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Complexity Explosion and Capability Building in the World Auto Industry: An Application of Design-Based Comparative Advantage

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Summary: Based on the framework of design-based comparative advantage, in which dynamic fit between organizational capabilities on manufacturing sites and architectures of products and processes affect competitiveness of the sites and industries, the paper describes and analyzes various issues of the world automobile industry. The current US auto crisis is seen as a long-term consequence of the gap between division-of-labor type capability and integral-type architecture of small cars. The Japanese competitiveness in small cars in the late 20^{th} century is illustrated as the fit between path-dependent accumulation of coordination-type organizational capability and stricter safety-energy-environmental constraints imposed upon the automobiles in advanced nations. The possibility of commodification of the automobiles is discussed from modularization's point of view. The modular nature of the Chinese locally-designed vehicles, as well as the integral nature of an Indian low cost vehicle, is indicated. The architectural differences between pure electric vehicles and hybrid vehicles are emphasized as the paper discusses possibility and limitations of the former. Toyota's recent recall problem is seen as the problem of product complexity overwhelming the company's organizational capability in design.

Keywords: manufacturing, automobile industry, Toyota, globalization, commodification, comparative advantage, electric vehicle

1 Globalization and Design-based Comparative Advantage

The 21st century is considered to be the century of globalization. Although the meaning of globalization is somewhat elusive, one interpretation is that it is a strengthening of interdependency between people, goods and services, money, and information that transcends national borders. The expansion of freer trade is a manifestation of globalization in terms of goods and services. In retrospect, the 20th century was a century that witnessed regressions in globalization, including two world wars, protectionism, and clashes of ideologies. As the 21st century has seen a reduction in these types of regressive phenomena and a dramatic decrease in the costs of moving goods and information due to technological innovations, these international movements are predicted to increase (Jones, 2005).

Admittedly, the unregulated globalization of speculative financial businesses in the first ten years of the 21st century brought about the economic crisis that began in the U.S. Thus, the regulations for speculative money will most likely be tightened for the foreseeable future. In addition, in some places there will most likely be a temporary strengthening of movements towards protectionism in response to the world economic downturn. However, on the whole, the globalization of actual economies—in other words, people making purchases based on their own needs and the global liberalization of transactions between producers at their own risk (i.e., the flow of the liberalization of trade)—is unlikely to reverse. In this context, I predict that the 21st century will continue to remain "the era of economic globalization."

When free trade progresses in actual economies, according to past prominent economists, the fundamental logic that inter-industrial differences in relative productivity between countries give rise to international trade and division of labor, known as "the principle of comparative advantage," is more likely to prevail. The comparative advantage theory indicated by classical economist Ricardo around 200 years ago is said to be one of the most robust theories in economics (Ricardo, 1819; Samuelson, 1948). Suppose that even if Country J has superior productivity in all industries compared with Country C, the industries remaining in Country J are only the industries that have larger advantages in productivity (relative ratio), leaving the industries with lower advantages unable to remain. This is because the relative ratio of productivity of both countries is reflected in the relative ratio of wages in both countries.

The above theory rests on the basic premise that there exist resources of production that do not move across national borders. In the days of Ricardo, labor and capital were envisaged. However, I am of the view that in this day and age, typical of "things that do not move across national borders" (excluding natural resources) is the organizational capability accumulated in each region.

Suppose that the development of free trade was anticipated and means “the persistence of the international division of labor through comparative advantage,” we as citizens of Japan (and citizens of each country in general) now have to ascertain through an objective evaluation of comparative advantage what types of industry are likely to remain in Japan, and what types of industries will move abroad. For the citizens of a country, raising the level of productivity of all industries and keeping industries with comparative advantage in Japan are just about the only steps that can be taken in improving living standards.

However, what I may call “microscopic intra-industrial trade”—for example, the phenomenon in which steel plates for the interior body panels of automobiles are imported from Korea, whereas steel plates for the exterior body panels are exported to Korea—is so common in today’s world that it is difficult to establish industries with a comparative advantage. So far, there have been several unexplainable cases in conventional economics, and in the existing standard industrial classification, it is difficult to define industries with a comparative advantage.

In response to these types of circumstances, I propose a concept of “comparative advantage in design” in which not only the production sites but also the comparative advantage based on the choice of design sites influence the industrial structure of the whole country and the world (Fujimoto, 2007). Here, design refers to the activities envisioning in advance the relationship between the functions, structure, and processes of traded artifacts prior to production, and the information generated by them.

2 A Broad Concept of Manufacturing Management

A broad concept of manufacturing refers to the total range of industrial activities that embodies the creation (development) of design information that provides utility to users (customers), the transcription of this into media (production), and its transmission to the market (sales). In other words, “Manufacturing (“monozukuri” in Japnese) theory” can also be about contemplating over the nature of what “design” is to the economy (Clark and Fujimoto, 1991; Fujimoto, 1999).

Manufacturing management rearranged from the perspective of design information comprises the three pillars: Organizational Capability in Manufacturing, Capability-building Environment, and Product–Process Architecture.

1. Organizational Capability in Manufacturing refers to a system of organizational routines for carrying out the processes of creating, transcribing, and transmitting design information to customers in a way that is more accurate (high-quality), more efficient (low-cost), and faster (reduced lead time) than competitors (Nelson and Winter, 1982; Fujimoto, 1999, 2007). In other words, an

organizational capability to conduct the simultaneous achievement and improvement of QCD. Here, this is closely connected with the ability of the site to engage in development, purchasing, production, and sales.

2. Capability-building Environment refers to the environmental factors (conditions such as workforce, capital, materials, design information, market needs, and government) that played an important role in building the organizational capability of that country's firms and sites.

Generally, it is considered to be the experience of prolonged periods of fast growth that determines the organizational capability or the organizational climate of a firm. Therefore, the capability-building environment before and after prolonged periods of growth is important. For example, as Japan's rapid economic growth started unexpectedly early because of the Cold War, businesses grew amidst chronic shortages of labor, capital, and materials, leading them into growth based on long-term employment and long-term trading that secured these resources. As a result, the organizational capability of "integrated-type manufacturing (monozukuri)" based on multi-skilled teamwork became disproportionate in Japanese firms. A typical example of this is the Toyota Production System. The key to the success of this system is minimizing "time not spent on the creation and transcription of design information" and creating "good flows" of design information to customers that do not stagnate.

