The Digital Factory framework: An International Standard for Semantic Interoperability

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"Smart Manufacturing" is an internationally agreed concept of an ideal state of the manufacturing industry. To achieve this, systems with different architectures must exchange information without compromising its meaning. In other words, systems must not only connect to, but also understand, each other. This crucial requirement is called semantic interoperability. The Digital Factory framework is an international standard that Yokogawa has contributed to its development. Its purpose is to achieve semantic interoperability and thus establish a foundation for Smart Manufacturing. This standard defines the structure of common model elements and their usage rules based on common concept dictionaries and integrates various information of a "system of systems" related to production. When related implementation technologies worldwide comply with this standard, digital information representing production systems (Digital Factories) will be available to all parties throughout the lifecycle of production systems while keeping up-to-date. This paper outlines the Digital Factory framework, the significance of international standardization for Smart Manufacturing, and Yokogawa's commitment to this effort.

INTRODUCTION

As society and the economy are globalizing and business values are shifting from goods to information, the international community is facing various challenges, such as the explosion of information, difficulties in transferring knowledge, decarbonization, and the response to the SDGs. New technologies such as AI, robotics, and the Internet of Things (IoT) may help solve these challenges, but there is also concern that these technologies may threaten safety and security and cause new problems such as job insecurity. Under these circumstances, developed countries have started activities aiming to build a global social and economic ecosystem. Prominent examples are "Shaping Europe's Digital Future"(1) proposed by the European Commission, its related

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project GAIA-X[2], and Society 5.0[3] promoted by the Japanese government.

The manufacturing industry is also required to respond to social and economic changes, and the concept of Smart Manufacturing has been discussed internationally in various situations.

This paper introduces the Digital Factory framework, an international standard that specifies the core technologies for achieving Smart Manufacturing.

SMART MANUFACTURING AND INTERNATIONAL STANDARDIZATION

Smart Manufacturing is a concept that represents a common international understanding of the ideal state of the manufacturing industry, covering the manufacturing value chain and the entire lifecycle of products and production systems. Smart Manufacturing aims to create new added value by using digital technology and connecting a wide variety of systems. To achieve this, systems must be not only connected but also understandable to each other.

ISO[4] and IEC[5], both of which are international standardization organizations, define Smart Manufacturing as follows.

"Manufacturing that improves its performance aspects[i] with integrated and intelligent use of processes and resources in cyber, physical and human spheres to create and deliver products and services, which also collaborates with other domains[ii] within enterprises' value chains."

As defined above, collaboration with management information is essential to improve manufacturing performance, and the ultimate goal of a company is to improve its management performance through this collaboration. This can be achieved only when all elements of the supply chain involved in manufacturing collaborate. Since the manufacturing industry has become deeply globalized, its supply chains are not limited to a single country but extend around the world. Therefore, to achieve Smart Manufacturing, it is necessary to establish universal definitions and rules independent of language, culture, country, region, industry, business type, and role. That is, Smart Manufacturing requires international standardization.

Its importance in Smart Manufacturing is evidenced by the fact that international standardization is positioned as the core of Industrie 4.0[6], which is Germany's initiative to achieve Smart Manufacturing, and that not only the EU but also many other countries such as the U.S., China, and Japan have expressed their support for this initiative. International standardization is an important measure agreed globally for achieving Smart Manufacturing.

It is important that companies and consortia work on Smart Manufacturing independently in a bottom-up manner. However, if they proceed without taking international standardization into account, they may become internationally isolated. In such a state, they cannot collaborate with companies and customers in other countries, with the result that Smart Manufacturing is only applicable to a specific region or technology.

The realization of Semantic Interoperability, which can avoid international isolation and achieve global collaboration, is attracting major attention in relation to international standardization for achieving Smart Manufacturing.

CHALLENGES IN ACHIEVING SEMANTIC INTEROPERABILITY

The importance of Semantic Interoperability is described well in "Semantic interoperability: challenges in the digital transformation age" (IEC Market Strategy Board, 2019)[7].

