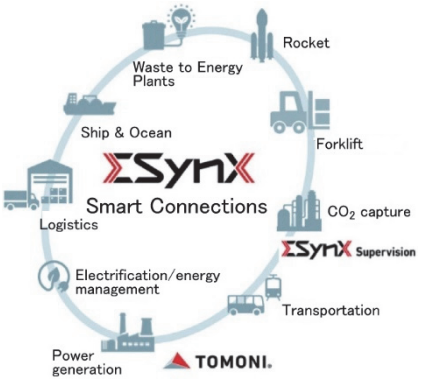
Company-wide Deployment of TOMONI Platform Technology with ΣSynX at the Core: Our Ongoing Initiatives to Bring About AI and Digital Transformation



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Our intelligent solution TOMONI® mainly provides a series of AI or machine learning-enabled solutions for plant performance enhancement, O&M (Operation & Maintenance), operability improvement, etc. thereby helping customers with their operations and management. With the aim of contributing to social transformation through AI and digitalization, Mitsubishi Heavy Industries, Ltd. (MHI) is promoting its digital innovation brand ΣSynX®.

In TOMONI, MHI has developed its experience and know-how in the energy field as TOMONI's platform technology, and are being deployed in other business areas and internal operations of the company as modules of ΣSynX. TOMONI is being used for remote monitoring solution in the CO_2 business, use of generative AI for in-house planning and maintenance work, and visualization of our manufacturing processes to improve productivity, and is thus playing a key role in enhancing the added value of products and improving work efficiency.

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1. Introduction

The incorporation of AI and digital technologies is occurring rapidly and ubiquitously. In manufacturing processes, elements such as perception, comprehension, action and manipulation, for which humans used to be fully responsible, are being digitized and cooperating with machines as intelligence.

Under such circumstances, MHI is working toward the creation of customer value under the banner of our digital innovation brand ΣSynX. Specifically, in-house best practices are made available as standard modules, and their combined applications enable a variety of products to be connected intelligently.

TOMONI is an intelligent solution embodying ΣSynX; it has many standard modules applicable under the banner of ΣSynX. **Figure 1** shows the "big picture and constituent elements of our digital innovation ΣSynX". In the CO_2 capture business, the concept of ΣSynX has materialized as a remote monitoring solution ΣSynX Supervision, which operates in coordination with some of the standard modules employed in TOMONI such as the large capacity data platform and the application framework. With proven solutions for improving power plant performance, optimizing O&M, etc., TOMONI not only supports remote monitoring of more than 150 power plant units inside/outside Japan, but also deploys solutions for internal and customer use, such as boiler AI combustion adjustment using AI and machine learning, gas turbine operation optimization and

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performance diagnosis, and a maintenance planner to support customers' inspection work after commercial operation starts.

Moreover, TOMONI platform technology has been developed in such a way as to be applicable in other business areas of the energy business. Each of our business areas is gradually starting to tap into MHI Group's technological and intellectual assets in a smooth, safe and secure manner. Our determined effort of promoting AI and digital transformation thus centers around ΣSynX, thereby aiming to accelerate digital transformation in society.

Chapter 2 of this report describes TOMONI platform technology. The data needed when monitoring the operation of equipment/products that have been delivered to customers are collected and stored in TOMONI's cloud server, whose platform is capable of handling huge amounts of process data in real-time while retaining security. The enhanced function of user support can maintain the service level high enough to cause no operational problems even in the case of critical infrastructures that are required to operate safely and continuously over a long period.

Presented in and after Chapter 3 are some application examples in fields other than energy, including the utilization of TOMONI in developing solutions in the CO_2 capture business, the use of AI to streamline our in-house business operations and the visualization of various types of data about production equipment in operation at manufacturing sites for higher efficiency and lower costs.