3. Product–Process Architecture refers to the formal pattern of dividing and connecting the design information of artifacts. Generally, the elements that are the target of design activities are product function (required specifications, etc.), product structure (parts, etc.), and production processes (equipment, tools, etc.), and while the domain of "specific technologies" deals with the concrete causal relationship between individual elements, it is the theory of architecture that argues the forms of divisions and connections of these elements (Suh, 1990; Ulrich, 1995). The forms of divisions and connections of elements of product function and elements of product structure are called "product architecture," while the forms of divisions and connections of elements of product function and elements of production process are called "process architecture."

Defined in this way, product–process architecture can be divided into two basic types: "modular- (mix and match) type" in which there is a one-to-one correspondence between the functional elements, structural elements, and processual elements; and "integral-type" in which there is a many-to-many correspondence between the elements. Actual product lineups are deployed on a spectrum somewhere between these two types (Ulrich, 1995; Baldwin and Clark, 2000).

3 Organizational Capability and Architecture:

Manufacturing capability can be broadly divided into two types: "division of labor-type capability" that emphasizes the specialization of each processing step of design information; and "integrated-type capability" that emphasizes the teamwork (the ability to adjust) of multi-skilled workers. From a historical perspective, I and others assert that the U.S.—a nation of immigrants—was of the "division of labor-type" that tended to make immediate use of existing individual talent, whereas Japan—a nation that experienced rapid economic growth amidst a chronic shortage of labor—had a disproportionate tendency towards the "coordination (integration) -type" based on long-term employment and long-term trading.

On the other hand, the formal aspect of design information—in other words, the abstract correspondence relationship between the design elements of function, structure, and process—is called "architecture (design conception)." Architecture can be broadly divided into two types: the simple "modular- (mix and match) type" that is close to the one-to-one correspondence between the functional elements, structural elements, and processual elements; and the complex "integral-type" in which the relationship between the design elements is intricate (i.e., they are deployed sequentially on the spectrum). Of these, integral-type products involve solving simultaneous equations between the functional elements, structural elements, and processual elements; in the case of complex products, what is required above all is the close mutual adjustment of design parameters through teamwork.

4 The Comparative Advantage of Design Location

Therefore, as a result of historical evolutionary processes, is it not the case that countries that have accumulated disproportionately the coordination-type organizational capability (the capability to adjust)—for example, Japan—tend to have a comparative advantage in design cost with products that require several adjustments; in other words, products with an "integral-type" architecture? Moreover, if design sites are left for products that have a comparative advantage in design, will this not influence the location of a production site (factory), i.e., the industrial structure of each country? The above is a hypothesis of the comparative advantage of design in which the organizational capacity disproportionate in countries and the appropriateness (fit) between the architectures of product and process bring about a comparative advantage in design. By applying the engineering principle of "design" to the industrial structure theory and trade theory, we can endeavor to gain a new insight into the comparative advantages of 21st century Japan (Fujimoto, 2007).

However, there is no architecture inherent in each product category (for instance, “automobiles”). For example, as the user environment and the evolutionary pathway of design information are different in Japanese and Chinese firms, even with the same compact cars, it is well known that there are substantial differences in the architecture. Japanese cars tend towards integral-type, while Chinese cars tend towards modular-type, i.e., even artifacts (products) that have the same function, due to differences in such things as the strictness of the user environment, the standards of functions required by users, and the strictness of regulations facing designers, the architecture is likely to differ by country, firm, and time.

5 Constraints and Architectures

Generally, in the event that the required standards regarding design function are high or the constraints relating to design structure are strict, if we consider other conditions as constant, then the architecture of the artifact (for example, a product) can be supposed as tending toward integral-type. If the conditions are strict, then there is a need to identify and optimize strictly both the functional parameters and the structural parameters. In this case, solving the functional and structural simultaneous equations corresponding to an artifact makes it easy to reach a specific solution for the product (this does not mean that the method of solution is specific, but that the value of the design parameters is product-specific). In other words, if in general the functions that customers require or the constraints of society (such as environmental and safety measures) become more sophisticated or complex, then I predict that dealing with these through modularization will become difficult, and the product architecture will become something that is both integral and complex.

Therefore, the recognition that “the 21st century is the era of globally-shared environmental constraints,” which continues to emerge as another characteristic of the 21st century, tends to have important implications. Needless to say, the present age is one in which constraints relating to the global environment are becoming strict. With issues such as the fierce international competition for scarce energy resources, controversy over global warming, the movement of environmental pollutants across national borders, and the international adjustment and increasing strictness of environmental regulations, energy consumption regulations and safety regulations in response to these, it has become an era in which both users and designers of artifacts share strict constraints that transcend national borders.

6 Competitive Advantage in the Integral-Type Products

On the premise of the above observations, I will provide an explanation of the theory of comparative advantage of design location from the theories of organizational capability and architecture.

The organizational capability of the fields of firms is imbued with the history of that field and the organizational cooperation through competition in capability building between firms and fields. On the other hand, the architecture of products also evolves through the unique influence of technology and market needs. Moreover, in the event that the fit (compatibility) between the organizational capability of the fields of certain firms and the architecture of the relevant products and processes is good, the competitiveness of that field ("deep-level competitiveness" such as productivity, initial costs, lead time, and the rate of defects) increases, which becomes linked with the competitiveness ("surface-level competitiveness" such as price and product strength) of products in the marketplace.

In other words, the organizational capability of firms is disproportionate in each of the world's main regions and it is the theory of comparative advantage of design location that considers this "regionally disproportionate organizational capability" and "compatibility" in architecture of the relevant products as in no small part influencing the industrial competitiveness of each region.

What would happen if, for example, this framework were applied to manufacturers in Japan? Clearly each firm has its own characteristics; however, we can consider those firms up against the same capability-building environment as tending to build similar organizational capacities.

For example, as previously described, as Japan in the second half of the 20th century encountered a capability-building environment of rapid growth amidst a chronic shortage of resources for production, it had a tendency to build "integrated-type manufacturing" organizational capacities based on multi-skilled teamwork through competitiveness in capability building that had as its base long-term employment and long-term trading. This was disproportionate in Japan.

