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Surprising disadvantage of uncoupled design in staying competitive in the global market

Masayuki Nakao[a*]

a Department of Engineering Synthesis, School of Engineering, The University of Tokyo, Hongo7-3-1, Bunkyo-ku, Tokyo,113-8656 Japan

* Corresponding author. Tel.: +81-3-5841-6360; fax: +81-3-5800-6997. E-mail address: nakao@hnl.t.u-tokyo.ac.jp

Abstract

Axiomatic design recommends uncoupled designs with independent functional requirements (FR) and minimum information in the design parameters (DP). When realized, such uncoupled designs should have advantages in production and business. When faced with trouble, namely, poorly configured parts are easy to identify, and later modifications are easy to implement. Conventional Japanese manufacturers, in contrast, have been producing heavily integrated products with intertwined FR and DP relations. Some, e.g., metallurgy and automobile industries, carry the coupled trend and continue to do so, whereas others, e.g., information device and home appliance steered their uncoupled product towards simplification and compatibility. When viewed from a pure design standpoint, uncoupled designs should be superb. The uncoupled design, however, turned out not so advantageous from the business perspective. Surprisingly, such uncoupled products are easy to copy. Some Japanese companies learned this shocking lesson against axiomatic design after they lost their businesses to new competitors in manufacturing.

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Keywords: Global market; Easy imitation; Redundant design

1. Skepticism about axiomatic design in Japan

Up until the Lehman Shock in 2008, such corporations like Sony or Canon were popular among engineering graduates. In the years that followed, companies in Canon group have well recovered, however, Sony is still in the red figures. Why is it that by now, Canon has succeeded and Sony has failed? Is there a significant difference in the engineers' skills in creating new design for developing new products?

The main difference is whether their main product design is uncoupled or coupled. The contrast is not due to engineering skills. Sony's main products of home electronics like LCD TV sets or IT devices like laptop computers have parts that are functionally independent and allow easy modular development and exchange as shown in Fig. 1(a). On the other hand, Canon has a main product line of office printers. This product has parts that have mutual chemical interference among exposure, image development, and image fixing as shown in Fig. 1(b). Exchanging, for example, the toner to cheap third party compatible part would influence the printed color. In other words, product development which takes in-house design of the whole printer as one module, thus, has long development phase and heavy cost. Countries that later entered the game hesitated in charging into this field.

Uncoupled design is easier to use, control, and service as Suh insisted [1] [3], but at the same time, easier to imitate. Coupled design, in contrast, is hard to manage, however, also hard to replicate. Fujimoto, in 2001, acknowledged this fact and claimed that "Integrated coupled design is the strength of Japanese companies" [2] [8] [9] [10]. His view was well accepted in the Japanese business world. He predicted that modular uncoupled design products, like home appliances or IT devices allow easy entrance into the market with new products by exchanging parts with compatible ones, and they will soon be caught up by new-comers in the competition. Japanese factories that produce semi-conductors, liquid crystal display (LCD) TV sets, solar batteries, cellular phone sets, and so on, as he envisioned, disappeared from our homeland.

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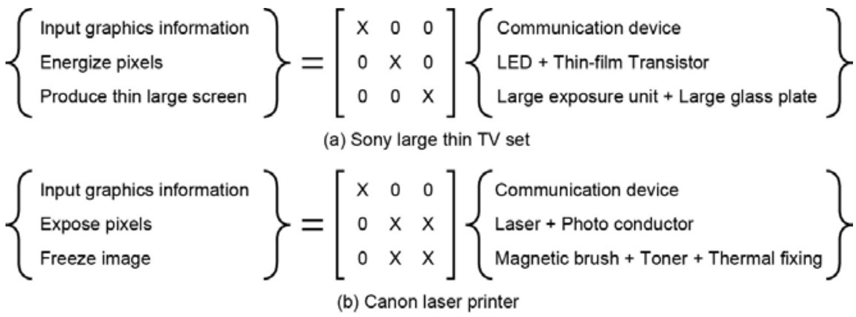

Fig. 1 Sony's product is uncoupled and Canon's is coupled.

Nakao and Hatamura introduced Suh's axiomatic design as translated in Japanese to spread the design methodology in Japan [1] [3]. Fujimoto's view, however, was better accepted in the Japanese industry and throughout our presentations, we always had to face opposing opinions that axiomatic design was misleading.