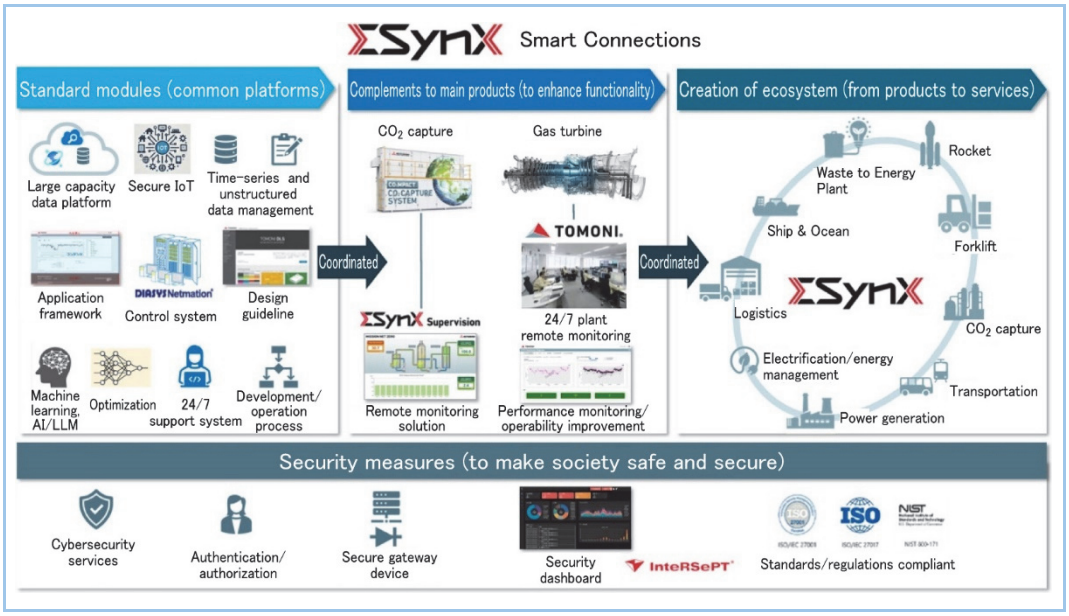

Figure 1 The big picture and constituent elements of ΣSynX

2. TOMONI platform technology with digital innovation ΣSynX at the core

2.1 TOMONI platform technology developed in field of energy business

TOMONI is comprised of the cloud and the edge. The latter in this report signifies a system or device connected to the customer's network. MHI has adopted Microsoft Azure, which has strong security and system scalability, as its cloud infrastructure and AVEVA PI System as its data management solution, respectively. As they work best combined with the originally developed applications, our services are a cut above IT companies in terms of enhancement of customer value. In regard to MHI's products delivered worldwide, a 24/7 support system has been set up to respond promptly and appropriately to customer inquiries and such. In this way, customers can securely access the applications being monitored and under protection by Azure security.

MHI engineers who are assigned to the domestic and overseas bases can access the dedicated work environment created in the cloud anytime anywhere. It has thus been made possible to securely take part in wide-ranging activities for collaboration from multiple locations, including data analysis and development of a new service.

With MHI's proprietary "Netmation Secure Gateway" being configured as the edge device, its embedded function of data diode communication ensures security, and the connection to the cloud is

possible through the closed network in a secure manner. The unstructured data in the edge such as process data, alarm events, texts and images can be securely and easily handled through applications via the API or gateway on the cloud.

Thus, data are integrated into the cloud without compromising the safety and security of critical facilities. With TOMONI platform technology, a system that can run various applications has been developed. Since this system is applicable in wide-ranging business areas as the common platform of ΣSynX, further improvements and refinements will be added according to the characteristics and service level for a facility or equipment, enhancing the customer value even more (**Figure 2**).

