in the global supply chain, both in terms of the number of suppliers and in their varying characteristics (Erevelles and Stevenson, 2006). For example, General Motors has approximately 30,000 suppliers, with approximately 9000 members in its supply chain (Gould, 2001). It is hard to collaborate with their huge numbers of suppliers and to exploit the enormous competitive potential advantages of applying modularity in the supply network management. Furthermore, there is an obvious trend towards stronger collaboration with suppliers in the supply network to improve the performance of the buying company (Avittathur and Swamidass, 2007).

However, literature on the effects of modularity on supply networks and methods to improve their performance when moving to modular supply is quite limited. The main purpose of this paper is to investigate and identify the capability requirements and configurations of supply networks for the different contexts of modular supply. Case study methodologies are adopted in this research, and the function level and role level in each case are observed following the 3C framework approach. Typical cases are analyzed to identify the context feature, capability feature and configuration feature of different modular supply networks. The results therefore lead to managerial insights and discussions, which is summarized into a 3C framework for future applications of modularity in the automotive industry. Finally, conclusions of the findings and future research directions are provided.

Methodology

Case study method

The research aims to obtain a broader perspective on the development of modular supply and the collaboration practices in the Chinese automotive industry. The research questions focus on “why” (why a certain type of modular supply network emerges) and “how” (how a certain configuration is needed to achieve certain capabilities within a certain context of modular supply network), and then the study discusses emerging issues. Therefore, case study methodology is adopted in this paper, which gives the explanatory nature of the research questions being posed (Yin, 1994). Sixteen case companies have been selected from the automotive industry and the logistics industry (see Table 1). Cases are chosen and administered in accordance with replication logic (Eisenhardt, 1989).

Table 1. Interview list

Participants	Company		People			Average time (hrs/person)
Supplier	7	*Seat* *1* *Air conditioner* *1* *Instrument panel* *1* *Tire* *4*	23	*Focused interview*	*16*	3
				In-depth interview	*7*	6
Manufacturer	6		16	*Focused interview*	*10*	2
				In-depth interview	*6*	8
3PL provider	3		9	*Focused interview*	*6*	3
				In-depth interview	*3*	7
Total	16		48			203 hrs

Data were collected via plant visits, documentations on official websites, and mainly through semi-structured interviews from 2005 to 2007 with senior engineers, senior managers, R&D managers and logistics operations managers. The use of interviews is regarded as the primary data collection technique for qualitative research (Cooper and Schindler, 2008) and the valuable and essential source of evidence for a case study method (Yin, 1994). This study conducts two types of interviews, focused interviews and in-depth interviews, in order to gain a comprehensive scope of modular supply networks from both the operational and strategic level. The average two to three hour focused interview was for middle level managers, while the in-depth interview was for top level managers and lasted six to eight hours, typically spanning two or three days. The reason for adopting longer in-depth interviews was to extract more in-depth personal opinions and insights from the top level managers based on their experiences and attitudes on modular supply. The in-depth interviews placed more focus on issues of history and strategy, while the focused interviews focused more on operational, technical and procedural issues. Both types of interviews were semi-structured with a detailed interview guide (Blumberg, Cooper et al., 2008). The questions in this particular structure were open-ended and modified continuously during this three-year study. Due to the open-ended nature of the interviews, 3PL with sub-assemble capability requirements emerged as a new theme during the interview which led to a richer understanding of the original research questions. For this reason, the study considers three logistics service providers in the interviews (see Table 1).

3C approach

This paper mainly focuses on how the supply network operates efficiently and effectively with modularity logic. Following the 3C approach proposed (Zhang, Shi et al., 2007) as a generic approach to the study of network organizations, this paper aims to investigate the environmental features (context), key success features (capability) and organizational features (configuration) of the modular supply network. The research framework is described in Figure 1.

The study of **context** aims to identify the environmental features of the modular supply network such as the driving forces, main barriers and key missions from the perspectives of complexity and dynamism. It mainly answers questions such as why a certain type of modular supply network emerges. The study of **capability** investigates the key success features of the modular supply network from the functional view of design, production, inbound logistics and information management, which helps to answer questions such as why a certain type of modular supply network operates better than another type. The study of **configuration** defines the constructional elements and typical patterns of the modular supply network including role structure, process structure and information architecture, which help to answer questions about how to establish a modular supply network to achieve certain capabilities in a certain context. Furthermore, within different contexts, the network has different capabilities and configurations, and different combinations of configuration elements lead to different capabilities for a specific modular supply network. Consequently, the interrelation of these three dimensions is analyzed in this paper to gain a comprehensive understanding of modular supply networks.

