Toward space system modeling with appropriate scope and abstraction level based on validation against constraints

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1. Introduction

Recently, the rate of change in the speed of space development has accelerated. Previously, spacecraft were developed by national space agencies as non-mass production with taking long time. On the other hands, a large number of spacecraft are being developed recently by private companies in a form close to mass production at high speed. Recognizing this situation, JAXA is carrying out digitalization of engineering that relied on documents and individuals in order to improve the QCD (Quality, Cost and Delivery) of JAXA's spacecraft development process. In the effort, various MBSE activities are being tackled, such as system modeling with SysML, system level simulation at the early phase, automatic code generation and so on. This paper focuses on our system modeling with SysML (static modeling).

Historically, JAXA has made several efforts regarding such static modeling. Kawai et al. [2] tried to create satellite models with SysML for several satellite projects, focusing on operational scenarios to implement user-oriented systems and to prevent reworking implementations caused by inconsistent recognition of their use. However, some issues were found in the trials. The most important one was that too many diagrams were created to be used for analysis or to be maintained. For the other purpose, Inaba et al. [1] used a model-based methodology to develop a quasi-zenith satellite system. The proposed method transferred operational envelopes from designers to operators as required.In these few years, Nakajima et al. [3] have challenged to generate satellite models with SysML and applied them for failure mode analysis.

A common but difficult RQ (Research Question) that has not yet been resolved is determining the correct scope and abstraction level of the information to be modeled. In [3], Nakajima said that models should be organized to consider how we consume model-generated SE artifacts, as lessons learned from his challenge. We also believe that the issues in [2] were caused by not considering this.

Based on this background, Section 2 proposes a static modeling method that enables modelers to create a system model with appropriate scope and abstraction level in order to realize well-suited architecture design. Also, the first evaluated result in a satellite project is described in section 3.

2. System modeling to create a system model with appropriate scope and abstraction level

2.1 Basic concept

As described in Section 1, the correct scope and abstraction level of the information to be modeled should be derived from the purpose of the model (Figure 2-1). Therefore, we first need to consider what the purpose is. It may be visualizing or sharing design results, but the most important one is architecture validation because validation is also the purpose of visualizing and sharing results. So, what the validation should be for have to be also considered.

Naturally, it should incorporate all requirements and constraints. Here we propose a method to create models primarily based on validation against constraints. If there are no constraints in designing the target, any system architecture could be selected. This is why we focused on constraints. In this paper, constraints is defined as a boundary condition of the design spaces in which any problems occur when there is a deviation. In other words, by focusing on constraints, SysML modeling can be expected to make it easier to contribute to the definition of simulation boundary conditions by mathematical models or to find spooky side effects that could cause some problems.

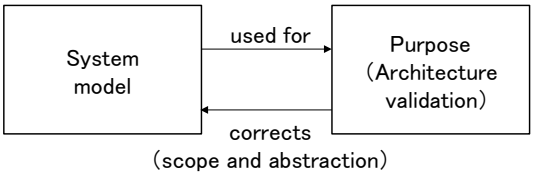

Figure 2-1. Basic concept of the method

2.2 Abstract of constraint-centric modeling

Figure 2-2 shows the abstract procedure of the proposed method.