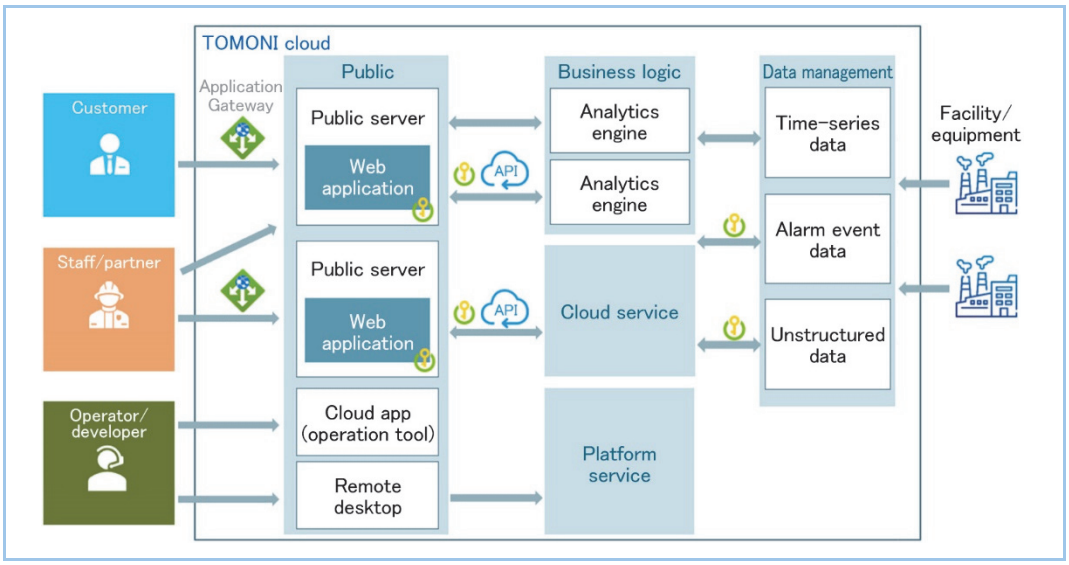

Figure 2 TOMONI platform technology in full view

The purposes of providing TOMONI's applications are to not only enhance the efficiency and quality of equipment maintenance work by customers, but also help to improve their work processes by solving the challenges they face such as personnel training and skill transfers.

"Maintenance Planner" visualizes the past equipment diagnosis results based on the inspection records. It typically becomes easy for customers to determine where to work on and what parts to be needed during the next inspection, thereby preventing them from overlooking any of the necessary work.

In "Smart Search," the technical information such as As-Built drawings and manuals at the time of equipment installation are centrally stored in the cloud. Searching for information is made efficient by the functions of search word suggestion and recommendation of related documents. In this way, information needed becomes quickly retrievable from enormous amounts of past information.

"Connect Room," which is a chat-style communication tool, can be used by customers for making an inquiry to MHI's engineers. Through Connect Room, support based on our OEM's expertise can be provided to customers. Moreover, exchanges through the TOMONI cloud platform enable the know-how to be accumulated/shared within the customer's company as well as between the customer and MHI (**Figure 3**).

Having pledged to achieve carbon neutrality by 2040 with net-zero CO_2 emissions, MHI Group is determined to promote energy transition for decarbonization. To make it feasible, we will build energy management systems using AI and digital technologies for the processes and devices that make up energy demand and supply on both sides of TOMONI's cloud and edge. By doing so, MHI aims not only to visualize CO_2 emissions but also to achieve optimal operation. Specifically, MHI's proprietary AI-based demand forecasting engine "ENERGY CLOUD" is employed to perform optimization calculations based on the predicted demand for electricity, etc. The operational plan is calculated in the cloud, while the output command for each equipment is given on the edge side according to the calculation results.

Figure 3　Example of application to help streamline equipment maintenance work processes

2.2　Improvement of application framework

For customers to access our applications, our focus is placed on not only the development of TOMONI's applications but also the improvement of standard framework, to ensure the provision of prompt services and their consistent level of quality. The examples of the latter include: DLS (TOMONI Design Language System) to offer the enhanced legibility of web applications to users, the data access method serving as the common element for the development of applications, the basic data structures for handling data from around the world on the same platform, and the standardization of logging system necessary for support after the start of operation. These are all intended to be introduced widely as standard modules of ΣSynX.

