

**COMPETENCE TO MANAGE INNOVATION IN
COMPLEX PRODUCT SYSTEMS -
THE CASE OF STORED PROGRAM CONTROLLED SWITCHBOARDS IN
CHINA**

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ABSTRACT

Traditional concepts of managing product innovation are not suitable for innovation in complex product systems (CPSs). This paper argues that firms developing and integrating the components of CPSs need specific competence for managing such projects. A framework for evaluating a firm's competence in CPS innovation is developed that covers managing the integration of internal and external key resources and building technological and supportive capabilities. The analytical framework that consists of 18 elements specifying the key resources and capabilities is tested at the firm level in the stored program control switchboard industry in China.

1. INTRODUCTION

Managing innovation and its diffusion into the market is critical for the firm to gain and sustain competitive advantages. Innovation is the process through which firms seek to acquire and build upon their distinctive competence. Traditional concepts of managing innovation in commodity products does not seem to be suitable for innovation in complex product systems (CPSs), such as, semiconductor fabrication plants, intelligent buildings, air traffic control systems, flight simulators, etc. For example, whereas innovation in simple telecommunications products such as telephone handsets, fax machines and pocket pagers can be fully captured and analyzed by traditional innovation process models, the innovation trajectory of CPSs in the telecommunications service industry is deeply influenced by large user organizations (Hobday, 1995). Innovating CPSs such as digital exchanges, cellular phone systems and broadband networks requires a high degree of user (operator) involvement who often engage directly in R&D and production as well as maintenance, upgrading and re-design.

Few studies have focused specifically on innovation in CPSs (Miller et al. 1995; Tidd, 1995 ; Gann, 1997), and there exists no coherent guide as to how innovation occurs or how such innovation projects can best be managed by the firm. Consequently, CPSs innovation theory and industrial practice have lagged behind the more visible, mass market, commodity industries. Because CPSs projects transcend the boundaries of the firm as they are developed in network structures, the analysis of innovation in CPSs apparently requires an explicit consideration of the particular characteristics of the product, production process, innovation process, technology and business strategy, industrial network structure and market.

2 LITERATURE REVIEW

2.1 MANAGING INNOVATION

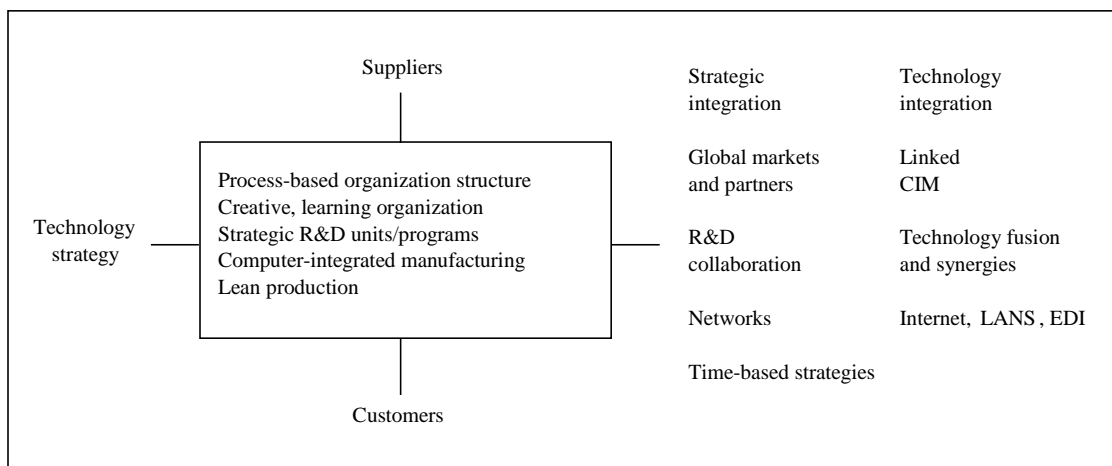
Several authors (e.g., Henderson and Clark, 1990; Utterback, 1994; Sundbo, 1995) adapted Joseph Schumpeter's original concept of innovation, which designates the activity of developing an already invented element into a commercially useful element, that is accepted in a social system (a firm, a society and so on). Innovation is defined as any newly developed idea, practice, or material artifact that is perceived to be new by early units of adoption within the relevant environment (Biemans, 1992). The result of innovation is a qualitatively new product, service or process which possesses a remarkable difference as compared to the previous state.