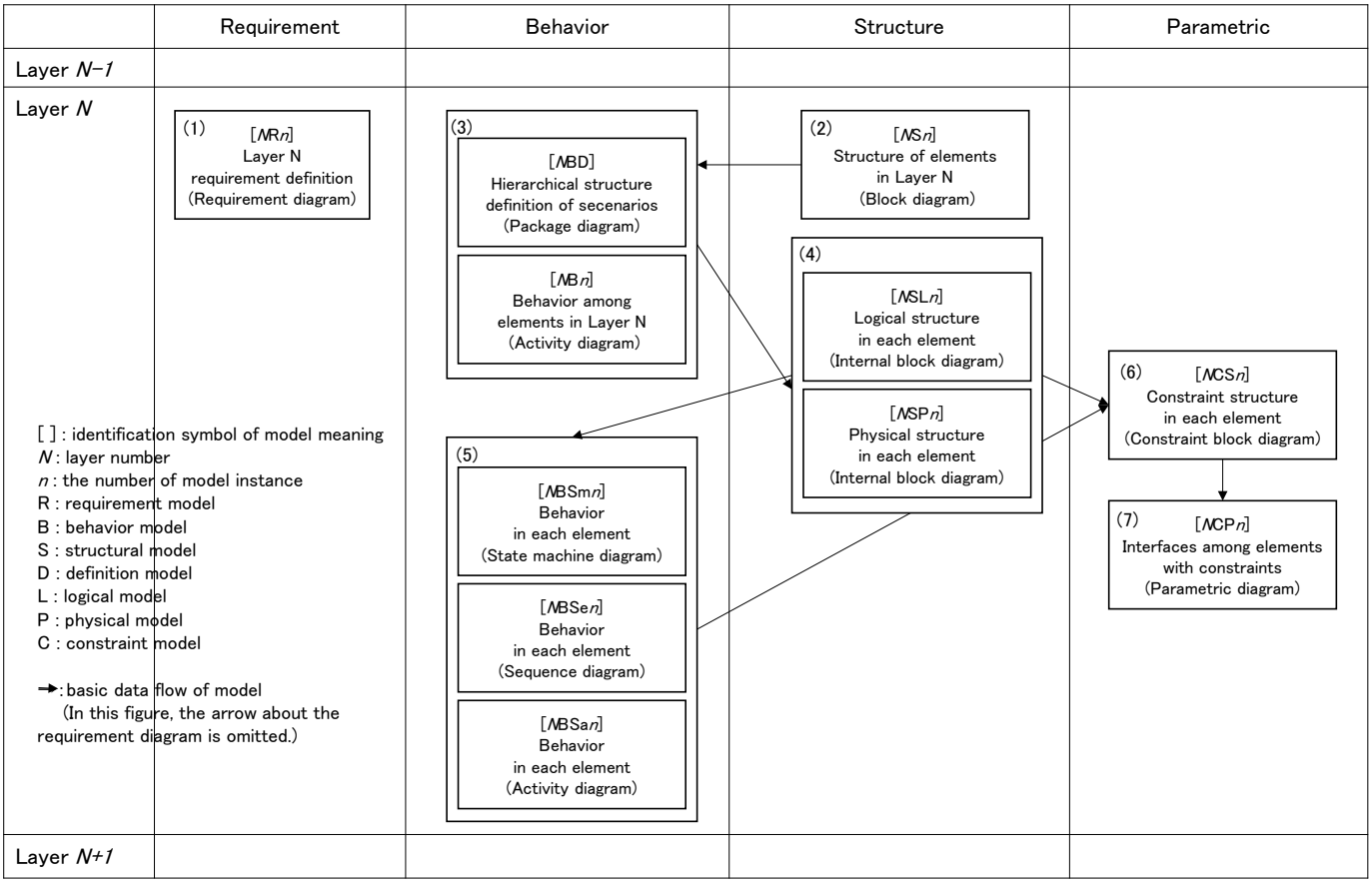

Figure 2-2. Constraint-centric modeling

In our procedure, the modeler sets the system elements in a certain layer ((2)), analyzes the external behavior between the system elements ((3)), and gains a rough idea of the context. After decomposing the internal elements

((4)) and further analyzing the behavior between the internal elements ((5)), the constraints are defined. Here, for example, if a constraint cannot be defined, it is necessary to review the model of behavior and structure, considering that it lacks the embodiment of elements or context identification. On the contrary, even if a constraint can be defined, it is necessary to review it if its satisfiability cannot be confirmed without making the behavior and structure more concrete from the viewpoint of the constraint. In this way, the method focuses on the constraints, confirms the model information sliced from the aspect of constraints, and applies corrections across the entire model.

3. Evaluation

In the first evaluation, the proposed method is applied experimentally to develop a payload in one of JAXA's satellite projects, RAISE-3 (rapid innovative payload demonstration satellite-3). This evaluation is currently underway, and some tentative results are shown in Figure 3-1, 3-2 and 3-3. These results show that the test design based on the SysML model created by our method can be performed more effectively than using documents at least.