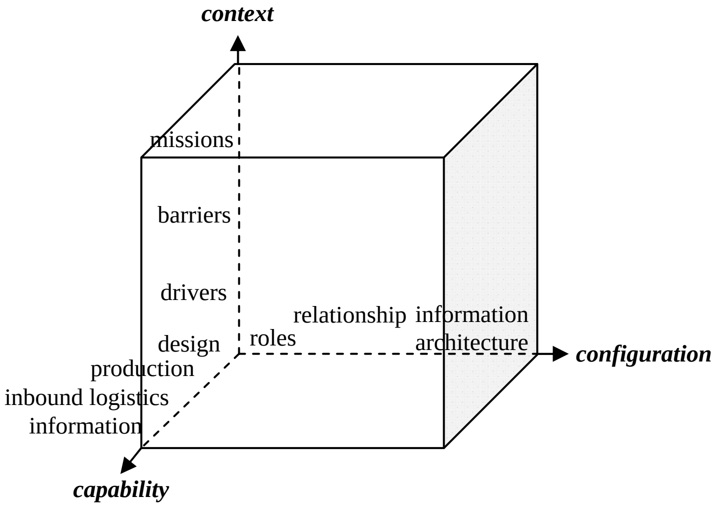

Figure 1. Research framework for modular supply network

This paper takes module suppliers, automakers and logistics providers into consideration. Four types of module suppliers are studied, including suppliers of seats, air-conditioners, instrument panels and tire/wheels. According to the interviews conducted with the automotive manufacturer and component suppliers from 2005 to 2007, 3PL providers play a very important role in modular supply. Some 3PL providers take responsibility for the sub-assembly of the modules before delivering them to the final assembly line.

Furthermore, the sub-assembly and the delivery services are synchronized with the pace at which the final vehicle is assembled through sharing the production information. Therefore, 3PL providers are involved in this study. Design, production, inbound logistics and information are the major function activities analyzed in this study, and these are also the fields in which this study tries to identify the capability features required to achieve efficient and effective operations of modular supply network.

With the 3C research framework, it is possible to capture the best practices in a specific industry and to get a better understanding on the relationship among context, capability and configuration of the modular supply network which is valuable for practical industries.

Key Findings

The findings summarized in this paper are mainly based on four key cases, and the analysis focuses on the context, capability and configuration. Table 2 presents an overview of the key companies in each case.

Case A, B and C are single case studies, while case D is a multi-case study, which is used to describe different patterns of modular supply network for the same module (Yin, 1994).

Case A: Seat module supply network

The supplier S1 investigated in this case is a joint venture (JV) of a Chinese seat supplier and an U.S. automotive supplier that is one of the world's leading components suppliers advanced in module integration. Company S1 has advanced technologies in design and engineering in specified fields, especially in module integration, the technology for which has been taken from the U.S. parent company. After the establishment of the JV, company S1 also extended its production and logistics facilities to reduce its inventory level from two-day to two-hour standards and to improve its logistics performance.

Company M1 is one of the earliest automakers devoted to modular design and modular production following the world trend. The seat module is one of the earliest modules, which is outsourced to the module suppliers S1. Company S1 has been equipped with a comprehensive knowledge of modularity, an advanced R&D capability, and sufficient logistics facilities. These insights ensure it can deliver seat modules directly to the final assembly line of automaker M1 with just in time (JIT) logic by itself. The seat module does not need any other sub-assembly processes before being fed to the final assembly line. According to the senior manager from the module supplier, the company is providing completed solutions not only regarding the design and production but also regarding the logistics service to the automaker. Furthermore, company S1 is located close to the automaker's assembly plant (about 1km away), which makes it easier to operate on a JIT basis with the Kanban information system. All of these allow the company S1 to be the only supplier providing seat modules to the automaker for five series of vehicles. The company S1 has also set up several plants in other cities as the major seat module supplier to other automakers.

Table 2. Overview of the key case companies

Cases			Company	Characteristics
A		S1	Seat module supplier 1	Joint venture of a Chinese company and an U.S. company that is leading seat module supplier in the world Providing M1 with seat modules for five series vehicle
		M1	Automaker 1	Top 5 automaker in China Joint venture of a Chinese company and an U.S. company
B		S2	Air-conditioner module supplier	Joint venture of a Chinese company and a French company that is one of the leading components supplier in the world Providing air-conditioner for automaker M2
		M2	Automaker 2	Top 5 automaker in China Joint venture of a Chinese company and a French company
		P1	Third party logistics provider 1	Joint venture of a Chinese company and a French company that is top 3 logistics supplier in Europe
C		S3	Instrument cluster supplier	Supplier of automaker M2
		P2	Third party logistics provider 2	Local logistics company
		M3	Automaker 3	Joint venture of a Chinese company and a Japanese company
D	1	S4	Tire supplier 1	Leading tire supplier in the world
		P1	Third party logistics provider 1	Joint venture of a Chinese company and a French company that is top 3 logistics supplier in Europe
		M4	Automaker 4	Joint venture of a Chinese company and an U.S. company
	2	S5	Tire supplier 2	Leading radial tire supplier in China
		S6	Tire sub-assemble supplier	A small supplier with sub-assemble line for tire module
		M5	Automaker 5	Top 10 automaker in China Joint venture of a Chinese company and a Korea company
	3	S7	Tire supplier 3	Joint venture of a Chinese company and an U.S. company
		P3	Third party logistics provider 3	A Chinese logistics company
		M6	Automaker 6	Joint venture of a Chinese company and a Germany company

The automaker and the module supplier play the major roles in this supply network. The structure of this modular supply network is simple, but the module supplier has a complex upstream supply network to manage. Company S1 only holds some high value-added assembly activities, while the low value-added activities are outsourced to its upstream supplier. As a result, company S1 should integrate the second-tier suppliers to produce the seat modules efficiently and effectively.