Thus innovation is not a technical term but an economic and social term (Edosomwan, 1989). Its criterion is not science or technology, but a change in the economic or social environment, a change in the behavior of people as consumers or producers, as citizens, etc. Innovation involves in addition to technological issues, also organizational and managerial dimensions, and can be distinguished along three categories, namely technological innovation, administrative innovation, and market innovation (Holt, 1977). In summary, innovation means the successful introduction of a new product or service into the market, or a new process into the business organization.

Numerous models of the innovation process have evolved over time, all aiming at improving our understanding of how to manage innovation projects. Rothwell (1992, 1994) distinguished five generations of process models, that each reflect the corporate strategy pattern and underlying macroeconomic conditions of their time. The first four generations of models depict the innovation process for simple products, as they were built based on studies of product innovation and the related production process in industries manufacturing commodity goods. These conventional models that explain innovation as the result of technology push, market pull and integration of cross-functional teams with linkages to suppliers and customers can not explain and predict the innovation process in CPSs.

The fifth-generation or system integration and networking (SIN) process seems to be more appropriate for managing innovation in CPSs. Rothwell (1993) characterized the SIN process as an extension of the integrated innovation process with additional features, namely a process of electronification of R&D that takes place along with the process of strategic networking and thus spreads innovation much more widely across company boundaries. Important environmental changes such as increasing cost of R&D, convergence of technologies, shorter product life cycles, increased global competition and rapid technological change have in many research intensive firms led to a shift from competitive to collaborative strategies. Innovators, as part of a process of co-development, exchange electronic data with primary suppliers, R&D collaborators and even customers. All this is leading to a speedier and more efficient innovation process (see Figure 1).

Figure 1: Towards the Fifth-Generation Innovation Process



Source: Dodgson and Bessant (1996)

The SIN model has dominant characteristics in terms of underlying strategic elements and primary enabling factors (Rothwell, 1994). Major underlying *strategy*

elements are faster, more efficient product and service development with the customer focus at the forefront of strategies based on quality and other non-price factors. Corporate flexibility and responsiveness leading to strategic integration with primary suppliers and horizontal technological collaboration are emphasized along with the policy of total quality control. The primary *enabling factors* encompass greater system integration, flatter, more flexible organizational structures for rapid and effective decision making, and fully developed internal data bases with effective external data link. A few leading-edge innovators have already introduced elements of the SIN process into their innovation management practices, such as using artificial intelligence in product design, quality control and productivity improvement. But the SIN process model is still in its infancy stage, and more empirical studies are needed to test it in the field.

2.2 COMPLEX PRODUCT SYSTEMS

The concept of CPSs has emerged in recent years. Similar names are used such as major or large capital projects (Gann, 1997), complex, networked or systemic activity (Dodgson and Bessant, 1996), or a large stand-alone product-system (Prencipe, 1997). Hobday (1995) defined CPSs as high cost, large scale, high technology, engineering-intensive product, sub-system, system or infrastructure supplied by a unit of production, purchased by one or more users, usually under one or more formal contracts within a recognizable, single project.

CPSs embody at least three general characteristics that set them apart from mass produced goods (Miller et al., 1995). They are (a) high cost goods, made up of many interconnected, often customized, elements; have (b) 'non-linear' properties, whereby small changes in one part of the system can lead to large alterations in other parts of the system; and require (c) a high degree of user involvement. Hobday (1995) proposed six dimensions that distinguish CPSs from simple mass products, which are product characteristics, production characteristics, innovation process, innovation management, industry structure and market characteristics. He further suggested that the units of analysis for CPSs should be: (a) the project and (b) its output.

