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Drivers for CPS Adoption in the Manufacturing Industry: Implications for Productivity Improvement

Abstract: - In recent years, digitalization has significantly progressed across various industries. The manufacturing industry, in particular, has been at the forefront of this digital revolution, embracing CPS, big data, and AI technologies since "Industry 4.0" in 2011. This transformative concept envisions integrating FA devices, factories, and the entire supply chain using standardized communication protocols to create more intelligent factories. The ultimate goal of Industry 4.0 is to revolutionize productivity by promoting automated production to the maximum extent possible.

At the heart of this technological revolution is CPS, a key technology that offers numerous benefits to the manufacturing industry, including improved productivity, cost reduction, and quality enhancement through predictive maintenance of production equipment. However, preliminary research in Japan and Germany has revealed that technical factors within networks between production facilities and the complexity of transaction subsystems pose significant challenges to realizing this vision, underscoring the urgency and importance of finding a solution.

As a result, many companies find themselves in a state of passive management, unable to fully exploit the potential of CPS technology. Therefore, this study is of utmost importance, aiming to identify the technical factors impeding the progress of CPS technology. This technology is not just critical, but it's a necessity for developing smart factories and maintaining and im-proving each manufacturer's international competitiveness. The proposed solution introduces a highly versatile middleware that can effectively overcome these technical challenges, enabling companies to gain a competitive advantage and instilling confidence in CPS adoption in the manufacturing industry.

Keywords: CPS, IoT, Communication protocols, ORiN

I. Introduction

Since 2011, the manufacturing industry has been focusing on implementing Cyber-physical systems (CPS), big data, and AI technologies to make factories smarter and more efficient, following the introduction of the German-originated "Industry 4.0" concept. The Industry 4.0 approach involves nationwide networking devices, factories, and supply chains using standardized communication protocols to promote automated production fields and improve productivity. CPS is a crucial technology. The benefits of CPS in the manufacturing industry can be summarized in three points:

1) Productivity improvement
2) Cost reduction
3) Quality improvement.

In the context of IoT (Internet of Things), CPS aims to connect "products" and "values". This is achieved by installing sensors on various production equipment that convert their operating status into real-time data. AI and other techniques are then used to analyze this data, optimize it, and send it to the production fields through production instructions, as shown in Figure 1. The objective is to maximize production efficiency.

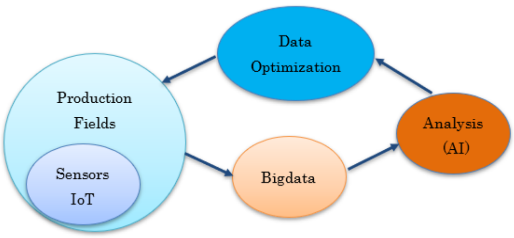

Fig.1 The concept of the cyber-physical system

Source: Created by the author

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For instance, in Japan's IoT market, growth is expected in consumer goods, smart home appliances, infrastructure, logistics, and connected cars, as shown in Figure 2. The goal is to improve the added value of products and services to promote DX (digital transformation). According to a previous survey by Porter and Heppelmann (2014), AI and IoT analysis and simulation are expected to increase productivity by efficiently utilizing robots and factory automation technology.

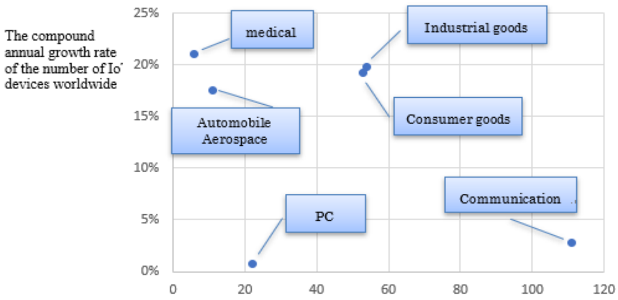

Fig.2 IoT devices growth forecast 2019～2022

Source: Based on White Paper on Information and Communications (2020)

According to the latest IoT user trend survey by IDC (International Data Corporation) in the United States, IoT increased by 0.1 points in 2020 from the previous year and by 1.9 points in 2015, as shown in Figure 3 (n=248) in Japan. However, the rate of increase for companies that adopt IoT is only 6.8%, indicating no significant growth overall.

