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EMERGENCE OF COUPLED AND COMPLEX FAILURES IN MATURE JAPANESE INDUSTRIES

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ABSTRACT

The designer's mind process of the engineering failures was analyzed from the Axiomatic Design perspective using the failure databases of Japanese industries. Besides the simple failures like careless operator's mistakes, we also found a lot of the coupled and complex failures like computer system down due to excess internet purchasing accesses. The notice of the troubles is beyond the designer's assumptions in planning. The simple failures are decreasing because Japanese industries become so mature that the job procedures are perfectly set up. But the complex failures are emerging because the systems become complicated nowadays. As a countermeasure, making a module with some coupled FRs is inexpensive and effective, visualizing and decoupling the failed design.

Keywords: Failure analysis, Axiomatic Design, Complex.

1 INTRODUCTION

So far, Japanese industries have been making much effort to reduce the so-called "human errors" in operation, maintenance or production. They become now so mature that they have already set up the perfect job procedure for all processes. They have also invested the conventional safety actions like a mental training or a double checking. They can reduce the failures, but still make some fatal accidents.

The authors have analyzed several databases of failures of Japanese industries such as software programming or hardware production [1]. Through the analysis, we found that the failures have quite another scenario of the designer's mind process. Besides the simple and human-error-like failures such as careless operator's mistakes, we found a lot of the complicated technical failures like computer system down due to excess internet purchasing accesses. The accident happened under many kinds of desires of millions of the customers; no engineer could predict the unexpected concentration of the customer's usage. The complicated technical failures are too complex to easily find the coupled interference between functional requirement (FR) and design parameter (DP). The notice of the coupled FR/DP is beyond the designer's assumptions in planning. They are increasing rapidly nowadays, looking as if they are suddenly emerging.

From the Axiomatic Design perspective, these complicated technical failures mean the coupled and complex designs [3]. The complex design is the real complex design with a great many coupled FRs. But we need a quantitative analysis; we should know how many FR is in this failed complex design, or how many percentages of the coupled and complex design is in the entire numbers of failures.

The paper introduces the coupled and complex design for failure analysis, and proposes some countermeasures for prevention of the failures.

2 THE DESIGNER'S MIND PROCESS OF ENGINEERING FAILURES FROM AXIMOTIC DESIGN PERSPECTIVE

From the Axiomatic Design perspective, we categorized the designer's mind process of the engineering failures as shown in Figure 1. Also we introduce an example of each sub-process from the failure data of a large-size company that manufactures computer systems as shown in Table 1.

2.1 Uncoupled but unrealized designs

This category in Figure 1 (1) includes the aforementioned simple and human-error-like failures such as careless operator's mistakes. For example, the engineer designed a safe device, but the operator ignored the safe process. Figure 1 (1) translated the failures into Axiomatic Design representation; originally, the design equation was uncoupled, but later, one FR was not realized. The diagonal component of the design matrix turns from X (affected) to 0 (non-affected). Table 1 shows this category has a 41% ratio of the entire 284 failure data.

This scenario has three sub-scenarios. The sub-scenario of (1a) includes the so-called human errors like a maintenance trouble illustrated in Table 1. The sub-scenario of (1b) and (1c) contains a business plan problem [3]. The (1b) is a sales problem. The planner expected that the product would be sold well, but the customer was not sympathized at it: the FR was not realized. The (1c) is a time-dependent trouble. For example, such a long development time lost the business chance. The FR is a function of time; the diagonal component turns to 0 from long delays after plan or design.

$$\begin{Bmatrix} FR_1 \\ FR_2 \end{Bmatrix} = \begin{bmatrix} X & 0 \\ 0 & X \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \end{Bmatrix} \longrightarrow \begin{Bmatrix} FR_1 \\ FR_2 \end{Bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & X \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \end{Bmatrix}$$

Originally, an uncoupled design was set up

Later, unrealized FR_1 emerged

(1) Uncoupled but unrealized designs

$$\begin{Bmatrix} FR_1 \\ FR_2 \end{Bmatrix} = \begin{bmatrix} X & 0 \\ 0 & X \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \end{Bmatrix} \longrightarrow \begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 \\ 0 & X & 0 \\ X & 0 & X \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \end{Bmatrix}$$

Originally, an over-simplified design was set up

Later, unnoticed FR_3 emerged

(2) Coupled but over-simplified designs

$$\begin{Bmatrix} FR_1 \\ FR_2 \end{Bmatrix} = \begin{bmatrix} X & 0 \\ 0 & X \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \end{Bmatrix} \longrightarrow \begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \\ \vdots \end{Bmatrix} = \begin{bmatrix} X & & & X & \\ & X & & & \\ & & X & & \\ & & & X & \ddots \\ & X & & & \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \\ \vdots \end{Bmatrix}$$

Originally, a smaller design with several FRs was set up

Later, a great many FR_n emerged

(3) Coupled and complex designs

Figure 1. Three typical scenarios of the mind process of designs that led to engineering failures.