The use of a standard framework requires application developers to determine only the minimum settings before completing the use of authentication, authorization, logging functionality and screen design. Thus, application developers can focus on the creation of content for customers, considerably shortening the period of creation and verification until the start of service provision.

2.3　Platform to withstand the use of large data

As power generation systems are critical infrastructure facilities, the adoption of the cloud in TOMONI's system development was a challenge for us. Looking at the current situation, by adopting cloud, this decision has brought real-time accessibility from all over the world and system scalability according to the number or scale of plants. It was also the right choice from the viewpoint of easy incorporation of Microsoft's generative AI services and such. The reasons behind the adoption of PI System as a data management solution are the high reliability and abundant proven record in the industry and our experience with its use in MHI Group.

Meanwhile, as the number of user units increased, the amount of data stored in the cloud server and the number of accessing users increased every year. As a result, issues about convenience and economy surfaced, requiring an urgent response. Therefore, we opened access to data widely to facilitate their utilization without compromising convenience. At the same time, data access trends were analyzed to rebuild the system for a better usability environment. When it comes to economy, stale data, which have little use value and have become a setback to scaling of the system, are being removed. The know-how acquired through in-house development of applications and the wisdom of many staff members involved in operation are made full use of to solve the above-mentioned issues and optimize operation.

The other necessities includes: cybersecurity measures to address software vulnerabilities on a daily basis for building and operating a safe and secure system, and large-scale system updates in the wake of the termination of middleware support. Therefore, a 24-hour support system has been launched so that the users are subject to minimum restraints. While enabling access to data, we are also engaging in activities to maintain the services provided without disruption.

In expectation of further increases in the number of TOMONI service users and the amount of data handled, we continuously optimize the platform technology without compromising convenience and economy, thereby aiming to help customers digitalize their businesses despite diversity.

2.4 Future directions

In providing solutions through TOMONI, we ensure security with various measures such as two-factor authentication, by reference to the security standards of organizations such as NIST (U.S. National Institute of Standards and Technology) to meet the requirement specifications from customers and the conforming standards. The Economic Security Promotion Law was enacted in Japan (in 2022); the Cyber Resilience Act is expected to be enforced in the EU (in 2024). The national requirements for measures against cyberattacks are thus specified in more concrete terms these days.

It is expected that more countries will start adopting similar requirements. These are not only applicable to product functionality, but also are aimed at taking measures against cyberattacks as part of after-sales services. The Cyber Resilience Act, for example, refers to the use of SBOM (Software Bill of Materials) as a software management tool.

An SBOM for TOMONI is also in development to strengthen software management. We will continue to develop functionalities and provide services in accordance with regulations, standards, and customer requirements across the world.

3. Application of ΣSynX to GX (Green Transformation)

3.1 Use of digital technologies for GX

As referred to in Section 2.1, MHI pledged to achieve carbon neutrality by 2040. To make it feasible and accelerate our efforts for decarbonization, GX (Green Transformation) Solutions was launched in April 2024. This chapter presents some examples in which TOMONI platform technology is utilized for GX Solutions.

GX Solutions specializes in development of hydrogen and ammonia businesses, and engineering and after-sales service/O&M businesses in fields such as CO_2 capture, ammonia plants, and transportation systems. The application of TOMONI platform technology is especially intended to strengthen the engineering and O&M businesses, specifically with the aim to accumulate design data and know-how, develop and deploy remote monitoring systems and maintenance support systems, and strengthen post-delivery support for customers.