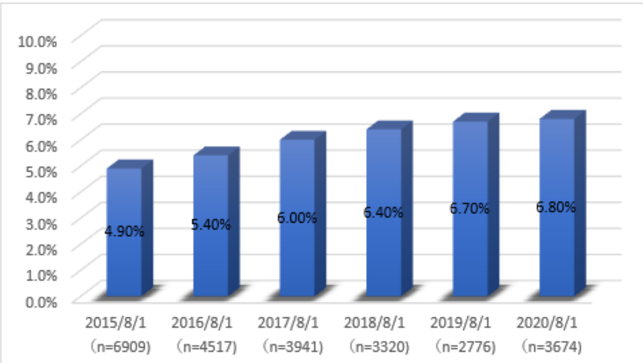

Fig 3 IoT Utilization Comparison Survey 2015～2019

* Among the results of the 2015~2020 survey. Companies with 100 or more employees in Japan were targeted.
Source: Based on Created from the Japanese domestic IoT market user trend analysis by IDC 2020

Currently, there is limited negative research on the IoT and CPS. However, some studies indicate that we should expect little progress in CPS for manufacturing fields. Additionally, we must be cautious about security concerns. (Yang et al., 2019)

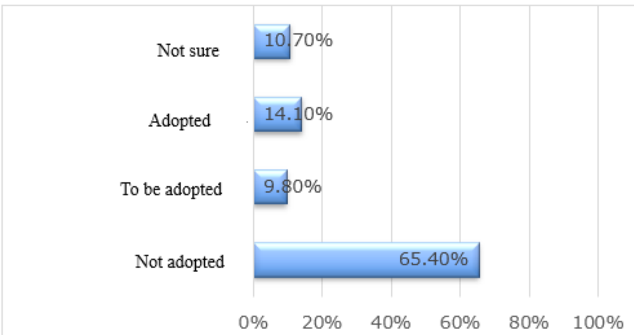

Fig.4 Status of IoT and AI systems adoption

Source: Based on White Paper on Information and Communications (2020)

Furthermore, according to preliminary studies, many companies hesitate to network their production equipment due to traditional business practices, which can hinder their management and capital investment.

II. Problem Statement And Methods

To implement a smart factory, it is essential to connect the various production equipment devices through technology that allows the acquisition of necessary data for analysis. Additionally, to enhance the usage and quality of production equipment and to be flexible in dealing with variable-mix variable-volume production, it is crucial to gather and analyze information from the equipment's operation status data and rapidly convert it into real-time data. However, establishing such a connected environment can be challenging. On the other hand, the author believes it is also necessary to emphasize the true feelings of many manufacturers regarding IoT and CPS. The author conducted field interviews with various companies, including small and medium-sized as well as major manufacturers in Japan and Germany. As a result, the author found that despite differences in industry and company size, many manufacturers do not see the need to connect their on-site production machinery to management PCs. They believe there is no problem in the production fields, even without a network connection. Moreover, it must also be noted that although security is improving daily, companies still feel a sense of crisis and resistance that "connection = hacking" is hindering the progress of IoT.

The production fields have more complex and diverse circumstances than imagined on paper. The production line comprises various equipment from different manufacturers, including Programmable Logic Controllers (PLCs) and industrial robots. Manufacturers of PLCs that control FA devices have also promoted differentiation by building unique network systems and leveraging their know-how to create unique ecosystems. Initially, many Japanese FA device manufacturers were global leaders and were fiercely competing with each other. PLCs that centrally control these devices are also highly competitive, and each manufacturer operates with different communication specifications (protocols) within the factory. This is not just limited to Japan but is a common system worldwide. When gathering and analyzing data that includes the operating status of each device, which is essential for IoT and CPS, it is necessary to develop a communication interface for the device from which one wants to acquire data, as shown in Figure 5. Also, Figure 5 highlights that developing and promoting unique communication systems (applications) increases workload and work efficiency, challenging networking in production fields. This is why standardizing communication protocols has been overlooked in production fields. Because adhering to the standardization concept of communication protocols where technical uncertainty remains, such as opening company knowledge, risks losing the unique technological strengths they have accumulated over time. Moreover, it is not difficult to imagine that incentives for "standardization of communication protocols" would be difficult to implement, considering the need to balance company interests.

