Ontology for Weather Observation System

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Abstract Why do humans develop systems? The answer is clear: to realize system capabilities by utilizing these systems. Unless a system realizes the intended capability, it is useless, even if the system itself is perfect. Every system needs something to be realized. The problem is that we do not know how to deal with unexpected problems that prevent the realization of the system capability. Of course, many studies have been conducted on how to develop robust, fault tolerant systems, but there is no existing research on how to determine the system's resilience in relation to its capability. The system capability can be realized by developing a resilient system. In this study, we developed a system ontology especially for a weather observation system. This ontology can describe the entire system by applying DODAF 2.0 and an enabler relationship. It allows us to determine all of the system entities and relationships. In addition, the ontology shows the system's resilience by considering the realization of the system capability. This ontology was applied to a weather observation system to verify its effectiveness.

1 Introduction

1.1 Motivation

In the past, space has been utilized as a sanctuary because its environmental characteristics are completely different from those of the land, sea, and air. Recently, the space infrastructure situation has changed. As technology has advanced, humans have developed and launched weather and GPS satellites. The importance of space infrastructure has gained recognition all over the world. For example, we usually

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M.-A. Cardin et al. (eds.), *Complex Systems Design & Management Asia*,
Advances in Intelligent Systems and Computing 426,
DOI 10.1007/978-3-319-29643-2_7

check the weather forecast before going outside and often utilize a map in order to efficiently reach our destination. Space infrastructure has become part of our daily life. What if someday we cannot use this infrastructure? What if our country's satellites are intentionally damaged by another country? In the past, some countries have succeeded in destroying satellites, which means today's space infrastructure could potentially be destroyed, either intentionally or by accident. Furthermore, a large amount of space debris is in orbit. The rising population of space debris increases the potential danger of accidental collisions [1]. Such collisions could eliminate the benefit derived from space infrastructure. However, we can develop a plan to avoid such a catastrophic situation.

For example, the United States has two kinds of counterplans to any threat to its space infrastructure. These represent a multi-layered approach to deterring attacks on its space capabilities and enhancing the resilience of these measures [2]. Japan also tries to enhance the resilience of its space infrastructure to deal with uncertain situations [3]. This resilience is defined as follows [4].

Resilience is the ability of an architecture to support the functions necessary for mission success in spite of hostile action or adverse conditions.

Based on this definition, a government can enhance the resilience by changing the space architecture design from intensive to dispersive [5]. However, in this research, we propose to enhance the resilience by developing an ontology that makes it possible to see the whole system. In other words, we develop an ontology to show the whole system and visualize how to maintain its capabilities.

In 2013, the Japanese government published its "Basic Plan on Space Policy," which provides a very important statement on its space policy [3]. Future decisions on Japanese space development will be made based on this statement. In the Basic Plan on Space Policy, Japan lists three major objectives to be achieved in the future.

1. Ensuring space security
2. Promoting space utilization in the consumer field
3. Strengthening and maintaining the space industry infrastructure, science, and technology

A small item related to the 1st objective is ensuring the stable utilization of outer space. The Japanese government must also enhance the resilience of its space infrastructure.

The first step to enhance this resilience is to understand the whole system. In order to do this, we propose an ontology especially designed for a weather observation system. Visualizing the system will make it possible to clearly see the whole picture of the relationships between individual systems such as a satellite and ground station. In the future, this ontology will tell us which part of the system lacks the appropriate resilience. For example, based on an analysis, a satellite manufacturing company will be able to design a satellite with enhanced resilience.

1.2 Objective

The objective of this paper is to develop an ontology to understand the entire space infrastructure, especially the weather observation system, and to acquire insights about what to do next in the space infrastructure development. The development of this ontology will make it possible to determine whether the system has resilience or not. Based on the results, we can obtain information about the steps needed to enhance the resilience of the system capabilities.

1.3 Related Works

James Martin proposed the conceptual framework for the entire Earth Observation System of The National Oceanic and Atmospheric Administration (NOAA) in the United States [6]. Figure 1 shows a diagram of all of the entity relationships in NOAA's Observing System Architecture (NOSA).