Information sharing plays a very important role in the success of modular supply and synchronized production. The information architecture mainly includes ERP/MRP and the Kanban information system. The automaker M1 shares production plan information with the company S1 one month ahead. Hence company S1 can organize the upstream suppliers and its own plant to produce the seat module at a pace synchronized with that of the automaker. Then the supplier delivers the seat module directly to the automaker with JIT logic followed by the Kanban order with the information on time, place and number for daily deliveries. The daily delivery order information is transferred through the Kanban system to company S1 two hours ahead. The Kanban information system was globally launched by the automaker in 1998 to support the application of JIT logic.

Case B: Air-conditioner module supply network

The air-conditioner supplier S2 is also a JV founded in 1994. The parent company is a French industrial group fully focused on designing and producing components, systems and modules for cars in the original equipment market. It has five R&D centers in seven countries to develop its advanced technology on compressors, but it does not focus on the whole module system integration. As a result of focusing on developing compressor technology, company S2 outsources some low-value components to other component suppliers. Consequently, company S2 still has a high capability for supplier integration to organize the upstream supply network.

Company S2 provides air conditioners for the automaker M2 for its six series of vehicles. The module is not delivered to the automaker directly but first delivered to a 3PL provider that provides warehouse and inbound logistics services to the automaker. The module is processed with some sub-assembly, such as plug-in electronic clusters, by the 3PL provider before being fed to the assembly line. The 3PL provider P1 is a new company issued from a French logistics company that has a long history of automotive logistics and a Chinese logistics company that owns a wide national logistics network.

The 3PL provider here performs not only logistics functions but also production functions (sub-assembly) to completely transfer the air conditioner into a ready-to-assemble air conditioner module before being delivered to the final automotive assembly line. Company P1 holds some production equipment and human capital to provide such production capability and finishes the sub-assembly after receiving the delivery order from the automaker two hours before. Company P1 also takes responsibility for collecting the low-value components to ensure the sub-assembly activities. Those low-value components suppliers also need to be managed efficiently to ensure the sub-assembly, and they receive delivery orders from the 3PL provider directly.

The module supplier, automaker and 3PL provider are the three key players in this modular supply network. There are still some component suppliers providing low-value components for the sub-assembly performed by the 3PL provider. The supply network in Case B is more complex than that of Case A; therefore, close collaboration is needed to ensure efficient operation, especially for the inbound logistics to the automaker. In this scenario, the air conditioner module is first delivered to 3PL provider. Normally, the 3PL provider holds two-day inventories in its warehouse. When the 3PL provider receives the delivery order from the automaker through the Kanban information system, the air conditioner is picked up from the shelf, unpackaged and finished through the sub-assemblies with the components provided by the low-value component suppliers. After that, the final integrated air conditioner system module is delivered to the assembly line. The information architecture mainly includes the automaker sharing production information with the PIM supplier, components suppliers and 3PL provider, and the 3PL provider sharing delivery information with both the PIM and component supplier. ERP/MRP and the Kanban system are still the main information sharing enablers.

Case C: Instrument panel module supply network

The instrument panel module consists of a panel, instrument cluster, instrument harness, instrument illumination lamps, etc. The integrated instrument cluster of supplier S3, which delivers to automaker M3, is only one component of the whole module. The automaker M3 completes the whole module in the sub-assembly line near the final assembly line. Company S3 is one of the largest instrument suppliers in China and has over forty years of history in the instrument field focusing on R&D of instruments, e.g. electronic speedometer, mileage counter, tachometer, etc. Automaker M3 is a JV of one leading Chinese auto company and a Japanese auto company leading in modular design logic. Due to the modularity pressure from the downstream customer M3, company S3 starts to concentrate on designing and manufacturing integrated instrument clusters, especially electronic ones. They import several assembly lines and supportive process technologies from Germany in order to meet customers' demands.

The performance of modularity in this scenario depends largely on the automaker's capability of modular design and sub-assembly. The Japanese parent company has advanced R&D capabilities, and it is one of the earliest auto companies to apply modular logic in designing an instrument panel module. Consequently, its helps M3 improve the instrument panel module design and the production process technology and equipment. There is a sub-assembly line for the instrument panel, which is close to the final assembly line in M3's assembly plant. It is the most important to ensure that the production pace of the sub-assembly line is synchronized with that of the final assembly line. Meanwhile, the 3PL provider feeds required components, such as instrument clusters provided by company S3, to the sub-assembly line with JIT logic.