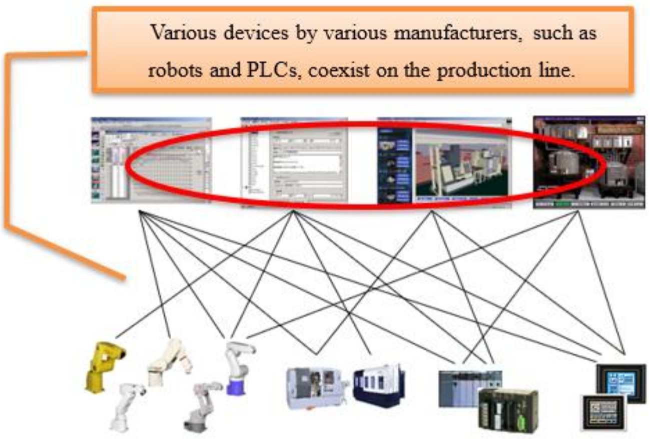

Fig. 5 Communication environment between the host application and FA device

Source: Based on ORiN Consortium

This situation stems from many of Japan's manufacturing industries being forced into fierce competition with overseas competitors after World War II. The only way to stay ahead was to eliminate the trade-off between high quality and low prices, which was the main challenge for Japanese manufacturers. Japanese manufacturers focused solely on achieving technological differentiation to survive in this competitive environment. They performed various trials and errors from scratch, leading to intense competition. This historical path-dependent competitive environment has created the unique trading system we see today, with set manufacturers at the top.

Given these circumstances, each device company's interests were focused exclusively on how to black-box their technology, including networking between facilities and maintaining their competitiveness. Therefore, finding a reason to participate in a standardized networking initiative in the PLC industry is also difficult. However, highly rational and historically dependent corporate behavior that relies on traditional ways of doing things may not be compatible with the IoT and CPS. To summarize the concept of Industry 4.0, it is an integrated network system that includes the OT layer (Operational Technology) responsible for controlling devices such as FA devices, including PLCs, and the IT layer (Information Technology), which manages the upper-level information system network. Simply put, the problem preventing progress in CPS is the need for more connectivity between the OT and IT layers, as shown in Figure 6. This structure makes it difficult to analyze real-time data for "operation monitoring" and "predictive maintenance." Also, it increases development time and maintenance costs for applications in the host system. A better horizontal and vertical network between the system's layers is needed to improve efficiency.

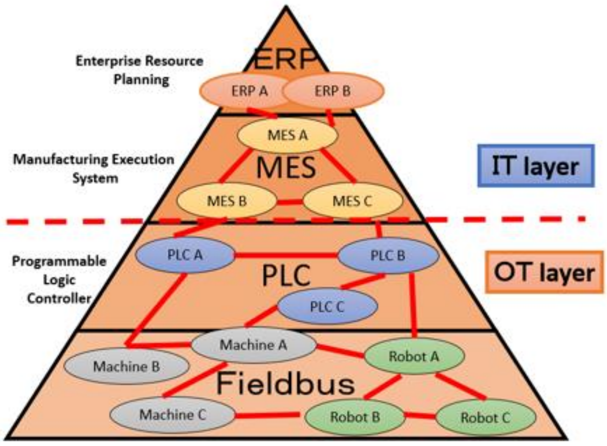

Fig. 6 Schematic of networks used inside and outside the factory

Source: Mitsuyama 2017

For instance, establishing a one-of-a-kind specific communication interface is important for gathering and analyzing data related to metrics such as "operation rate." This interface should be developed to ensure seamless data collection and analysis, as illustrated in Figure 5. On the other hand, It is important to note that the data is stored separately for each device, resulting in longer development times, additional work for employees, higher maintenance costs, and a more complex system configuration. Intelligent systems may be increasingly being sought after in the manufacturing field. Smart factories aim to connect factory equipment in a unified manner to enable the sharing of equipment and line operating data. This data can be visualized to understand the equipment and the entire factory. This "visualization" can help evaluate the current status of the whole production line, prevent defective products, and maintain quality control while improving production.

The following discussions will explore the technical bottlenecks hindering CPS adoption using the case of D Corporation, a major Japanese automobile parts manufacturer. In the early 2000s, D Corporation implemented IT systems in their production facilities as the IT industry began to gain momentum. The key performance indicator (KPI) data, such as operating rate and product number, was standardized and integrated into the Programmable Logic Controller (PLC) to promote the overall information systemization of equipment. PLCs, using ladder language, are used for the overall control of devices in the manufacturing process of the automobile industry. However, the company faced challenges in systematizing the process due to various factors.

