Hitachi Research Institute Report

Evolution of Integration between the Cyber and the Real where the Industry Metaverse Accelerates

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Hitachi Research Institute has been researching about the value and challenges among the cycle of Cyber Physical System (CPS) －The reality that occurs in industrial infrastructures is converted into data, which is digitally processed in cyber space, and the results are feed back (implemented) into real space. During the process of these researches, we have always focused on considering where to apply CPS in the horizontal and vertical aspects of manufacturing, i.e., the supply chain from suppliers of materials and components and manufactures to end customers (the horizontal aspect), and the engineering chain from R&D and designing to production and O&M (the vertical aspect). This is because that the functions required to CPS are different for each aspects.

This report reviews the significance and potential of industrial application of the metaverse, which is attracting attention in recent years, in focus for functions required to expand the application of CPS.

1. Value and Challenges of Integration between the Cyber and the Real

At Hannover Messe in Germany, Prime Minister at the time Merkel presented the Industry 4.0 initiative and proposed a new production system based on CPS in April 2013. In Japan, the Commerce Distribution and Industrial Safety Policy Group was established in the Industrial Structure Council in 2014, and started discussion with a view to the arrival of a data-driven society based on CPS. In the nearly 10 years since then, these efforts have moved from the stage of visions and concepts to the stage of implementation where they are practically applied on site, and some challenges have been highlighted in this movement, including the need for customization of the application site and the limited effectiveness of partial application of CPS.

In this chapter, we define the scenes of implementation of the CPS and discuss the challenges of CPS around the supply chain and the engineering chain in manufacturing.

1.1 Application of CPS in the Supply Chain

The planning system, which the operation of the supply chain relies on, is designed to forecast demand, allocate resources, and adjust the schedule of the upstream and downstream processes in the supply chain. In the logistics industry, for example, 80% of productivity of warehouse operation is said to depend on the planning of daily work and the arrangement of resource allocation. Based on information such as data on orders from shippers upstream of warehouse operation, data on inventory management of the warehouse, data on attendance of workers, and truck shipment times of the day corresponding to the downstream of the operation, it is necessary to schedule a work plan that reduces work waiting time in each process and minimizes the non-operating time of people and equipment. This is the point for field leaders to demonstrate their skills. In order to improve the productivity of such a planning task, it is important to deploy CPS to improve the efficiency of the cycle including visualization of actual work, prediction of impacts of trouble, and presentation of countermeasures based on cause analysis.

However, in improving the preciseness of support for planning tasks and enhancing the productivity of warehouse operation, a challenge is to incorporate more detailed data on operations to be managed. For example, precision of work requirements can be improved by taking

in data on the weight and shape of each packet and calculating the required work man-hours individually based on the packaging, or by taking in classification data according to the skill level of workers, calculating the time efficiency of each worker and reflecting it in the simulation. It is also important to increase points of sensing actual site conditions and increase the frequency of measurement, so that differences between planned value and actual estimates can be detected more quickly and accurately, leading to quick countermeasures.

For the worker support system at the sites in the supply chain sites, it is important to communicate the contents of work instructions to the site more accurately and efficiently. For example, in the factories of the aircraft industry, which use over 3 million components and require strict work procedures in accordance with safety standards, the reliable execution of work is the most important challenge for site management.

The deployment of CPS in such a site enables communication of work instructions according to the progress of the work and to change the contents of the instructions according to the skills of workers. Furthermore, by enhancing the accuracy of sensing and analysis of images and temperature of objects handled by the work, more detailed instructions of the work procedure can be issued and the work efficiency can be improved while maintaining the quality of the work, whereas a challenge is to improve the accuracy of analysis and prescription in the cyber space and the reliability of execution in the real space by increasing information input from the site.

1.2 Application of CPS in the Engineering Chain

In the upstream process of the engineering chain of manufacturing such as R&D and designing, the examination should take into account the downstream process such as manufacture and transportation. This is because the modification and verification of design would be required in the upstream process every time a defect is found in a downstream manufacturing process after the production method and the specifications of components used are fixed, resulting in a significant delay in the schedule of development and production.

In contrast, the utilization of CPS simulations enables prediction of potential defects in the manufacturing process and preparation of countermeasures in advance at the stage of designing and development. For example, it is effective to check the motion of equipment and personnel at the production site more broadly and precisely when confirming how to control and place manufacturing equipment and change the allocation of workers and the work procedures in response to the modification of product design. In this process, a challenge is to redesign how the work flow or the work efficiency is impacted and how loads concentrate on specific equipment or workers according to the change of the production process by mutually linking the motion of equipment and people who take charge of the production activities.

