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Integrated Platform and Digital Twin Application for Global Automotive Part Suppliers

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Abstract. For global automakers that manufacture products through a globally distributed supply chain, it is essential for this supply chain to be managed efficiently to enhance the efficiency and responsiveness to uncertain changes in the market. These manufacturers face limitations associated with independent applications, such as difficulties in collecting information from distributed sites and the inability to make quick decisions. To solve this problem, researchers have been actively investigating the application of smart manufacturing technology to improve productivity as well as the optimal use of manufacturing resources in dynamic environments. Furthermore, different countries have different cultures, regulations, and policies. Hence, a universal integrated platform is required to address these difficulties. Accordingly, this study proposes an integrated cyber-physical system-based platform that reflects international standards and has versatile applications. This platform can be used to utilize information from various distributed manufacturing sites in real time. In addition, the proposed system was verified through a field application case study.

Keywords: Cyber-Physical System (CPS), CPS-based Platform, Digital Twin, Global Supply Chains, Smart Manufacturing

1 Introduction

Currently, several manufacturers design, engineer, and produce their products through a globally distributed supply chain. In particular, the automotive industry is a typical assembly industry wherein a small number of automakers procure tens of thousands of parts from several suppliers to produce automobiles. These agents form a global supply chain in which suppliers provide parts to automakers. It is estimated that more than 1,000 part suppliers directly or indirectly affect a single automaker [1].

Global automotive supply chains are also expanding geographically, owing to the increasing globalization and the reductions in production costs. As consumer preferences become more individualized, production systems have been recently shifting toward the build-to-order (BTO) model; such changes have been observed in Eastern

Europe, Southeast Asia, South America, and India [2]. In such an increasingly complex and uncertain automotive manufacturing environment, part suppliers must effectively manage their distributed global supply chains to enhance their efficiency and responsiveness [3]. Firms must manufacture high-quality, reasonably-priced products that satisfy the needs of various customers, while simultaneously meeting delivery times. For this purpose, researchers have been actively investigating the application of smart manufacturing (SM) technology to improve productivity as well as the optimal use of manufacturing resources in dynamic environments [4, 5]. SM is a collection of advanced technologies that facilitate effective and accurate real-time decision-making by combining various information and communication technologies (ICTs) with the existing manufacturing industry [6]. Although SM has not been clearly defined thus far, it can be described as “a fully-integrated and collaborative manufacturing system that responds in real time to meet the changing demands and conditions in the factory, supply network, and customer needs.” This enables technologies and systems to respond to internal and external changes in real time, thereby facilitating the construction of lighter and more flexible production systems [7,8]. However, the production plants of global manufacturing companies are spread across different countries, which have different cultures, systems, regulations, units of measure, and languages. This introduces limitations for independent applications, such as difficulties in collecting information from distributed sites and the inability to make quick decisions [9,10]. Consequently, studies on the design and application of cyber-physical systems (CPSs) have been conducted to address these limitations [11]. A CPS, which is a core technology of SM, extends beyond static systems and recognizes, adapts, and variably responds to situations, based on the data collected in real time in the field, thereby enhancing the efficiency of the entire production process [12, 13]. A cyber-physical production system (CPPS) is created by applying a CPS for manufacturing using a variety of technologies [6, 14]. A digital twin (DT) is one of the core technologies that constitutes such a system; it is a virtual model that can analyze, evaluate, optimize, and predict current situations by synchronizing and simulating the information and functions of the production site [15].

To address the difficulties faced by global automotive manufacturers who deal with different cultures and systems, this study proposes an integrated CPS-based platform that reflects international standards and has versatile applications. This platform can be employed to utilize site information from various distributed external data and systems in real time. In addition, a system that provides a cloud-based service to add and extend various applications is proposed.

2 Research Backgrounds

A CPS is defined as an innovative technology for managing interconnected systems between its physical assets and computational capabilities [16]. Currently, to realize competitive advantages in advanced ICT technology and big data, numerous manufacturers and researchers are investigating methods to implement the CPS structure and methodology in their respective industries [17, 18]. A CPPS consists of autonomous and cooperative elements and subsystems based on the data collected throughout the

production and logistics system; it comprises three main characteristics: intelligence (smartness), connectedness, and responsiveness towards internal and external changes [17]. To implement a CPPS, the integration of analyses and simulation-based approaches for big data collected in large quantities is considered more important than other components [17]. In this regard, a DT is a core technology that can more quickly and accurately conduct simulations by synchronizing the information and functions of the production site [15].

Grieve first introduced the concept of DT in 2003. Since then, it has continued to develop [19]. A DT is defined as “an integrated virtual model of information and functional units based on the composition of heterogeneous physical elements.” In the manufacturing field, a DT is also defined as a virtual factory that reflects the configuration information of a physical factory, for synchronizing information and functions related to the design, operation, and production in real time [19-22].