This diagram makes it easier to understand why it was previously difficult to understand what they had and what they were doing with what they had. This diagram allows the viewer to understand the whole system and the relationships with other system entities.

L.C. van Ruijven tried to develop a system engineering ontology to enable model-based systems engineering (MBSE) by creating a set of information models as defined in ISO 15926-11 [7]. This ontology makes it possible to solve the lack of

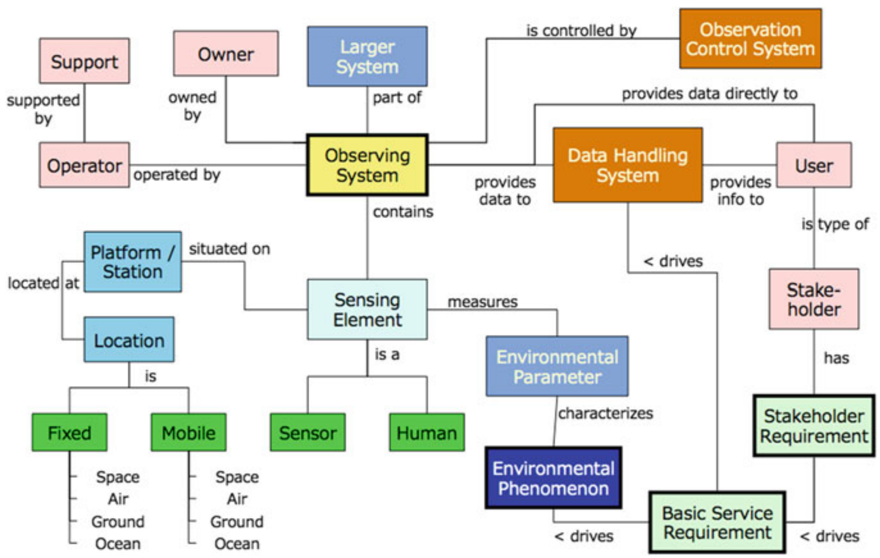

Fig. 1 Entity relationship diagram for NOAA's observing system architecture

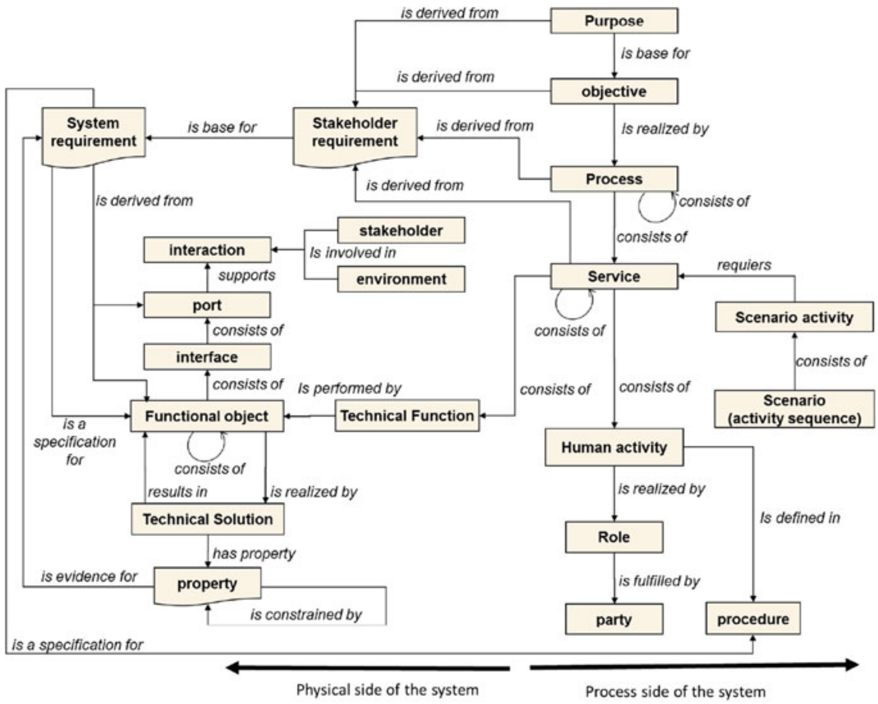

Fig. 2 Generic design model

interoperability and verbal chaos between the various parties involved in a project. He focused on the processes described in ISO 15288, including the stakeholder requirement definition process, requirement analysis process, and operational and maintenance process. He integrated the generic design model shown in Fig. 2 by developing an ontology that included each process.

