Digital Transformation Piercing from Developments to Services

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1. Introduction

Digital transformation (DX) was proposed by Professor Erik Stolterman in 2004 in his comment, “Digital technology changes people’s lives for the better in every aspect.” Mitsubishi Electric’s DX provides optimal solutions for customers and society and helps to create a sustainable society. DX has attracted much attention in recent years, and as the discussions have progressed, key terms such as “model-based development” and “digital twin” have become widely used. Both are introduced as a means of DX, but model-based development is sometimes introduced as DX itself. However, both model-based development and digital twin are concepts and are interpreted in various ways.

Mitsubishi Electric considers that model-based development and digital twin are closely related to the realization of business DX, and has defined each of them in its own way and clarified the technical concept for realizing DX from development to services by linking them.

This paper describes our model-based development and the definition of digital twin, and how they work together to realize DX.

2. Model-based Development

It is well known that model-based development in which design is performed on the cyber side reduces development man-hours [(1)]. Conventionally, products (mainly equipments) were developed based on experience, prototyping, and evaluation, but by using models to digitally adjust development, rework can be reduced. Most development work uses 3D models, or a logical model (1D model) is used for analyzing one physical phenomenon.

However, Mitsubishi Electric positions everything from requirement & function analysis to detailed design as model-based development, and defines model-based development as realizing holistic optimization that includes not only equipments but also systems.

2.1 Scope of model-based development

Mitsubishi Electric has set the scope of model-based development as model-based system engineering (MBSE), which performs requirement & function analysis and functional design, and model-based design (MBD), which performs logical design and detailed design (Fig. 1).

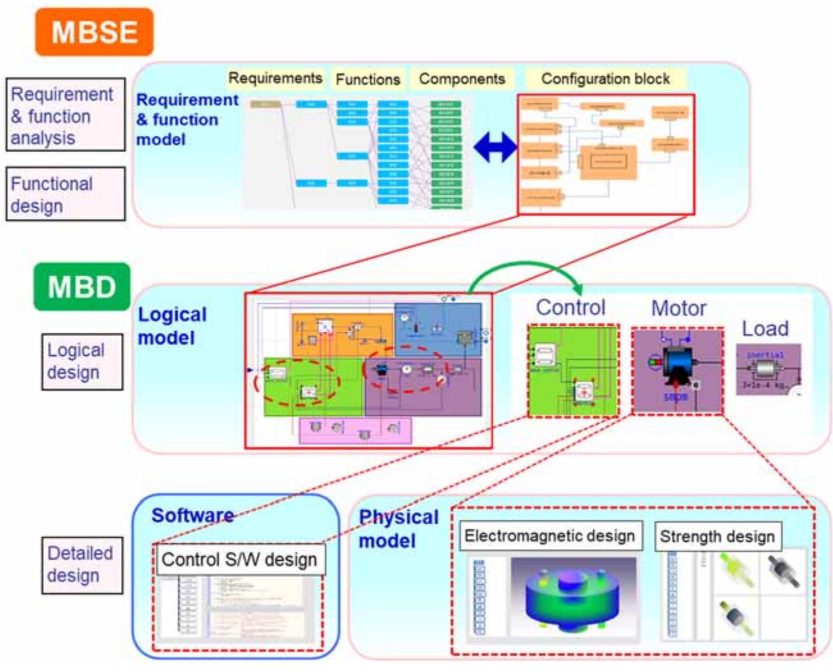

Fig. 1 Scope of our model-based development

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The origin of product development is the requirements for the product. These requirements are analyzed in consideration of the life cycle and stakeholders of the product to be developed. The requirements are defined not only for product operation and performance, but also for cost and quality.

Next, all the functions that realize the requirements are extracted, and the components that realize the functions are assigned. Functions and components are represented by several means such as tree diagrams, block diagrams, and orthogonal arrays to prevent omission.

These are the requirement & function analysis and functional design processes, which are implemented using the MBSE method. The "requirement & function model" created in this process is shared between the discipline engineers that combine individual elements after the logical design and the systems engineers, and is used to solve problems that arise in individual element design.

Once the components are determined, the process proceeds to logical design. Logical design uses a "logical model" including a 1D model that abstracts physical phenomena. The 1D model is expressed by mathematical formulas representing related physical phenomena. Detailed design embodies the logical model expressed in mathematical formulas into something tangible to satisfy physical requirements. Logical design and detailed design are defined as MBD.