What was good about this type of organizational capability and compatibility was the aforementioned products of "integral-type" architecture. As a result, through these types of integral-type products, a strong tendency could be observed in Japanese industrial competitiveness. This is one hypothesis relating to the Japanese industrial competitiveness predicted by the comparative advantage of architecture. This tendency of comparative architecture was established in the second half of the 20th century and is a tendency that I see continuing for a while in the first half of the 21st century.

7 The Industrial Architectural Geopolitics

With regard to the countries and areas other than Japan, although at this stage these are impressionistic hypotheses from case studies, I forecast the following (my analysis focuses mainly on Asia, with only a rough analysis of Europe. Fujimoto, 2006).

1. Japan, with its disproportionate “coordinative (integrative) capability,” has its strength in integral-type products that emphasize hidden competitiveness (manufacturing site) due to the historical development of its postwar economy.

2. Continental Europe, with its disproportionate “expression capability,” has its strength in the integral-type products that emphasize the hidden competitiveness (brand design) due to its history of maneuvering between medium-scale countries.

3. The U.S., with its disproportionate “conceptualization capability,” has its strength in knowledge-intensive modular-type products due to its historical background as a nation of immigrants.

4. Korea, with its disproportionate “concentration capability,” has its strength in capital-intensive modular-type products due to a history of zaibatsu growth without the dissolution of zaibatsu.

5. China, with its disproportionate single-skilled “mobilization capability,” has its strength in labor-intensive modular-type products due to its history of suddenly moving away from a Soviet Union-type model to an open economy based in coastal areas.

6. Compared with China, a section of the ASEAN members that in general have a high labor-retaining capability has the potential to be strong in labor-intensive integral-type products.

7. I also get the impression that, with the noteworthy exception of the Bangalore information industry, Indian manufacturers also tend more towards “integral-type” than China.

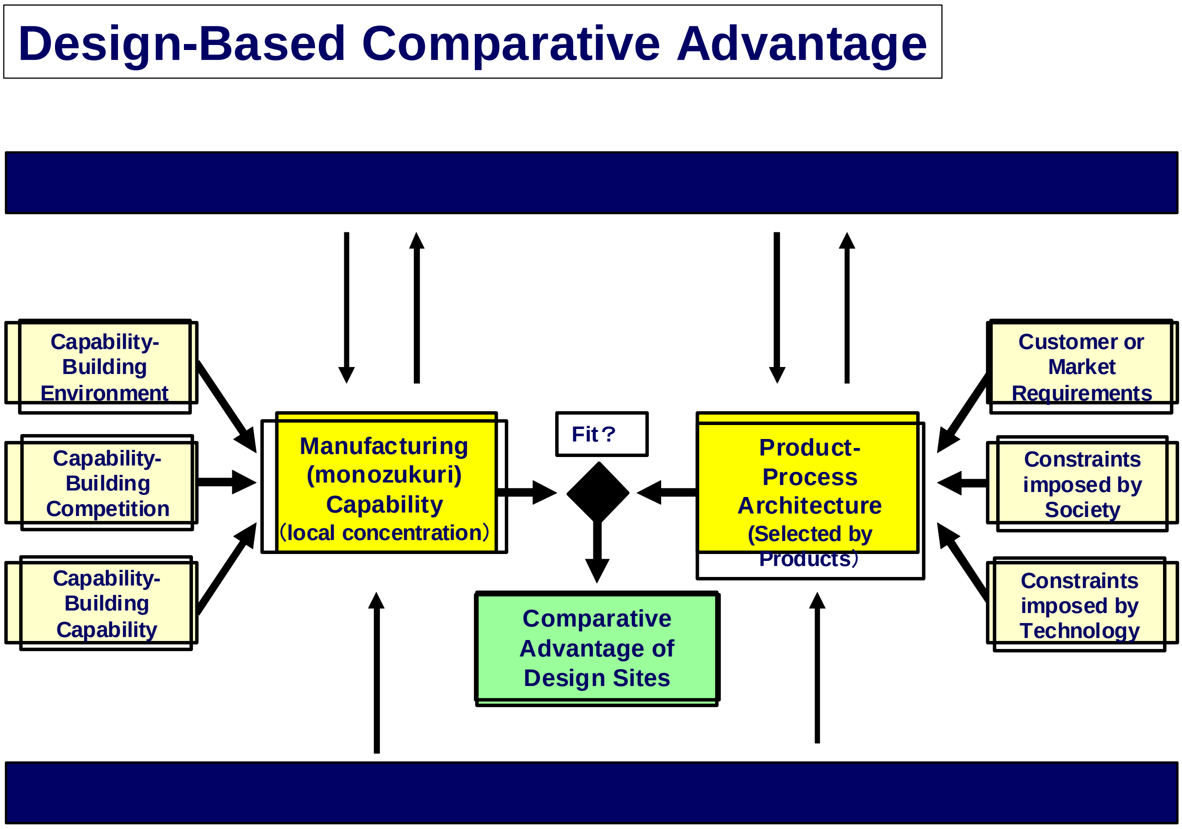
8. Taiwan, which is located on the so-called “intersection” of the U.S. and China “modular-axis” and the Japan/ASEAN “integral-axis,” has the ability to change its business partners swiftly in response to product architecture.

Thus, if we consider the theory of comparative advantage in architecture originating from design, then we can anticipate that both those types with disproportionate organizational capability and those that excel in organizational capability will differ by region. This is because each country and region shoulders its own differing history. Moreover, this can be a basic framework for us to analyze the global economy in the 21st century and the comparative advantages of the industries that become evident in it.

8 Both Organizational Capability and Architecture Evolve

This paper's analytical framework, which conjectures on the "comparative advantage of design field" from the fit between "adjustment capability of the design field" and "adjustment load of the product design," is a dynamic theory that should embrace evolution if viewed from a broader perspective. Both the organizational capacity of design field and product architecture will evolve together and the fit between both of these will be a dynamic adaptation.

As shown in the figure, the organizational capability of the manufacturing field evolves while taking influence from the capability-building environment of regions, the capability-building competitiveness of industry, and the capability-building ability of firms (Fujimoto, 2007). On the other hand, the architecture of products and processes also evolves while taking influence from the



requirements of users as well as social and technological constraints that designers encounter. Therefore, in evaluating the types of designs that Japanese industry will have to challenge in the future, an extremely long-term level of insight is necessary in relation to how the environment surrounding fields and products will change in the future.