As previously shown, the ontology approach is a very efficient method for determining the whole picture of each field at a highly abstract level. The ontology can be easily understood by people who are not familiar with the field. Thus, the ontology would promote understanding and beneficial discussions at the same abstraction level without any misunderstandings.

2 Research Process

In this research, we first developed an ontology for a weather observation system utilizing the Department of Defense Architecture Framework 2.0 (DODAF 2.0) and an enabler relationship. Then, we applied this ontology to a weather observation system and confirmed its resilience from the results.

In the future, by refining and using this ontology, we can develop a resilient system that can maintain the system capabilities.

3 Ontology

3.1 What Is an Ontology?

What is an ontology? An ontology identifies and defines concepts and terms [8]. An ontology provides descriptions of concepts and their relationships in a domain of interest. Furthermore, an ontology provides usage definitions, more than a dictionary or a taxonomy [9], which means an ontology is not just a classification system.

An ontology has two advantages. First, the user can obtain a consensus. When numerous parties are involved in a project, it is very difficult to obtain a consensus because there are many different interpretations of concepts. If they have the same dictionary containing definitions at a very deep conceptual level, misunderstandings between the parties can be prevented compared to the case when such a dictionary is lacking. Having a common dictionary makes it possible to explicitly express tacit knowledge. The second advantage is the ability to reuse and share knowledge. It is possible to identify the basic concepts that constitute such knowledge by considering the original object to be an object entity. Then, by considering the hierarchy according to the abstraction level of the knowledge, the user can consider the origins of this knowledge from the basics and find shared and reusable knowledge. Mainly, an ontology contains three types of relationships, as shown in Fig. 3.

(A) Class relationship between concepts
There are several categories of satellites, including earth observation satellites and communication satellites. Earth observation satellites also have sub-categories like weather satellites and intelligence satellites. The Himawari

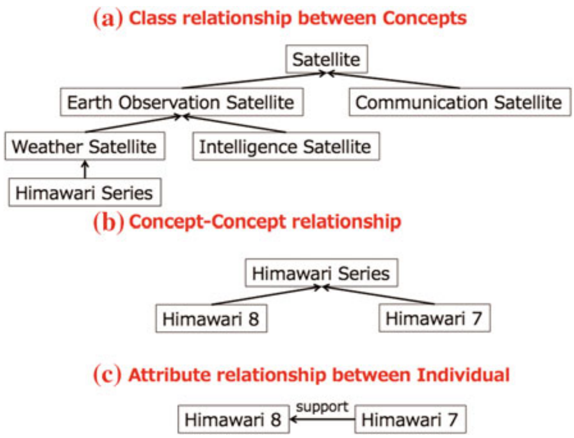

Fig. 3 Three basic relationships of ontology

series refers to a kind of weather satellite. A Himawari satellite is a geostationary satellite, operated by the Japan Meteorological Agency (JMA), and supports weather forecasting, tropical cyclone tracking, and meteorology research.

(B) Concept-concept relationship
The Himawari series includes eight satellites (Himawari 1–Himawari 8). Here is shown that Himawari 7 and Himawari 8 are part of Himawari series.

(C) Attribute relationship between individual satellites
Currently, Himawari 8 is in operation, and Himawari 7 supports Himawari 8 as its backup. In the ontology description, we can write that "Himawari 7 supports Himawari 8."

3.2 How to Develop Ontology

Before introducing the weather observation ontology, we will discuss its framework. When we attempted to develop an ontology and capture the entire space system, we applied an existing framework (DODAF 2.0) [10]. DODAF is used by United States engineering and acquisition communities to describe the overall structure for designing, developing, and implementing systems [11]. DODAF provides a visualization infrastructure for the concerns of specific stakeholders organized by viewpoint. DODAF 2.0 utilizes eight viewpoints: the all viewpoint, capability viewpoint, data and information viewpoint, operational viewpoint, project viewpoint, services viewpoint, standards viewpoint, and systems viewpoint. DOD utilized this architectural framework to develop a perfect defense system without any omissions.