1. Constant facility improvement requires constantly changing communication protocols. The production fields do not feel cost-effective values.
2. Improving production devices is challenging and requires reconsidering the entire IT system systemization.
3. Data cannot be collected from non-PLC-connected devices like CNC or RC-centered equipment.

4. Establishing a standardized communication protocol to facilitate information linkage is important.

The issue of systemization faced by D Corporation is not uncommon and is occasionally encountered in the manufacturing sector. However, the product life cycle of the FA device is quite long, ranging from 20 to 30 years, and many devices still operate without a network interface. Prioritizing "connecting" can lead to complex business decision-making, such as giving up devices that still function correctly and investing in new devices with a network interface.

This research aims to suggest technical solutions to enhance CPS technology and evaluate innovation management in the digital era. To achieve this, we conducted a qualitative survey between September 2017 and March 2024, which included semi-structured interviews with various companies. Each interview lasted for about 2 hours. The data collected contains responses from 8 German and Japanese automakers, 23 German and Japanese robot and parts manufacturers, and 9 German and Japanese software vendors. Due to confidentiality reasons, we cannot disclose the names of the companies.

III. Findings And Discussion

i.The Key to The Progress Of CPS

The proposed idea is to place an "IoT Data Management Platform" between applications and devices to manage their linkages. This would allow the applications and devices to respond more flexibly to various situations, as demonstrated in Figure 7.

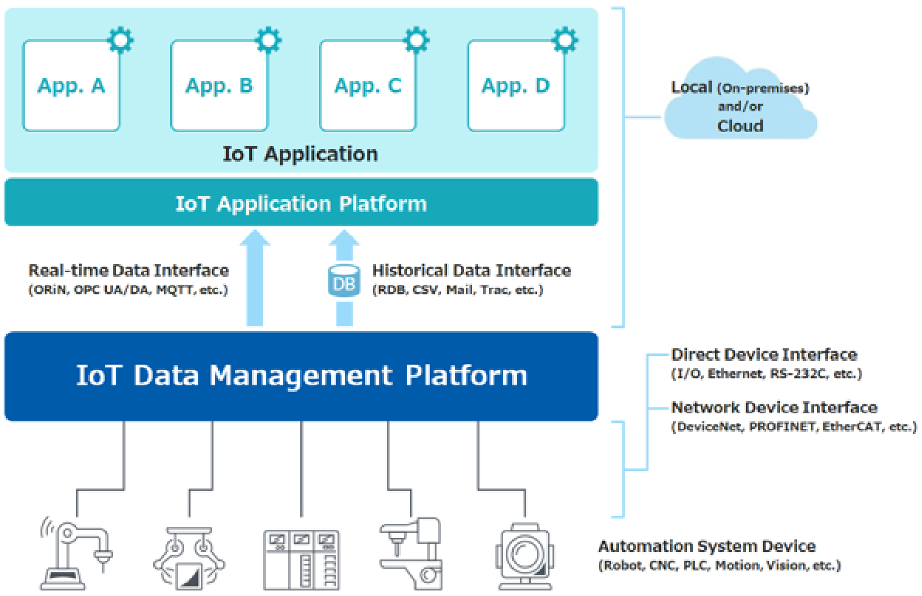

Fig. 7 IoT Data Management Platform

Source: ORiN Consortium

The "IoT Data Management Platform" allows for easy linking between applications and devices while maintaining a simple, secure, and standard interface for the IoT system. Here is a summary of the linkage patterns and ideas.

・**Linkage 1: Application ⇔ Devices**

FA device data is aggregated in an IoT Data Management Platform. This platform easily connects with upper-level applications to secure and simplify IoT system configuration.

・**Linkage 2: Devices ⇔ Devices**

By connecting FA devices to the IoT Data Management Platform horizontally, the platform significantly minimizes the program changes required on the FA device side, streamlining operations and reducing potential disruptions.

・**Linkage 3: Application ⇔ Application**

The "IoT Data Management Platform" enables cross-application data integration, optimizes the standard application platform, and reduces costs.

D Corporation has developed a PDCA system integrating the "IoT Data Management Platform" middleware. The system is designed to prioritize IoT in the field and maximize human potential. D Corporation has identified three key challenges and is already taking steps to overcome them.

Challenge 1.

Connecting only devices that can be connected is ineffective and hinders the PDCA improvement loop. Instead, connect all necessary devices.

Challenge 2.