Here, what we should pay attention to regarding architecture is the fact that, as previously stated, there is no architecture specific to each product category (for example, "automobiles"). Even with the same compact cars, there are substantial differences in the architecture of Japanese cars that tend towards integral-type, and Chinese cars that tend towards modular-type, i.e., even artifacts (products) with the same function can have a different architecture. There is no architecture specific to products.

Generally, in the event that the required standards regarding design function are high or the constraints relating to design structure are strict, if we consider other conditions as constant, then the architecture of the artifact (for example, a product) can be supposed as tending toward integral-type. If the conditions are strict, then there is a need to identify and optimize strictly both the functional and structural parameters. In this case, solving the functional and structural simultaneous equations corresponding to an artifact makes it easy to reach a specific solution for the product. If in general the functions that customers require or the constraints of society (such as environmental and safety measures) become more sophisticated or complex, then the compilation of already designed products through modularization will become difficult, and the product architecture will become something that is both integral and complex.

As automobiles are "heavy objects that travels at high speeds through public space," they have negative impacts on society, such as traffic accidents, air pollution, and global warming. In fact, requirements and constraints imposed by society on automobiles are becoming stricter every year.

In general, when constraints become stricter, the product design becomes more complex. Although what is meant by design is the vision to connect the functions and structure that an artifact should have, if the required functions and constraints become stricter, then it is difficult to deal with them by modular-type design concepts (architecture) in which functionally-complete parts are accumulated, and a new array of integral-type design parts that have been finely-adjusted for total optimization is required.

Thus, the design of automobiles in industrial nations became more complex. For example, compared with ten years ago, the ratio of common parts in the average car in Japan has decreased, the ratio of electronic control has increased, and the volume of new product developments has increased. Although engineers have made efforts to simplify design, the selective environment, i.e., society, does not permit the persistence of modular-type designs, and products as a whole have become integralized. This is the difference between the design evolution of automobiles and personal computers.

Assuming this, the perception of the "21st century as an era of environmental constraints" has important implications. Even after recovery from the global recession, we still face a century beset with issues such as the fierce international competition for scarce energy resources, controversy over global warming, the movement of environmental pollutants across national borders, the international adjustment and increasing strictness of environmental regulations, and energy consumption regulations and safety regulations in response to these; it will be an era in which both users and designers of artifacts share strict constraints that transcend national borders.

9 Constraints and the United States Automobile Industry Crisis

Due to the latest economic downturn, although the world's main automobile manufacturers across the border have experienced a slump in business, it is the U.S. firms that are facing a more serious and structural crisis. The root of this is the divergence that has existed for a long time between product design as required by society and the organizational capability of the U.S. firms.

The design concepts behind U.S. cars were established in the first half of the 20th century, an era of lax fuel, safety, and environmental constraints, and were in essence "truck-type," i.e., the chassis and body were of the modular-type with clearly assigned functions. For example, the 1908 Ford Model T had a chassis of an integral design, although the overall structure was that of a truck-type (Abernathy, 1978). Given that GM's famous full-line and model change policies were also truck-type, the car body was diversified while the common use of chassis took place, satisfying both product change and the mass production of parts.

In the post-war era, U.S. automobiles moved further toward growth in size, increase in horse power, and emphasis on style; however, between the 1950s–1970s, the Chevrolet and Cadillac, which were the main source of revenue for GM in its heyday, also had a truck-type design concept, although with a luxurious body design. Those vehicles that supported the high profits of GM during the rejuvenation of the U.S. firms in the 1990s, such as mini vans, sports cars, and pickup trucks, were mainly large vehicles of truck-type. In the end, the "profitable business models" that made their appearance over a century of U.S. corporate history were all presupposed on truck-type design concepts.

On the other hand, organizational capacity is also a product of history. In the U.S., which made immediate use of the existing individual talent of the immigrants flowing into the country to extend its national strength, the production concepts of "emphasis on the division of labor and avoiding adjustment" had a long history. The 19th century "American production method" increased the processing accuracy of parts and incorporated the "compatible parts" that eradicated adjustment work in the assembly process. It was Ford that perfected this and succeeded in a drastic reduction in costs through production lines, specialized machines, vertical integration, and mass production.

Accordingly, in the first half of the 20th century, U.S. manufacturers built an economic superpower with standardization and mass production as their weapons. In the second half of the 20th century, although the U.S. lapsed into a competitive disadvantage with miniaturized and diversified integral-type products (domestic electrical appliances and compact automobiles), the end of the century saw a U.S. economy that had encountered the digital technology that was compatible with their style of "emphasis on the division of labor and avoidance of adjustment," which they used as leverage to rejuvenate their economy and dominate in information services, software and financial commodities.

10 Integral-type Compact Automobiles and U.S. Firms

However, the evolutionary pathway of automobile design was not compatible with the US style of "emphasis on the division of labor and avoidance of adjustment." Because of the aforementioned constraints, except in the US, the mainstream of automobile design shifted to compact automobiles. With their high fuel prices, it was inevitable that Japanese and European cars would become downsized and lightweight, anticipating constraints, densifying the arrangement of parts, and developing monocoque bodies (body-chassis unified structure) that gave rise to complex front-wheel drive vehicles and body rigidity with steel plates. Control, combustion, and catalytic technologies all developed rapidly in compact engines, and the whole vehicle gradually moved toward integralization.

The organizational capacity of Japanese manufacturers was naturally suited to this design concept. In the post-war period, against a backdrop of long-term employment and long-term trading, many Japanese design and production fields had built an coordination-type organizational capacity due to multi-skilled teamwork, and compact cars were well suited with this (Fujimoto, 1999).

On the other hand, the U.S. firms that generated profits from large automobiles were indifferent to the development of compact automobile technology. When hit by the first oil crisis, the response of the U.S. was to weather it out by "reducing the size of large profitable automobiles." However, with the second oil crisis, large cars with wasteful fuel consumption ran into an impasse and the U.S. firms emerged into the market for coordination and front-wheel drive compact cars in earnest for the first time. This is the so-called global battle between compact automobiles.