Semantic Interoperability is defined in this White Paper as "the ability of computer systems to exchange data with unambiguous, shared meaning" and "a requirement to enable machine computable logic, inferencing, knowledge discovery, and data federation between information systems." Of course, this includes the ability of machines not only to understand each other but also to make the information understandable for humans. Semantic Interoperability is the ability of systems with different architectures (using different languages and protocols) to exchange information and use it without compromising its meaning. This means that systems not only connect with each other but also understand each other regardless of differences in language, culture, countries, regions, industries, business categories, roles, and so on. Semantic Interoperability is an essential element for achieving Smart Manufacturing.

As the manufacturing industry continues to globalize, supply chains that cross the boundaries of companies and countries are no longer unusual. For example, a company in France designs a product, companies in Bangladesh and Brazil manufacture its parts, a company in China assembles them, and a company in Japan releases the finished product into the market. Tools and mechanisms used by each company in this supply chain typically have architectures adapted to the culture of each country. If this supply chain is fixed, this collaboration can be maintained through efforts of the companies involved. However, we are in the era of VUCA (volatility, uncertainty, complexity, and ambiguity), full of unexpected incidents such as the COVID -19 pandemic, natural disasters, political changes, and technological innovations. This puts supply chains at risk of sudden disruption for almost all companies. In response, a global system must be established that can select the most suitable supply chain elements at any time and replace them with minimum time and effort, not only within a specific company or supply chain, but also from a variety of open options independent of the implementation technology. To enable flexible horizontal collaboration and optimize the value chain, it is necessary to integrate information throughout the lifecycle of products and production systems (from planning and design to disposal) and enable each stakeholder

i Agility, efficiency, safety, security, sustainability, or other performance indicators specified by a company are included.

ii In addition to manufacturing, other domains specified by a company are included, such as engineering, logistics, marketing, procurement, and sales.

to use the information seamlessly. This is achieved by Semantic Interoperability.

Currently, the following obstacles hinder the establishment of Semantic Interoperability.

■ Decentralized information

Information on manufacturing systems is dispersed among various documents, drawings and lists.

■ Fragmented information

Even if it is digitized, information is stored in different software systems, and so must be re-entered or converted for use in other systems.

■ Isolated information

Updates of data in one system are not automatically reflected in other systems.

Currently, substantial human intervention is needed. Meanwhile, digitization has caused an information explosion and the amount of data already exceeds the capacity of human beings to process it. Semantic Interoperability is expected to free people from this information flood. This is a fundamental issue to be solved to achieve Smart Manufacturing.

WHAT IS ACHIEVED BY THE DIGITAL FACTORY FRAMEWORK

To establish Semantic Interoperability and allow different systems to understand each other, dictionaries that define concepts in an identifiable and understandable way are needed (e.g., IEC 61360-4 - Common Data Dictionary[8]). A method that shares structures for combining the shared concepts and using them as complex information is also needed.

The Digital Factory framework defines the structures of model elements based on common concept dictionaries and their usage rules. When the concepts defined in the dictionary are used based on the common structure (model) of each component and its usage rules, various systems with different architectures will be able to connect with and understand each other.

When communication technologies and tools around the world comply with this standard, it will be possible to build a digital representation of a production system (Digital Factory) and keep the information updated throughout the lifecycle of the system. As a result, those involved can share and use the information at any time.

Although a Digital Factory is defined as a digital representation of a production system, it is not a simple digital representation technology but a solution to the obstacles to Semantic Interoperability, such as the decentralization, fragmentation, and isolation of information. The as-built drawings digitizing the information of a production system that is handed over after design and construction are shared as the Digital Factory among various activities and software programs of the companies involved throughout the life cycle of the production system. Any additions, deletions, and changes to the Digital Factory are reflected and updated. This enables the Digital Factory to improve maintenance efficiency such as by referring to the inspection history or failure information of production equipment, checking the inventory information of spare parts, and drawing up efficient maintenance plans in addition to improving design, procurement, construction, engineering, and commissioning efficiency. Figure 1 shows the relation between the Digital Factory and corporate activities throughout the lifecycle of a production system.