The component suppliers, 3PL provider and automaker comprise a three-echelon supply network. The supplier delivers the instrument module to the 3PL provider P2 first, and then company P2 feeds it to the sub-assembly line following daily Kanban order information. Information is also shared through the Kanban system and the ERP system. In order to ensure the synchronized production between the final assembly line and the sub-assembly line, scheduling collaboration is needed to maintain the same production pace.

Case D: Tire module supply network

The tire module includes two components: tires and wheels. It is the simplest module analyzed in this paper. This study reveals that there are several patterns of supply network suited for the tire module. Consequently, this paper divides case D into three sub cases to describe the different characteristics of the same module by using multiple-case studies.

Sub case 1: Sub case 1 is similar to Case A; however, tire supplier S4 delivers tires to automaker M4 through a 3PL provider. Company S4 is a leading tire supplier in China, and its parent company provides advanced R&D capability and technology support to the company S4. Company S4 produces not only tires but also wheels. Consequently, it is possible to assemble the two components into a tire module and then deliver the completed tire module to the automaker. However, company S4 is far from the automaker M4; therefore, it has to send the tire modules to the warehouse of the 3PL company, which later feeds it to the final assembly line.

Sub case 2: Sub case 2 is similar to Case B. However, supplier S5 uses a sub-assembler instead of a 3PL provider. The tire supplier S5 is among the largest in China, and recently entered the tire market with a fast growth rate. Company S5 only produces tires; hence, it is impossible for it to produce a tire module for the automaker. The tire supplier S5 transports tires to the 3PL provider every month. The wheel supplier transports wheels to the same 3PL. After receiving the delivery order one week in advance, the 3PL company delivers the tires and wheels to the sub-assembly supplier S6 near the final assembly plant. After company S6 finishes the sub-assembly, it then performs the necessary component tests. After that, company S6 delivers the tire module directly to the automaker following JIT policy.

Sub case 3: Sub case 3 is similar to Case C. There is a sub-assembly line in the automaker's plant close to the final assembly line. The tire supplied by supplier S7 and the wheel supplied by another supplier are transported to the 3PL provider P3's warehouse every two weeks. After receiving the delivery order from the automaker M6 four hours in advance, company P3 picks up the required tire and wheel and then delivers them to the sub-assembly line in the automaker's assembly plant. The tire module is formed in the sub-assembly line and then transferred directly to the right workplace to install on the car.

According to these three sub cases, there are different patterns of the supply network for providing the same module. It largely depends on the automaker's manufacturing capability and involvement in modularity logic. Most of the automakers choose to outsource it to the supplier, because the tire module is a simple one.

Table 3 summarizes the results of each case from the perspectives of context, capability and configuration. For the commonality with Case A and C, sub case 1 and 3 are not listed in this table.

Discussions and 3C framework of the modular supply network

The major purpose of this research is to identify the effect of modular supply on supply network and to explore how to improve the performance of the modular supply network.

Fully integrated module and partly integrated module

The findings show that there are normally two types of modules, fully integrated modules (FIM) and partly integrated modules (PIM), depending on the integration level accomplished by the module supplier. The FIM is a completely integrated module that does not need any more sub-assembly before being fed to the final assembly line (such as seat module in the Case A), while the PIM is the module that is not completely integrated by the module supplier and needs some sub-assembly activities by third parties or the automaker before being fed to the assembly line (such as air conditioner, instrument panel, door, tire, etc.).

For FIM, both the supplier and automaker are devoted to modularity, and the supplier usually has advanced modular technology both for design and production. As a result, its modularity has become common practice across the automotive industry, and the best example is the seat module (Ro, Liker et al., 2007). The seat module differs from the cockpit, for it is almost accepted by all the automakers with developed modularity logic, while only a few suppliers can supply fully integrated cockpits to the automakers. In real practice, only a few suppliers have advanced R&D capabilities to design FIM and have sufficient resources to produce it.

For PIM like the air conditioner, instrument panel and tire module, most of the suppliers usually focus on the core technology development, such as the compressor and instrument cluster, in order to gain competitive advantage in their specific fields. Therefore, most of the suppliers are just getting involved in the logic of modularity, or are pushed by the automaker into the modularity wave. To some extent, the modules that the FIM suppliers provide normally need sub-assembly before being fed to the final vehicle assembly line.