However, as the U.S. took long time in the development of unfamiliar compact cars and competed in the same arena, it became clear that their on-field capability was inferior to Japan in areas such as productivity, production quality, and development speed (Womack et al., 1990; Clark and Fujimoto, 1991). In short, it became evident that there was a divergence between the division of labor-type organizational capacity of the U.S. firms and the integral-type design concept of compact automobiles.

11 The Extension of the Life of Large Automobiles and Associated Limitations

Consequently, this led the U.S. into emphasizing on trade friction with Japan and in 1981 the U.S. voluntarily imposed restrictions on imports of Japanese automobiles (in practice, import restrictions), thus buying time. Concurrently, the U.S. learned from the coordination-type organizational capacity of Japanese firms such as Toyota and started making efforts at catching up with Japan in field competitiveness. This is the boom of so-called "lean production systems." (Womack, et al., 1990)

On the other hand, the U.S. planned the rejuvenation of its "profitable truck business." As might be expected, in this aspect, the strategic structural capability of the U.S. firms was very high, and their strategy in cultivating a market for truck-type products was a success. There were also mistakes in the strategies of the Japanese firms who had entered the U.S. truck market at a later stage, and in the 1990s, the U.S. firms made a profit that surpassed Japanese firms. We can say that this is a successful example of the U.S.-style competitive strategy of getting around the competition and making easy profit.

In other words, the U.S. firms facing a divergence between the organizational capacity and design concept adopted a bifacial strategy where on the one hand they strived to increase coordination-type organizational capacity in line with the design concepts of compact automobiles, and on the other hand set apart for later use the truck-type design concepts that suited their traditional division of labor-type organizational capacity.

However, after this, the irony is that the highly profitable truck strategy was so successful that it led to U.S. firms making errors on long-term judgment. In the end, the construction of coordination-type organizational capacity by the U.S. firms was left unfinished. Although the difference in the productivity of factories and production quality when compared with Japan was reduced, the productivity of product development was approximately half the level of Japan, and the development speed also remained approximately two thirds for a long time. The greatest weakness was delays in the developmental power of compact cars; however, this recognition was lacking among several management personnel in the U.S. In order to plug the holes in its vast U.S. sales network and its insufficient development power, GM collaborated and merged with some Japanese and Korean manufacturers that had developmental power, and committed their compact cars. This could be considered as nothing more than a stopgap measure that neglected their own capability building.

There were also environmental factors that prolonged the life of large automobiles in the U.S. First, the price of gasoline was kept low for political reasons and thus the continued existence of large automobiles was made easy. Second, the period between the 1980s–1990s was the period of the formation of standard families for roughly 70,000,000 members of the U.S.'s baby boomer generation, and many parents felt the need to purchase comparatively large vehicles such as mini vans to accommodate their children. Third, these standard families began to break down due to the independence of the children and from around the year 2001, which is when the price of gasoline increased, and the demand for large automobiles were showing signs of declining. Around the same time, a bubble occurred in Wall Street, leading to several U.S. consumers buying luxury automobiles and large automobiles with loans that they could not really afford to pay back. Truck-type large automobiles were produced in U.S. factories, while integrated luxury automobiles were imported from Japan or Europe.

Thus, regarding the evolution in the design of automobiles that began in the U.S. around the 1970s, the U.S. firms that concentrated too much on ways of extending the life of trucks were unable to continue to grapple squarely and in a step-by-step manner with the fundamental problem-solving that was the construction of coordination-type developmental and organizational capacity. Although problems were delayed through clever strategies from headquarters and collaboration with international firms combined with transient successes and the failures of competitors, resources gradually ran out, insufficiencies in capability building came to light, and business performance worsened.

In addition, financial subsidiaries became obsessed with the financial bubble, with examples of firms digging their own graves by engaging in coercive selling; with other examples of firms investing vast sums of money into the service industry due to large misperceptions in design theory by managers that "prime profit-making sources moved to services downstream," and this money subsequently vanished into thin air; and examples of the characteristics of their own firms being erased due to the confused policies of partners in mergers, the present situation emerged through the repeated administrative mistakes of headquarters and shouldering the burden of vast labor costs, such as pensions and medical fees.

What lessons can we learn from this? If anything, it is the fear of neglecting long-term capability building based on seemingly a wise competitive strategy. In this industry there are no clever schemes. We cannot reverse to electric vehicles at once. There is no basis in the fantasy that we will not survive if we do not make 4 or 6 million units. In the end, it is about how we can supply better products of higher class that fulfill the requirements of safety, environment, and fuel efficiency at an affordable price, and with rapidity through steady competition in capability building and technological development. The next move will be the resumption of a competition of steady capability building and product evolution in what will be a change from luxury large-sized automobiles to the arena of environmentally safe automobiles.

12 Commodification and Loss of Competitiveness of Japanese Industry

Concurrently, with the intensification of global competition, Japanese firms and production fields have lost the competitive advantage in a range of products. In many cases, this occurred when on the one hand a large part of the global market came to attach importance to price difference rather than functional difference, while on the other hand firms and production fields in developing nations came to provide extremely cheap products, despite some degree of drop in function. To a large extent in the market, Japanese products lost ground in their branding as "excessive design, excessive quality, and excessive function," and were defeated. This phenomenon is generally called "commodification."

Although commodification is close to the phenomenon called standardization in the product cycle hypothesis, at present, this is a weak point for the Japanese industry. Japanese products, which pursued extreme performance and lapsed into excessive design, repeatedly lost their market to the low-priced products of developing nations in Asia that emulated, researched, and simplified them. Many of these were digital data goods such as CD media in which the emergence of Taiwan meant a significant drop of prices, thus overwhelming Japan, and DVD players that started as Japanese products but ended up with the main production moving to China as Japan could only watch on.