In addition, the durability and safety testing of products are the most important processes in the engineering chain. Today, tests are primarily carried out by using prototypes placed within various reproduced use environments in a laboratory, for which long-standing challenges include shortening the test period and reducing test costs.

On the other hand, an important role is played by driving tests using CPS, which simulates use environments of products and checks their behavior, durability, and safety. Here, a challenge is how to assume use environments in various circumstances, and accurately reproduce and analyze them from various angles.

Regarding to an innovation in manufacturing in the engineering chain, Dr. Takanao Uchida, Research Consultant of RIKEN, contributed an article on the theme of industrial innovation brought by virtual engineering, which provides suggestions including the possibility of the metaverse.

Chapter 1 has focused on the supply chain and the engineering chain to examine how to address two challenges faced during the stage of implementation of CPS, as shown at the beginning of this article. Challenges here include the need to adjust the collection and processing of more input information in accordance with the site

environment when implementing CPS, and the need to conduct mutual impact analysis between processes and elements (products, production equipment, workers, etc.) for a wide range of operations. Chapter 2 will examine potential roles played by technical elements of the metaverse in addressing these challenges.

2. Metaverse-Related Technologies and Business Models to Accelerate the Expansion of Application of CPS in Industrial Sectors

2.1 Increasing Movement toward Industrial Application of the Metaverse

What is the metaverse? The following is a summary of many arguments concerning the metaverse. The metaverse is a three-dimensional virtual spaces constructed on the Internet. Users can immerse themselves in a three-dimensional virtual space while watching high-definition video on an augmented reality (AR) device. Users can have a simulated experience through interaction with surrounding structures, other participants, and various items.

While the metaverse has appeared in the sectors of gaming, entertainment, and product promotion, it is expected that the metaverse will be used more in industrial sectors, accelerating the industrial application of CPS.

In the creation of three-dimensional virtual spaces, game engine (development) companies that provide drawing functions, particularly Unity and Epic Games of the United States, have taken the lead. These two companies have been establishing the development environment and improving drawing functions to make game production more efficient (Table 1). In particular, they are focusing on the development of digital materials (three-dimensional models of people, vehicles, buildings and equipment, computer graphics images, etc.) that are needed to create games. Those materials are organized in a library in a reusable form, and the users have spread not only to the game industry, but also to the production of films and television programs, the building industry, urban development, and the manufacturing industry. Game engine companies are expected to play a leading role in the construction of the metaverse in industrial sectors using rich digital materials as their weapons.

Table 1. Overview of Unity and Epic Games

Company name	Overview
Unity	・Established in 2004 ・Provision of Unity, a game development environment supporting multiple channels including PCs and mobile devices ・Enhancement of functions to jointly develop material data and contents
Epic Games	・Established in 1991 ・Provision of Unreal Engine, a game development environment ・Implementation of technologies for automated integration and adjustment of data in different formats, and data compression technologies

Sources: Documents published by the companies

On the other hand, companies of information systems, services, and equipment control systems are also moving toward the industrial application of the metaverse. Microsoft of the United States is developing an environment that integrates three-dimensional models and process simulations and augmented reality (AR) as an industry metaverse. In June 2022, Siemens of Germany announced an initiative to realize a metaverse for industry in partnership with Nvidia of the United States1). Industrial software vendors including PTC and Autodesk of the United States have acquired AR-related companies.

Here, we will focus on two technological elements in the view that those companies' efforts to apply the metaverse to industrial sectors will accelerate the application of CPS, which has entered the implementation stage.

2.2 Enhancement of Digital Materials (Collection and Processing of Input Information)

Enhancement of input data is an important challenge in expanding the application of CPS in industrial sectors. For example, when conducting a travel test of a self-driving car in a virtual space, it is necessary to prepare three-dimensional data of the road, and digital data to express changes in road conditions according to the weather and use environments including surrounding buildings, other

cars, and pedestrians, etc. On the other hand, game engine companies provide libraries of digital materials that can be used in a virtual environment, development environments, developer networks, and mechanisms for trading materials by external developers, which forms a common base for development work in a virtual space in manufacturing.