Table 3. A summary of case study

Dimensions	Elements	Key Characteristics			
		Case A	Case B	Case C	Case D – sub case 2
Context	Mission	Deliver completely integrated module to the automaker with JIT logic	Deliver partly integrated module to the automaker with JIT logic, sub-assembly finished by 3PL	Deliver partly integrated module to the automaker with JIT logic, and sub-assembly finished by automaker	Deliver partly integrated module to the automaker with JIT logic, sub-assembly finished by different roles
	Driver	Modular production, inventory reduction and cost reduction	Modular production, time saving, inventory reduction and cost reduction	Modular design and production	Product variety, Synchronized production, inventory reduction
	Barrier	R&D capability, logistics facility, distance proximity, and information sharing	Transportation, sub-assembly capability, management of low-value components, information sharing	R&D capability, modular design capability, synchronization issues	Sub-assembly capability
Capability	Design	High level in modularity for both supplier and automaker Supplier designs the whole module, advanced R&D capability, devoted into modular design	High level in modularity for both supplier and automaker Supplier designs the whole module Supplier is focusing on compressor technology	High level in modularity for automaker Medium level in modularity for supplier Automaker designs the module Supplier design the sub-module	Medium level in modularity for automaker Low level in modular logic for supplier Low level technology get involved
	Production	Supplier assembles the module before feeding it to the final assemble line	3PL finishes some sub-assemblies in their warehouse (low value-added activities)	Automaker finishes the sub-assembly in their sub-assembly line (medium value-added activities)	Sub-assembly supplier finishes the sub-assembly (low value-added activities)
	Inbound logistics	Delivered by the supplier Supplier close to the automaker's assembly plant	Using 3PL 3PL is close to the automaker's assembly plant Supplier far from automaker	Using 3PL 3PL is close to the automaker's assembly plant Supplier far from automaker	Using 3PL and sub-assembly supplier 3PL is close to automaker Supplier far from automaker Sub-assembly supplier close to automaker
	Information	High-level information sharing	High-level information sharing	Medium-level information sharing	Medium-level information sharing
Configuration	Network structure	2 roles (seat module supplier, automaker) two-echelon supply network	3 key roles (air-conditioner supplier, 3PL, and automaker), and some low-value component suppliers three-echelon supply network	3 key roles (instrument cluster and other components suppliers, 3PL, and automaker), and some low-value component suppliers three-echelon supply network	4 key roles (tire supplier, sub-assembly supplier, 3PL provider and automaker), and some low-value component suppliers four-echelon supply network
	Process structure	Simple with JIT logic	Medium complex via 3PL with JIT logic	High complex via 3PL with JIT logic	Simple via 3PL and, sub-assembly supplier with JIT logic
	Information architecture	Kanban information system, ERP system Automaker shares production plan information with module supplier in advance Diary Kanban information between automaker and module supplier	Kanban information system, ERP system Automaker shares production plan information with module supplier in advance Diary Kanban information between automaker and 3PL Diary Kanban information between 3PL and low-value components suppliers	Kanban information system, ERP system Diary Kanban information between automaker and 3PL	Kanban information system, ERP system Diary Kanban information among automaker, sub-assembly supplier and 3PL

3C framework of modular supply network

Based on the above module categorization, the operational characteristics of the modular supply network providing these two different modules are summarized in Figure 2 from the perspectives of context, capability and configuration. These essential elements of three prime categories are identified and refined by empirical studies.