Our application development environment enables the quick realization of field ideas in addition to the top-down IoT system.

Challenge 3.

To expand factories worldwide, it is important to create a system accessible to everyone, not just developers.

D Corporation proposes that more than simply relying on past thinking and making incremental efforts is needed. To maximize the potential of connecting applications and devices, it is advisable to implement an IoT Data Management Platform with hub-like capabilities and middleware-like functions to accommodate various standards. As the research progressed, it became clear that the "ORiN" technology would be essential for creating the "IoT Data Management Platform" with a middleware-like standard. ORiN can connect with various devices and standards, making it a valuable asset for Japan in promoting CPS based on IoT worldwide. It has the potential to be a secret weapon in this field. The next chapter will introduce more about ORiN and its features.

ii.Middleware that enables smart factories to exist in Japan.

The technical concept of ORiN is effective in network environments where different devices and communication specifications coexist in production fields. ORiN stands for Open Resource Interface for the Network and is a standard middleware specification for factory information systems established by the ORiN consortium. The ORiN provides unified access from software on PCs to industrial robots, NC machine tools, and PLCs from various manufacturers without depending on access methods to manufacturer-specific control specifications. As shown in Fig. 8, the features of the ORiN allow for a unified connection, which enables software in PCs to access various devices in a production field, regardless of their manufacturer or communication specifications.

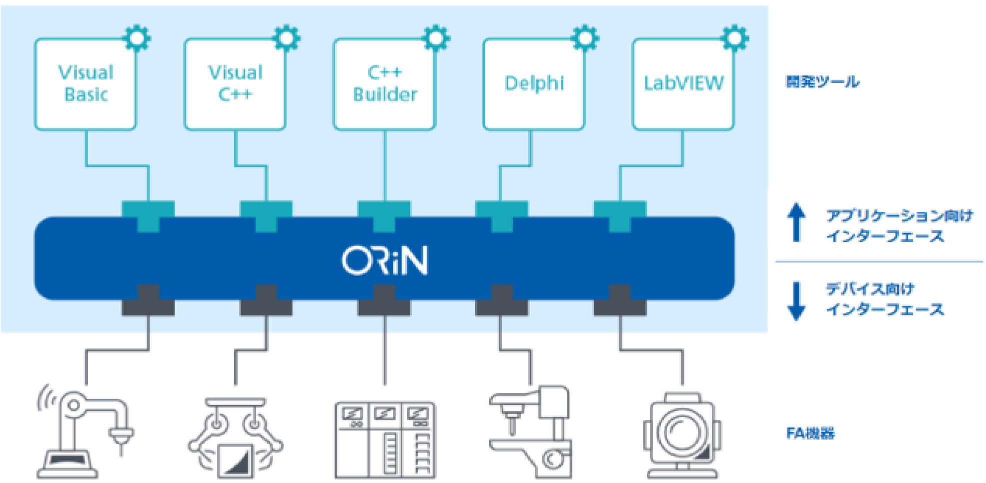

Fig. 8 Image of ORiN

Source: ORiN Consortium

This process allows users to choose their preferred programming language and development environment, improving reusability and maintainability. It enables the collection of information from industrial PCs and provides controller control of various FA devices. In the automobile industry, it is standard practice for FA equipment manufacturers to perform line-integrated control using a dedicated language such as ladder language. One major obstacle in equipment automation has been the need for compatibility between industrial PCs and the environment in which they are used. However, with the introduction of ORiN, industrial equipment can be controlled using PCs, and users can also have more flexibility in selecting their preferred environment. ORiN technology has multiple applications, including obtaining "information" from devices. It can be linked to the target FA devices to build customized applications that can respond to several situations, such as integrating with manufacturing information systems, enhancing work efficiency, and anticipating and averting failures of FA devices on production lines. The utilization of ORiN technology significantly aids in constructing a host system. ORiN offers two interfaces for accessing multiple FA devices: "applications" and "devices." It provides common functions for the standard program interface on the application side, allowing for greater flexibility in application development without worrying about device-specific differences. This means that application vendors can develop client applications without depending on various FA devices, while FA device manufacturers can also use device functions without relying on client applications.