The design results of each process are verified, such as requirement & function analysis, functional design, logical design, and detailed design, and consistency across different functions and different physical elements in the processes is also verified, thereby eliminating the major rework of reconsidering requirements and functions from the test results after prototyping. Starting with the requirements based on the product life cycle, the level of abstraction is lowered step by step for verification, and problems are also solved in the downstream process with an overview of the scope of impact, thereby realizing more efficient development beyond the scope of adjustment based on pre-prototype models. The scope of our model-based development is the combined scope of model-based system engineering (MBSE) and model-based design (MBD).

2.2 Holistic optimization by model-based development

Our model-based development, including MBSE and MBD, not only improves development efficiency but also realizes holistic optimization (Fig. 2).

In conventional MBD, the discipline engineers read and define the required specifications of their own parts from the higher-level specifications and proceed with the design so that only the requirements of their own field are satisfied. This causes them to lock themselves in their own work and lose sight of their surroundings. As a result, in some cases the requirements of target products may not be achieved in tests and evaluations that combine multiple element designs, or consistency with other elements may not be achieved.

On the other hand, in Mitsubishi Electric's model-based development, the model created by MBSE is used to comprehensively understand the relationship between the individual element design in charge and other elements. After that, logical design is performed using a 1D model, and verification is performed at the higher-level in combination with other elements, thereby making it possible to confirm that the requirements of the higher-level are satisfied, beyond the responsibility of the person in charge. Furthermore, when it is difficult for the person in charge to satisfy the requirements within their responsibility in the logical design or detailed design, the requirements of the object can be satisfied with the optimal solution by returning to the requirement & function model, and discussing and coordinating with the higher-level person in charge and other element designers. Holistic optimization can be realized by allowing the element designer to maintain an overview of the whole.

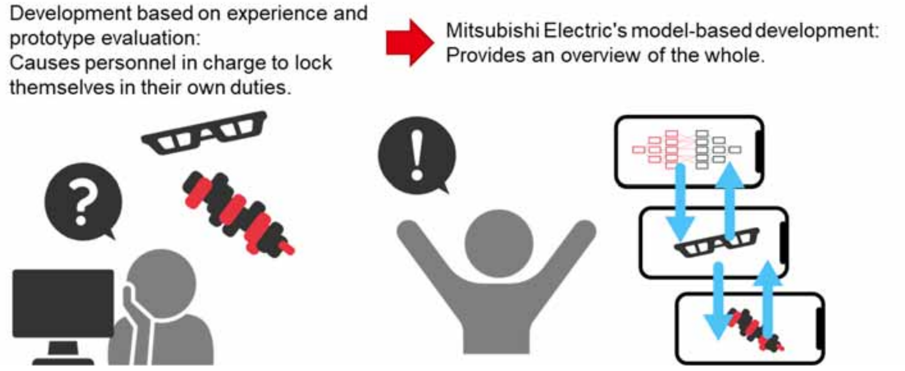

Fig. 2 Holistic optimization by model-based development

2.3 Model-based development from systems to elemental technologies

The processes described so far, from requirement & function analysis to detailed design, are not limited to the processes of equipments. The development is carried out step by step from systems (System of Systems (SoS) at a higher-level) to elemental technologies such as parts and software (Fig. 3).

Figures 1 and 2 show the case of equipments as examples. However, the source of the value delivered to customers is the "systems" in which equipments are linked together, or the SoS in which systems are linked together. Figure 3 shows how model-based development is applied to stages from systems to parts and software. First, in the system stage, processes from requirement & function analysis to logical design are performed, and the equipments that make up systems are defined. In the next stage, processes from the requirement & function analysis of equipments to logical design are performed, leading to the detailed design of parts and software. Parts and software design results are verified by equipments, and equipment design results are verified by systems. In this way, starting from the customer's requirements, the systems, equipments, and ultimately the parts and software are studied, and the customer's environment is envisioned and verified, thereby enabling the reliable provision of continuous customer's value.

3. Digital Twin

A digital twin is defined as a digital representation of an equipment or system; the digital twin itself does not create value.

Mitsubishi Electric defines a digital twin as "a means of reproducing, at a remote location, the invisible situation of a phenomenon at the operating site." This is a method, so it is necessary to clarify the purpose, that is, the "value," and to build a digital twin that can realize the value. Values can include:

(1) Realization of services such as operation and maintenance optimization
(2) Realization of manufacturing and construction as planned
(3) Confirmation of phenomena occurring in tests at the development stage

In order to precisely reproduce phenomena that cannot be seen at the operating site, Mitsubishi Electric's models are utilized of its products obtained through the model-based development described in Chapter 2, and also utilizes necessary models other than its products based on its abundant knowledge in the industry to create a digital twin.