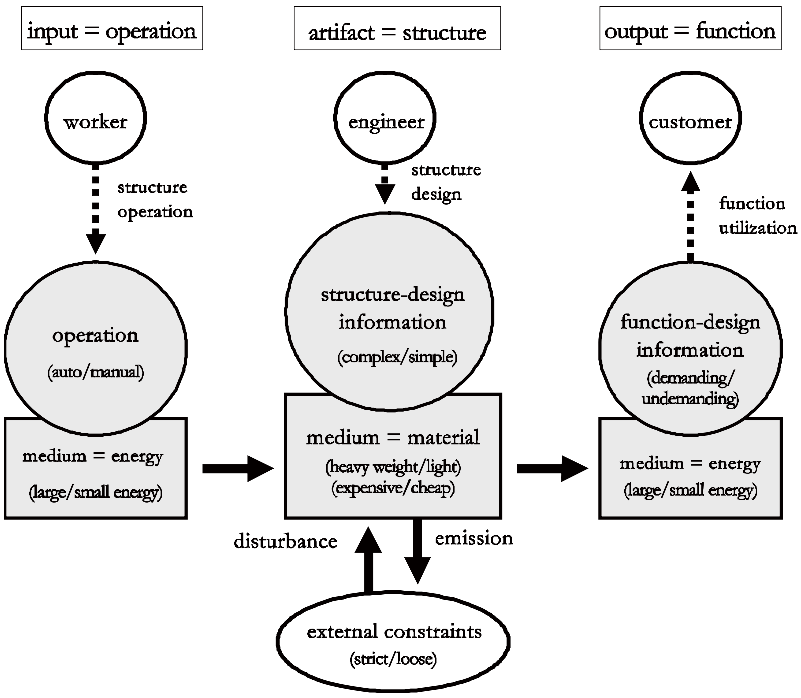
Thus, due to these repeated instances of Japan—a country renowned as a nation of technology—losing its share in high-tech products, it became tied in with growing pessimism in the Japanese economy itself. Although exports of luxury goods from Japan such as automobiles during the U.S.'s economic bubble were booming, this was also wiped out, and once again the world was shrouded with pessimism in Japanese manufacturing.

However, if household electrical goods are commodified, then is this not also the case with automobiles? To begin with, there is a need to observe actual products open-mindedly and to analyze the fields of their design, production, and consumption.

13 The Design, Production, and Consumption of Artifacts

Here, let us try to reinterpret commodification from the theory of design (Fujimoto, 2007). First of all, "manufacturing (monozukuri) field" refers to the space where people become involved with artifacts. Designers design artifacts, workers operate artifacts, and users gain function and utility from artifacts.

Basic form of production (structure, function, and operation of artifacts)



As shown in the figure, an "artifact" is a designed object, in other words, it refers to individual objects that have had design information (❍) transcribed into media (□). Moreover, what is meant by "design" is the conception that forms connections between the function and structure of an artifact. Structure-design transcribes objects, whereas function-design transcribes energy.

Those people connected with the field are workers that operate the structure of artifacts, users that use function, and designers that design structures. Details will be left for another time, but in the case of material goods consumption, the owner of an artifact = user = worker; in the case of production, artifact = manufacturing facilities; and in the case of services, user ≠ worker. All of these are fields.

At any rate, design is by nature information and media is material and energy. In other words, from the perspective of fields, we must ascertain the characteristics of the design information of products and processes, and the characteristics of the material and energy of media. The basic of industrial competitiveness analysis is to concentrate on field observation, putting aside for a moment the government's industrial classification, industry groups, and the competent authorities.

Design is also the activity of simulating consumption and production in advance. The designers of consumable goods simulate the consumption process in advance, while the designers of production goods simulate the production process in advance, tracing the structure from the required functions of users, operating environment, and operating content.

For example, in the case of automobiles, designers trace the structural parameters (such as dimensions and configuration) of such things as the body, chassis, engine, transmission, and control system from the required functions and constraints, including fuel consumption, emissions, safety, horsepower, ride quality, and good style. We can consider that this is a task of solving simultaneous equations from functional elements and structural elements.

Generally, when the required functions or the constraints of consumers and producers become stricter, then modular-type design becomes difficult. There is a many-to-many entanglement of structural elements and functional elements, and designers come under pressure to solve complex simultaneous equations. The solving of equations becomes specialized (in other words, parts become product-specific) and the search for the optimum solution becomes problematic, and modular-type design is not carried through. As previously stated, this type of complex design format is called integral-type architecture.

Thus, we understand that the commodification that has given Japanese firms a tough time has, in many cases, accompanied modularization. In fact, the reality that Japanese firms, products, and fields lose the competitive advantage when structural parts and production facilities become functionally complete, body and connecting parts become standardized, and the miscellany of these are able to gain customer satisfaction has been made clear by many researchers, both inside and outside Japan.

14 The Conditions of Commodification

However, does this mean that all products become modularized and commodified? I do not feel that this is the case. What becomes necessary is the level-headed confirmation of Genba (site) and Genbutsu (actual product).

As previously stated, as product design is a simulation of consumption, we cannot decide whether or not the design is simplified or the product is commodified without individually investigating the strictness of functional requirements and constraints that occur at the field of that product's consumption. If the constraints become lax, then there is the immediate possibility of products becoming modularized, although if the constraints are strict, then there is the possibility of modularization not being carried out.

Returning to the artifactual analysis of the field, let us now consider the artifactual characteristics (the characteristics of information, objects, and energy) of products that are easy to modularize or commodify.

First, when the functional requirements that customers expect in a product are lax, then that product is easy to modularize and commodify. This is because lax requirements can be taken care of even through the miscellany of parts that are already designed.

Second, for the same reason those products on which society places lax constraints are also easy to commodify.

Third, in the event that the mass (size) of the media of the product (artifact) is small, then there are few constraints relating to collision safety. The media of digital goods that are becoming microscopic fall in this category.

Fourth, in the event that the function of products developed through operating does not have a large input or output of energy, then the energy saving constraints that have become an inevitable part of contemporary society can be avoided. Typical of these are light-electrical digital products that are driven by electrons.

Fifth, in the event that the media—in other words, the material—of a product is cheap, then the mass production of those products and parts becomes directly linked with cost cutting, and thus commodification is easy. In this regard, we can say that silicon and iron are examples of low-cost media that exist in abundance on earth.

Therefore, it is also easy to simplify the design information for products with a small mass, low input and low output, comparatively lax constraints and customer requirements, and that have cheap media costs. In other words, they are easy to commodify. Those modular-type digital products such as computers that Japanese firms have struggled with in recent years were, undoubtedly, close to these conditions.

However, on the contrary, it is also easy to complexify the design information for products with a large mass, high input and high output, strict constraints and customer requirements, and that have high media costs. Compact cars are a typical example of this.