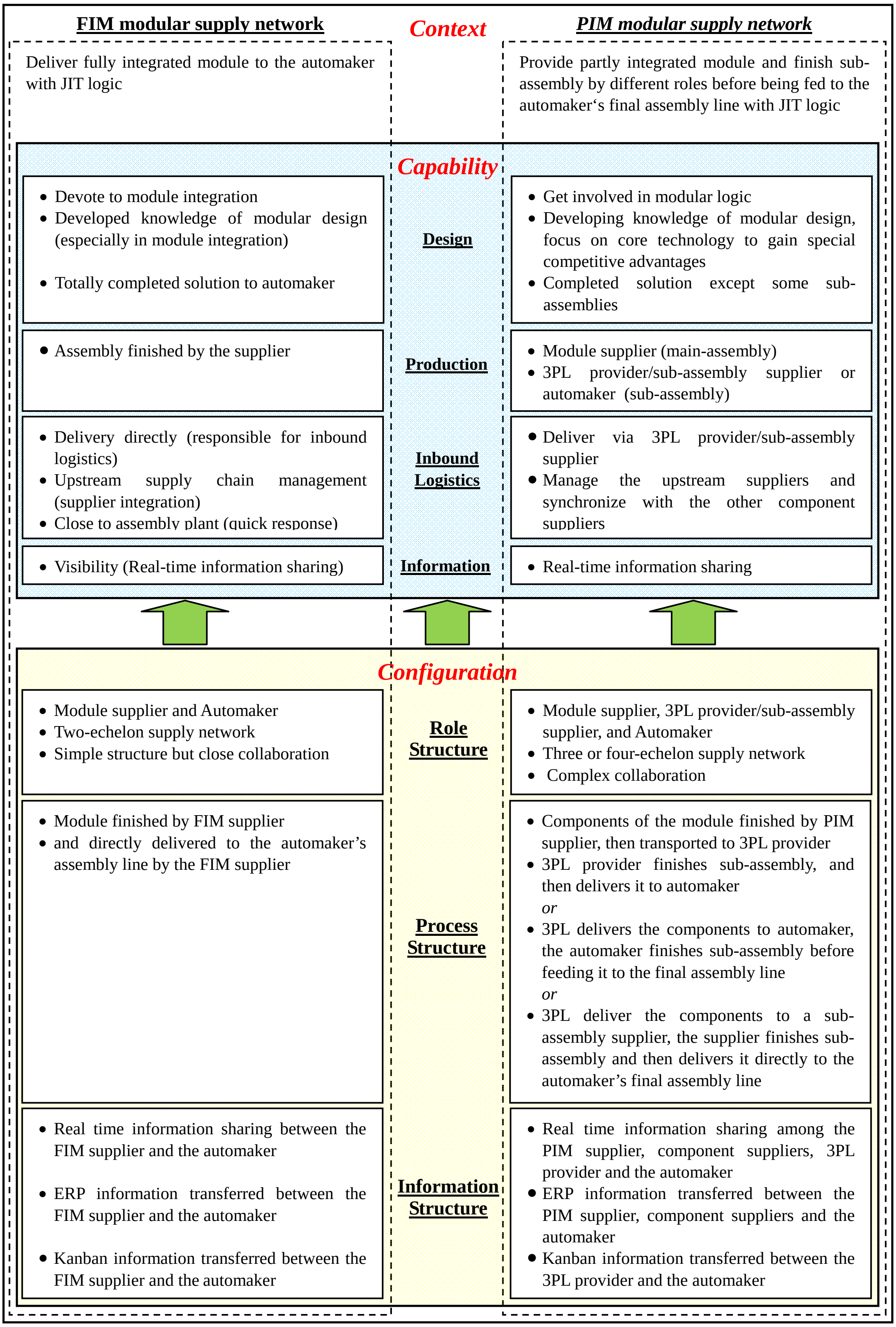

Figure 2. 3C framework of modular supply network

This study proposes the concept of the modular supply network for the application of modularity in supply network context. This 3C framework can help researchers and practitioners acquire a better understanding on the operations of two patterns of modular supply network in automobile industry.

Capability requirements for modular supply network

The findings suggest that the modular supply network is a complex system that largely depends on the R&D capability and corporate strategy for technology innovation of both module suppliers and automakers. The modularization progress of the automaker and the module supplier are interdependent. If both are trying to be comprehensive modular integrators and have advanced modularity technology or invest a lot on modular design, the supplier will become a FIM supplier providing fully integrated modules just like a total solution, which is what the automaker really wants. The automaker also devotes to modular design and modular production. The automaker is devoted to modularity logic if the supplier's strategy priority lies in core-technology development to gain special competitive advantages, or if it does not have sufficient R&D capability or investment, the supplier will leave the low-value components to other suppliers and then the sub-assemblies have to be finished by other partners (3PL, sub-assembly supplier, or automaker) before the module becomes a FIM being fed to the final assembly line. With increasing pressures from automakers devoting to modularity, more and more suppliers start focusing on modular design and modular production in order to keep pace with their customers.

The results demonstrate that the Chinese automaker is following the international trends of outsourcing responsibility of design and production to suppliers (Fine, 1998; Camuffo, 2000). Modular involvement reflects the automaker's trade-off decision between modularity and outsourcing. The greater focuses on modularity, the more outsourcing there will be. While such outsourcing is different from the original idea of the Volkswagen and Mercedes-Benz's modularity case, it is similar to the cases of European and U.S. automakers (Corrêa, 2001). Nevertheless, for most of the component suppliers in China, there is a lack of R&D capability and technology. The findings also demonstrate that these Chinese component suppliers are in the wave of M&As Operations (Camuffo, 2000), which helps them to get advanced modular technology quickly and directly. Suppliers in Case A and B are all joint ventures of Chinese companies and world-leader component suppliers who have advanced capability for modular integration in their specific fields.

Along with outsourcing of design and production, the automaker will maintain strategic relationships with the module supplier, especially an FIM supplier. But for the module suppliers, the research findings suggest that they should take more responsibility for managing the upstream supply network effectively and efficiently. For the automaker, the complexity of the supply network is decreased when the responsibility for the modules is transferred from itself to the module supplier. Consequently, capability of managing upstream supply network is vital to the module supplier.

Within the modular supply network, visibility that is required to achieve information sharing of production planning and logistics-related information and to improve the modular supply performance can be achieved through suppliers and manufacturers working on joint initiatives (Bartlett, Julien et al., 2007). Furthermore, top management involvement plays an important role in achieving high-performance logistics collaboration between the module supplier and the manufacturer (Sandberg, 2007).

The important role that a 3PL provider plays in a PIM supply network is demonstrated in this paper. It can provide not only the inbound logistics services but also the sub-assembly activities which are not a requisite but a valuable service to the automaker. It is more interesting that postponement is possible with the help of 3PL providers in finishing the sub-assembly, which is the same function as that of the supplier (Reichhart and Holweg, 2007). The findings also suggest that the close location between the module suppliers and the automakers will be helpful to modular supply. That is the reason why the supplier park is widely introduced to achieve JIT supply in the automotive industry (Reichhart and Holweg, 2007). In fact, being close to assembly plants is essential to achieving postponement and JIT logic in the scenario of PIM.