ORiN's distributed object technology also uses Microsoft's DCOM (Distributed Component Object Model) to enhance the client/server system, allowing FA devices to be placed anywhere on the network. Factory automation requires a direct connection to various devices and flexible cooperation with multiple standards. ORiN, a highly versatile architecture, is expected to attract more attention. Next, we will discuss the relationship between the OPC (OLE for Process Control) standard, which led to the "visualization" of FA equipment, and its successor standard, OPC-UA (Unified Architecture), and ORiN. Due to space limitations, we will not delve into the details. The first thing to remember is that when controlling FA devices from a PC using OPC-UA, the FA devices must have been released on the market after 2008 because OPC-UA was introduced in 2008. Furthermore, even when a network is connected, only 10 to 20% of the functionality and performance of FA devices can be achieved.

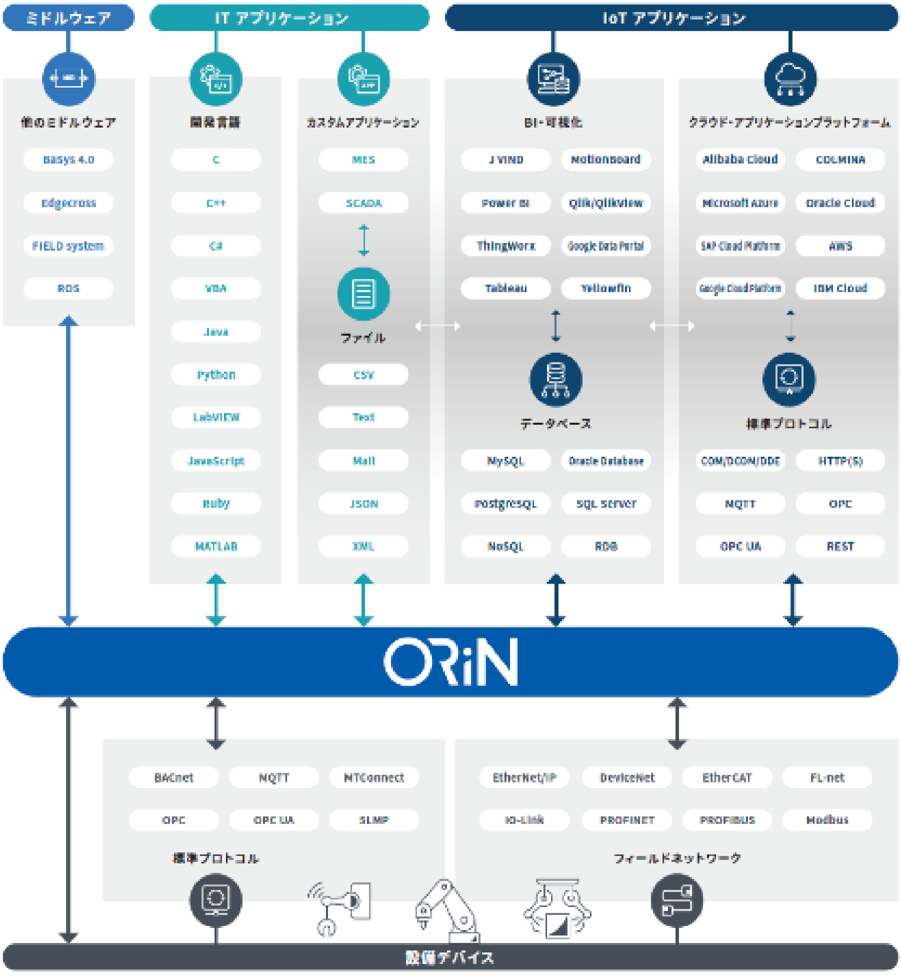

Fig. 9 Image of ORiN's concept

Source: ORiN Consortium

So what if the software comes out in the future that overcomes all the current issues with OPC UA? The key point is that ORiN's architecture does not follow the conventional idea of overall control; instead, it has a structure in which functions other than the main functions can be expanded at any time. This means that even if new FA devices, various software platforms, and application vendors are introduced, ORiN is designed for the interface, which is the connection part and can be "expanded" each time. In other words, ORiN's architectural concept is based on a universal middleware concept that can harmoniously fit everything instead of being hostile to different standards, including OPC-UA. It is possible to link simulations with actual devices while developing and verifying device operation, which results in a consistent system covering everything from design to implementation, operation, and maintenance. ORiN, an incredibly adaptable architecture, can become a central hub for future communication standards based on these points.