3.2 Use of TOMONI to provide solutions in CO_2 capture business

Holding the world's top market share, our CO_2 capture business has a proprietary CO_2 capture process called KM-CDR Process™. To make the world carbon neutral, its application is not limited to only conventional facilities such as coal-fired thermal power plants and chemical plants, but also targets various sources of CO_2 emissions including biomass power plants, ironworks, cement factories and waste to energy plants. A demonstration test using a compact CO_2 capture system "CO_2MPACT™" and the business development are in progress.

In CO_2MPACT, a remote monitoring system has been introduced to assess verification items and improve O&M efficiency efficiently and reliably. To successfully handle the rapidly expanding need for CO_2 capture, a remote monitoring system has to be implemented within a short time frame (about 3 months). Therefore, the development has been carried out based on TOMONI, because of its abundant proven record among power producers and reliability in terms of security measures, etc. The system has thus materialized as an O&M platform for the CO_2 capture business called "Σ SynX Supervision"; GX Solutions started its operation in 2022. A total of 10 units are currently in operation under this system.

Figure 4 is a conceptual diagram of O&M platform for the CO_2 capture business. It provides functions of remote monitoring to collect and visualize operational data in real-time, as well as remote operation that allows, from a distant location, the equipment to start or shut down automatically. A framework for monitoring from various bases around the world including Japan has been established. To ensure that operation/maintenance support services can be offered if customers are unfamiliar with operation, the collected big data is analyzed using AI and machine learning technologies, and trials have been started to provide advice on when to replenish and replace CO_2 absorption solvent, early detection of equipment abnormalities, and detection of signs of abnormalities.

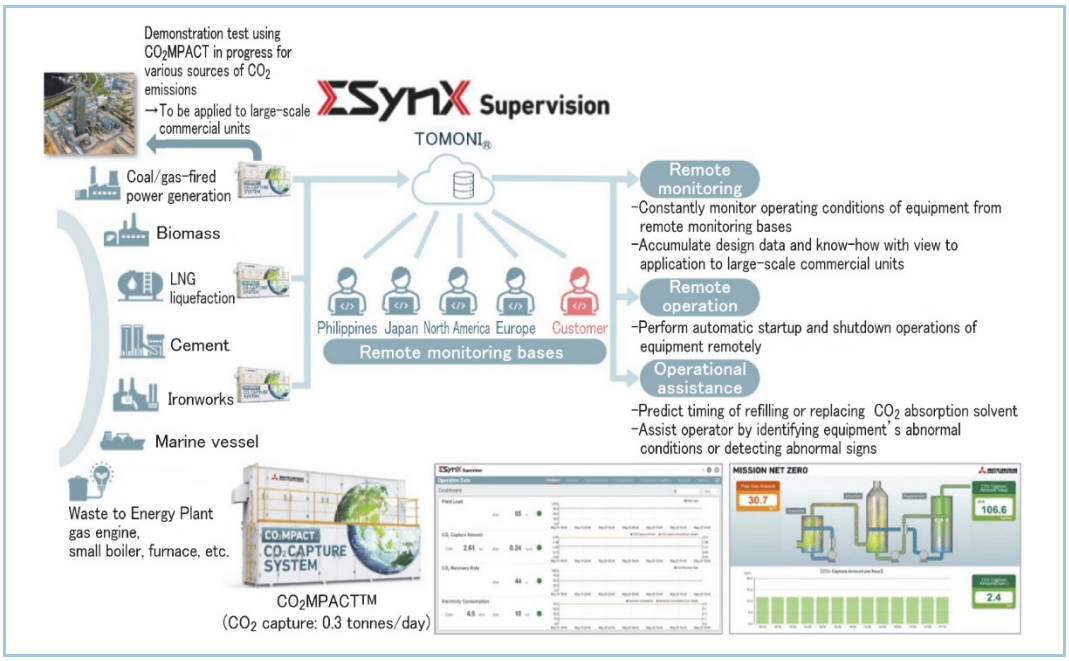

Figure 4 O&M platform for the CO_2 capture business

3.3 Future directions for GX

With a view to creating a customer service menu and value chains for large plants and carbon dioxide capture, utilization and storage (CCUS), we will expand the application to other facilities including CO_2 compression, liquefaction, transportation and storage, and develop new functions. Specifically, as a service menu for customers, we will develop operation and maintenance support and operation agency services for CO_2MPACT, and a support system for ordering and receiving various spare parts and CO_2 absorption solvent and will study services to further reduce the burden of operation and maintenance by customers. The test data will be used to develop a function of assisting the operator by means of predicting abnormal events, and eventually achieve sophistication that enables equipment to operate in an automatic and autonomous manner.