In addition, companies can use this information when revamping their production systems. Conventional as-built drawings have become obsolete by that time, and so it takes an enormous amount of time and effort to understand the current state of the production system and document it. Once Semantic Interoperability is established by using the Digital Factory framework, this time and effort can be greatly reduced.

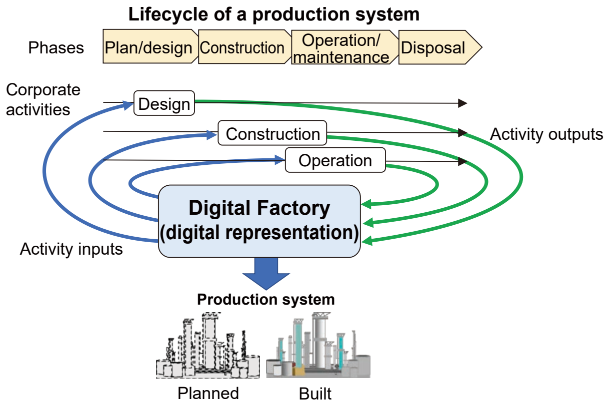

Figure 1 Relation between Digital Factory and corporate activities

OUTLINE OF THE DIGITAL FACTORY FRAMEWORK

The IEC 62832 Digital Factory framework was developed by IEC TC 65/WG 16 and published in October 2020. It provides the basic structures of model elements needed to digitally represent an entire production system and their usage rules. It consists of the following three parts.

- IEC 62832-1 General principles (Part 1)[9]
- IEC 62832-2 Model elements (Part 2)[10]
- IEC 62832-3 Application of Digital Factory for lifecycle management of production systems (Part 3)[11]

Most of the international standards and specifications under development for Smart Manufacturing specify data dictionaries as well as systems including system configuration, communication/information security, and hardware/software implementation. Meanwhile, the Digital Factory framework integrates information beyond these systems.

Its contents are described in the following sections.

Digital Representation of Production Systems

A Digital Factory is a digital representation of a production system. Each asset (e.g., devices) in an actual production system is represented by a model element called a "DF asset." The "DF asset" can represent not only the characteristics of an asset but also its role. The relationships among assets are represented by a model element called "DF asset link." A Digital Factory is a collection of "DF assets" connected through "DF asset links." At the same time, a Digital Factory is a model element called "Digital Factory." Figure 2 shows an example of a simple Digital Factory.