Compared to conventional simulation models, a DT possesses several advanced features. By combining predefined models and functions with ICT, it can quickly generate models that reflect site information as well as enhance processes through optimization and conduct dynamic diagnoses and predictions by calculating repeated simulation results [19, 22-25]. To apply a DT, a data exchange system that can be connected to the site must be constructed; four studies are actively being conducted to create this data exchange system [20, 26, 27].

To utilize CPS and DT for integrating and linking the information in distributed environments and for providing various services, a platform that provides a large-scale service system must be constructed. This is a highly complex problem [27]. Each component of a DT is configured as a heterogeneous system; to utilize these components for monitoring and predictions, an efficient platform that employs distributed computing-based modeling and simulation must be developed. Moreover, interoperability is essential to ensure the exchange of information between these systems [27].

3 CPS-based Integrated Platform and Applications

3.1 Platform and Applications

The proposed CPS-based integrated platform supports various design, engineering, manufacturing, and logistics applications and services for SM in global manufacturing companies. This platform integrates real-time information from heterogeneous environments and incorporates DT technology to construct virtual factories and site applications for smart assembly systems. The smart assembly system largely consists of 1) a smart quality control system comprising a quality impact analysis model between processes and a quality prediction algorithm that considers the characteristics of an operator performing manual assembly processes, and 2) a smart production control system comprising an analysis and control model for factors that impact productivity in the assembly process, such as the number of workers at the production site, skill levels, and task difficulties, and an optimal production control algorithm. The core advanced technology proposed in this paper is an advanced analytics technology based on DT and machine learning; it serves as a basis for service applications applicable to logistics and

production processes in the global automotive industry environment. Figure 1 depicts the conceptual architecture of the proposed CPS-based platform, and Table 1 presents an overview of the major technologies and applications that constitute this platform.

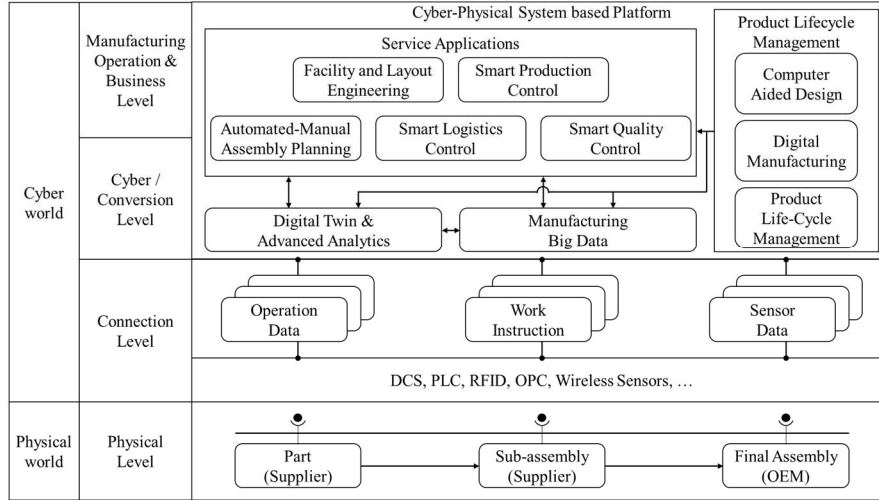


Fig. 1. Conceptual Architecture of Cyber-Physical System (CPS)-based Integrated Platform

Table 1. Summary of CPS-based platform and services

| Name | Sub-technology or service name |
|--------------------------------------|-------------------------------------|
| CPS-based platform and cloud service | Digital-Twin |
| | Advanced Analytics |
| | Manufacturing Big Data & Repository |
| Cloud based application service | Facility and Layout Engineering |
| | Smart Production Control |
| | Smart Quality Control |
| | Smart Logistics Control |
| | Automated-Manual Assembly Planning |

3.2 User Scenario

Primary users of the proposed platform and services are supervisors, operators, and managers. Operators are the personnel who directly operate equipment in the field, supervisors are those who direct operator activities, and managers are those who manage the overall production process. Each user has different strategic goals depending on his/her purpose of using the platform and services. Appropriate selection and operation of these key performance indicators (KPIs) are critical success factors for an enterprise [28]. Therefore, considering the environment of global manufacturers, this study proposes the use of KPIs based on international standards for the proposed platform [29, 30]. International Standard ISO 22400 presents 34 KPIs for understanding and

improving the performance of manufacturing systems. In the proposed platform, the KPI screen can be configured according to the specific purposes of each user.

Figure 2 presents the main screen of the user scenario proposed in this paper. The platform monitors sites in each region of the global supply chain in real time and analyzes and visualizes user-designated KPIs. This scenario consists of a dashboard, a simulation, an analysis, and information functions. The numerous functions described in Section 3.1 are performed. The user can view sites from high-level summaries to specific details, from the country to the factory itself, production lines inside the factory, and individual equipment. In addition, the platform tracks specific site information collected in real time, thereby helping the operator make decisions.