15 Will Automobiles in Developed Nations Commodify?

In this respect, automobiles are “heavy objects that move through public spaces at high speed.” They have a large mass, input, and output. Customers have high standards; they require multiple functions such as movement, leisure, self-expression, and a substitute for the home, although these are accompanied by the strict constraints that society imposes on automobiles. Automobiles are associated with the hastening of traffic accidents, air pollution, global warming, and the depletion of resources. Automobiles are objects that came into existence with the original sin of being harmful to society and efforts to offset these negative aspects are endless. Society monitors strictly with regard to such matters and public regulations are also actively moving towards becoming even tougher. Moreover, the discerning eyes of the consumers that pay large amounts of money for cars are also strict. This is the definitive difference between automobiles and digital commodities that are driven by electrons that can disregard the existence of mass.

As previously stated, if the conditions of consumption are strict, then the relationship between the required functions and structural elements becomes one of complex many-to-many correspondences. One part takes on many functions and many parts support one function. Fuel efficiency as a function receives the support of many functions, including the body, chassis, engine, transmission, tires, and auxiliaries. The body as a part contributes to many functions, including the safety of occupants, the safety of pedestrians, fuel efficiency, external appearance, quality of the interior, sound insulation, heat insulation, ride quality, and the ensuring of visibility. Moreover, the need to adjust the parameters of these becomes increasingly intense.

On the other hand, if safety and environmental regulations and the functional demands of customers become lax, then automobiles are quickly commodified and no longer become products that fields in Japan, whose strengths lie in team planning in large rooms and multi-skilled team production planning, have a comparative advantage over. At this point, as with many digital products, it may be necessary to accept the reality of transferring fields overseas; in other words, the Japanese automobile industry as a collection of fields in Japan might lose substance.

16 The Dissemination of Electric Vehicles is Not Easy

However, if nothing else, the design information of automobiles in developed nations is becoming more complex. In extreme cases, there are 10 million lines of code in control software, 100 chips in microcomputers, and 30,000 single parts. These are joined together with 4,000 bolts and 4,000 welding points. The ratio of common parts has decreased over the last decade and there are an increasing number of key tasks and labor hours required in development.

Although the main forms of power are gasoline in Japanese and U.S. automobiles and diesel in European automobiles and large commercial trucks, both are powered by internal combustion, and hybrid and electric vehicles are in the minority. A keynote of the next few decades will be the diversification of engine types, although it is inconceivable for the near future that internal combustion engines will disappear, and it will thus be difficult for firms that cannot develop a good combustion engine to prosper.

When automobiles become more complex, the key to survival is “how to make complex things at a low cost” and not “simplifying products to make them cheaper.”

Although details of electric vehicles and Chinese and Indian local automobiles will be left for another time, they can be predicted to a certain extent from the framework of artifactual analysis highlighted above.

First of all, the design of electric vehicles, at present a popular topic for discussion, has a high possibility of modularization in the future, although this will not be directly connected with commodification. This is because the fact that automobiles are moving objects with a large mass, large input, and large output will not change. Electric vehicles, which confine energy and run, require battery materials with high energy density, which are extremely expensive. At present, Mitsubishi’s electric vehicle, which is one of the best electric vehicles available, is fitted with a cutting-edge lithium-ion battery considered to cost around ¥2,000,000 (more than $20,000) and weigh 200 kg that has a realistic 100 km of continuous driving. There is no sign of any other type of revolutionary battery material that will replace this.

Due to this, there is no choice but to reduce the absolute amount of the battery for each driver to a fraction of the current amount. This is exactly the case with hybrid vehicles. As purely electric vehicles, we can consider a battery-sharing system, although this will mean limiting their use to short distances within cities. Whatever the case, the system selling of electric vehicles would be possible with some elaboration, although it is inconceivable that we will reach a stage in the near future where this will replace combustion engine-type privately-owned automobiles through standalone sales (although it is possible with commercial vehicles, such as taxis). Keeping in mind the economic principle that the cost of battery materials is high, the material cost is a variable cost, and that variable costs will not decrease even if you produce 1,000,000 vehicles, we need to engage in level-headed discussions rather than being swept away by the situations. The articles that one often sees proclaiming that the age of the electric vehicle is at hand lack theories regarding the fields of production, design, and consumption and are thus jeopardizing.

17 Between Increasing Complexity and Commodification

Level-headed discussions are also needed regarding low-cost Chinese and Indian automobiles. Many of the low-cost automobiles of the Chinese firms are yet a miscellany of commercial parts, copied and modified parts, and self-manufactured parts and thus are not of the functional standards required by the markets and societies of developed automobile nations. The low-cost automobiles developed by India's Tata Motors greatly surpass Chinese automobiles with respect to fulfilling the required functions and constraints, although in actual fact they are quite integral and have a completely different architecture than typical Chinese automobiles.

In short, electric vehicles are modular but expensive. China's low-cost cars do not fulfill the required functions of the global market. On the other hand, India's low cost cars—for example, Tata Motors' NANO—are more sophisticated functionally, although they have many specially-designed parts, and tend towards integral-type rather than modular-type. Whatever the case, the reason that the commodification occurring frequently in household electrical appliances and electronic products does not occur easily on an overall scale in the world of automobiles is suggested from an industrial analysis of architecture.

In general, even if it is a product that requires a diverse range of functions and models, products which do not have strict required standards from customers, are formless, have little limitations on capacity, are light, are not consumed in social places (so as not to cause inconvenience to others), and do not put much pressure on energy and the environment, can be modularized and commodified relatively easily. However, the compact automobiles on sale in the markets of developed nations do not satisfy these conditions. Therefore, even if designers make the utmost effort to create a modular architecture in advance, following these efforts is likely to remain on the integral side for the foreseeable future due to constraints in safety, environment, and energy becoming stricter.

As things stand at the start of the 21st century, it is difficult to envision automobiles imposed on automobiles suddenly having architectures that are modularized like those of digital electronic devices. On the other hand, there is no shortage of fields that confront the long-term issue faced by firms of "the growing complexity of artifacts," including automobiles that transport people safely, medical devices that likewise target the human body, production equipment that processes delicate products, industrial instruments that processes difficult-to-handle materials, electronic devices that require extreme miniaturization, and embedded software that requires the complex control of real time. In the first half of the 21st century, which is characterized by environmental constraints, many industries and firms have no choice but to respond simultaneously and in line with the increasing complexity and commodification against a backdrop of rapidly changing design conditions, production conditions, and usage conditions surrounding artifacts.