In this study, the analysis of project management thus focuses on the firm developing a CPS within the network of user/operator organizations, government and regulator agencies, and component suppliers by integrating its internal resources with critical resources provided by network partners. Thus the project is considered to be located within the network across the boundaries of several partner organization. There are two reasons for this approach. First, the success of CPS innovation projects depends on the producer's technological and management competence that is determined by resources and capabilities (competence-based view). Second, by definition, a typical CPS project is so complex that it needs several partner organizations to undertake. It should be emphasized that selecting as unit of analysis the firm within its network of partner organizations is significantly different from traditional studies of innovation in commodity products. There, the unit of analysis is a single firm and its internal factors and conditions that determine the innovation success. The relationship to external organizations of customers, suppliers, public agencies, etc. is treated only as a source for occasional inputs of information and resources at certain stages of the innovation process.

The CPSs theory represents a distinct and important analytical category for the purpose of innovation research. The process and management of innovation in CPSs contrast sharply with those of mass-produced commodity goods. Within CPS innovation networks, numerous organizations match their capabilities and resources over time. This phenomenon calls into question several basic notions of innovation and industrial economics. Therefore, it is necessary to distinguish the management of simple product innovation from managing innovation in CPSs.

2.3 COMPETENCE IN SPC SWITCHBOARD TECHNOLOGY

Technological competence in general refers to the ability to develop and design new products and processes, and to operate facilities effectively which include the ability to learn (Prencipe, 1997).

When Prahalad and Hamel (1990) introduced the concept of core competence they changed the basic notion of strategic management from the traditional focus on price/performance attributes of current products to the firm's ability to build core competencies that spawn unanticipated products and enable to enter new business. This is contrary to Porter's (1985) perspective, in which the development of technological competencies is viewed as a burden that firms should avoid.

In the following widespread discussion, academics and practitioners tried to operationalize the competence-based approach to sustaining competitiveness. A broad agreement was reached on the functions of core competence. The presence of core competences enabled firms to master diverse production skills and integrate multiple streams of technologies (Prahalad and Hamel, 1990), to enhance the effectiveness of problem-solving procedures, using of external knowledge, and understanding of demand and users' requirements (Dosi and Malerba, 1996).

Efforts to define the term core competence itself, however, were less consistent. Some authors defined core competence as the combination of *organizational resources* of greatest strategic value that enable differentiation from competitors (Dodgson and Bessant, 1996; Marino, 1996), or as a function of the resources which the firm owns (Joseph and Rajendran, 1992), while others introduced the concept of strategic *core capabilities* (Grant, 1991; Leonard-Barton, 1992). While core competencies represent technological and production expertise at specific points along the value chain, capabilities encompass the entire value chain; thus, they are two different but complementary dimensions of the new corporate strategy paradigm (Stalk *et al.*, 1992). Both, resources and capabilities are the foundation for new approach to long-term strategic management (Grant, 1991; Prencipe 1997). Competence is based on interweaving of resources and innovative capabilities, being created, directed and embellished by innovative capabilities Dodgson and Bessant (1996). Thus, critical resources and core capabilities complement each other to create and sustain core competence. The firm can increase its core competencies through capability accumulation (Sharif, 1995).

The actual measurement of competence is complicated due to three basic dimensions, namely *tacitness, specificity and complexity* (Dosi and Malerba, 1996) that

create difficulties in empirical assessment. Core capabilities, on the contrary, are more visible to the customer in a way that core competencies rarely are.

As the studies of CPSs in the aerospace, electronics and telecommunication industries show, the production volume, system scope and technology uncertainty together provide a rough indication of the complexity of a system (Shenhar *et al.*, 1995). The analysis of the product, production, innovation process, management, industry structure and market characteristics of the stored program control (SPC) switchboard industry confirm that SPC switchboards have most characteristics of ideal-type CPSs proposed by Hobday (1995) and can be classified as one type of CPS (the detailed analysis of the SPC product, production, innovation process, industry structure and market characteristics is given in the Appendix). Thus the research design for assessing the competence of SPCs manufacturers to manage innovation in this industry must focus on the analytical framework depicted by the fifth generation SIN innovation process.

3 COMPETENCE TO MANAGE CPS INNOVATION

Building of competence for product and process innovation is now widely accepted as the critical strategic task and a necessity for the firm to attain and sustain competitiveness (Prencipe, 1997). For securing effective innovation the management must examine how specific innovation projects can enhance the firm's competitiveness.