We will continue to contribute to strengthening MHI's businesses by making it applicable as an O&M platform for other products such as transportation systems.

4. Use of generative AI for streamlining in-house planning/designing work

4.1 Challenges in planning/designing work and trials using TOMONI TALK

Having built an environment in which generative AI can be used securely while protecting the data assets of customers' as well as our company's, we started providing the TOMONI TALK service. It has the "chat function" with prefabricated prompts and the "file QA function" which scans documents and interacts with the user. While being applied practically, TOMONI TALK is also undergoing the process of improving and verifying the functions to achieve better work efficiency under cooperation with related divisions of MHI, as described below.

(1) Shortening time necessary for reading up on inquired requirements in planning work

In a new build project, not only the equipment configuration and design conditions but also risk information needs to be extracted from several hundreds of pages of Invitation To Bid (ITB). The technical proposal (specification for tender) to the customer is made based on these types of information. Although this series of planning work necessitates careful and prompt formulation of specification, those in charge often have to keep juggling multiple projects until the point when the contract is signed. It is important to urgently make the work less demanding in terms of the required manpower and workload. Therefore, we are working on the use of generative AI to enable only the key points to be extracted from ITB through inquiring in natural language. The extracted portions are then referred to for the planning work, thus needing less time.

(2) Improving efficiency in handing over project responsibilities while still on a contract

As the maintenance contract is valid over a long period, the person in charge of the project is likely to change during that period. It is therefore important to manage records of meetings,

history of amendments, etc. For example, even if the handover is done properly, there is a possibility of causing a slight difference in the level of recognition of the agreed matters or work responsibilities. When this happens, it is necessary to recheck the details of past agreements. However, such information is often provided portion by portion through various media such as e-mails, meeting minutes, documents and drawings. It therefore would not be easy to grasp how the details had changed with time, unless you were in charge at that time. However, making an inquiry in natural language through TOMONI TALK enables you to search the uploaded past files for information in need. You can get assistance in writing an answer to the inquiry accordingly. We are currently working to shorten the search time and improve the accuracy with which the inquired situation can be understood (**Figure 5**).

As the number of inquiries regarding GTCC power plants has been increasing in recent years, the importance of the above-mentioned work is also increasing. The requirement specification and past agreements should be correctly understood from the stage of receiving an order for the project until entering the stage of long-term maintenance and operation after product delivery, along with the capability of accessing huge amounts of information quickly and accurately.

