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Modularization, Design Optimization, and Design Rationalization: A Case Study of Electronics Products

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Abstract: The purpose of this paper is to provide a review of modularization by Japanese firms on the basis of the analytical framework of product architecture. Japanese firms try to create system control modules, and attempt the rationalization of the design. However, they always design systems using the basic concept of integral type architecture. Modularization by Japanese firms is not a random design. It is the result of a design strategy that simultaneously achieves the optimization and rationalization of the product design.
This paper reviews the product modularization processes of Japanese firms based on the analytical framework of product architecture theory. Basically, Japanese manufacturing firms have created system control modules to achieve rational product designs. However, conceptually, the system was always designed as an integral type. We conclude that, to Japanese firms, modularization is not a random choice of design but is the result of design strategies to simultaneously meet the optimization and rationalization of the product design.

Keywords: design optimization, design rationalization, design solutions, system control module

Introduction

Manufacturers in newly industrialized economies (NIEs) are catching up with Japanese firms in the Asian region at an increasing pace. Digital products such as LCD televisions and DVD players are typical examples. It has been acknowledged that Japanese firms have played a leading role in the product innovation of these digital products. A product with new concepts and the latest elemental technology is generally thought to face difficulties in terms of commercialization and operation, especially if neither in-depth product knowledge nor technology is at hand. However, recently, there have been cases in which firms with no technological capabilities have designed successful products. The proliferation of technology and the catching-up of the NIE countries are threatening Japanese firms. As a result, the first-mover advantage of Japanese manufacturers will be lost in a very short period.[1]

An analytical research study based on the united framework of product architecture theory has made an attempt to illustrate the various inter-firm relationships of these catch-up firms. Fujimoto and Shintaku (2005) shed light on Chinese manufacturing businesses that use the analytical framework of product architecture.

Shintaku, Tatsumoto, Yoshimoto, Tomita, and Park (2008) claim that the drivers of this business phenomenon are the proliferation of technology at an accelerated pace and the international division of labor. Product architecture theory expressively explains the impact of modularization on industries and manufacturers.

However, the answer to the question of who initiated modularization is not clear yet. Modularization did not occur by chance; it is the result of design rationalization efforts by manufacturers. Manufacturing firms in NIE countries merely utilize the outcome of design rationalization. We attach importance to the fact that there is a difference in the design capability of manufacturers who strategically convert a product's architecture and those who passively accept modularization. Japanese manufacturers promote product modularization. Chinese manufacturers accept modularized products from the Japanese. A typical example of this is the electronics industry in Asia.

This paper distinguishes product modularization based on the differences in a product's "conceptual architecture" and "physical architecture." Conceptual architecture is the basic design concept chosen at the design stage of production. Physical architecture is how the final product is structured, that is, the pattern of the physical embodiment in which the functional and structural elements are shaped.

Developing modularization requires integrated knowledge of the product's system as a whole. We should remember that modularization is the result of design efforts. Japanese manufacturers design products with a dual nature: Conceptual architecture (basic design concept) is integral, but "physical architecture" is modular. This has been presented in comparison with Chinese manufacturers.

Japanese manufacturers basically design a product system with highly integral characteristics to realize differentiation. However, once the product is conceptualized, the system is prone to modularization. Focusing on product knowledge, the ability to achieve successful modularization is based on the design capability of highly integral systems.

It is generally acknowledged that Japanese manufacturers strategically adopt an integral product

[1] Akamatsu (1962) and Vernon (1966) claim that the production of new products first begins in advanced countries and is then transferred to low labor-cost developing countries. However, they do not mention the effect of the proliferation of technology at an accelerating pace. Sakakibara (2005) instituted the problem of the innovator's profitability.

model with higher performance in order to hinder catch-up countries like China. However, as observed, Japanese manufacturers have competed with Chinese manufacturers in the realm of modular products by improving their product performance. For Japanese firms, upgrading each module is not the answer: their differentiation strategy is to tune up total system performance. Even if physical architecture has turned into the modular type, the product system will be designed under the conceptual architecture of an integral type.

Japanese manufacturers try to achieve the optimization and rationalization of a product's design simultaneously. In order to do this, a "self-solution to the problem" is attempted by using digital control technology. The performance of the entire system is achieved by optimizing product design. In this case, an integral type is selected as the product architecture (basic design concept). At the same time, any error in the entire system is replaced with the design solution for a specific module (partial design solution) in order to enhance rationalization. On the other hand, Chinese manufacturers procure worked-out systems as solutions, ex-post.

