# Design and Implementation of Digital Twin-Based Application for Global Manufacturing Enterprises

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**Abstract.** Nowadays, global competition in the manufacturing sector is increasingly fierce. Thus, global manufacturing companies must have a manufacturing system that ensures the production of reasonably priced, high-quality products, while meeting the needs of various customers. To address this issue, smart manufacturing should be implemented by adopting various information and communication technologies and convergence with existing manufacturing industries. One of the key technologies required for the implementation of smart manufacturing is a cyber-physical system (CPS). One of the major factors for the successful construction of a CPS is digital twin (DT). In this paper, we propose a standards-based information model for building a DT application, which is a key technology of a CPS-based integrated platform, by overcoming the heterogeneous device environment of global manufacturers and using data collected from various manufacturing sites. Furthermore, we propose a concept of modeling and simulation-based DT application. The DT application proposed in this study facilitates monitoring, diagnosis, and prediction at manufacturing sites using real-time data collected from various environments by ensuring interoperability. Moreover, its validity is verified by applying the technology to a global manufacturing company of automotive parts.

**Keywords:** Cyber-physical system (CPS) · CPS-based platform · Digital twin · Information model · Smart manufacturing

## 1 Introduction

Nowadays, global competition in the manufacturing sector is increasingly fierce, and companies need to implement smart manufacturing systems that support effective and accurate decision-making through the adoption of various information and communication technologies (ICT) and convergence with existing manufacturing industries to


Published by Springer Nature Switzerland AG 2021
A. Dolgui et al. (Eds.): APMS 2021, IFIP AICT 634, pp. 12–19, 2021.
https://doi.org/10.1007/978-3-030-85914-5_2

produce reasonably priced high-quality products, while meeting the needs of various customers [1, 2]. To address this issue, many advanced manufacturing countries are leading the advancement of manufacturing at the national level, starting with Germany's Industrie 4.0 [1–3]. The major technologies that drive the Fourth Industrial Revolution include the Internet of Things (IoT) and cyber-physical systems (CPSs) implemented in the manufacturing environment [1]. In the future, manufacturing companies will build global networks to integrate and manage various manufacturing resources, such as their products, machines, and production facilities [1].

A CPS is based on a concept of managing systems where physical resources and the cyberspace are interlinked through a communication network [1, 4]. In such an environment, each physical device is represented as a virtual representation defined as a digital twin (DT), which comprises various types of models and data [4]. A DT is appraised as a next wave of simulation and optimization technology for products and production systems [5, 6]. By applying a DT to the production system, the field information and functions are synchronized, facilitating the analysis, evaluation, optimization, and prediction of the current situation [7]. The implementation of a CPS allows global manufacturing companies producing products in multiple countries to increase the efficiency of the whole production process by recognizing, adapting, and flexibly responding to situations based on the data collected in real time from the field beyond the conventional static manufacturing systems [8, 9]. However, various problems, such as heterogeneous device environments, need to be overcome to integrate and utilize the information of the distributed environment using CPS and DT technologies. Global manufacturing companies must overcome heterogeneous environments that have not been standardized in various geographically distributed manufacturing sites.

Accordingly, to solve this problem, studies have been conducted on CPS-based integrated platforms reflecting international standards [10]. In this paper, we propose an information model for building a DT by overcoming the heterogeneous environment of global manufacturing companies and using data collected from various manufacturing sites. This information model is designed based on Open platform communication unified architecture (OPC UA) proposed by the OPC Foundation to overcome the heterogeneous environment of distributed manufacturing systems. Furthermore, we propose a concept of modeling and simulation-based DT. Then, the technology is applied to a global manufacturer of automotive parts to verify its effectiveness.

## 2 Research Background

Since the introduction of the concept of DT in a study by Grieves in 2003, it has been continuously evolving to date [11]. A DT is a virtual representation of a physical asset and synchronizes the physical asset's information and functions, and it can be used to perform simulations accurately and quickly [7]. Because a DT enables the integration of simulation-based approaches with the technology that analyzes big data collected in massive quantities, it is considered a key technology for the adoption of CPS [12].

