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Capturing the Value Chain in a Large-Scale Project

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Abstract

In a large-scale development project—a development project of space systems, for example—it is very important to share high-quality design information at each level of the system. Especially in a high-context culture like Japan's, it is vital not only that the engineers transmit their requirements through documents, but also that they share the value with each other. On the other hand, there are some cases when engineers of a higher-level intervene with lower-level design activities and hinder effective design activities because of a possible principal-agent relationship between the higher- and lower-level engineers.

This study visualizes the value transmission mechanisms in design activities, analyzes them using a theoretical method and simulations, and proposes effective strategies for value transmission.

Introduction

In a large-scale and complex development project, such as space systems, various technological activities, including systems engineering (INCOSE 2007) are conducted.

In the early planning phases, the system of interest is defined hierarchically, flowing down from top to bottom. A part of this system design is the higher level determining the requirements for the lower level, as shown in Figure 1. At the lower level, the engineers design the system complying with the requirements. The design results are integrated at each level.

Engineers at the each level conduct system studies and compare design alternatives under given constraints and conditions in order to find the best compromise.

In a large-scale system development project, it is necessary both to enhance the quality of the requirements and to manage them strongly. The quality of requirements is one of the most important elements for mission success. For this reason, requirement engineering is emphasized and numerous research on requirement management and communication coupled with project management methods have been done in Japan (Ishii 2006) (Liu et al. 2007).

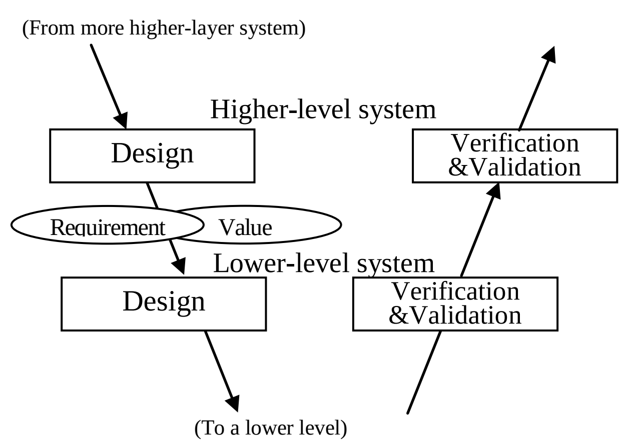

Figure 1. Concept of V-Model.

Conversely, Hall defined "context" as "the information that surrounds an event," and observed that Japan was originally an extremely high-context culture (Hall 1976). In a high-context culture, people communicate in situations where they share the information in advance. In other words, the information is transmitted not only through documentation but also through the activities in which the people share space and time. It has been observed that pursuing high-quality requirement transmission using documents sometimes results in engineers becoming exhausted (Okada et al. 2009).

When engineers make trade-off studies of alternative design solutions, sometimes they cannot achieve a system that meets the customer's needs because they mistake the criteria of evaluation. That is to say, it is very important to record the customer value into the criteria accurately when engineers select a design solution. The customer value is an important piece of design information that is transmitted from the higher-level engineers, who state the requirements, to the lower-level engineers

This study visualizes the value transmission mechanisms in design activities, analyzes them using a theoretical method and simulations, and proposes effective strategies for value transmission. Firstly, we discuss the principal-agent relationship in design activities that is caused by asymmetric diversity of the information when engineers receive requirements from higher-level engineers and conduct design activities hierarchically. Secondly, we visualize the design process at a certain level of the system including the aspect of value transition. Thirdly, we analyze the factors that cause the transmission failure of value information. Finally, we discuss the impact of the value transmission on the design using both theory and simulations, and propose effective value transmission strategies for improvement.

Principal-Agent Issue in Engineering

In a system development project, the higher-level engineers (who determine the requirements in a higher-level system) and the lower-level engineers (who design in a lower-level system) execute design activities cooperatively.

On the other hand, as shown in Figure 2, the lower-level engineers give priority to the information of design technology and higher-level engineers give priority to the customer value information, resulting in asymmetric diversity among them concerning design information. The asymmetric diversity is a kind of principal-agent relationship (Milgrom et al. 1997).

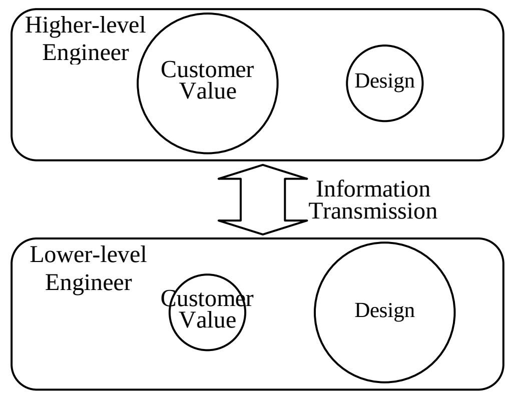

Figure 2. Concept of Information Asymmetry.