This paper examines the case of color televisions in Asia.

1. Encapsulation of integral expertise

1-1. Product architecture

Product architecture is the basic design of corresponding patterns between functional and structural elements (Fujimoto, 2008; Ulrich, 1995; Ulrich & Eppinger, 1995). The integral type shows more complexity in corresponding patterns, and the modular type shows more simplicity. Integral type architecture is composed of mutually adjusted parts. This type of architecture is chosen when the final product value and performance are higher. The corresponding functional and structural elements are intricately related (a many-to-many correspondence between functional and structural elements), and a number of specific functional parts are used in the product. In modular type architecture, modules, in which functional elements are attached to structural elements, are combined on a relatively simple interface (one-to-one correspondence between functional and structural elements). The modular design concept is characterized by this simplicity. Once an interface is created, addressing and attaching functional elements to the structural elements in the "physical embodiment" are very simple.

Since architecture is an analytical concept that concerns the ways in which patterns can connect to each other, the focus is on the fundamental design regardless of the subject. Therefore, architectural analysis allows classification across various different industries and products.

Ideally, integral type and modular type patterns are abstract concepts that are difficult to observe in reality. We assume that these two ideal types are the polar points on a continuum. A specific type of architecture can be placed at some point on the continuum and conceived of as belonging to either type by way of the degree of relativity (Fujimoto, 2002; Oshika and Fujimoto, 2006).

It is necessary to take into consideration the hierarchies of a system when adopting an architectural approach. Most products are systems that consist of two or more types of architecture at the sub-system level. That is, different types of architecture are combined into a hierarchical structure. It is necessary to note which level of hierarchy we are targeting when we analyze product architecture.

Product architecture theory does not evaluate whether an industrial structure or corporate strategy is advantageous, either from a technical or an engineering point of view. The focus of architecture theory is to examine the dynamic profile of the architecture (i.e., diversity and variability) and to understand the live appearance of industrial structures and business strategies.

The dynamic profile of an architecture is defined by various conditions (e.g., customer preference, technology, organizational capability, etc.), which we call the "selection" problem of architecture. The dominant architecture will differ among identical industries and products according to the time period and place/region (Shintaku, 2007). For instance, with regard to customers' needs, if customers in a certain region prefer integral type architecture, it becomes the dominant architecture.

However, gradually in the same region, the customers' choice of architecture may change. Accordingly, manufacturers change their products' architecture in keeping with the market demand, thus indicating that selected architecture depends on the customers' needs.

The technology and capabilities of each manufacturer are different. As a result, the architecture that is selected or that can be selected depends on the firm. Different manufacturers are likely to select different types of architecture for a single product in the same time period and place/region. In general, the integral type is selected when improved performance is aimed at. Differentiation strategy pushes product architecture toward the integral type.

Manufacturers select architecture under various conditions. Product architecture is strongly related to product development management and market strategy decisions (Ulrich & Eppinger, 1995).

1-2. Good design and modularization

In this chapter, we consider the relationship between modularization and design theory. Suh (1990, 2001) argues that axiomatic design builds the functional-structure model of products.

Suh distinguishes a good design from a bad one on the basis of the principles of design. The principles provide guidance for evaluation and decision-making in design processes. The design axioms provide principles. Suh describes the two axioms necessary for a good design: the independence axiom and the information axiom.[2]

[2] Suh points out the following: There is no standard that selects "good design." The reason is that the decisions taken behind creating a design are not good.

In this paper, we focus on the independence axiom. Our goal is to consider the relationship between a good design and product architecture.[3]

The independence axiom values one-to-one mapping between functional requirements and design parameters. Suh classifies design into uncoupled design, decoupled design, and coupled design. Uncoupled design maintains an independent relationship between the function and design parameters even when the parameters are changed. The axiomatic approach considers uncoupled design to be a good design. Coupled design, on the other hand, is labeled as a bad design.

When taking the axiomatic approach, designs without any trade-off problems are good designs. Coupled designs always bear the trade-off problem. With uncoupled designs, however, the trade-off problem is solved. In other words, an uncoupled-design solution is modularization. In the axiomatic approach, the modular-type design is a good design.

Baldwin and Clark (2000) introduce a design philosophy to solve the interference between the parameters and the trade-off problems of complex systems. They eliminate the interdependencies of functions. Therefore, by definition, architecture is strictly different from the modularization concept of Ulrich (1995) and of this paper. However, both take up the same issue, which is to solve the interference problem in coupled designs.