Fujimoto's idea of "integrated design" is what Toyota applies in its automobile production. For example, the hemi-cylindrical slide bearing for the crank shaft is picked out from a bin so that it has a thickness that matches the gap found by measuring the diameters of the shaft and the connecting rod. Up until year 2000, the piston was assembled into the engine after selecting the right one with a diameter that provided an adequate gap to the measured cylinder diameter. The assembly processes being so, when a bearing or piston breaks, the entire engine module has to be replaced. In Europe and the US, parts are controlled with dimensional tolerance and "on-the-spot mating" is a technique that is out of question in building airplanes or firearms. Toyota engineers, however, are against the integration methodology and say that Suh's axiomatic design is ideal (The author has been consulting Toyota about its production engineering for 15 years).

The cynical results, however, is that home appliance and IT device manufacturing have been forced out from Japan, and the Japanese industry is surviving in the material and automobile fields. Axiomatic design still has not gained popularity.

In section 1, this paper discussed the "disadvantage" of uncoupled design in the company or nation level. Of course, in the product or process level, the uncoupled design is better than the coupled one, as the axiomatic design theory proved the advantage of uncoupled design. Next section 2 explained the inevitable trend that the global manufacturing system will spread the technology, sooner or later, not only of uncoupled design but also of coupled one. Moreover, Section 3 discussed an effective business method to delay the spreading trend, explaining it with a design matrix. Lastly, Section 4 shows a new design method, which is familiar to young designers, to re-make the uncoupled design from an original redundant design using principal component analysis. This design method may solve any secret couplings.

2. Natural movement from global manufacturing to local production and consumption

Although intellectual property (IP) is well protected today, the system has loopholes for new technologies to get imitated and spread around the world. For example, in circa-2000, Japanese industries had about 30,000 patents for LCD; Korean 300, Taiwanese several. Japanese, however, reduced the share from 80% in 1997 to 13% in 2006. During the decade, Japanese industries could not make any large investments for next fifth generation of LCD, and most of Japanese IPs were only peripheral or process-related; whereas Korean or Taiwanese could import Japanese manufacturing devices protected by process-related IPs, and the original IPs of the US or Europe were expiring. In results, this trend of imitating was economically rational and we could not stop it. It is like enthalpy that keeps increasing. The IP should be protected by the compound strategy of process, product, asset, or investment. The modular uncoupled LCD had been produced in the new factory easily and rapidly.

Fig. 2 shows the history of Japanese industries, e.g., automobile, about how their overseas business models changed. The historical transition is not unique to Japan nor to its automobile industry. Advanced countries in Europe and the US had experienced similar transitions.

The first stage, shown in Fig. 2(a) was when the industries produced in domestic factories and exported the products. Japan was in this stage before 1985 in the 20th century. The FR was to "make sales in different regions" and the DP was local "sales offices." Because production took place only in Japan, the first column of the design matrix shows interference. The system was heavily constrained with making repair based on Japanese drawings and sales offices transferring their local sales to the headquarters in Japan.

From 1985 to 2010, foreign countries put political pressure on Japan who was forced to build assembly factories in those countries. This was the stage when only key components were manufactured in Japan to be exported. Many parts were, however, procured from various optimum areas overseas and the design matrix was full of interferences as in Fig. 2(b). If a problem arose in one area (e.g., the 2011 flooding in Thailand),