We applied this architectural framework to capture the entire weather observation system. We selected four viewpoints: the capability viewpoint, operational viewpoint, service viewpoint, and system viewpoint. These viewpoints have a relationship called an "enabler relationship." This enabler relationship is one of the relationships between viewpoints [12]. In Fig. 4, viewpoint 1 is enabled by viewpoint 2, and viewpoint 1 is utilized by viewpoint 2. This relationship can be applied to the DODAF 2.0 viewpoint. The capability is enabled by the service, and the service is enabled by the operation and system. Applying the enabler relationship to DODAF makes it possible to explicitly understand the layer structure.

In addition to the four-viewpoint structure, we decompose the system viewpoint in detail. In Fig. 5, we can clearly separate the roles of the function and physical viewpoints. This idea is similar to the systems engineering process in IEEE 1220 [13]. After the requirement analysis, we consider the functional analysis process and synthesis process. This decomposition makes clear the difference inside the system. It is also possible to apply the enabler relationship to the function viewpoint and physical viewpoint. We can clearly visualize this relationship.

By integrating Figs. 4 and 5, we can obtain the ontology for the weather observation system shown in Fig. 6.

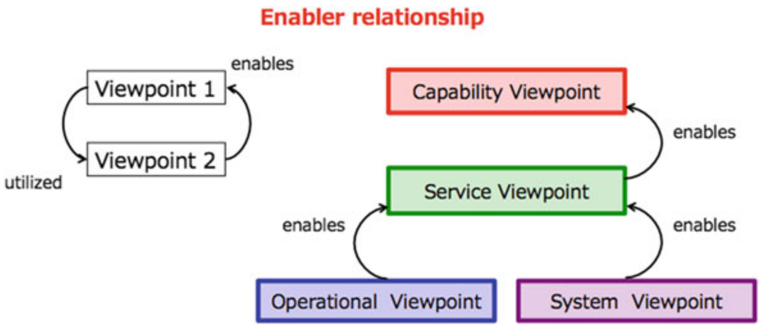

Fig. 4 Enabler relationship and its application to DODAF 2.0

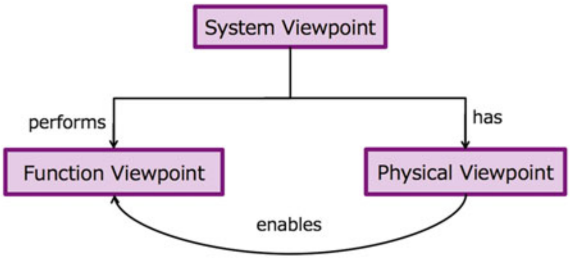

Fig. 5 Structure of system viewpoint and relationship

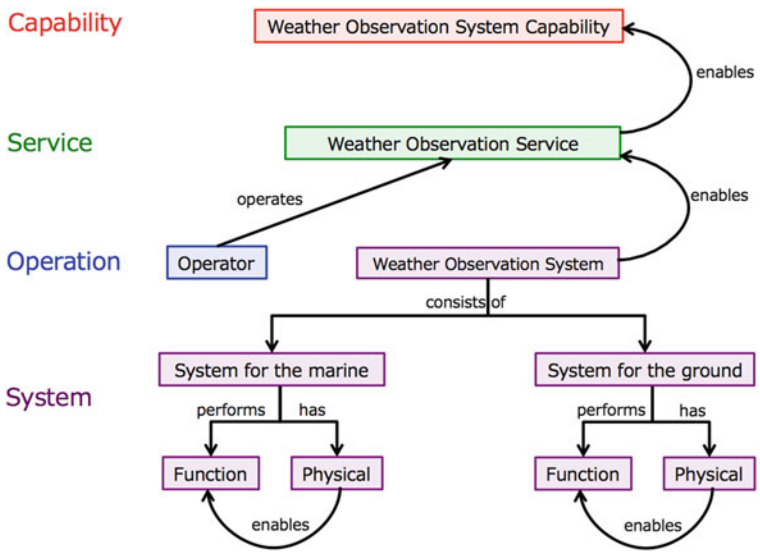

Fig. 6 Ontology for weather observation system

This figure shows the basic relationships between the viewpoints in this paper. In the system viewpoint, the weather observation system consists of the ground system and the marine system. Each system has a physical structure and performs functions. Of course, as previously mentioned, a physical structure enables functions. The weather observation system enables a weather observation service. The service is operated by an operator and enables the weather observation system capability. This is the whole picture of the weather observation system.