Uncoupled design is characterized by one-to-one correspondence between functional elements and design parameters. However, this kind of relationship does not arise naturally in most designs. Design efforts by designers are a necessity. For instance, when a certain function is designated to two or more design parameters, the designer will try to bundle them together in a group.

Designers should recognize the very complex nature of modularization. Making product architecture modular requires prior product vision (i.e., a basic type of thinking in terms of engineering). Effort must be put into resolving complexities (Baldwin & Clark, 2000). Clustering methods that use the design structure matrix (DSM) and others form the module. In other words, these techniques are methodologies to modularize architecture.

Designers who encounter complexities in design requirements are puzzled. They try to divide the problem into individual pieces and find a solution for each piece. These partial design solutions are then build up again into a system, using design rules. Modularization is not a specific design approach. It is an economic approach to design that applies the principles of divide-and-rule.[4] The axiomatic approach and modularization have the same intention, which is to help the engineer.

[3] Refer to Okuma and Fujimoto (2006) for axiomatic design and product architecture.

[4] The methodology of the analysis of functions, the resolution of functions, and the synthesis of partial solutions is called “universal knowledge in design”; this has been presented by Pahl and Beitz (1988).

The independence axiom and modularization, according to the design theory, are concepts of good design solutions.

1-3. Rationalization and optimization

Product integration and systematization knowledge (in-depth knowledge) are necessary to achieve modularization (Aoshima & Nobeoka, 1997; Gu, 2008). When functional requirements increase, systems get more complex. Therefore, when a narrow range of design parameter is acceptable, the task becomes harder.

It is not easy to achieve uncoupled design with modular architecture. When a modular product (real machine) is dissolved into modules, we can see that the function running at the level of each module is very sophisticated. As functional interdependencies between modules become weaker, the corresponding patterns between the function and structural elements become simpler.

When we wish to avoid function coupling (i.e., interference) in a system, we can contain interfering features in closed components. This narrows the range of functional interferences in the whole system. Clustering and reintegration are basics for building modular-type architecture products.

Manufacturers select types of architecture based on various conditions. However, the constraints by which firms are bound differ, as do their capabilities. Even if modularization is aimed at, constraint conditions and capabilities may not allow it.

When differentiation strategies are chosen, systems are often designed from scratch. In this case, modularization is difficult. Function coupling is closely related to the acceptable range of the target function (Suh, 1990, 2001). The tolerance of functions is frequently open to compromise. However, competition or market needs may not permit any compromise. In cases where differentiation becomes the important competitive factor, it is necessary to seek maximum performance. The complexity of design increases when the least functional compromises are tolerated.

The trade-off problem in design occurs when the complexity of design increases. When a coupled design cannot be avoided, an optimization method is used (algorithmic, etc.). Coupled designs give priority to functions. Less important functions are considered to be constraints. The Pareto-optimal solution is a typical case. The Pareto-optimal solution selects design solutions from the leading edge of performance. Design solutions accept the coupling function as a given. The best performance is selected from two or more solutions.

Axiomatic design or modularization is the “rationalization approach to design.” It is a device for handling complex systems (Baldwin & Clark, 2000). The optimization method is the “optimization approach to design,” which seeks maximum performance. These are the types of architecture (basic design concepts) of integral type products.

In other words, the rationalization approach aims at modularization; the optimization approach aims at integration.

1-4. Modularization in the electronics industry: Encapsulation

Modularization requires the conversion of coupled designs into uncoupled designs. In practice, it is difficult to modularize a new design. For the latest products, competition is keen and market requirements change very quickly. When corresponding patterns between structures and functions are not yet clarified, it is necessary to build the product using coupled design. The integral type is then selected as the type of architecture (basic design concept). In these cases, manufacturers try to find common grounds for the best design solution.

Shintaku, Ogawa, and Yoshimoto (2006a) clarified the following in the case of DVD product development (and additionally, optical disk development). Products with new concepts and technology become integral-type products. However, a lot of electronics products are changed into modular types over time. This is made possible by improvements in design. There is an intentional process of pushing the product toward the modular type. Products are thus often changed from the integral type to the modular type. However, there are cases in which a new product has appeared as a modular type from the very beginning. Typical examples of this are highly differentiated products (high-end segment models). There is performance competition in modular products as well, when the best performance is aimed at. Architecture (product design concept) is of the integral type. However, the actual product (physical embodiment) is of the modular type. The design concept does not match the architecture of the realized product. Recent advances in software (embedded software) and semiconductors have brought innovative changes to electronic products (Ogawa, 2007). Japanese manufacturers positively use the edifice of knowledge of semiconductors and software technology as the driving power for upgrading and rationalizing product design.