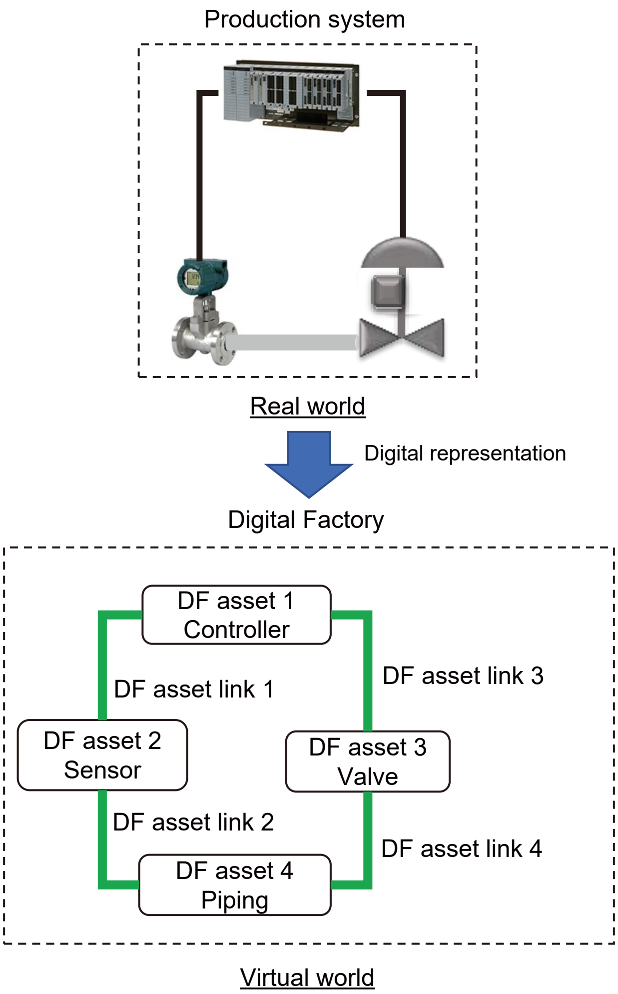

Figure 2 Example of a simple Digital Factory

Structure of the Digital Factory Framework

Figure 3 shows the basic structure of the Digital Factory framework. A company that owns a production system (owner company) creates a DF dictionary and a DF library to build and manage the Digital Factory. The DF dictionary is a dictionary specific to the owner company and is compiled based on a concept dictionary, which is managed by international standardization organizations, consortia, or asset manufacturers. The DF library is the in-house master data of the assets of the production system in the owner company and is created by incorporating information (product catalog data) such as the specifications of the required assets selected from the supplier library provided by asset manufacturers. The information in the DF library can be interpreted with the DF dictionary.

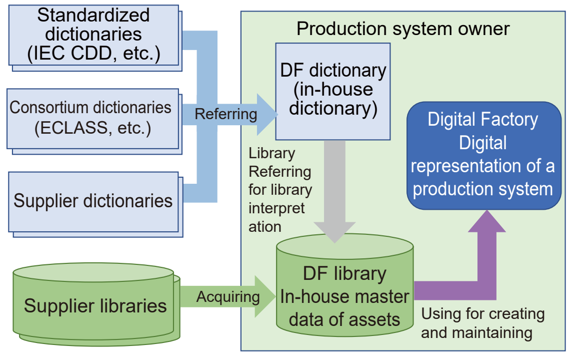

Figure 3 Basic structure of the Digital Factory framework

Model Elements and Data Elements

The structures of model elements (Digital Factory, DF dictionary, DF library, and others) and data element types for specifying model elements are defined in Part 2 of IEC 62832. Note that the format of model elements is not specified to ensure flexibility and extensibility for implementation.

The concept identifier is a key data element to Semantic Interoperability. This is a globally unique identifier for each entry in the dictionaries. This identifier enables anyone to accurately identify each concept regardless of their language and culture. The concept identifier used in the Digital Factory framework conforms to the international registration data identifier (IRDI) specified in ISO TS 29002-5 Exchange of characteristic data - Part 5: Identification scheme[12].

Figure 4 shows typical relations among model elements at three levels. The "DF asset" in "Digital Factory" represents each asset that has been (or will be) installed (e.g., those given a tag number [e.g., FT-101] or serial number). The "DF asset" is derived from the "DF asset Class" in the "DF library." The "DF asset Class" represents the type-specific characteristics and performance of the asset (e.g., digitalYEWFLO). The "DF asset Class" is derived from the "DF asset Class Definition." The "DF asset Class Definition" defines the specification items for all possible functions and characteristics of the "DF asset Class" (e.g., vortex flowmeter). The "DF asset Class" represents the specifications of an asset of a particular type by using all applicable specification items in the "DF asset Class Definition" and their corresponding values while the DF asset describes the asset by adding the asset's or manufacturer's identifiers, application-specific functions, characteristics, parameters, and other information based on the corresponding "DF asset Class."