A DT facilitates the construction of a model that quickly reflects field information by incorporating ICT, which will allow dynamic diagnosis and prediction, unlike conventional simulation models [13]. To evolve from conventional discrete event simulation to DT, technologies, such as synchronization with networking devices and pattern identification, should be developed [6]. Moreover, the technology for linking data collected from manufacturing sites in real time is an important technology for building a DT [14, 15]. In a virtual space, a DT is built as a simulation model with components for a physical shop floor and requires the establishment of a mapping information model for the shop floor elements based on the Unified Modeling Language or another information modeling method [16]. These information and simulation models are integrated, providing a basic environment where the operational information of the shop floor is synchronized [16]. However, it is not necessary to model all physical assets depending on the cost and time constraints, and only the physical assets required for the purpose of DT should be modeled [17].

To build the aforementioned DT technology, a CPS-based platform that provides various services by integrating the information in the distributed environment should be built, and the interoperability for exchanging information on the platform is crucial [10, 15]. Grieves who first proposed DT also mentioned the data interface between the DT and physical assets as the third component of the DT system. If the data interface is not available, then the interaction between the DT and physical assets will be impossible, and consequently, the intelligentization of DT will not be achieved [11, 17]. A DT should comprise a variety of information collected from heterogeneous systems, and it can be used to support decision-making by monitoring and predicting the manufacturing sites. Accordingly, this study introduces a DT technology that can be used on an integrated platform, which secures interoperability and provides various services by integrating data collected from distributed manufacturing sites.

## 3 DT-Based Application

### 3.1 Concept of the DT-Based Application

The DT-based application proposed in this study integrates and virtualizes the real-time information collected in a distributed manufacturing environment; evaluates key performance indicators (KPIs), such as productivity; and predicts various situations and results based on simulations and big data. The application mainly comprises (1) a DT library composed of base models predefined for a fast construction of a virtual model; metadata showing the definitions of the data and the relationships between data; and production logics, such as dispatching rule and scheduling; (2) a manufacturing database that keeps a variety of production management information; (3) a simulation engine for performing diagnosis and prediction based on the information; (4) component modules of the DT; and (5) a DT interface for exchanging data with the system's external environment and the legacy system. Figure 1 shows the components and concept diagram of the aforementioned DT-based application.