18 Application: Toyota's Quality Crisis and Increasing Complexity

The so-called "Toyota quality problems" that came to light in 2010 is a phenomenon that should also be interpreted in the context of "the increasing complexity of artifacts" (MacDuffie and Fujimoto, 2010).

With the risk of litigation and sanctions by the U.S. authorities, Toyota's quality problems, which included a large-scale recall of products, have created a highly unpredictable situation. In regaining trust, focusing mainly on the U.S., Toyota has no choice but to implement quality assurance to a degree of thoroughness that exceeds the expectations of customers, citizens, the government, and the Congress. Although the initial actions of Toyota and the crude reporting on part of the U.S. media have left problems, what is needed to see through developments henceforth is a level-headed analysis based on theories of field (Genba), actual product (Genbutsu), and pragmatic logic.

Although some have remarked that these problems were due to the failure and decline of manufacturing at Toyota's production fields, this is logically inconsistent. The flaws that were the target of this criticism all had their origins in design and cannot be seen as problems with production quality; in other words, defects not made according to the design. Although issues are accumulating at production fields, we cannot accept that these have any causal relationship. Recently, I have been spending many days in Toyota-related factories conducting investigations of the actual situation; however, even upon facing a drastic reduction in production after the Lehman Shock, I have not seen any noticeable laxity in morale and management at fields.

So, was it the design fields that collapsed? I have also spent many years conducting investigations regarding this, but as far as my data shows, Toyota's product development capability is still one of the best in the world.

Then, what is the problem? Although the causes are of a complex nature, I have been focusing on the possibility that Toyota's excellent capability building could not keep up with a sudden increase in load due to the rapid increase in complexity of automobile design in developed nations.

For example, in the case of the problem in which the floor mat got caught in the accelerator pedal, the fact that users in the U.S. use mats in unexpected ways was not sufficiently worked into the designs of things such as pedals. In the case of brake problems in the hybrid vehicle (HV) Prius, these were due to regenerative braking for improving fuel efficiency, ABS (Anti Lock Brake System) for running safety, and control software that was important for quietness causing complex interactions under specific conditions and giving rise to the disconcerting feeling that it was difficult to brake. The cause of defects in parts in the accelerator pedal was acknowledged by Toyota as being the inappropriate choice of materials by a U.S. parts manufacturer. The real nature of the problem was that simple parts and complex control systems became jumbled and the pattern could not be read.

Thus, the causes were diverse and what made them difficult to foresee was the fact that the design of the entire automobile had become too complex. Mainly in developed nations, social regulations from the aspects of automobile safety, fuel efficiency, and the environment, along with the increasingly sophisticated requirements of customers, means that designs have had to become more complex. Admittedly, in recent years, Toyota has rapidly expanded production and has rapidly increased the number of automobiles in its lineup; however, these were only secondary factors that exacerbated the problems, with the main cause being the increase in complexity of designs.

This is an issue confronting not only Toyota but also the entire global automobile industry. Taking the opportunity to learn from this recent case, if the requirements of customers and society regarding automobiles are to become even stricter and if automobile designs in developed nations are to become more complex, then this would be advantageous to Japan's manufacturing fields that were originally well suited to complex designs and production. If Toyota takes sincere steps to deal with the recent issues and does not make any mistakes in these initial steps, then a medium-to-long-term recovery is possible.

19 Conclusion: The Crisis in the Japanese Automobile Industry and the Future

The 2008 global recession that had its roots in the U.S. financial crisis also landed a major blow to the Japanese economy. Until then, the demand for luxury automobiles and home electrical appliances originating from the U.S. bubble benefited Japan either directly or indirectly. However, with the U.S. economy in shambles, the Japanese export and commodity industries and firms that relied on exports to the U.S. experienced a drastic decrease in production and a worsening of its financial performance in 2009.

From the reliance on the U.S. luxury SUV market, Japanese automobiles, particularly those of Toyota, increased in size, became heavier and more complex. This brought huge profits from the U.S. to Toyota; however, with the demand collapse of the U.S. bubble, there was a sudden reduction in sales volume and a worsening of finances. Toyota's worsening finances were exacerbated due to the major strategic mistake of its overly slow construction of a U.S. truck factory. Product development inclining towards luxury automobiles and the latest ecologically-friendly automobiles to meet demand from developed nations such as the U.S. meant that there was a delay in detailed product development aimed at the markets of developing nations, and the development of competitive low-cost automobiles. On the other hand, in the U.S. and European market, Toyota could not keep up with capability building in line with the rapid increase in complexity of products and operations, meaning that it caused substantial problems in quality.

In other words, due to the over-reliance on the market for luxury automobiles, large automobiles and complex automobiles originating in the U.S. and their own strategic mistakes, Toyota became crisis-ridden. However, granted that the strengthening of social constraints in safety, environment, and energy and the increasing sophistication of the functional requirements of customers in developed nations continues into the future, in the long term this will not necessarily be a disadvantage for Japanese firms like Toyota who excel in maintaining coordination-type organizational capability, and in integral products that become complex. In the future, although the battle with design complexity in developed nations will continue and in the short term the reoccurrence of crises is also foreseen, Japanese firms should observe the recovery of markets in developed nations like the U.S. and gently revive their own business performances.

Concurrently, the challenge for Japanese firms, particularly Toyota, is on the one hand to tackle the increasing complexity of products and on the other hand to move forward with product development and market cultivation in the medium-low price zone (the so-called volume zone) in newly-developing nations. With regarding to the cultivation of markets in newly-developing nations, taking Japan and Korea as an example, there is a tendency for Korean firms to transcend Japanese firms, and thus there is a lot Japanese firms can learn from this. On the one hand, while dealing with the problem of design quality in developed nations—in other words, the problem of under-engineering— and simultaneously dealing with the problem of over-engineering of Japanese automobiles in newly-developing nations. The formulation and implementation of this double-sided strategy will not be easy. This challenge is not only for Japanese firms, but it will most likely become an important issue for all automobile manufacturers aiming at the global market in the first half of the 21st century.

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