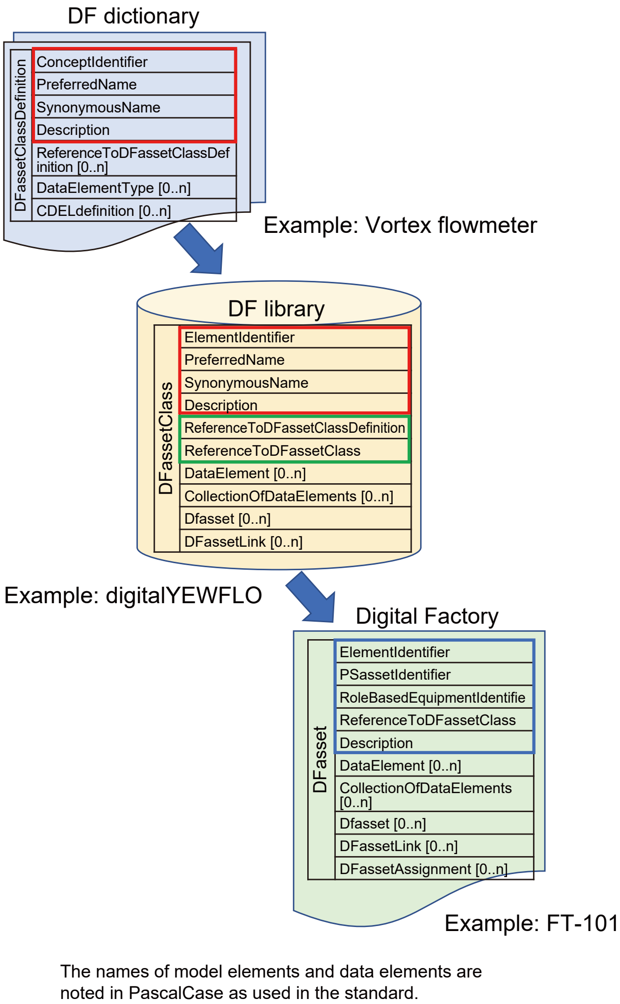

Figure 4 Typical relations among model elements

Usage Rules of the Digital Factory Framework

Part 3 of IEC 62832 specifies the usage rules of the Digital Factory framework regarding the following functions, which are needed for managing the information of a production system throughout its lifecycle.

- Representation of a production system by Digital Factory
- Representation of assets and their roles by DF asset
- Representation of relationships among assets by DF asset link
- Representation of the hierarchical structure of assets
- Confirmation of compatibility among related assets
- Mutual derivation of model elements

YOKOGAWA'S EFFORTS IN INTERNATIONAL STANDARDIZATION

IEC 62832 is an international standard for Digital Factory. Its development began in 2011, when the terms "digital transformation" and "digital twin" were not generally known and the concept of Semantic Interoperability was not yet widely recognized. Yokogawa has been playing a major role in developing this standard as an original international expert and has made significant contributions through discussions, such as definitions of terms and proposals of specific model structures. As a result, the IEC Secretariat recognized its importance. The outline of this standard was introduced in the IEC supporting document[13] and related topics were widely publicized in IEC News[14], blogs[15], and SNS[16][17][18]. In Japan, these activities were reported in a bulletin of the Japan Electric Measuring Instruments Manufacturers' Association (JEMIMA)[19]. Yokogawa has contributed greatly not only to the development of standards but also to the dissemination of these standards.

However, there are many issues facing the manufacturing industry as well as the realization of Smart Manufacturing. Amid the flood of jargon and explosion of information in today's world, international standardization is expected to become even more important as its scope and form change. Yokogawa will maintain a high presence in international standardization activities and contribute to the development of appropriate international standards in not only the field of Smart Manufacturing but also various other fields, to bring order to society.

CONCLUSION

The purpose of the Digital Factory framework is to bridge international standards and forum standards of high-level abstraction (conceptual dictionaries such as IEC Common Data Dictionary) and more specific ones that are implemented in production systems (AutomationML of types and instances[20][21]). The Digital Factory framework is referenced in various international standards that are currently being developed for Smart Manufacturing, as well as in the German Standardization Roadmap Industrie 4.0[22] published by the Standardization Council Industrie 4.0 of Germany.

Many upcoming Smart Manufacturing implementation technologies and related tools are expected to have structures that comply with the Digital Factory framework to ensure that Semantic Interoperability going beyond individual implementation technologies can be established. This will help to realize Smart Manufacturing.

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