Table 1. Examples of the typical failure scenarios in the company that manufactures the computer system

Scenarios	Sub-scenarios	Examples of the failures
$\begin{bmatrix} 0 & 0 \\ 0 & X \end{bmatrix}$ (1) Uncoupled but unrealized designs 41%	(1a) Ignored the safe process shown in manuals or rules 15%	The maintenance technician installed the server of a telecommunication company; he wired the power line from a table tap temporally. The connecter at the tap was pull off; the system was suddenly shut down.
	(1b) Not sympathized by customers with new plans 14%	A new groupware system with multimedia devices was on sale. The customer was interested in it at first as designed, but didn' t decide to buy it due to its expensive price.
	(1c) Lost requirements from long delays after design 13%	The engineers had been developing a high-speed system of ISDN for two years. But the system had an unexpectedly short lifetime because a next broadband network replaced the conventional ISDN.
$\begin{bmatrix} X & 0 & 0 \\ 0 & X & 0 \\ X & 0 & X \end{bmatrix}$ (2) Coupled but over-simplified designs 28%	(2a) Interfered with unnoticed requirement 17%	The CPU of a new note-type computer, not only ran the programs, but also controlled the buttery charging. When the CPU was jammed, the battery charging became too slow.
	(2b) Interfered due to communication errors 11%	The technician of a subsidiary maintenance company locally changed the program without any shut down processes, breaking the original main program. He should ask the engineer about the the procedure in advance.
$\begin{bmatrix} X & & & X \\ & X & & \\ & & X & \\ & & & X \ddots \\ & X & & \end{bmatrix}$ (3) Coupled and complex designs 31%	(3a) Too complicated beyond human understanding 16%	A Japanese resin maker made a new "ecological" material with inorganic phosphorus. An American company used it for covering the LSI of an HDD fabricated by in a Korean company. The HDD company using the LSI had a copper migration trouble due to the phosphorus at half year later.
	(3b) Too vague to define customers requirements 15%	The system company hurriedly received a 10 M$ order with a top-sale. Later, the engineers negotiated the FRs with the customer; but the customer required a new FR gradually and endlessly; eventually, the loss increased to 100 M$.

2.2 Coupled but over-simplified designs

This category in Figure 1 (2) is the coupled, but not complex design. The designer couldn't notice the additional FR; he originally over-simplified the design. Later, he found that a coupled FR is existed. This has 28%.

For example, the ultra large scale integration chip looked a complex design. But the scenario of this failure was simple; e.g. a re-crystallization trouble of the aluminum wire line at unexpected high operation temperature; namely, the wire line and the operation temperature were coupled. The numbers of the focused FR/DP were only two, but the engineer could not notice the FR of cooling.

The sub-scenario of (2a) has a coupled technological relation on the additional FR. We found many failures of this sub-scenario of (2a) in hardware production. The (2b) has a coupled non-technological one, especially due to communication errors. We found many failures in maintenance operation. The miscommunication turns to X in the non-diagonal component.

2.3 Coupled and complex designs

This category in Figure 1 (3) is the coupled and complex designs, having 31%. Compared with the scenario (2), the (3) has a larger number of FR such as 10 to 1000. For example, the pension calculation system has about 100 of laws and rules, which mean FRs. Moreover, some city officers have their local interpretation clauses, which mean constraint (C). Consequentially, the designer could not define all FRs and Cs on the specification.

The sub-scenario of (3a) includes the real complex design with many coupled FRs in manufacturing. For examples, the worldwide supply chain management makes an unexpected trouble in a trivial part as if the designer steps on a hidden mine. The (3b) is also the real complex design, especially in planning. The engineer often made a mistake to translate from customer's attributes (CA) to FR.

3 ANALYSIS OF THE DATABASES OF THE ENGINEERING FAILURES

We quantitatively analyzed the category of failure databases in Japanese industries. Figure 2 shows the ratio of the aforementioned three typical scenarios of the six companies; computer system making, software programming, copying machine manufacturing, sheet metal manufacturing, railroad operation, and research and education [2].

Software industries in the left sides of Figure 2 have a high ratio (31 and 40%) of the coupled and complex designs of (3) in Figure 1. Hardware industries on the center has a middle ratio (23 and 25%), and service industries in the right has a low ratio (11 and 18%).

Generally, software industries have larger numbers of FR than hardware or service industries. Then, the software doesn't have any standard DPs, e.g. common subroutines or fundamental calculation, while the hardware has many standard DPs such as screws or bearing. The designer can fix the many standard or modular FRs for hardware, while for software he should check the interference for each non-standard or integrated FR.