While it is impossible to say that "one standard" can cover everything when considering the realization of smart factories from a broader perspective, the development concept of ORiN is designed to coexist with various other standards of the physical and cyber worlds. By making the most of ORiN, it is possible to gather and quantify facility data from multiple devices that make up factory facilities and analyze them. By utilizing the insights gained from the analysis, it is possible to create an intelligent production system to improve productivity significantly. This will eventually lead to the realization of a smart factory, which aligns with the CPS concept that forms the foundation of Industry 4.0. The ORiN design concept represents a next-generation approach that can be dynamically reconfigured organically, as opposed to the fixed production line advocated by Industry 4.0. As part of the Industry 4.0 project, the Fraunhofer Institute in Germany faced technical difficulties that required middleware for implementation. The research organization realized the significance of ORiN early on and has been collaborating with the ORiN Council since 2016 on the ORiN3 project. Currently, ORiN is in the process of standardizing itself (ISO 20242) and working with other industry groups to promote the use of CPS in factories worldwide. Japanese companies can benefit from utilizing ORiN and contribute to international standards, showcasing a new form of manufacturing to the world.

IV. Conclusion

In the previous discussion, we analyzed the challenges inherent in the network environment, specifically from the manufacturing field perspective. We also discussed the slow progress in implementing CPS and the feasibility of smart factories using ORiN. To summarize the technical challenges, every company has a unique technical knowledge and know-how set in each system layer that has evolved over a long period. This uniqueness is what sets them apart from their competitors. Therefore, the concept of standardization in Industry 4.0 is incompatible with this uniqueness and hinders the adoption of CPS. In simpler terms, if we try to network all manufacturing fields using standard communication protocols, manufacturers may lose the competitive edge that comes from their existing uniqueness. As technology advances at an unprecedented rate, manufacturers may lose their unique strengths built up over time if they fall prey to fleeting propaganda. However, we must continue to develop better devices and applications as productivity improvement is essential. While times are moving so fast that there is hardly any time to implement medium-term plans and evaluate the PDCA cycle, it is crucial to understand what "real-time data" means for each company and how much it contributes to stable management. For instance, determining the real-time data companies need when launching a project to reduce power consumption can be challenging. Whether data should be collected every second, minute, hour, or week or if it even matters. Often, decision-makers at companies need to determine the semantic interpretation of data and its usefulness. There is no clear distinction between data that is meaningful and data that is not. Real-time data collection, which should have been a means, has ended, causing unnecessary work and increasing costs in the field. Many times, companies need to pay more attention to the correct identification and response to this issue. It is essential to understand the original purpose of technologies such as real-time data collection, big data, and AI and why concepts such as Industry 4.0 and CPS generate interest.

By doing so, companies return to management basics and can reevaluate the essence of these technologies to determine the management issues that must be addressed. Decision-makers must be able to handle buzzwords and propaganda such as Industry 4.0, IoT, and AI. Although these technologies can lead to stable management and are understandable, companies must reconsider their unique strengths and management resources based on productivity improvement. They must build a unique strategic view, such as seeking fusion with new technology. The sophistication of automation aimed at Industry 4.0 and CPS is merely a replacement for elemental technologies. After all, there are processes and parts in the factory that cannot be automated. Decision-makers should reconsider their approach to these technologies and focus on two points: returning to their origins and building a unique strategic view.

1. To ensure steady management based on a sustainable competitive advantage.
2. "Resolving conflicts between IT and OT layers" in the manufacturing industry.

1. To ensure steady management based on a sustainable competitive advantage.

Companies must again recognize the "sustainable competitive advantage" concept to survive today. As previously stated, the source of competitiveness lies in having a "uniqueness" that allows differentiation from other companies, which cannot be achieved through standardization. The current situation, where companies tend to be swayed by empty propaganda, requires much reflection as the fundamental point of "differentiation" has been neglected, which is the basis of strategic management. In this data-driven era, where technology is advancing daily and the market is unpredictable, the question is how to use and deploy "real-time data" swiftly. In this way, Decision-makers should prioritize sustainable competitive advantages and improving productivity instead of relying on buzzwords and propaganda.

2. "Resolving conflicts between IT and OT layers" in the manufacturing industry.

Taking Japanese production sites (OT layer) as an example, rare and unique technical knowledge (know-how) has been created and accumulated through repeated trial and error. On the other hand, in many cases, the series of know-how that is the source of such competitiveness is not shared with the IT (decision-making layer) responsible for steering management. To effectively tackle this issue, it is crucial to process data to enable the IT and OT layers to identify any problems or issues that may arise swiftly. Furthermore, it is essential to establish a system that promotes seamless sharing of information at all times. Although many businesses already recognize the need for better communication between IT and OT layers, they have yet to identify the root cause of the problem and take practical steps to resolve it.