The semiconductor and software technologies used for electronics products are control technologies. Japanese manufacturers secure the integration of the total product system by using digital control, namely, semiconductors and embedded software. They encapsulate integral expertise in specific modules that control the total product system. Modules form complex systems and provide high performance capacity (Aoki, 2002). This paper distinguishes modules that control the total system from modules that are subject to control. The former kind of module is called the “system control module”; it achieves modularization and acts as an adhesive medium between modules. Shintaku, Ogawa, and Yoshimoto (2006a, 2006b) refer to the creation of system control modules as the “encapsulation of the system-integration element (encapsulation of the integral expertise).”

The system control module is created by consolidating product integration knowledge into specific modules. This consolidation requires integrated knowledge. In order to modularize product architecture, one should be able to conceive the total system beforehand. In the case of electronics products, integration expertise is replaced by digital control technology. In recent electronics products, the system control module has replaced integration elements with digital control technology.

The application of system control modules turns the rationalization of design into a reality. Knowledge systems and integrated design are indispensable for rationalization. The system control module is a means of simultaneously achieving optimum design and system rationalization.

In the same hierarchical tree structure, modularization operates at the upper level, and integration operates at the lower level (Aoshima & Takeishi, 2001).

The encapsulation of integration elements allows functional partition, structure segmentation, and re-coupling as an engineering system. Designers who are ignorant of the trade-off condition in design are unable to create modular systems. Optimization and rationalization require the same knowledge. Turning electronics products into modular types requires design efforts from both the rationalization approach and the optimization approach.

If modularization proceeds, the basic concepts of modular types can easily be selected in the following products as long as the system is not drastically changed. An extreme example would be a manufacturer who lacks either the technology or the knowledge, but who is able to build commercialized products. Manufacturers do this by assembling ready-made modules. This is already happening with DVD players. Manufacturers only have to procure semiconductor chipsets (system control modules) and optical pickups. The products of Chinese manufacturers fit into this model. Designing such products is very simple (Shintaku, Ogawa, Yoshimoto, 2006a, 2006b).

Chinese firms are modeled on the manufacture of modular type products. Japanese firms bring forth modularization. Therefore, there is really a distinction per se between Japanese and Chinese firms, and this difference lies in the design capabilities of the firms.

2. Product design of the TV set business of Chinese and Japanese firms

2-1. Case: Japanese firms

First, we consider the cathode-ray tube (CRT: picture tube) television business of Japanese manufacturers. The knowledge of systemizing products is the source of Japan’s differentiating strategies. Many Japanese manufacturers possess original technology and design expertise. Designs of TV-set chassis are unique to each company. The system design solutions for chassis become product differentiation.

For example, a number of elemental technologies have been developed for better pictures and have been absorbed into the system. In the process, engineers revise the system and clear the interdependencies between components.

Let us describe a case in which a new CRT is introduced. This introduction demands major changes to the system. For instance, if a flat CRT is adopted instead of a round shaped CRT, the design factors for systemization change drastically.[5] The new design will be uncoupled design, and the engineers select integral type design concepts. The concept is reflected in the chassis design. Japanese firms reduce the load of the chassis design by using semiconductor technology while maintaining the uniqueness of the chassis.

Japanese firms have used the advancement of semiconductors for the purpose of differentiation and cost reduction (Hiramoto, 1994; Shintaku, 1994; Sugiyama, 2000; Yoshimoto, 2007). Semiconductors are system control modules. The number of electronic components decreases with the encapsulation of integral expertise; the functions of the physical components are described by the control technology system. This is achieved by design rationalization. The TV set, however, has been designed under integral type architecture. The system control module brings the physical appearance of the system close to the modular type.

Next, we consider LCD TVs. Generally, image processing Large Scale Integrations (LSIs) are designed by each company individually and are then installed in the chassis. The reason for this is the same as in the case of the CRT TVs. Digital control technology has made it easy to solve problems in the case of LCD TVs. Among television products, LCD TVs are relatively easy to design.

However, effort must be put into an optimal solution for better pictures. Newly developed panels that use the latest elemental technology require new systems. This is the same as in the case of flat CRTs. Modularization is achieved by encapsulating the technology in the system control module.