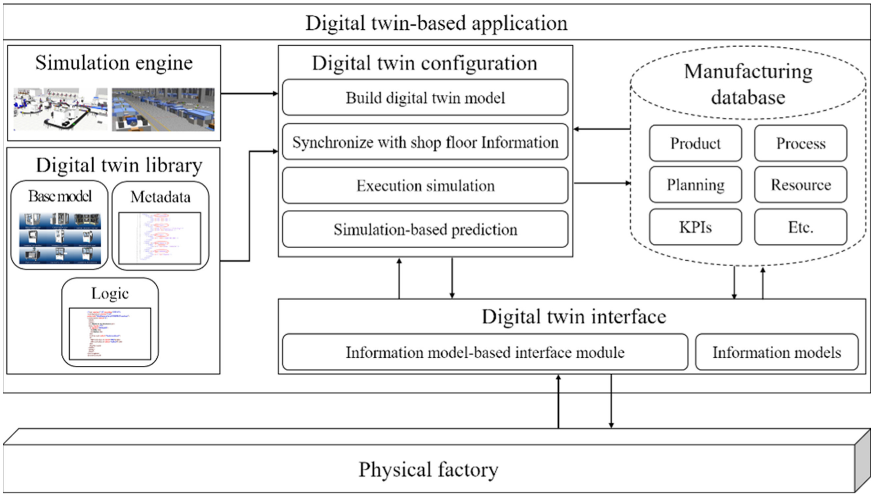


**Fig. 1.** Components and concept of the DT-based application system

There are four main stages in the construction process of a DT. In the first stage, a DT model suitable for the purpose is created using the DT library, manufacturing database's information, and simulation engine. In the second stage, synchronization is performed, which combines the created DT model and the information model collected from the field in real time. This stage facilitates dynamic modeling by reflecting abnormal situations, such as various equipment problems occurring in the field. In the third stage, a simulation stage exists, in which the DT model reflecting the on-site situation in real time is simulated, thereby facilitating the prediction of simulation-based results in the last stage to support the decision-making of decision-makers through the calculation of KPIs appropriate for the purpose.

### 3.2 Information Model for the DT Application

A key factor for the successful application of a DT is the description of physical and synchronized assets, which is entailed in a standardized information modeling.

OPC UA is a communication standard that provides information modeling and real-time data exchange for manufacturing systems [18]. OPC UA provides a relatively simple and flexible information modeling method to deal with a wide range of industrial equipment and production systems [18–20]. Liu, Chao, et al. proposed a CPMT (Cyber-Physical Machine Tools) Platform based on OPC UA that enables standardized, interoperable and efficient data communication among machine tools and various types of software applications [20]. In this paper, we propose an OPC UA-based information model to overcome the heterogeneous environment of a distributed manufacturing system and secure versatility. It contains various elements composing the production site, relationship between the elements, and planning information for manufacturing processes and production, etc. It consists of five classes, i.e., Product, Process, Plan, Resource, and Instance. Excluding the Instance class, the remaining four classes contain some dynamic information and static information. The Instance class is a class in which the other predefined four classes are instanced, and the overlapping information can be minimized by defining the reference relationship. The information model consists of the node name, browse name, data type, access level, parent node, modeling rule, cardinality, manifest, and description. Table 1 shows the definition and major components of each class.

**Table 1.** Definition and components of each class in the information model

| Class name | Definition | Major components |
|---|---|---|
| Product | Information on products produced at the manufacturing site | Information on the bill of materials, products, semi-finished products, and parts |
| Process | Process information, such as equipment and input materials, for the production of products | Information, such as process, input materials, and logistics |
| Plan | Information on part and product procurement and production plans | Information, such as material procurement plan, targeted production volume, job schedules, and non-operation plan |
| Resource | Information on manufacturing resources for the production of products | Information on equipment, buffer, moving equipment, and workers, etc. |
| Instance | A class that creates and synchronizes the above four classes in a DT model | Layout, physical locations of manufacturing resources, and on-site information collected in real time |

## 4 Implementation

We apply the proposed DT application and information model to an actual industrial site to verify their validity. This study was conducted as a part of the international joint research of South Korea and Sweden to develop a key technology of a CPS-based integrated platform to integrate and use information collected from a distributed manufacturing environment of a global manufacturer, as described above. Figure 2 shows a screen of the platform's user interface for visualizing and monitoring the data collected based on the information model from the distributed manufacturing sites. The center of the screen shows the status of the manufacturing site through the Google Map application programming interface. On the right side, various events occurring at the distributed manufacturing sites can be checked, and at the bottom of the screen, the user-defined comprehensive KPIs can be checked.