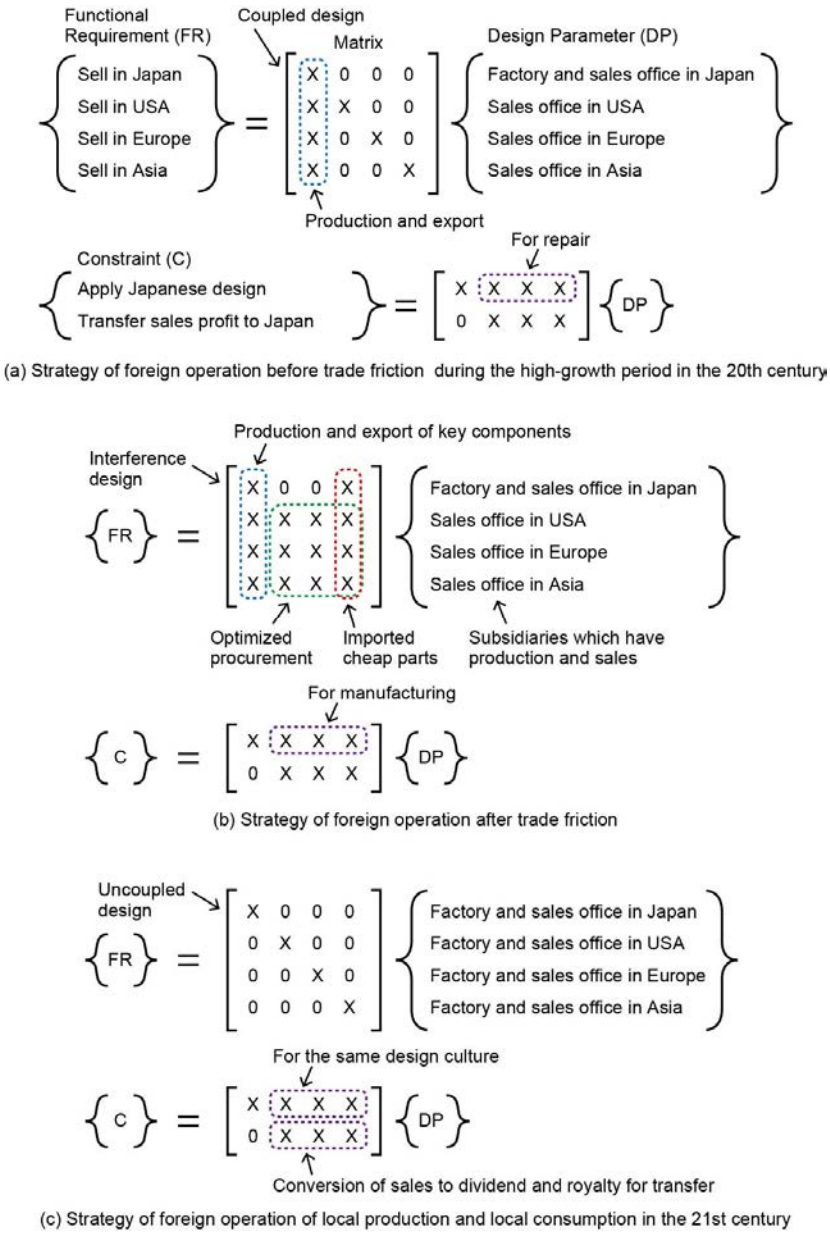

Fig. 2 Local production and local consumption model is an independent design.

all factories over the world were affected and the production stopped.

Fig. 2(c) shows the current stage of "local production and local consumption." Products are manufactured and sold in the area and thus the design equation becomes uncoupled. In Japan, Toyota, to keep employment of the Japanese, maintains about 30% domestic production, whereas, Honda is aiming at complete local production and consumption. Nevertheless, the constraint to transfer profit to Japan remains. If this constraint is also removed for independence (no transfer), the local business is completely isolated from the Japanese operation except for its brand name.

This spreading trend is also depended on a value change in the global market. The profit is not generated in a manufacturing factory, but in service field. This trend is the same as the progress of a "shared business", for example, of car, house, factory or office. The local service field is important for business.

When local engineers alter the original design, Toyota and Honda will be forced to rethink what the value of their design culture is. Japanese engineers will name the trouble-free high reliability and refined ease of use, and such features will be kept even in their own local evolution for understanding the local needs. Headquarters in Japan, to gain R&D funds, have its subsidiaries which transfer profit in the form of dividend or royalty. If, however, such R&D activities also can take place in overseas locations, the perfect uncoupled design will be structured. At this time, the fact that Toyota or Honda was a Japanese company will turn into a mere historical fact.

In other words, local business over the world will make legal replicas modified to suit the local needs. The spreading of technology in the form of imitation cannot be stopped. Uncoupled design that follows axiomatic design is easy to replicate and they spread faster than coupled design. Is there a way to delay this imitating trend?

3. How uncoupled design can win the business

The only way to delay imitation is to conceal the design equation. Once a product is in the market, anyone can use the product and thus, the customer needs in FR will be open as well as DPs after the products are disassembled. Thus the design philosophy should be to hide needs so that they are difficult to identify from just looking at the hardware. That is, the design matrix should contain (a) secret interference among FRs and (b) secret non-functional FRs. Such non-functional FRs are difficult for the user to point out, but are added by the designer for enhanced reliability or ease of use.