Moreover, software industries have larger numbers of challenging FR than hardware or service. Generally, the new challenging technology includes some unknown risks. For example, nuclear power plant or transportation system continues to use the same design for 40 years while the

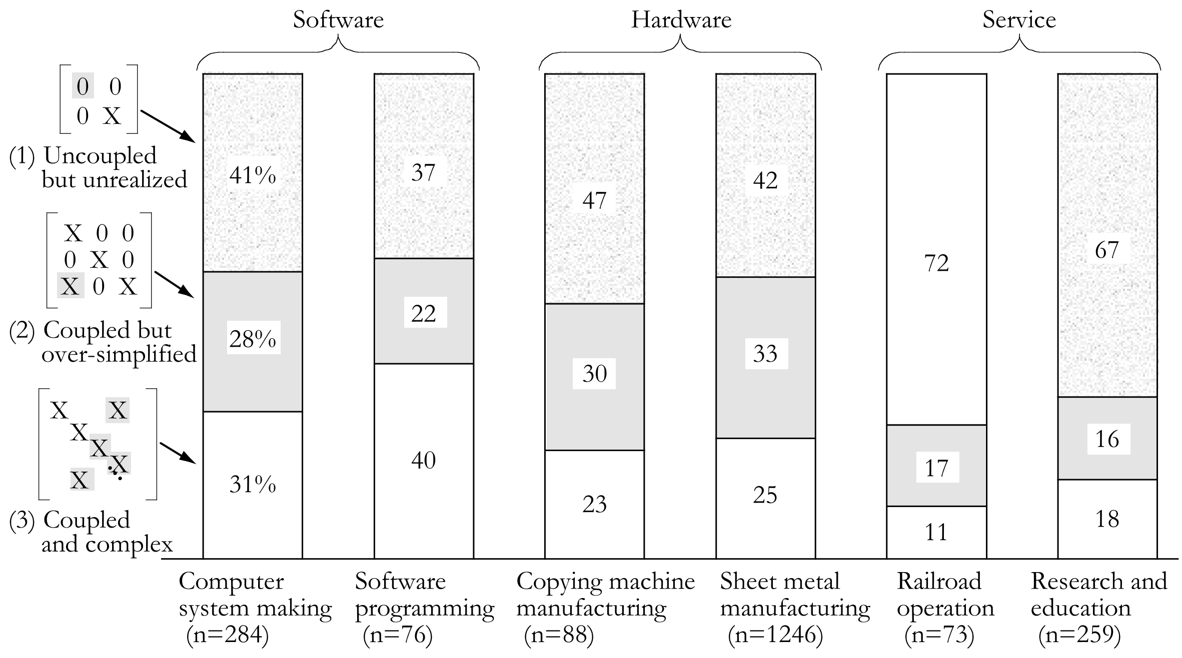

Figure 2. Share of the failure scenarios in various organization

computer or its software should be frequently changed or revised every 5 years.

Table 2 shows the examples of the coupled and complex designs in various organization of Figure 2. The authors could not count the numbers of FRs of the failure designs accurately. For example in the upper column of Table 2, the computer system was shut down at midnight when the access of an unexpected volume emerged. Extra accesses invade the bass line at a worst timing, but no one could not predict the trouble, e.g. which line was wrong and what time was it. In order to know the possibility of coupling, we need some simulators to automatically check the all possible situations. The six failures in Table 2 are very difficult for us to imagine the detail in designing or planning.

4 DISCUSSION FOR REDUCING THE COUPLED AND COMPLEX FAILURES

Japanese industries need an endless cost-down effort to survive against an emerging east-Asian countries' business. They, however, don't notice a coupled FRi affected by the DPj, which was expected to improve the cost-down for FRj.

Table 2. Examples of the failures of coupled and complex design in various organizations

Organization	Examples of the failures
Computer system making 31%	Too many customers bought the soccer lotteries at one o' clock; the computer system worked slowly and shut down because the access increased by 100 times of the average.
Software programming 40%	A tax accounting program set the maximum value for all parameters of the calculation. But the tax low changed; only four companies out of 10,000 exceed the maximum of one parameter, claiming the tax accounting.
Copying machine manufacturing 23%	The additional chemical content of a developed toner could improve the red color. But the engineer had to re-optimize all conditions of the charging, fixing, or discharging process, losing the business eventually.
Sheet metal manufacturing 25%	Sheet metals were plated; but some had a slight corrosion trouble, eventually being recalled. The pump of a cleaning tank before plating had stopped; a debris was remained on the tank, making a pinhole of the metal surface.
Railroad operation 11%	The signal controller of a preliminary side line in a small station was broken, and continues to send the ghost alarm. Gradually, the alarm stopped the neighboring signal; the entire line was stopped eventually.
Research and education 18%	An organic material was reacting at a little bit high temperature in the laboratory. But the poisonous secondary production that could not be assumed was generating; the operator unexpectedly had a heavy headache.