Japanese firms make products modular. Integral type architecture (design concept) is confined to partial design solutions (digital control of the systems) as the intention is to reduce design complexity. In each case in which a Japanese firm offers a new differentiation system, a new system control module has been developed for it. The final product achieves differentiation by integral type design, but the physical appearance of the product is of the modular type.

Japanese manufacturers modularize their products as a means of easing design complexity. This is not open modularization, but rather is a closed approach, intended for in-house use.

2-2. Case: Chinese firms

Chinese businesses rely on the procurement of the CRT and the LSI from overseas companies. These firms often lack product integration knowledge and therefore purchase knowledge from outside. Knowledge has been input into the universal LSI Application Specific Standard Product (ASSP), which is available at reasonable prices in the

[5] The case of flat-CRT TV development at Sony, illustrated by Katsumi (1998), serves as a reference.

commercial marketplace and is purchased by Chinese firms. It can be considered a system control module of the commodity type. LSIs have become easier to use as performance has improved. LSIs help the designer of the product regardless of his/her product integration knowledge. Modules evolve independent of any adjustments between manufacturers (Baldwin & Clark, 2000; Aoki, 2002).

The dependence on external knowledge also appears in the case of CRT TV development by Chinese firms. The CRT and the deflection yoke must be mutually adjusted to achieve compatibility. Japanese firms procure the deflection yoke and the CRT and assemble them into an optimal design. Chinese firms buy ready-made modules called integrated-tube-components (ITC), in which the deflection yoke and the CRT are encapsulated with optimal adjustments. An ITC is a conditioned CRT, provided by a vendor. With ITCs, knowledge of how to make the adjustments is unnecessary, and Chinese firms are able to design and produce TV sets even if they possess neither the knowledge of nor the expertise for adjustments.

However, ITCs do not guarantee the best performance. Chinese manufacturers procure several ITCs from different manufacturers and adopt them for the same product model as if they are compatible (Marukawa, 2007). As a result, the final goods show varied performance in the same product model category.[6] Chinese manufacturers design the TV system by putting together universal LSIs and commodity cathode-ray tube modules.

The same can be said for LCD TVs. Chinese manufacturers buy LCD panel modules (i.e., modules consisting of drive circuits mounted on panels and backlight units, pre-assembled) and image processing LSIs from outside (Shintaku et al., 2008). LSIs and panel modules are commodity type products. Although LCD panels look similar, performances (color representation, view angle, etc.) differ with each panel manufacturer. As a result, there is a need to match panel modules and image processing LSIs, and engineers need to make design adjustments. However, in Chinese firms, parameters are just selected from an installed list.

The LSI is the system control module for LCD TVs. The design solutions for the basic functional systems of the LCD TV are installed in the LSI. The most common way is to apply the LSI vendor's reference design. Chinese firms consider the option of installed parameters in LSIs to be the system design in LCD TVs.[7] That is to say, the nature of TV set design of Chinese manufacturers is passive.[8]

3. Discussion

As previously noted, Japanese firms' active

[6] There are two kinds of deflecting yokes integrated into the ITC: The user-specific specification（optimum coordination）and the standard specification. CRT vendors set either of these two. Japanese TV manufacturers produce the former, and Chinese TV manufacturers produce the latter. When using the ITC without specification requirements, the optimization of the performance (for instance, picture quality) is difficult (Shintaku et al., 2005).

[7] Refer to Shintaku et al., (2007) for the designs of LCD-TV by Chinese firms.

[8] Examples of designs by Chinese firms are cellular phones, room air conditioners, and microwave ovens.

modularization has resulted from the efforts made to achieve rational designs. The modular approach is the canon of "good design" for engineers who wish to exclude complexities. Yet, competitive goods cannot be created just by rational design.

Design rationalization is not the only source of competitiveness. The differentiation strategy is as important as rational design.

It is necessary to rationalize design when improving the performance of the TV product system. Japanese manufacturers should take the optimization approach and the rationalization approach simultaneously, because they face intensified competition. As further differentiation is sought, the system gets more complex and the design becomes coupled. Japanese manufacturers incorporate control engineering knowledge based on digital technology into the product design. In fact, they create the system control module.

Modularization by Japanese engineers is the result of closed in-house efforts to achieve rational design. The final goods (i.e., televisions) are not modular products of the ideal type. Televisions do not allow infinite flexible combinations of modules. "Noise" (that is, the decreased functional status of the system) is generated in the system if modules are merely put together at random. Noise is an obstacle to product differentiation. It adversely affects the whole system.