Maintenance optimization is a well-known example of a digital twin [(2)]. Also, the manufacturing industry [(3)] and construction industry [(4)] use digital twins for realizing manufacturing and construction as planned, and for confirming prototypes through testing [(5)].

As a use case, this chapter describes a digital twin for the purpose of optimizing operations in a temperature-controlled warehouse warehouse.

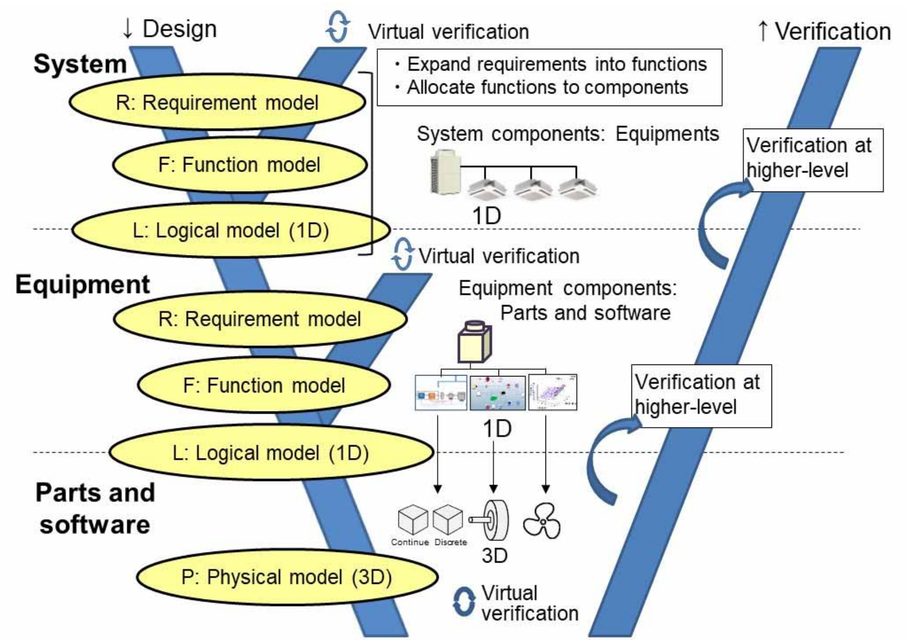

Fig. 3 Model-based development from systems to parts and software

3.1 Optimization of the operation of a temperature-controlled warehouse

When building a digital twin for optimizing the operations of a temperature-controlled warehouse, the value, means, and services to be provided must be considered (Fig. 4).

(1) Customer value (purpose)

The assumed customer is the owner of the warehouse. In order for the owner to make a profit, it is necessary to (i) make the most of the warehouse space, (ii) ensure product quality (ability to control the temperature suitable for products), and (iii) reduce operating energy costs.

(2) Means of achieving customer value

Possible means to achieve the value (purpose) of (1) are: (i) optimization of product placement (positioning that maximizes space utilization while improving temperature control efficiency), (ii) optimal control of refrigerators (control that does not reduce the quality of products and does not cool them too much), and (iii) provision of refrigerators that consume less power.

(3) Services that need to be provided in addition to equipments

In order to deliver value to customers, it is necessary to provide business optimization consulting services or business optimization programs (control simulators), in addition to equipments.

3.2 Digital twin for optimizing temperature-controlled warehouse operations

A digital twin has been built to optimize the temperature-controlled warehouse operations described in Section 3.1 (Fig. 5). By linking IoT data with models created by model-based development, the digital twin is realized as a means of creating value.

The warehouse model, which is the core of customer value, consists of a wall model, an airflow model, and a product model. When considering value, the temperature of the products in the warehouse is of concern. The temperature of the products is “the invisible situation of a phenomenon at the operating site,” and as a component necessary for reproduction, a model was derived through the process of model-based development. Regarding the temperature inside the warehouse, the wall model is used to derive the inner wall temperature from the outside air temperature and the amount of solar radiation on the wall, and the airflow model is used to estimate the temperature changes of the products.

Equipments and their control are the main elements for “achieving both product quality and minimizing energy costs” provided by Mitsubishi Electric. The models created in the design process are used for the indoor unit and refrigerator models (control model and physical model) of the refrigeration equipment.