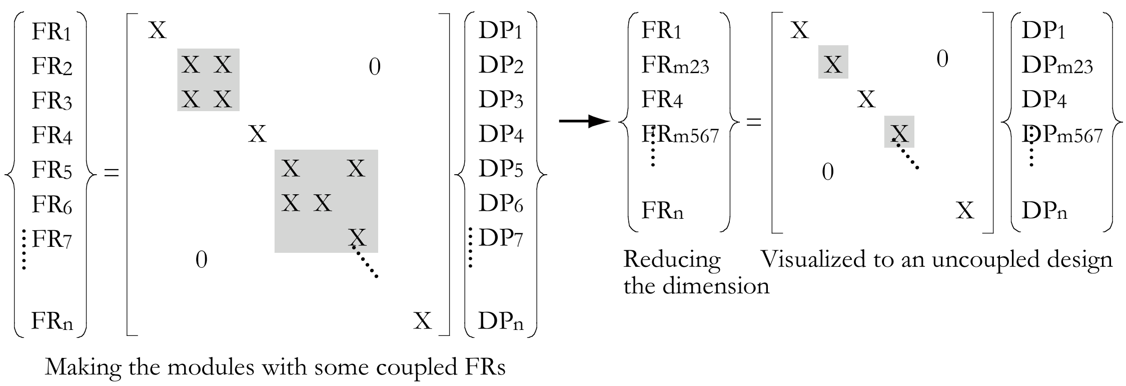

Figure 3. Countermeasure for the coupled and complex designs: making a module with some complied FRs.

Eventually, the cost-down effort for FRj will suffer a claim-up for FRi. The non-diagonal component (Aij) in the design matrix represents the interference.

For example, an automobile company changed the process of assembly of the oil scraping-down piston rings from manual snapping to automatic robot inserting for the cost-down requirement. But this automation slightly damages the blades of the ring; the lubricant oil moved upward along the cylinder through the ring and burned with the gasoline; the automobile alarmed against oil shortage and engine overheat; the company recalled all engines. The production engineer didn't notice the coupled influence between ring's circularity and assembly damage. He should check all non-diagonal components of the design matrix using historical knowledge.

For another example, a railway company merged the other company's prepaid IC cards. In that time, the company must check the fares of all routes of 1.2 billion patterns. Nevertheless, a discrepancy of the fare was appeared in final checking. The number of this 1.2 billion is more than human checking ability; an automatic checking program is necessary. Then the checking process is almost as long as the programming process.

Referring the Axiomatic Design knowledge, we can propose some effective countermeasure plans: (a) making an uncoupled design even at the early design stage; (b) automatically checking all of complex patterns like the mentioned IC cards; (c) transferring the knowledge of a decoupled design to a next designated engineer like the mentioned snapping ring: (d) making a module with some coupled FRs, getting a decoupled matrix.

The plan (a) of designing independently is ideal but empirically impossible. The plan (b) of checking automatically is a royal road to success but so expensive and troublesome. The plan (c) of transferring the knowledge is conventional and inexpensive, but nowadays difficult under non-lifetime employment and quick change technology.

The remaining plan (d) is promising. We can manually check all non-diagonal components if the numbers of FR/DP is 10 or less according to our experience of the seminars. Reducing the dimension of the design matrix is important for visualization of design. Figure 3 illustrates the method to make a module. Some FRs, which are coupled each other but are uncoupled with the group of the other FRs, was transformed to a module. After the process, the design matrix becomes the diagonal one. Though the parts are still coupled in the module, the engineers in the organization for the module can design it without any coupled failures. He already has the knowledge about the coupling. Relating to the mentioned snapping ring, at least, one engineering manager should take care of the oil scraping-down piston ring, the lubricant oil, and the snapping process by himself.

5 CONCLUSION

The designer's mind process of the engineering failures is analyzed from the Axiomatic Design perspective. The failure data of a Japanese company making computer system can be categorized into the typical three categories. (1) uncoupled but unrealized designs (41%), (2) coupled but over-simplified designs (28%), and (3) coupled and complex design (31%). Nowadays, the category of (3) is an emerging mind process for the huge and complicated system, especially in software industries. It is too complex to understand beyond the designer's assumptions. For prevention of the complex failures, checking all interferences automatically and making a module with some coupled FRs are useful. Especially making a module is inexpensive and effective for visualization of decoupling.

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