The selection of architecture is an issue of the "selection of the design concept." In general, when a product system is described as an integral type, we assume that the architecture characteristic (i.e., the physical embodiment) is of the integral type too. However, in the case of TV systems, total product performance cannot be enhanced merely by applying the latest technical updates to specific modules. The differentiation strategy must be sought by simplifying complex design problems, using the optimization approach.

Fierce competition calls for differentiated products with rational designs. Japanese manufacturers combine the optimization approach with the rationalization approach in digital control technology (engineering). Consequently, they have come to design modular type (physically modular built) products with integral type design concepts. Japanese firms have always been challenged to both optimize and modularize product design.

Japanese systems are driven by control mechanisms that are peculiar to each company. To Japanese firms, modularization is aimed at in-house use only. The purpose is to exclude complexities that they face, not to promote open architecture.

Japanese firms build into their products optimal solutions for modularization. That is, they create the system control module themselves. Conceptually, these system control modules are of the integral type. The physical framework is modular, with conceptual architecture of the integral type.

Of course, there is the alternative of not making system control modules. The physical product can be of the integral type. Modularization is only one of the options, since Japanese firms can select from two physical architecture types (integral and modular).

Most Chinese firms are not capable of modularizing products themselves. They take advantage of the modularized output of overseas manufacturers. Chinese firms buy system control modules because creating these modules is difficult for them. The Chinese design concept (architecture) is of the modular type. This is the difference between Chinese and Japanese firms.

Semiconductor divisions in Japanese electronics firms sell system control modules as ASSP.[9] IC specialized producers in Europe, the United States, and Taiwan also sell system control modules. These producers refer to Japanese manufacturers' module units for functional partition (and system partition). Module vendors follow the system designs of Japanese manufacturers.

Many Chinese firms have no intention of repairing the defects that come with coupled designs. Moreover, they do not rationalize the designs by themselves. They only recycle systems that have been rationalized in the past by leading industrial firms. As a result, the designs of Chinese firms show the characteristics of imitation. The conceptual architecture of products made by Chinese firms coincides with their physical embodiment.

4. Concluding remarks

Design efforts to exclude complexity as much as possible lead to the pursuit of modular design, and the result is modularization. Product knowledge of rational design becomes the "modularity driver." Japanese firms have pursued active modularization as means of overtaking competition. What is notable in the modular designs of Japanese firms, as compared to the modular designs of Chinese firms, is that Japanese firms can differentiate themselves even with modular products. They lead modularization and seek technical differentiation simultaneously. Their capability lies in the fact that integral type architecture can also be selected. They are able to convert physical architecture (embodiment characteristics) and to optimize system design. Modular design is only a choice. They can compete on the basis of the performance of the modularized products.

The capabilities of producing modular designs and of producing modular products are different. Firms that manufacture modular products may face difficulties designing the original systems. It is hard to differentiate only by combining modules. If products are not differentiated, they get caught in fierce pricing wars. Typically, this is what Chinese manufacturers face in their markets.

Chinese firms rely on others' product designs for design solutions. As a result, they do not accumulate knowledge and cannot design original new products. It is difficult to design products that will

[9] The final goods division (at Japanese electronics firms) designs the system control module. However, it is not sold. The semiconductor division develops the ASSP by referring to the design of the final goods division.

appeal to customers by imitating existing modular systems. An in-depth knowledge of systems and rigorous concepts is extremely important for a value-added product. System technologies are not the aggregated result of component technologies (Ishii, 1987).

Modularization from Japanese firms is a result of the design efforts to unite design optimization and design rationalization. It is clearly a design strategy to improve competitiveness by using digital control technology.

The catching-up of firms in NIE countries remains a threat to Japanese manufacturers.[10] This catch-up has been accelerated by the proliferation of modules created using Japanese technology. The action assignments of Japanese firms can be solved by business evolutions that make the best use of double-face design strategy (that is, a strategic design approach that synthesizes rationalization and optimization). The impact of system control modules cannot be effectively mastered. The mind-set to improve the appeal of modular products (physical embodiment) created by integral design concepts (conceptual architecture) is necessary.

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[10] The catching-up of firms in NIE countries is owing to the complicated relationship between competition and cooperation. Asian manufacturing turned this relationship into a growth engine. As Shioji (2008) calls it, the “East Asian domination industry” is an industry in which East-Asian firms gain a high share of global production.

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