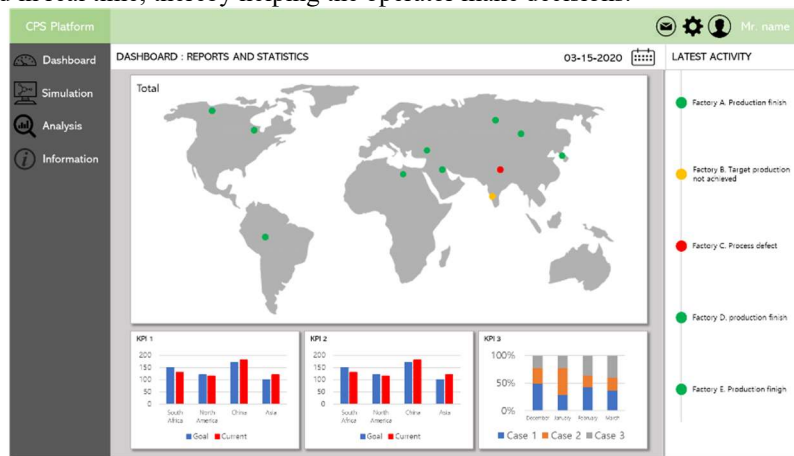


Fig. 1. Conceptual scenario main screen of CPS-based platform

3.3 Information Model for Digital Twin

This study proposes an information model for creating a virtual factory model that reflects real-time site information. To employ a DT, tuning is required to construct a simulation model from the collected site data. To reflect these requirements, this study used the Core Manufacturing Simulation Data (CMSD) proposed by the National Institute of Standards and Technology (NIST) of the United States. The information model proposed in CMSD was utilized for the configuration and tuning of parts, resources, production operations, and production planning [31]. The information model defined in this study consists of a header, a resource instance, a simulation execution, and results for the DT construction. The header corresponds to the simulation model and the library information in the model; the resource instance represents the instance configuration information of the manufacturing resource for constructing the cyber model

4 Implementation

This study is currently being conducted as part of an international joint research between South Korea and Sweden. It involves the design and implementation of various

applications for the CPS-based platform, such as cloud service, DTs, advanced analytics, and site applications. To construct the CPS-based platform, research is being conducted on detailed design, analysis of user requirements and standards, scenario establishment, and platform implementation. Moreover, a library that defines the information model and various data for DT construction is being built. A virtual factory model linked to the data of operators and processes collected in real time at the production site is also being built. Figure 3 presents a DT model for site application and the verification of the CPS-based platform. The model is linked to operator information collected at the site in real time using a short-range wireless communication device; a global automotive wiring harness manufacturer from South Korea is considered as the site. This can be used to construct a system that predicts a variety of problems and evaluates alternatives by linking algorithms for production management and predicting various quality issues. Furthermore, a platform that reflects international standards through a cloud-based service is provided, and it can be used in global environments involving different cultures and systems.

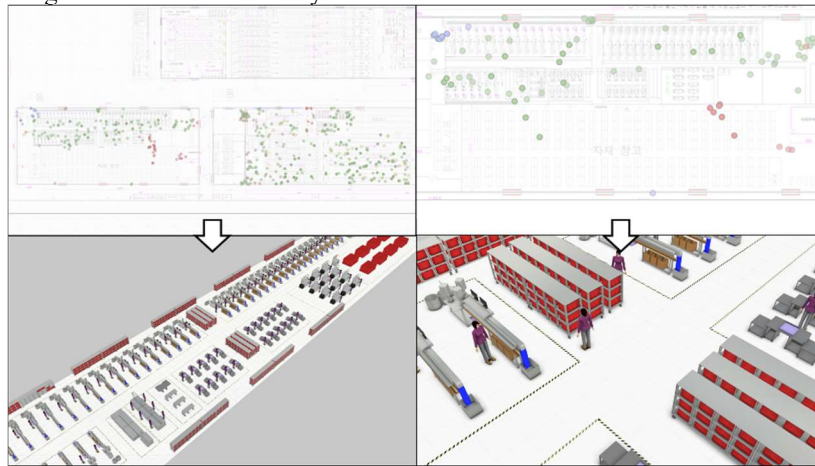


Fig. 2. Virtual factory model synchronized with real-time data

5 Conclusion

This paper presented a CPS-based integration platform for integrating and efficiently managing information from the distributed sites of global automotive manufacturers. The proposed platform was verified through a case study involving a global automotive wiring harness manufacturer from South Korea. The CPS-based platform and various service applications were designed and implemented in accordance with international standards, and a detailed information model for the DT was defined. However, there are a few limitations associated with collecting various data to implement smart manufacturing, in addition to the problem of identical data requiring different management systems. Future studies must investigate the construction of a data collection system to obtain valuable, high-quality data and support more accurate and rapid decision-making.

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