4 Applying Ontology to Weather Observation System

4.1 Result

Let us now apply the previously propose ontology to a weather observation system, particularly the Japanese weather observation system. The result is shown in Fig. 7.

We assume the situation that the weather observation system tries to forecast a typhoon. The weather observation system's ability to forecast a typhoon can be divided into forecasting the typhoon's track and forecasting its intensity. The main capability is enabled by the typhoon forecast service, which consists of providing a

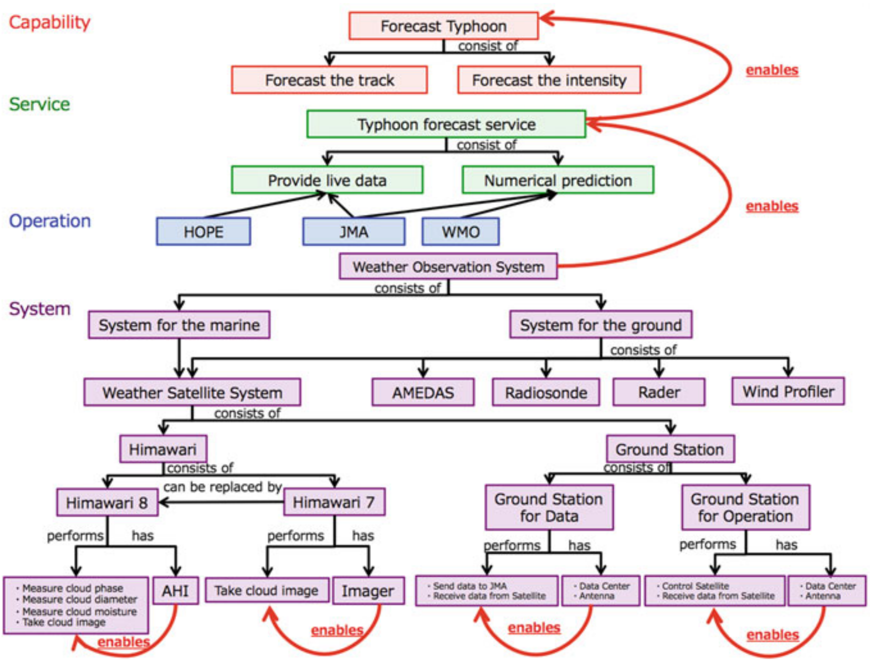

Fig. 7 Applying ontology to Japanese weather observation system

live data service and conducting numerical prediction. These services are operated by the Himawari OPeration Enterprise corporation (HOPE), JMA, and World Meteorological Organization (WMO). Then, the weather observation system enables the service. As shown in Fig. 7, the marine system is the weather satellite system, and the systems for the ground are the Automated Meteorological Data Acquisition System (AMEDAS), radiosonde, radar, and wind profiler on the weather satellite system consists of the Himawari satellites and ground station. The Himawari satellites consist of Himawari 8 and Himawari 7, and Himawari 8 can be replaced by Himawari 7. Thus, we define their relationship as "can be replaced by." There is a large performance difference between these two satellites. Himawari 8 has an imager called the Advanced Himawari Imager (AHI), which has more functions than Himawari 7. These functions include measuring the phase, diameter, and moisture of clouds, as well as acquiring images of them. These functions are enabled by physical structures. The ground station consists of two entities. The first is a ground station for data. It has a data center and antenna as physical systems. These make it possible to send data to JMA and receive data from the satellites. The second is a ground station for operation. It has the same physical systems as the ground station for data, but it has different functions for satellite control.