Here, we show the case of a space system development project, as shown in Figure 3.

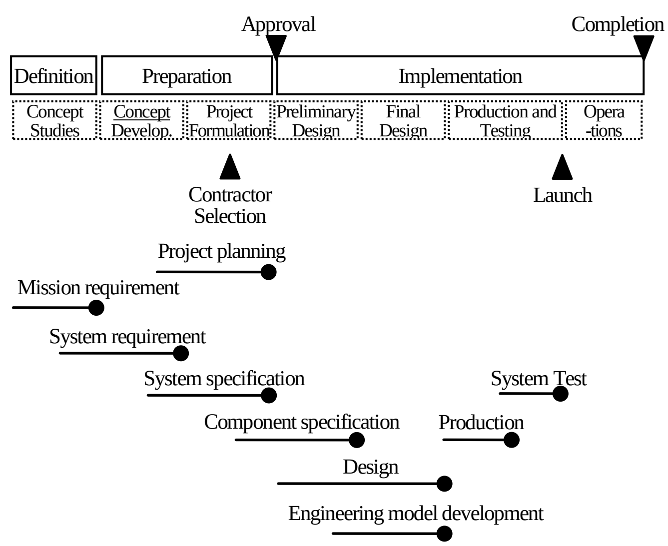

Figure 3. Lifecycle Process of a Space System.

When the prime contractor works based on the contract, the space agency (as a principal) executes procurement management, including the technical inspection, for the prime contractor as a purchaser. The space agency gives information priority to the value of the mission because it is the main organization defining the mission itself. On the other hand, a space system is basically a single-unit production compared with that of an automobile, which is developed through mass production. Therefore, the reusability of the existing design data is low and flexibility of the design solution is high. That is, the prime contractor as a design organization (as an agent) gives information priority to design technology. Through the existence of such asymmetric information, when the space agency manages the procurement, the problem of the space agency intervening in the activities of the prime contractor occurs in excess.

The main purposes of their intervening in the prime contractor's design activities are as follows:

- (i) Correction of technical errors
- (ii) Correction of evaluation criteria and evaluation process in design activities
- (iii) Oversight of proper execution of the whole design activities

In the development project of the space system, much of the intervention on the prime contractor by the space agency is caused by the space agency attempting to avert any unintended consequences by the prime contractor (abovementioned (ii)).

Visualization of Value Transmission

The design information is transmitted integrally from the higher-level engineers (principal) to the lower-level engineers (agent) through the explicit requirements of the design and the value of design, as well as the sharing of context concerning designs by engineers of both levels. For instance, Toyota Motor Corp. has their own product development system (Morgan et al. 2007) in which the chief engineer expresses and shares the new car's vision to the lower-level engineers using a concept document. The document describes customer value and targeted performance, cost, quality, and so on.

To clarify how the value information is treated in the design activities of a certain system level, we visualize the process including the value transmission in Figure 4.

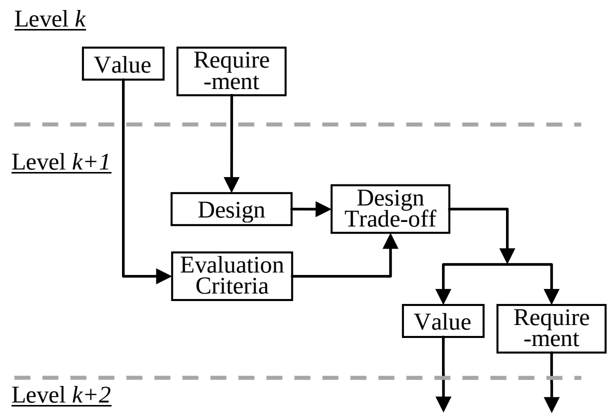

Figure 4. Value Transmission Model in Design Process.

In Figure 4, the requirements are mainly transmitted by specified documents and the value is included in the document as well as other context.

The highest-level engineers (k=1) have a direct connection to the customer. Therefore, they can relay the customer's value to the design by defining the priority of the design parameters using methods such as Quality Function Deployment (Akao 1990) among others. They can then attain a design solution in order to maximize the value by setting it as valuable.

On the other hand, lower-level engineers are restricted in design flexibility because the higher-level engineers state the design requirements. Under such a restriction, the lower-level engineers conduct designs by understanding the requirements from transmitted design requirements. The engineers make a comparative study of the obtained alternatives based on the evaluation criteria and select a design solution. The lower-level engineers confirm the validity of the selected design solution with the higher-level engineers. To reduce the amount of rework, the higher-level engineers sometimes monitor the comparative study by lower-level engineers. This corresponds to the intervention in design activities.