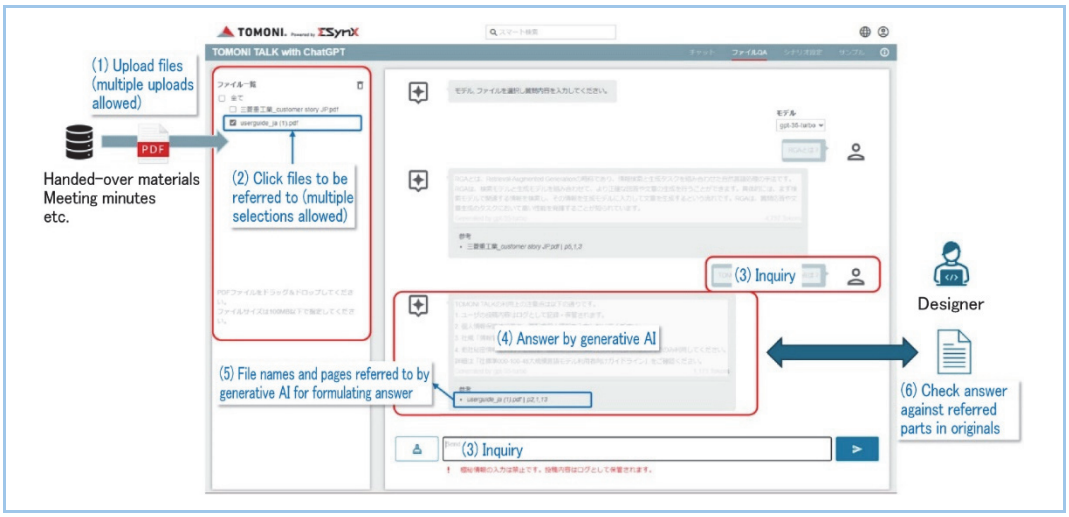

Figure 5 TOMONI TALK, reading in huge amounts of handed-over materials

4.2 Improvement of TOMONI TALK and future directions

Through the trials, the following functions were identified as necessary to make the full-fledged practical application of the system feasible.

In both (1) and (2) above, it is required for AI to recognize technical terms and learn the relationships between the terms. A model that has learned technical terms to target technical daily work.

When information was stored and managed by each department according to its own rules, it was difficult to utilize such information with ease in a cross-functional manner. However, generative AI is about to overcome this problem.

We aim to develop more functions that can be used widely as standard modules of ΣSynX and, through trials, improve TOMONI TALK's functions and expand its applicability in the future.

5. Collection of process data of production equipment and visualization of factory energy consumption

5.1 Use of data for better productivity and less energy consumption at manufacturing sites

With recent digitalization and development of AI technology at production sites, the importance of factory-IoT platforms is increasing, especially for utilization of production equipment data. Factory-IoT platforms can record and manage huge amounts of measurement data and operation history data of production equipment that is in operation on daily basis. The use of accumulated data enables real-time equipment monitoring and quality control. When combined with machine learning

or AI technology, it becomes possible to detect abnormal conditions of equipment and perform predictive maintenance.

As the worldwide movement toward decarbonization is gaining momentum, the manufacturing industry is required to reduce its energy consumption and control CO_2 emissions. Understanding the consumption of energy in a manufacturing process and linking it to more efficient actions, we can reduce the burden on the environment and contribute to the realization of a decarbonized society.

In MHI, the data of in-house factory facilities and sensors are also aggregated and accumulated centrally by employing TOMONI platform technology as a factory-IoT platform. In this way, we are working toward better productivity with a company-wide efforts. When IoT is introduced, it is essential to ensure security by properly separating IT (information technology) from OT (operational technology). Utilizing the know-how acquired through TOMONI as the standard framework, we have developed/introduced a system that can securely collect data from various types of equipment. Presented in the following sections are some such application examples.

5.2 Utilization of TOMONI as a factory IoT platform

5.2.1 Visualization of humans, goods and equipment for better equipment availability

Even if operating conditions of production equipment at a manufacturing site and the shutdown alarm information can be collected, it is difficult to use such collected data for taking concrete action that can improve equipment availability. Therefore, we have introduced an IoT device that can track the flow of humans (workers) and goods (products), thereby gathering logs that make it possible to grasp where workers were and what types of operations they were doing at the time of shutdown. Although the communication standards for data collection differ between machine tools, PLCs and IoT devices, the gateway device to enable data linkage with TOMONI supports such diversity in communication standards. Therefore, these data can be aggregated centrally. The accumulated data on humans, goods and equipment are used to visualize redundancy in production processes. The equipment availability can be improved by reallocating the factory's resources in an optimal manner.