Epic Games, for example, is calling digital materials "Assets" and working to make them easier to collect, accumulate, and use. First, in order to expand its libraries of digital materials, the company is laser-scanning various objects in the real world on its own, and sending employees to various places around the world to scan and digitize three-dimensional geospatial data. In addition, by making development environments for digital materials available to external creators at low cost or free of charge, and by establishing environments for trading materials with development companies, the company is incorporating digital materials provided by external creators into its own libraries.

Moreover, the company offers technology to dramatically improve the efficiency of the development of these digital materials. The company provides simulation functions to check how the appearance changes when various situations change, for example, the position of sunlight changes over time. The company's MetaHuman also has a photorealistic human look, natural behavior, and the ability to reproduce the natural movement of a crowd. It is also designed to create an original digital human by changing settings including the skeletal structure.

The provision of digital materials that are rich in both quality and quantity, as well as those development environments, is effective in preparing a large amount of data and assumed environments necessary for the product testing and the process for learning accident prevention measures in a virtual space. There have been advanced movements using virtual environments for manufacturing. In 2020, BMW of Germany announced the construction of a three-dimensional virtual space using the game engine Unity for the development of autonomous driving.2) In 2021, Renault and the CAD company Dassault of France announced the establishment of a joint venture aimed at strengthening a multi-purpose driving simulation environment using Unreal Engine, the game engine of Epic Games3).

2.3 Evolution of Data Processing Technology (Mutual Impact Analysis)

The second technological element of the metaverse that is expected to accelerate the application of CPS is the evolution of data processing technology to analyze mutual impacts between various objects reproduced in the metaverse.

Pixar Animation Studios (Pixar), which produced the world's first full computer graphics animation film, is developing a data format, USD (Universal Scene Description), which enables the exchange of work results between different three-dimensional computer graphics production software.

Pixar released USD as open source in 2016 4), and Unity, Epic Games, Nvidia and others have adopted it. Particularly in the field of industrial applications, Nvidia built a metaverse environment called Omniverse in USD. In August 2022, Nvidia announced a concept and a plan to develop a roadmap for enhancing support for USD for industrial use together with Pixar, Adobe, Autodesk, Siemens, and others5).

During prototyping of products and trial operation of systems, various parties involved in the development access the virtual environment to conduct final checks, including changes in functions and system settings. It is important to quickly reflect the status of trial and error in the virtual environment, and there is an increasing need for real-time rendering technology that converts numerical data into images and videos, and vice versa.

3. Value Creation by Communication and Virtual Experience in a Metaverse Space

The use of the metaverse in industrial sectors will accelerate the implementation of CPS in a variety of industries. In a virtual space, automobile production plants,

power generation plants, and assumed situations in which products and services are consumed will be constructed, and various verifications will be carried out to provide new value in manufacturing.

3.1 Expansion of Collaboration between People and Industrial Systems

Augmented reality (AR) is becoming increasingly important as a mechanism for efficiently implementing the results of studies of the supply chain and the engineering chain on virtual environments into actual business and work environments. (Dr. Masaaki Mochimaru, Director of Human Augmentation Research Center of the National Institute of Advanced Industrial Science and Technology, contributed an article on the theme of industrial application of the metaverse realized by human augmentation, in which he discusses the possibilities of human augmentation technology.)

AR technology is an important technology for accurately transmitting work instructions and supporting reliable execution by superimposing virtual videos on the real world. AR software is linked with CAD/CAE [1] product design data and BOM[2] (Bill of Materials) in a cyber space, and supports the execution of work with high efficiency and fewer mistakes by projecting the assembly work procedure to the actual object through AR devices (goggles) based on those data and the result of examination in the metaverse. In addition, a small camera attached to the AR device can track a worker's gaze to check their movements. Through this function, the system points out errors and corrects work, and displays differences between standard and actual work time on the AR device to help adjust the work pace.

Nvidia's Omniverse provides functions for reproducing the entire production process and the progress of each process of a production site in a virtual space, adjusting examined work instructions to match actual work progress, and communicating them to workers. Workers are provided with functions to display instructions on the order and timing of picking up products flowing on the conveyor through AR goggles in real time. It has been announced that these technologies have been adopted in plants of PepsiCo of the United States6).

By combining the metaverse and AR in industrial sectors in this way, the results of process examination and adjustment in the virtual environment can be transmitted not only to industrial systems but also to people, which will promote accurate work coordination between them.