4.2 Considerations

As a result of applying the ontology to the Himawari system, we can show the entire Himawari system from the capability viewpoint, operational viewpoint, service viewpoint, and system viewpoint, which has both the function viewpoint and physical viewpoint. The model makes it easy to understand and obtain insights with the need to classify the entities and their relationships with the other entities. For example, Himawari is composed of two satellites, and Himawari 7 exists as a backup satellite for Himawari 8. If Himawari 8 suddenly stops working, Himawari 7 can be substituted to obtain cloud images. However, the other three functions (the cloud phase, diameter, and moisture measurement functions) cannot be carried out by Himawari 7. Thus, action should be taken to compensate for this lack.

In addition, we can consider the system resilience from Fig. 8. The definition of resilience was already discussed in Sect. 1.1. If the system of interest loses part of its architecture, can it maintain its capability? That is the question that we really want to answer.

<u>Case 1: Lose a1</u>
The system retains A and a2. Thus, the system performance becomes poor, and the redundancy becomes bad.
<u>Case 2: Lose a2</u>
The system retains A and a1. Thus, the system redundancy becomes bad.
<u>Case 3: Lose A</u>
Viewpoint X also loses a1 and a2. Thus, the entire viewpoint (X) will be lost.

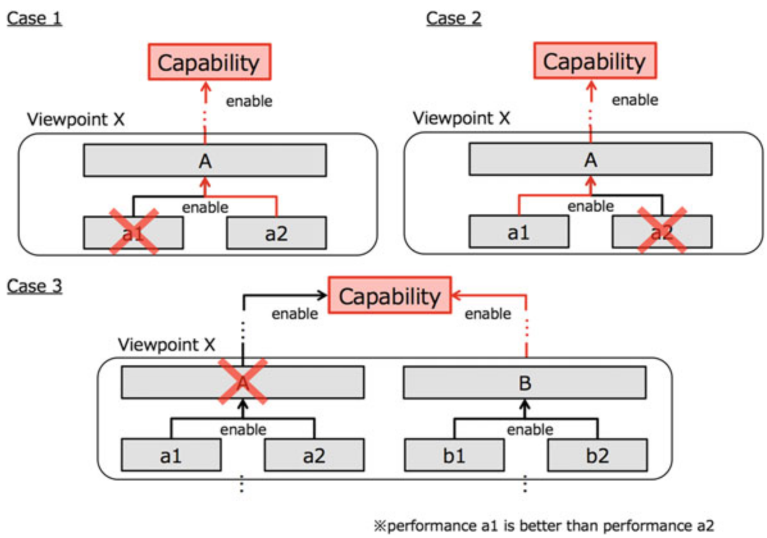

Fig. 8 Resilience in each case to maintain capability

In these three cases, case 1 and case 2 retain system capability. Of course, the performance and redundancy become bad in both cases, but the only concern is whether or not we can maintain the system capability. Hence, case 3 is the only catastrophic case that the system developer must avoid. If the system is in case 3, another entity (like entity B) needs to be developed to retain the system capability.

For example, we can conclude that a weather satellite plays a very important role for weather observation from Fig. 7. Assume a situation where this satellite is destroyed. Of course, the system capability will still be realized because this is case 3 (A: marine system, B: ground system), but the accuracy of the forecasting will become poor. This system ontology can provide many insights about system resilience.

5 Conclusion

We developed a weather observation ontology that covers the entire system utilizing DODAF 2.0 and the enabler relationship. This ontology shows the system in a structured way because every entity belongs to the capability, operation, service, or system category. By visualizing the system entities and their relationships, users can develop a common understanding of the system. Because the ontology is described in common words and simple relationships, it is easy for many people to understand, even those who are unfamiliar with weather observation systems. This weather observation ontology helps to bridge any gaps in knowledge or conceptual understanding. The developed ontology was verified to be of benefit in real systems by applying and using it to identify the vulnerabilities of a weather observation system.

The ontology also provided information about system resilience based on three cases. The model can assist with understanding the current system situation from the resilience perspective and in taking action to maintain the system capability when something happens to system entities.

6 Future Work

In future work, the ontology should be refined to clarify the intensity. The ontology could also be used obtain information to enhance the system resilience in both a qualitative and quantitative way. In order to realize this research, we should define how to measure resilience. This means we should quantify the resilience by setting a criterion.

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