As explained in the power consumption section, the main reason for this issue is the lack of communication between the decision-makers and OT layers. The IT layer should share concrete grounds with the OT layer, such as "what kind of data is needed to improve productivity and what kind of impact it will have on management," and maintain close communication. Otherwise, obtaining cooperation from the OT layer would be challenging, as it is overwhelmed with daily operations. Miscommunications can accumulate and lead to a loss of unity in the organization, so caution is required. We should also build an organizational structure and system that enables high-quality communication.

Furthermore, the author's research revealed, "This is because the IT layer is far from the field." In the background, miscommunications are likely to occur (Mitsuyama 2020). These problems of miscommunication are common in many companies. Much of the knowledge accumulated daily in the OT layer is usually difficult to convert into explicit knowledge. However, the IT layer should not steer management based on curiosity and the recognition that "real-time data seems to be important..." instead, it must go to the production fields regularly and constantly sharpen the understanding and sensitivity of the company's technical and organizational strengths, as well as deepen comprehensive insight into the raw data (know-how) accumulated at the fields. As mentioned above, the first step toward solving problems is to promote smooth communication based on a common language, such as "What kind of data will contribute to productivity improvement?"

Additionally, much of the data accumulated in the OT layer is important enough to influence management and must be handled carefully. For example, the following behavior of specific big companies in data management is very interesting.

This company provides cloud computing services but does not store its data in cloud computing; instead, it manages it on-premises (in-house physical servers). In other words, this indicates that "Nobody wants to store important data that is the lifeline of my company" ("No one wants others to see their home situation.") on a cloud far away from my company. In the future, it will become increasingly important for companies to focus more on the unlimited potential of such data that lies dormant within their own companies and incorporate it into their strategies.

The reality is that the production fields of small and medium-sized manufacturers are also not in such trouble that they have to rely heavily on digitalization and networking. Paradoxically, this situation suggests that companies still have a deep-rooted common understanding that their "unique strengths" lie in their "analog parts." However, considering the speed of recent changes in the market environment caused by the borderless market, we should understand that it will be difficult to maintain competitiveness if we do not adopt the latest technologies, such as CPS and AI. In brief, we always watch for the rapidly changing external environment, regularly deepen our knowledge of the latest technology, and create a system that can use the "unique data" accumulated daily in our OT layer as a "unique strength." Summarizing the discussion so far, to demonstrate sustainable competitiveness,

"Unique Strengths" + "On-field Data" + "Digital Technologies" = Implementation of Differentiation

In addition to the essential perspective, it is also vital for each employee to feel a sense of ownership and desire for self-improvement every day to improve organizational capabilities. Of course, we must remember that deepening our knowledge of such new initiatives and technologies is only a means to implement a sustainable competitive advantage.

Finally, for manufacturers to continue to be globally competitive in the future, it is necessary to maintain a "unique manufacturing philosophy" (a mass of know-how that is difficult to imitate) that relies on the unique historical path seen in the field. It can be said that it is the inheritance of the essential understanding that "the source of differentiation is inherent in the closed part that dwells in the unique data" accumulated daily in the OT layer. If we can successfully integrate the latest digital technologies, it may lead to rebuilding our unique "new manufacturing capabilities" in the data-driven era.

References

[1] White Paper on Information and Communications.2020

[2] Hui Yang, Soundar Kumara, Satish T.S. Bukkapatnam, Fugee Tsung. "The Internet of Things for Smart Manufacturing: A Review," IIE Transactions: Published online, pp. 1190-1216. 2019

[3] Japan Robot Industries Association Technology Department ORiN Consortium

[4] Michael E. Porter and James E. Heppelmann, "How Smart, Connected Products Are Transforming Competition." November 2014 issue of Harvard Business Review, pp.66-88. 2014.

[5] Mitsuyama,H, Nakazzawa, T, 2017. "The Collapse and Beyond: Fantasies of Industry 4.0". November 2017 winter issue of Hitotsubashi Business Review, pp.108-121.

[6] Mitsuyama,H, Nakazzawa, T, 2020. " Experience in the manufacturing field" Chikuma Shobo

[7] ORiN Consortium HP