3.2 Facilitation of Cross-Sectional Collaboration

In a metaverse, a person in charge of a task can view three-dimensional high-definition video, communicate with other participants in a realistic manner, and experience realistic virtual reality in a virtual space. Here, multiple people log in at the same time and share the experience. For example, when adjusting the schedule in the supply chain, if schedulers from shippers, logistics warehouses, transportation companies, temporary worker agencies and other different sectors can participate in the simulation at the same time, they can share the process up to the development of the overall schedule. It is expected that joint planning across companies or organizations will enable understanding of the situation by each sector and its position in the whole, making concessions to each other, and proposing operational design improvements.

It also enables reviews that jointly reproduce and evaluate past planning processes by going back in time. It will also enable joint efforts to minimize the total of man-hours, personnel, and waiting times required in the entire supply chain and consider how to improve operational rules, while reproducing past operational failures, such as the time and frequency of delivery and the timing of order changes, in a virtual environment in the metaverse.

A strength of the metaverse, the ability to participate remotely via a network, will also make it smoother for supply chain managers at overseas sites to discuss possible improvements in the adjustment of production schedules with the advice of mother plants in their home countries.

[1] CAD/CAE: Computer Aided Design/Engineering

[2] BOM: Bill Of Materials

4. Simultaneous Improvement of Social, Environmental, and Economic Value through Industry Metaverse

The use of the metaverse in industrial sectors accelerates the integration between the cyber and the real in manufacturing and encourages collaboration among companies, organizations, and stakeholders across time and physical distance. Similarly, in the social infrastructure sectors such as energy, transportation, and water supply, where digitalization is advancing and operation has been established through the cooperation of various businesses, the possibility of the use of the metaverse will expand as the implementation in industrial sectors progresses. For example, regarding the adjustment of local power supply and demand and the examination of operational rules, it will be possible to carry out the adjustment of interests such as government requests for power saving through repeated simulations of the operation of power infrastructures, in addition to the supply plans of power generation and power transmission and distribution companies on the supply side, the business plans of large users such as factories and building management companies on the demand side, and the forecasts of household demand.

In this regard, the National Digital Twin Programme (NDTp) of the UK, which is introduced in the "Voice from the Business Frontier" section , is attracting attention as an effort to coordinate the operation of power, transportation, and other social infrastructures in virtual space. This is a program promoted by the UK's Department for Business, Energy & Industrial Strategy (BEIS), and is developing a framework for the sharing and integration of necessary data in order to coordinate the planning and operation of various social infrastructures and optimize benefits for society as a whole, necessary resources, and environmental loads.

This article summarized the integration of the cyber and the real and challenges in CPS, and discussed the possibility of using the metaverse in industrial sectors.

As the business environment surrounding us is changing and fluctuating more and more drastically, companies must realize flexible and resilient management and business operations. To this end, it is necessary to establish a mechanism to accurately understand the situation and put considered countermeasures into practice as soon as possible. The metaverse is expected to contribute to the construction and enhancement of such a mechanism by improving the accuracy of prediction by simulations and decision-making.

In addition, companies will be increasingly required to undertake initiatives that cannot be achieved solely through their own business activities, but require cooperation with other companies, such as the realization of a net-zero society. It is important to carry out planning and cooperation with other companies to simultaneously achieve different objectives in a trade-off relationship, such as achieving balance between what's optimum for an individual company and what's optimum for society as a whole, and achieving balance between investment in greenhouse gas reduction and the pursuit of business profits. The metaverse will play an important role as a solution that provides a forum for multiple participants to share the experience of simulations and consider better solutions while repeating them.

The metaverse is expected to serve as an engine in the realization of Society 5.0, which aims at a human-centered society, as it is more and more applied to industrial sectors, especially the social infrastructure sector.

1) Nvidia (2022.09) Siemens and Nvidia to Enable Industrial Metaverse
2) Unity (2020.08) BMW's autonomous driving journey with Unity
3) Epic Games (2021.05) Multi-purpose car simulation environment gets a boost from Unreal Engine
4) Pixar (2016.07) Open Source Release — Universal Scene Description 22.11 documentation (pixar.com)
5) Nvidia (2022.08) Nvidia and Partners Build Out Universal Scene Description
6) Nvidia (2022.03) PepsiCo Simulates and Optimizes Distribution Centers with Nvidia Omniverse and Metropolis

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