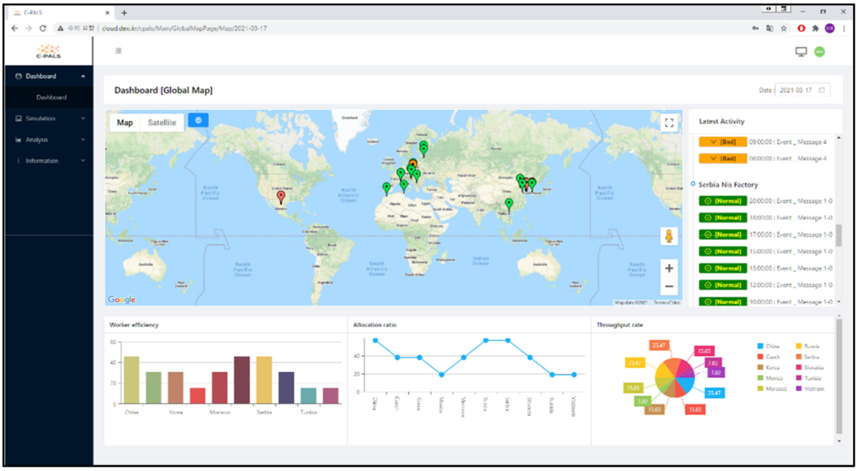


**Fig. 2.** User interface screen of the CPS-based integrated platform

The proposed model and application are applied in a factory of a South Korean global automotive part manufacturer, which produces automotive junction boxes. After producing printed circuit boards, which are semi-finished products, finished products are produced by the workers in this plant using automated processing and assembly equipment. Most equipment is automated, and the data collected from the equipment and the information on the products under production are stored on the production management server. Afterward, the server sends the data suitable for the proposed information model to the interface module of the DT application. Hence, real-time monitoring is facilitated by visualizing the data collected from the site. When a process failure or abnormal situation occurs, a simulation model that reflects the situation is created to perform the diagnosis and prediction. Figure 3 shows a screen of a DT model based on the real-time data collected from the plant site. The right side of the figure shows a screen where the information collected from the on-site equipment and products is recorded as event logs.

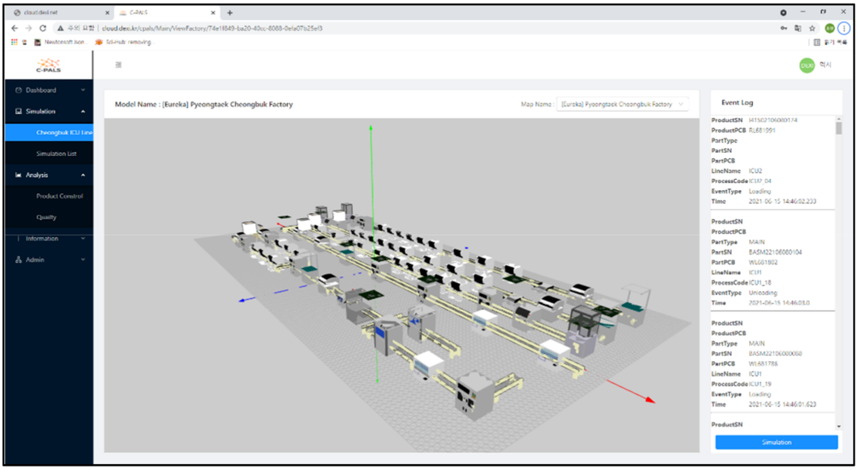


**Fig. 3.** Real-time monitoring screen of the subject plant

## 5 Conclusions

In this paper, we propose a DT-based application, a key technology of CPS-based integrated platform, for the smart manufacturing for global manufacturing companies. We designed and implemented DT-based application technologies and proposed an OPC UA-based standardized information model to secure interoperability in a heterogeneous device environment. Finally, we applied the proposed technologies to the production plant of a South Korean global automotive part manufacturer to validate this study. In the future, we will expand the application scope of the information model and DT technologies proposed in this study from the current scope of production lines, extending from the product level to the supply chain level. Furthermore, the big data analytics technology will be integrated with the monitoring and simulation-based prediction technologies to improve the DT model's intelligence.

**Acknowledgement.** This research was supported by the Ministry of Trade, Industry and Energy (MOTIE) and the Korea Institute for Advancement of Technology (KIAT) in South Korean through the International Cooperative R&D program [P0009839, the Cyber Physical Assembly and Logistics Systems in Global Supply Chains (C-PALS)]. In addition, it was supported by the Ministry of SMEs and Startups through the WC300 Project [S2482274, Development of Multi-vehicle Flexible Manufacturing Platform Technology for Future Smart Automotive Body Production].

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