The concept of competence is especially important for managing innovation in CPSs. The resources required for CPSs are complex, so a firm needs to possess rich resources to match the demands for CPSs innovation (Hobday, 1995). Due to the complexity of CPS innovation projects, traditional strategic concepts such as the industry-structure-based and resource-based analysis can not satisfactorily capture and analyze the wide range of factors affecting the innovation process and output. For firms operating under such conditions of environmental complexity, change and uncertainty, Dosi and Malerba (1996) propose to design strategies as proximate and broadly rational plans for action whose formulation and effective implementation depends on the firm's competences.

In this paper, the concept of competence to manage CPS innovation refers to the quality or state of being functionally adequate or of having sufficient key resources and capabilities to manage CPS innovation successfully in the long run.

Effective management of CPS innovation requires a whole range of contributing factors, both relating to the firm's resources and capabilities and external network of collaboration. Like managing innovation in mass-production and commodity industries, internal resources and technological capabilities are necessary. In addition, the characteristics of CPS also require external resources from users, suppliers, research and government organizations and special supportive capabilities for acquisition, integration and human resources development. These sets of resources and capabilities are combined to build the competence to manage CPS development. Resources are the base for cultivating capabilities. Without appropriate resources, capabilities can not be developed efficiently, while the firm needs certain capabilities to allocate and use resources effectively. Resources provide the foundation for the competence to manage the innovation process, and the analysis of firm resources can help to improve awareness of why and where to invest in building up critical resources for innovation.

The competence to manage innovation in SPC switchboard technology is based on the interaction of the following key resources and capability elements:

Internal Resources include critical *design and manufacturing technologies, R&D facilities and assets, human and financial resources* within the firm. Design and manufacturing technologies involved in SPC industry are very broad and complex. Among of them, application specific integrated circuits (ASCII) technology and software technology are most important. Advanced ASCII technologies can improve functions of SPC switch and reduce the volume as well as save energy. In addition, software is the "brain" of SPCs.

External resources for SPC design and development complement the in-house R&D function. As the scope of technologies required is great, even large integrated SPC switch producers are involved in some form of cooperative research with other organizations. Their external network for sourcing specific information on component specification, technical standards and physical resources include all those linkages

formed with users, suppliers, shareholders, research institutes and universities, regulators, standard agencies, and consultants.

Capabilities required to use these key resources effectively and efficiently in the innovation process refer to the skills and abilities needed to generate and manage technological and organizational change stemming from innovation. SPC switch producers need technological capabilities as well as supportive capabilities to improve their competence to manage the complex innovation process.

Technological capabilities: The capability of acquisition is critical to identify, assess, negotiate and purchase the resources, especially technologies to be acquired while capabilities of adaptation and exploitation allow to learn applying these technologies. R&D and Design capabilities are needed to move from imitation to the creation of a new generation of products and services for business growth and exploitation of new opportunities.

Supportive capabilities to improve the competence to manage the complex innovation process are the capability of human resource development to encourage and enable employees to make more contributions to improvement and innovation. Capability of integration is especially important for CPS producers, that must effectively integrate different internal functions and divisions, and coordinate them with the external inputs to the innovation success.

The elements and factors of key resources and capabilities required by SPC switch producers are given in Table 1 and 2 below.

Table 1 Elements and Factors Key Resources

Elements	Factors
Internal resources	
Human resources	Percentage of employees holding a degree higher than bachelor
	Percentage of R&D employees
R&D facilities and assets	R&D laboratories and workshops
	Average annual R&D fund during the last three years
	Average R&D fund as percentage of annual turnover
	Number of patents owned by the firm
Financial resources	Assets
	Debt ratio (debt/assets)
Plant and equipment	SPC production capacity
	Percentage of fixed assets
External resources	
Users	No. of users involved in SPC switch R&D, design and manufacturing
Suppliers	No. of suppliers involved in SPC switch R&D, design or manufacturing
Academic agencies	No. of research institutes cooperating in R&D, design or manufacturing
	No. of educational institutes cooperating in R&D, design or manufacturing
Government and regulators	Direct financial support from government
	Average annual tax exemption ratio
Investors	Percentage of purchases on credit in total sales
	Credit class evaluated by banks