Configurations of modular supply network

The results show that the complexities of the supply chain roles, supply network structures, process structure (process of production and inbound logistics), and information architectures will decrease when suppliers and automakers move closer to a more integrated module supply, a phenomenon also noted by past research (Baldwin and Clark, 1997; Camuffo, 2000; Doran, Hill et al., 2007).

Four patterns of modular supply networks are summarized in Figure 3 (1). This study uses sub-assembly as a main criterion to differentiate these four patterns. For FIM, because no sub-assembly is needed, the supply network is described as (a) in Figure 3 (1). For PIM, the sub-assembly can be finished by the 3PL provider (see (b) in Figure 3 (1)), the automaker (see (c) in Figure 3 (1)), or the sub-assembly supplier (see (d) in Figure 3 (1)). For different patterns, the modularity level varies from module to module, and the complexities of supply network, process, and information are different (see Figure 3 (2)).

Obviously, the more mature the modularity, the simpler the supply network and process. The maturity level of the modularity of FIM is higher than that of any PIM supply network. For a medium level module like air conditioners and instrument panels, because there are other component suppliers, the structures of supply network, process and information become more complex than those of the FIM supply network.

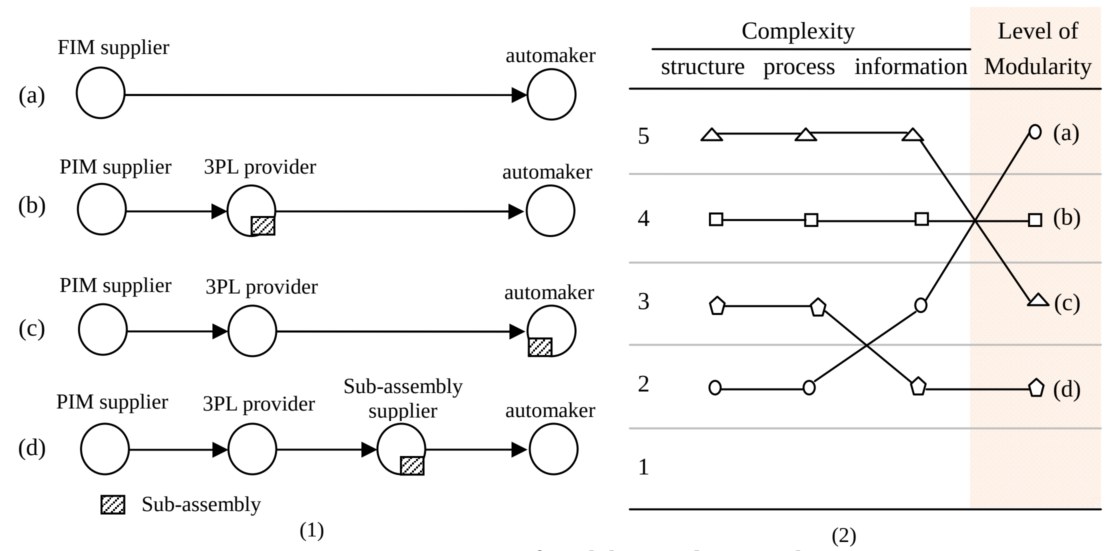

Figure 3. Patterns of modular supply network

It is the most important that there is no uniform pattern for one module, and the tire module is a good example with its three sub cases. Patterns (b, d, c) in Figure 3 present respectively the supply network of sub cases (1, 2, 3) in Case D, which depend on the capabilities for R&D and manufacturing of different players forming the supply network.

In the FIM scenario, it is a relatively simple two-echelon supply network (see Figure 3 (a)), comprised of module suppliers and automakers. There is a strategic relationship between them. The module is produced totally by the FIM supplier, and then it is delivered directly to the final assembly line by the supplier. Obviously the process structure is accordingly simple, which is described as the double line arrow in Figure 4.