As mentioned above, lower-level engineers give information priority to design technology. Therefore, if they conduct a comparison investigation using the appropriate evaluation criteria that are derived from a well-transmitted value, monitoring of the design by higher-level engineers is reduced and both levels of engineer conducting their activities autonomously can be expected.

Simulation of Value Discrepancy

Here, we discuss how value information is transmitted, and how it affects the design result and process.

Influence on Rework within a Level. When the value information sent from the engineers of Level k to the engineers of Level k+1 is insufficient they have discrepant evaluation criteria in Figure 4. We discuss the influence of evaluation criteria on the result of comparative design alternatives within a level, as shown in Figure 5.

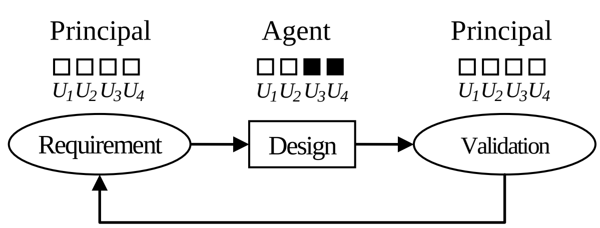

Figure 5. An Example of the Iteration Process.

As an example, two (Ui, i=3,4) of the four evaluation criteria (i=1,2,3,4) have fluctuations of importance (here, $Wp_1=0.2$, $Wp_2=0.3$, Wp_3=0.25±<u>0.025</u>, Wp_4=1-Wp_1-wp_2-Wp_3) because the higher-level engineers cannot define the significance of the value, and as a result, the fluctuations (here, $Wa_1=0.2$, $Wa_2=0.3$, Wa_3=0.25±<u>0.10</u>, Wa_4=1-Wa_1-Wa_2-Wa_3) by the lower-level engineers increase.

Here, we assume that the knowledge acquired in the design process is accumulated gradually through trial and error (Nomaguchi et al. 2009). Comparative studies of the design alternatives are repeated until a design solution can be selected.

During each design study, the overall score of each alternative is quantified as a total score (S^*) multiplied by its importance as follow;

$$S^* = \sum_{i=1}^{4} Wpi \times Ri \qquad (1)$$

Here, Ri is the rate of i^{th} evaluation criterion for alternative.

Then we assume that the study results affect the following study result like a random walk and the total score of n^{th} study $S(n)$ is corrected as follows:

$$S(n) = \frac{S(n-1) + S^*(n)}{2} \qquad (2)$$

Here, $S(1) = S^*(1)$. $S(n)$ is affected by the importance Wpi and Wai even if the rate Ri of higher-level engineers is equal to one of the lower-level engineers.

The simulation results in Figure 6 represent the possibility that the selection result of alternatives differ from each other when the importance of value is different.

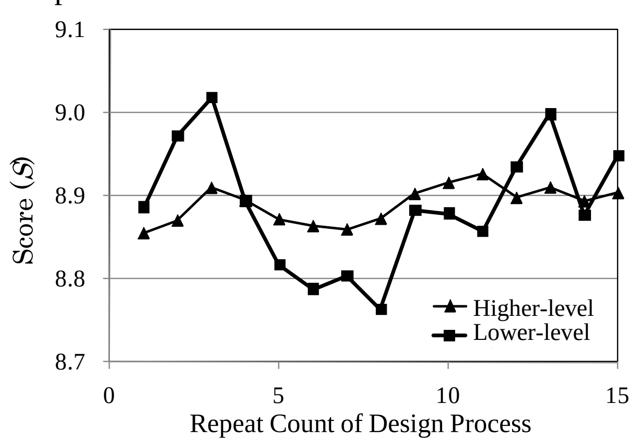

Figure 6. An Example of Evaluation Results of Design Alternatives.

Influence on the Whole Process in a Hierarchical System. When the engineers of level $k+1$ cannot transmit enough value information to the engineers of level k, rework occurs in design validation. Here, we discuss the detection timing of design non-conformance at the lower-level. We also discuss the rework probability using the simplified model shown in Figure 7.

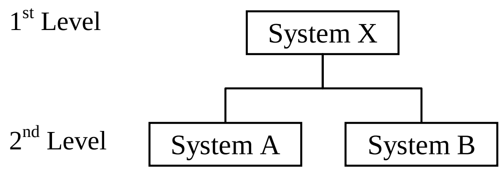

Figure 7. Simplified System Model.