Table 2 Elements and Factors of Key Capabilities

Elements	Factors
Technological capabilities	
R&D and Design capability	R&D projects completed per 1000 employees
	Percentage of software design projects in total R&D projects
	Completion of R&D projects as percentage of new R&D projects
	Percentage of research contracts fund received from outside in the total R&D budget.
	Number of new products designed per 100 employees
	Percentage of annual sales from new products not older than 3 years
	Number of printed circuit board in one SPC switch
Capability to adapt & exploit technology	Adapted technology as percentage of purchased technology
	Products moving from imitation to creating new products in percent of total output
Manufacturing capability	Installed SPC switch lines as percentage of bidding per year
	Average rate of product modification/rework requested by users
	Average manufacturing cost per product
Supportive capabilities	
Acquisition capability	Average price of resources purchased
	Quality of resources purchased
Market and service capabilities	Domestic market share
	Average time needed from problem occurring to returning to normal operation of the system
Capability of human resource development	Average time of training per person per annum
	Average percentage of employees leaving the company of total employees
Capability of integration	Average annual productivity (revenue per employee)
	Average ratio of product function and price (BHCA/100 yuan)
	Number of new overseas customers
	Average time needed to let user operate after winning the bid

BHCA: busy hour calling amount

4 THE CASE OF A SPC SWITCH PRODUCER IN CHINA

TX Co. Ltd. is a joint venture co-established by Ministry of Post and Telecoms (MPT), and a Chinese telecoms company located abroad. In 1997, its revenue reached 520 million yuan, almost 8 times as much as that in 1995. TX obtained profit of 46 million yuan in 1996. At the end of June 1997, the company owned fixed assets in the value of 601 million yuan.

Table 3 Development of TX

	1993	1994	1995	1996	1997
Employee (person)	50	230	490	710	1061
Net assets (million yuan)			77.5	110.3	* 121.2
Contract Selling (million yuan)	0	6.1	74.0	470.0	570.0
Revenue (million yuan)	0	9.8	66.3	358.0	520.0
Productivity (million yuan/person)	--	0.043	0.135	0.504	0.490
Profit (million yuan)			-1.78	45.97	* 10.92
Installation of SP30 (million lines)	0	0	10.0	60.0	90.0

* first half of the year

The critical elements building TX's competence to manage innovation in SPC switch technology are shown in Figure 2. The main factors are discussed below.

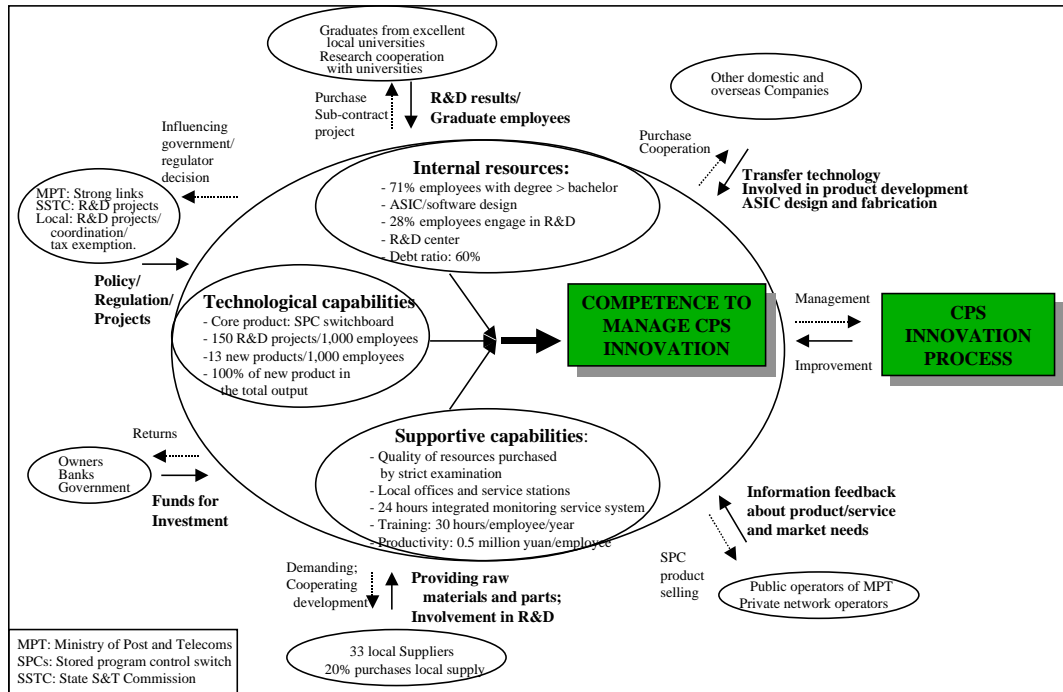


Figure 2 Competence to Manage SPC Switchboard Development in a Chinese Manufacturing Company