The (a) interfering components of the design matrix can be analyzed for similar functions, however, if the functions vary by a large amount, the analysis is difficult. The number of functional requirements for stock exchange systems are said to be about 10,000, thus the number of interferences is its square 1 million, a number that human can no longer handle. Such interference have very small rates of occurrence and are impossible to follow [4] [7].

Fig. 3 shows the design equation of regular products. The (b) non-functional requirements for the software industry, e.g., are expandability or maintainability. When a satisfied customer requests to expand the system capacity by 10 times, it takes more than just providing 9 more copies of the same product. The initial design should be ready for an expansion by a factor of 10, otherwise the narrow database will choke with congestion. Moreover, bank accounting systems and automobile automatic driving systems can update the programs when they are stopped. But systems that promote 24 hours, 365 days operation cannot, thus they require redundant systems to work during maintenance of the main systems. Eventually, about 70% of the DPs seems to be provided to satisfy these non-functional requirements in Japan. For example, Japanese railroad systems have much smaller outage rates than those in Europe or the US and that is because they satisfy this non-functional requirement. These DPs do not surface unless there is a trouble and are difficult to replicate unless the designer explicitly learns about them.

Interference that at least has to be analyzed is the system interference with the electrical power supply. The 2011 Fukushima Daiichi nuclear power plant accident was a case of

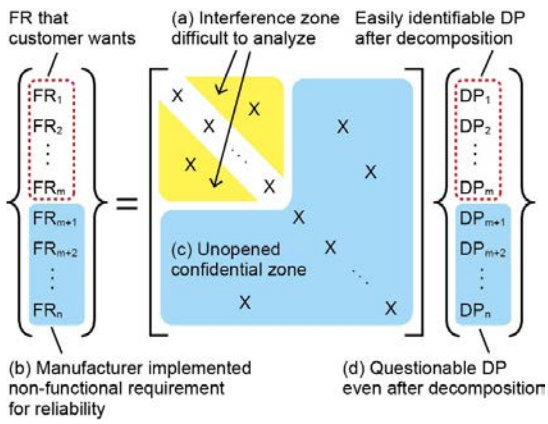

Fig. 3 The confidential zones in the area of (a) related with interferences of FR in non-diagonal components of the design matrix, and the area of (b), (c) and (d) related with non-functional requirements in the design equation.

this interference [5]. During this accident, all DC power including backup batteries were lost and sensor signals of water level and pressure could not be read, as well as signals to activate valves were unavailable. In other words, the plant was in the state of “brain death” with eyes, nose, and limbs still alive but unavailable. After the terror attack on World Trade Center in 2001, the US authorities analyzed the case and enforced regulation to all US nuclear power plants to prepare portable DC batteries for backup. If Japan had followed the decision, Fukushima would probably not have gone through such a catastrophe.

To discourage quick replication of products, the manufacturer should analyze its design in detail and cover the non-functional requirements and interference of the FR for future better service. This concealing is easier for the software and material industries compared to those in the hardware business which can be disassembled for analysis.

4. Future design methodology where the computer automatically builds uncoupled designs

The drop of price in memory, sensors, and actuators led to increased number of designers that builds redundancy into the DPs that far exceed the number of FRs and even cover all predictable environmental conditions. The amount of information from such systems is huge, and information processing that extracts meaningful information from the big data, e.g., deep learning, artificial intelligence or Internet of Thing are now the topic of interest. This trend has lessened the attention to axiomatic design, most of designers don’t take care of the number of dimensions of how many independent FR are.

Fig. 4 explains the redundant design methodology. First, as Fig. 4(a) shows, all redundant DPs are set exhaustively. The designer, for example, places about 100 temperature and vibration sensors on the machine tool. Of course, he can also include the other 100 business issues as DPs, for example, budget, schedule, regulation, or product category [6]. He then acquires big data from a long learning period. Then as Fig. 4(b) shows, he selects all events to match the number of DPs from both periods that constantly produced good products and those that generated defective results. Putting the data through multivariable analysis leads to "eigenvalues" that match of number of DPs. In other words, the so-called principal component analysis are pick up a set of new sensitive FR and DP with the widest variation. This principal component looks like the eigenvalue in a design equation.

The characteristic matrix has to its left and right, matrix A with eigenvectors in its rows, thus, multiplying the inverse of matrix A to the event (EV) and DP vectors result in new FR' and DP' vectors as Fig. 4(d) shows. The physical meaning of the components of these new FR' and DP' are not that easy to come by. The eigenvalues are set to make the variation of FR' large and how to name the components with large variation is up to the skills of the analyzer. For example, a DP' component that is the sum of 3 times the pressure in MPa plus 5 times the temperature in degrees C will just puzzle the analyzer about its physical meaning. He would be very lucky if he knew that the quantity expressed, for example, the critical state of the reactor.