We compare the two cases shown in Figure 8 to consider the presence of the validation process using the simplified model shown in Figure 7.

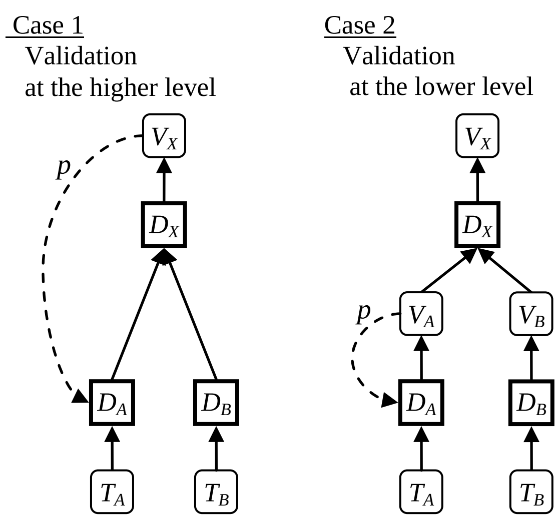

Figure 8. Comparison of Processes.

Here, each *T*, *D*, and *V* in italic type represents the amount of information transmission, design and validation processes with the subscripts X, A, and B signifying the systems of interest. p is the rework probability from the validation process to the design process. Each amount of rework in the design and validation processes is defined as d and v. Expectation of the total process amount is as follows:

Here, to simplify the problem, the amount of processes in each system is assumed to be the same. That is, $T_A=T_B=T_X=T$, $D_A=D_B=D_X=D$, and $V_A=V_B=V_X=V$. Moreover, the rework probability p is assumed same.

The expectation E_1 and E_2 of each total amount of processes, and those differences ΔE are derived as follows:

$$E_1 = 2T+3D+V+(2d+v)\sum_{j=1}^{\infty} p^j$$

$$= 2T+3D+V+(2d+v)\frac{p}{1-p} \quad (3)$$

$$E_2 = 2T+3(D+V)+(d+v)\frac{p}{1-p} \quad (4)$$

$$\Delta E = E_2 - E_1 = 2V - d\frac{p}{1-p} \quad (5)$$

Therefore, we find the relationship between the rework probability p and the expectation of total processes E.

As described in the preceding section, when the more value is shared in advance to the design process, evaluation criteria of the design are established more appropriately. As a result, design validity increases and the rework probability in the validation process decreases. That is, the value transmission is larger in quantity and the validation process is reduced more while shrinking the total amount of processes. On the other hand, when the rework probability is larger because of a small value transmission quantity, the total amount of processes can be reduced by introducing more validation activities after the design process.

Methods of Improving Value Transmission

Based on the above discussions, we propose improvement strategies for the effective value transmission as follows:

(A) To reduce the fluctuation of value transmissions, using value breakdown that visualizes the final customer value and transmits the value from the highest level to the lower levels consistently including the significance of the value, is effective.

(B) When value transmission is difficult, to minimize the total amount of both design and validation processes, it is important to set the design and validation processes effectively and efficiently by measuring the total amount of the processes.

Conclusion

In this study, we visualize the value transmission process in design activities, and analyze the effect on the design by theory and simulation. We also suggest the importance of value transmission, especially in a large-scale system development, and propose improvement strategies.

In a Japanese development project that is characterized by an integrated-based method, it is important to keep close information transmission under strong leadership. This study is based on a space development project, so it is applicable to other similar national technology development projects, such as nuclear energy development.

We will establish the framework of value transmission by evolving the proposed strategies and put to practical use the various cases in a future study.

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Biography

Masashi Okada is a systems engineer of JAXA. He is responsible for development of systems engineering process, management of strategic technology roadmaps at the agency level, establishment of knowledge database and independent assessment of the current projects in JAXA, as one of the start-up members of Chief Engineer Office.

Most part of his career started in 1989 was a launch vehicle engineer. He was engaged in hot firing tests of the liquid rocket booster engine, system design of the following H-IIA and a conceptual study of next generation launch vehicle.

He received a master’s degree in aeronautics and astronautics in 1989 from the University of Tokyo. Now, he takes a doctoral course at Graduate School of System Design and Management, Keio University.

Masaru Nakano is a professor of Graduate School of System Design and Management, Keio University, Japan. He was a principal researcher and laboratory manager at Toyota Central R&D Labs., Inc before joining Keio. He received a B.S. and M.S. from Kyoto University and a Dr. Eng. from Nagoya Institute of Technology. Dr. Nakano has studied in the fields of robotics, manufacturing system design, enterprise integration, business process reengineering, marketing research and sustainable manufacturing. He is a member of IFIP, JSME, ORSJ, JIMA, and etc.