(1) New product development:

TX developed 13 new products out of which the SPC switch product group is the core, contributing some 80 per cent to the total sales value in 1997. The other products, such as business communication networks and wireless switching products will play a more important role in the near future.

- 1994 Intelligent Network Platform
- 1995 SP30 Super Digital SPC Telephone Switching System
- PBX30 Digital Branch Exchange
- 1996 SP30CN Business Communication Network
- 1997 M30 Mobile Digital SPC Switch
- WAS450H Wireless Access System
- WL30-F Wireless Local Loop System
- WL30-S Wireless Local Loop System

(2) **Human resources** provide some advantages for TX. The company has over 1,000 employees, of which 12 per cent hold a doctoral or master degree, and 59 per cent a bachelor degree. All the technicians and workers in manufacturing have undergone special technical training. The average age of the employee is 29 years. About 30 per cent

of employees working in R&D, 20 per cent in manufacturing, 40 per cent in marketing and service, and 11 per cent in management. Each year, several hundreds of new graduates with doctor, master and bachelor degree from universities are recruited.

(3) Systems: The SP30 Super Digital SPC Telephone Switching System applies the mode of switching network tandem offices distributed structure to enhance the adaptability to the network. The system has adopted application technologies of ASCII designing, optical transmission and switching into one system. The M30 Mobile Digital SPC Switch has been purchased by Motorola which will cooperate with TX to install this switch in the CDMA system of Hangzhou Motorola Mobile Telephone System Company.

(4) Market: The SP30 switching system is the company's core product. At the end of 1997, there have been 1.6 million lines with SP30 switches operating on the network, giving the company 1.6 per cent market share. The CN30 Business Communication Network was introduced in Guangzhou in November 1997, and will expand to Guangdong Province.

(5) Service: TX also offers high quality of customer services, such as the 24 hours integrated monitoring service system. Through this system, all the switching systems operation at local telephone offices can be controlled from the company's system monitoring center.

(6) Background of shareholders: TX is owned by institutions with a strong background of over 25 years experience in China's telephone network technologies and standards and development experience of several generations of central office switches.

TX's largest owner has access to 11 telecommunications related research institutes located in Beijing, Shanghai, Chendu, etc., while the telecoms company abroad provides information on worldwide market and technology developments.

(8) Government support

Subordinated to MPT, the company got support from the Ministry directly and from the State Science and Technology Commission. TX participated in several Key Technologies R&D Programs, such as the M30 mobile switching system project. In addition, there is strong support from the Provincial Government which approved that the company was publicly listed to help in financing its operations. TX received the privileges of tax holidays for the first 3 years and reduced tax payment later on. The company recruited over 300 excellent graduates from regional universities.

(9) Suppliers: TX has established good connections with 33 companies inside the province where it purchased about 20 per cent of the components and equipment.

(10) Technology Sources: TX relies mainly on its own resources and capabilities to develop the product technology through in-house design of infrastructure and software, SPC switching, manufacturing, marketing and after-sales-service. Cooperation with other domestic companies is only in electric power and electrical equipment, while integrated circuit (IC) designs are done in cooperation with firms abroad. In the past, universities

have not yet been involved as TX had more advanced knowledge based on 30 years of research experience of its founder. As telecommunication technology has developed very fast over the last years and the scope of new product development become much broader, TX has started to search for cooperation with university based telecoms research department to familiarize themselves with new technologies and to speed up the development time.

TX is recently facing tough competition from both national SPCs manufacturers and foreign companies. To compete successfully under the new market conditions, TX must increase the cooperation with network partners to improve tapping critical new knowledge in telecoms product and system development. To strengthen its marketing and service capabilities, TX will have to increase the number of local offices and network service stations, and do systematic market research to design an integrated product development and marketing strategy.