Also, if the dimension of FR' is as large as the original count of DP components of 100, the outcome will be more confusing, thus, we shall select about 5 eigenvalues with large effect to keep the dimension of the design equation small. In most cases, the added sum of the 5 multiplications exceeds 90% of the sum of all 100 components. Once the dimension is down to about 5, we can sit back to identify the physical meanings of the FR' and DP' components as shown in Fig. 4(e). This figure shows an uncoupled design.

When we, however, execute this redundant design methodology, we reach the conclusion that designing the position of the sensors in Fig. 4(a) is most critical. A sensor that signals zero at any event is useless, and if the measured signal waves are all the same for any event, the result cannot add any dimension to the system.

Even if the designer concealed the design equation as in abovementioned Fig. 3, a forceful analysis in Fig. 4 at the end can reveal the design equation of the uncoupled design automatically. The author is puzzled if this is the design methodology of the future, however, as of 2016, such an analysis is possible, and at least monitoring the independent DP' is effective in pointing out abnormal events.

For Suh's complex design [11], the redundant design methodology might be useful. So far, we pointed out the eigenvalues intuitively; in near future, the computers do that automatically.

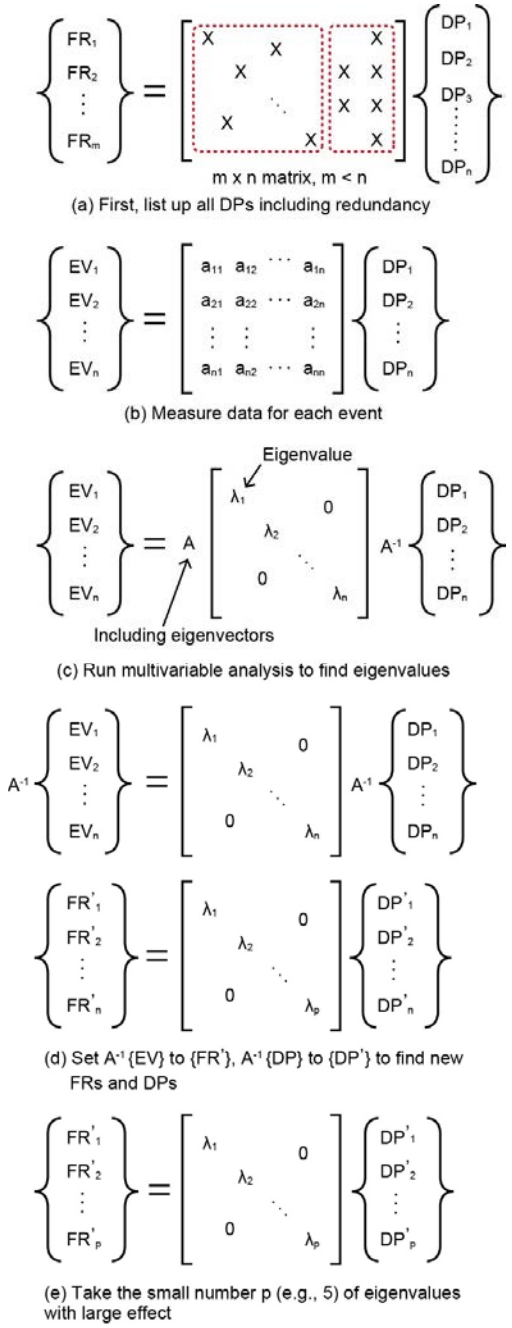

Fig. 4 The computer automatically constructs an uncoupled design.

5. Conclusion

In the product or process level, uncoupled design has advantage in easier use, control, and maintenance compared to coupled design, however, it has the disadvantage that it is easy to imitate in the company or nation level. In the education class of axiomatic design, the independence axiom should be discussed with students in the various levels. The globalization of manufacturing today, however, suggests that the spread of technology including its replication is a natural trend. To delay this trend to gain and keep a business advantage, it is important to conceal the interference components and the non-functional requirements of the design equation. The advancement of information technology will, however, sooner or later realize uncoupled design and the concealed components will be automatically identified. In the end, however, uncoupled design, which may not be advantageous in terms of business, gives us better value as human property in the world.

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