Although it is difficult to make an accurate evaluation only from these tentative results, it can be said that it is possible that a model with an appropriate scope and abstraction level with which designer can confirm the validity has been created.

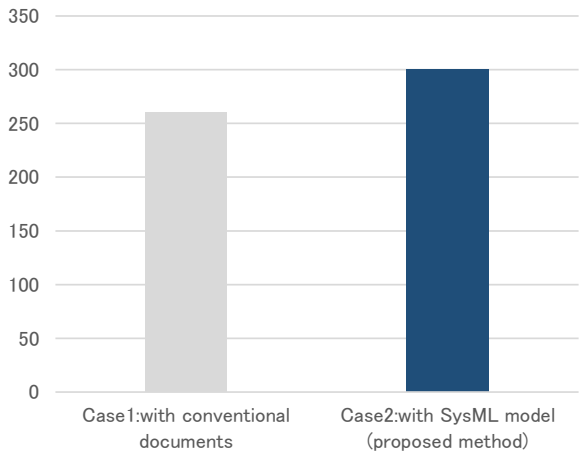

Figure 3-1. Time spent understanding specifications [minutes]

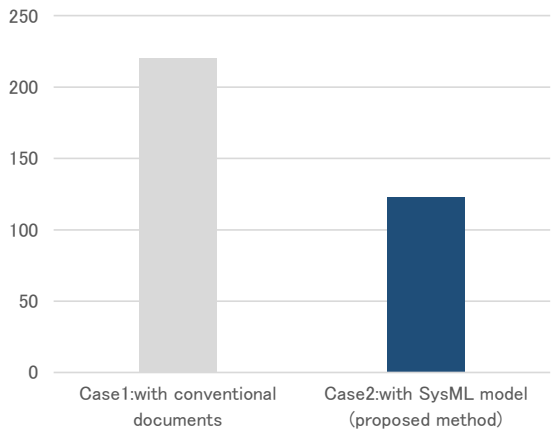

Figure 3-2. Time spent creating all test cases[minutes]

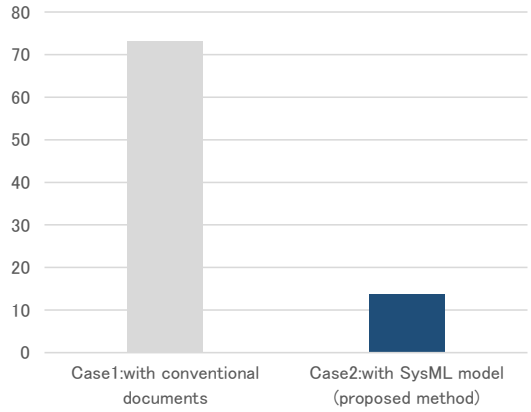

Figure 3-3. Average time spent creating a single test case[minutes]

4. Conclusion

This paper proposes a static modeling method that enables modelers to create system model with appropriate scope and abstraction to realize a well-suited architecture design. Based on the tentative results of the first evaluation, we confirmed that it works effectively. However, the evaluation is underway. The system used as the design target in the experiment was a device that dealt with mainly information transmission, not a system that depends on physical phenomena, so we will have to conduct evaluations of systems with such characteristics in the future.

References:

[1] Noriyasu Inaba, Hidemi Hase, Hiroyuki Miyamoto, "A Satellite Simulator and Model Based Operations in Quasi-Zenith Satellite System", proc. AIAA modeling and simulation technologies conference 2009.

[2] Azuma Kawai, Yuji Nishihara, Yuko Miyamoto, "The Operation Design Process and Model-Based Operation Analysis for a Satellite Development", 29th International Symposium on Space Technology and Science, 2013.

[3] Yuta Nakajima, Tsutomu Fukatsu, "Applications of Model-Based Systems Engineering for JAXA's Engineering Test Satellite-9 Project", ESA MBSE2020.