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Appendix: Identification of SPC as a Kind of CPSs

CPSs / Project characteristics	SPC Characteristics	Simple Product / Mass Production
Product characteristics		
Hierarchical/systemic	- System with interactive components and sub-systems.	Assembly-based
Complex interfaces	- Many customized, sub-systems and components with complex interfaces.	Simple interfaces
Very high cost	- Very high cost for large system.	Low cost
Products cycles last decades	- Long products cycle, although the functions are increasing continuous.	Short product life cycles
Multi-technology inputs	- Very wide range of designing and manufacturing technology inputs needed.	Few technology inputs
(Many) tailored components	- Customized sub-systems and components tailored for specified customers and/or markets.	Standardized components
Software-intensive	- Software modules are complicated and costly.	Hardware intensive
Complex, multi-functional	- More functions demanded by customers require more complicated interfaces and software technologies, as well as more complex system architecture.	Simple functions
Non-linear properties	- Small change in one part or software can lead to larger changes in other parts or the whole system.	Predictable linear properties
Upstream, capital goods	- Support capital goods.	Downstream consumption goods
Production characteristics		
Project or small batch	- Produce individually for a certain telephone operator	High volume, very large batch
System integration	- System integration is the core production process, but design for manufacture and assembly are also needed for hardware production.	Design for manufacturer
Software engineering intensive	- A lot of software engineering work is needed, the costs of which account for over half of total R&D investments.	Manufacturing-intensive
Scale-intensive, no mass production	- Scale-intensive, but mass production maybe relevant for hardware parts.	Incremental process, cost minimization central
Innovation process		
User-producer driven	- Telephone operators influence the innovation process from the design to installing, testing, and debugging.	Supplier driven
Business to business	- Production and installation of SPC business to business interactions with feedback between telephone operators and SPC manufacturers.	Business to consumer
Innovation/diffusion overlapped	- Innovation and diffusion cannot be neatly separated.	Innovation and diffusion separate
Innovation paths agreed ex-ante among suppliers, users, etc.	- Suppliers, users and some other network partners provide resources from the initial process stage.	Innovation path mediated by market selection
People-embodied knowledge	- Successful SPC manufacturers need wide range of information, skills and know-how in related industry sectors, such as manufacturing, electronics, and software industries.	Machinery embodied know-how

Competitive strategies and innovation management		
Focus on product design and development	- Focus on product design and development; economies of scale and cost are needed for hardware production .	Focus on economies of scale and cost minimization
Organic	- More organic with project managers stand a better chance of coping with uncertainty and dealing with feedback so as to respond quickly and effectively to changing environment.	Formalistic
System integration competence	- Technological competences including firm's resources and innovative capabilities are needed. Here, integrating these elements is must.	Volume production competencies
Management of multi-firm alliances	- Management of external networking resources is required, but TQM will be helpful for this kind of management.	Focus on single firm (i.e., lean production, TQM)
Industrial structure, organization and evolution		
Highly complex institutions	- Bilateral oligopolies with a small number of a few large user as buyers historically.	Large firm / supply chain structure
Project-based multi-firm alliances	- Multi-actor share context-specific resources to produce customized products.	Single firm, mass production
Long-term stability despite radical technical change	- Main SPC firms in the world show a remarkable degree of long-term stability despite technological change and progress in many fields.	Dominant design signals industry shakeout
Market characteristics		
Duopolistic structure	- Tend to be monopolistic or duopolistic with large corporations dominate market.	Many buyers and sellers
Few large transactions	- A few transactions in number but with high volume expressed in switching line.	Large numbers of transactions
Non-market mechanisms vital	- Markets are developing following the telecommunications deregulation and liberalization.	Regular market mechanisms
Institutionalized / politicized	- Government purchase behavior and purchasing loan exist, and national government tending to favor locally owned firms.	Traded
Heavily regulated/controlled	- Governments in many countries own, control or closely oversee production, installation and operation.	Minimal regulation
Negotiated prices	- Elaborate new prices negotiated between SPC producers and users from transaction to transaction before production.	Market prices
Often non-contested	- Competition following deregulation and liberalization	Highly competitive

Source: Hobday (1995)

Literature on the to SPC industry