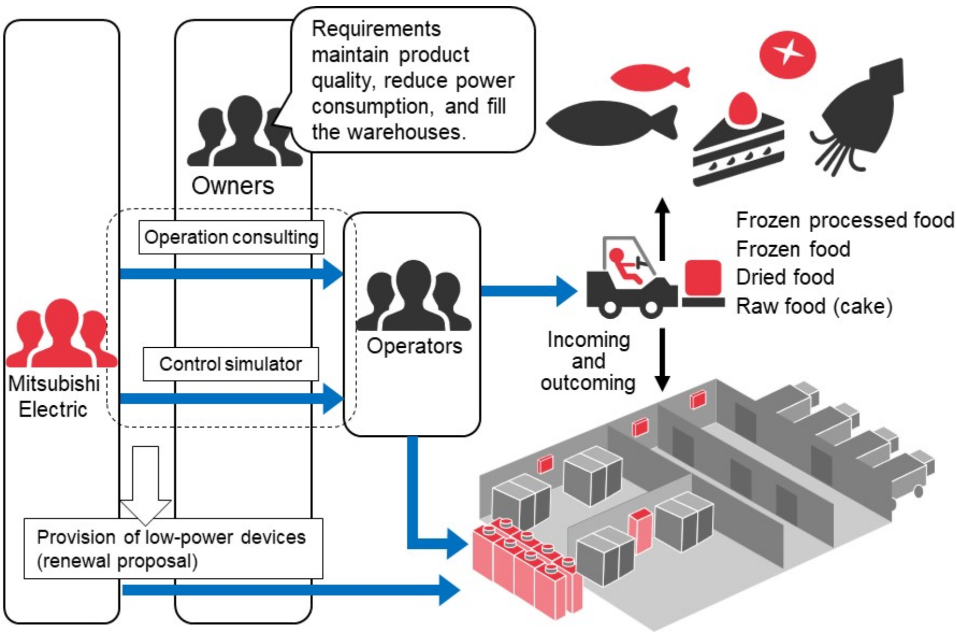

Fig. 4 Optimization of operation of temperature-controlled warehouse

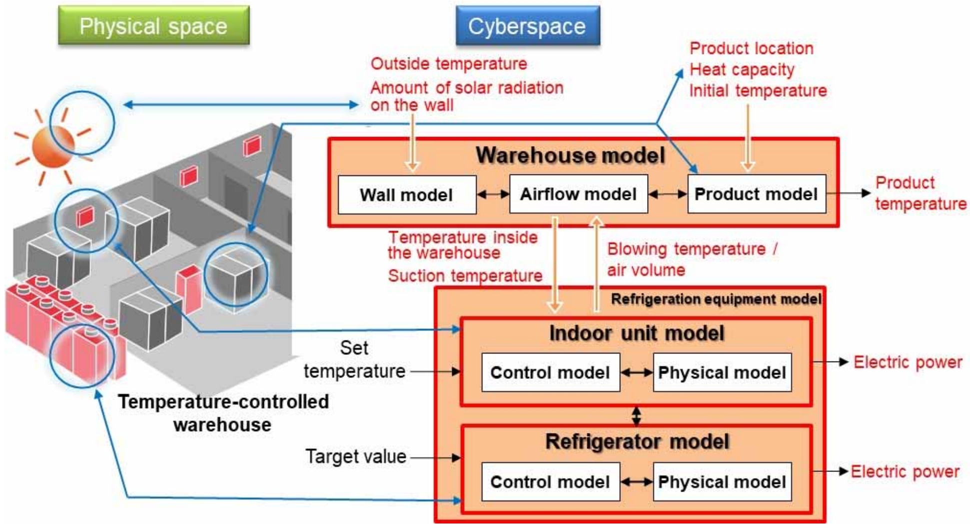

Fig. 5 Digital twin system for optimizing operation of temperature-controlled warehouse

Models configured in this way are linked with IoT data to reproduce the warehouse situation with high accuracy. The weather and temperature at a certain point in time, as well as the state of products (heat capacity of products, location, temperature at the time of delivery) are input into the warehouse model, and the sensor data and setting values of equipments are input into the equipment models. From this initial state, control is performed to minimize power consumption without impairing the quality of products, and the resulting power is obtained as an output. The warehouse state at the time the sensor data is input into the model is reproduced, and the future state is predicted based on optimal control thereafter.

Maisart's[(6)] latest AI technology is used for estimating the detailed internal state, predicting the future state, and optimization based on the future state. In addition, ClariSense performs the collection of IoT data, data processing such as removing noise contained in data and data correction/coordination, connection with models, and library creation when reusing models.

4. Conclusion

This paper described Mitsubishi Electric's model-based development, which not only improves development efficiency through digital adjustment, but also optimizes systems and equipments as a whole. It also described our digital twin, which reproduces the invisible situation at the operating site through estimation and prediction based on models created during the development process and IoT data, and showed the digital twin of a temperature-controlled warehouse as a specific example. Both the model-based development and digital twin are DX from development to service based on customer value. With our DX, we will continuously deliver value to customers through our products, both equipments and systems.

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