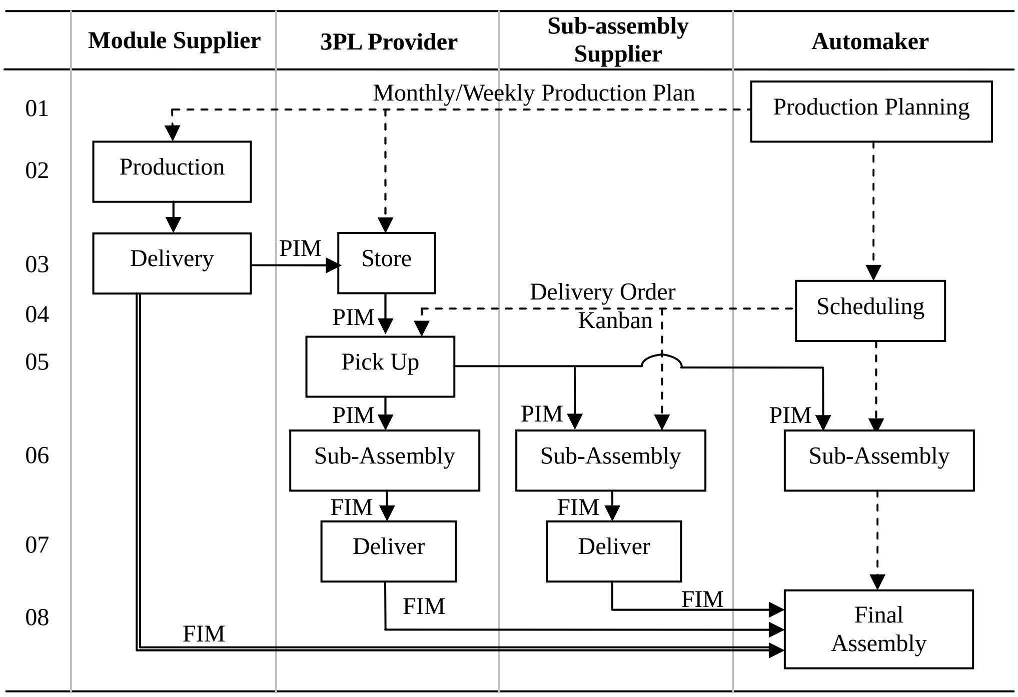

Figure 4. Process structure and information architecture of modular supply network

In the PIM scenario, there are three options for the modular supply network, which largely depends on the R&D and manufacturing capabilities of both the supplier and the automaker. The PIM is normally finished by the module supplier. Before it can be fed to the automaker's final assembly line, there are some sub-assemblies which should be completed by a third party, such as a 3PL provider (see Figure 3 (b)), automaker (see Figure 3 (c)), or sub-assembly supplier (see Figure 3 (d)). All of them either operate a sub-assembly line or have related manufacturing facilities to complete the task. Not only for a high value PIM such as air conditioners but also for a medium value PIM such as tires, most of the sub-assembly activities are low value-added.

For these supply networks, close relationship and collaboration are necessary because of the complex nature of the supply network in the automotive industry. ERP and the Kanban system are the typical IT architecture used to achieve information sharing in automotive industry. Within the complex modular supply network, visibility (Bartlett, Julien et al., 2007) and information accuracy (Waller, Nachtmann et al., 2006) are essential to successful modular supply. More and more advanced technologies, such as RFID (Vijayaraman and Osyk, 2006), are used to achieve visibility within the supply network and to improve the information accuracy both in a 3PL provider's warehouse and in the assembly plant.

Conclusions

Through literature reviews and case studies, this research defines two types of modules: fully integrated module and partly integrated module. Correspondingly, there are different types of modular supply networks. The findings are summarized into a 3C framework from the perspectives of context, capability and configuration. The 3C framework suggests a way to improve the performance of modular supply network. Also, the findings point out the areas to target to improve and enhance the modular logic in the automotive industry for automobile suppliers.

The findings suggest that the module suppliers should devote themselves to improving the capability of module integration (product design), process integration (production process design), and upstream supplier integration. That is to say, they should develop their skills on supply chain management even though it is traditionally regarded as the responsibility of the automakers. The research results also imply that not only the automaker but also the module supplier should match their modularity strategy with their corporate strategy, which will directly affect the performance of the modular supply network.

The findings also suggest that if the 3PL provider possesses production capabilities, it will be more helpful for the sub-assembly activities in the PIM modular supply context. For example, it helps to achieve postponement. Otherwise, a sub-assembly supplier can play the same roles. If they do not follow the outsourcing strategy, automakers have to set up a sub-assembly line in their assembly plant to finish the sub-assembly process. Consequently, the synchronization is essential to the success of the PIM supply network. The synchronization refers to both the delivery with JIT logic between the 3PL provider and the automaker and the production between the sub-assembly line of the 3PL provider, the sub-assembly supplier, and the automaker's final assembly line. All these tasks require well-organized information systems to achieve visibility and real-time information sharing both on the planning level and the operational level.

Since the research is conducted in Chinese automotive industry, with specific consideration on seat, air conditioner, instrument panel and tire modules, the findings and implications need to be further studied and verified to ensure the universal applicability across sectors. Regarding the future research on this topic, more in-depth case studies and comparisons across a wider range of countries would improve the validity and reliability of the findings, helping refine the 3C framework. This paper summarizes the results of capability only from the perspective of design, production, inbound logistics, and information management. One area that needs further research is to identify new capability dimensions of the modular supply network. Furthermore, applicable tools and models should be developed to evaluate the capabilities of different modular supply networks. Another interesting area is that the patterns of the network structure and process structure of the modular supply network should be extended in future research. Due to the complex nature of the modular supply network, it is essential that the collaboration mechanism, management system and framework of support system be more detailed and specified for each modular supply network, which in turn has very important practical meanings for the automotive industry. Consequently, the strategies and tools for the modular supply will be more specified in the future research as well. Finally, research on the relationships among the patterns of modular supply network and innovation, M&A trends, and outsourcing will be helpful to better understand the development trends of modularity logic applied in supply network.

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