5.2.2 Optimization of manufacturing conditions for better quality

When manufacturing conditions in the processes and the quality data are used to perform quality analysis for each product number or worker, the past data on the processes are needed in addition to equipment data. However, such data are often collected via on-premises networks rather than using a factory-IoT platform. We have therefore developed a mechanism to transmit the settings of equipment to TOMONI and enable the data of in-house production systems to be linked. This makes it possible to visualize manufacturing conditions and quality by product number, whereby quality variation factors can be analyzed efficiently. It also becomes possible to not only streamline the processes but also extract bottlenecks in the upstream processes. Real-time feedback of measurement results on manufacturing conditions can lead to further improvement of product quality.

5.2.3 Reduction of the factory's energy consumption

To gauge the energy consumption of each unit of equipment in a factory, it is necessary to connect every control system to the network. In the case of using TOMONI's cloud platform, however, not all control devices or sensors need to be connected to the on-premises IT network. Instead, the devices are connected to the cloud environment via a closed network from the factory's OT network, thereby enabling data to be accumulated securely. Furthermore, by installing a distance sensor, etc. at the facility and acquiring the position information of the product to be fed into the facility or the factory crane, it is possible to reduce factory energy consumption if the product is not expected to be fed into the production facility for a while, the facility power supply can be turned off or set on standby.

5.3 Future directions

MHI has an increasing number of factory-IoT applications of TOMONI among various business divisions. This enables us to not only accumulate and visualize data on equipment and sensors, but also enhance productivity and quality by linking with production systems and quality data. The operating conditions of production equipment and the location information of goods (products) are also used to reduce factory energy consumption.

We will create an AI model to optimize manufacturing conditions and settings of equipment at production sites, thereby developing a system that can automatically lead to better productivity and less energy consumption in the future (**Figure 6**).

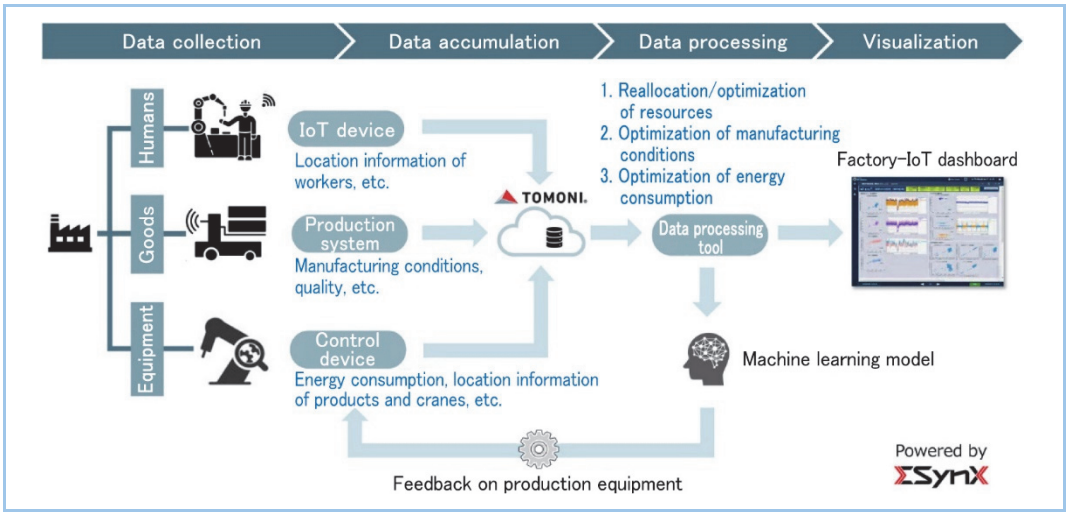

Figure 6 Use of TOMONI as factory-IoT platform

6. Conclusion

This report presents TOMONI platform technology, into which our experiences and know-how accumulated in the field of energy are organized as ΣSynX standard modules. In addition, this report introduced examples of how the platform technology is being applied in other business areas and internal operations of MHI.

Using the above-mentioned platform technology, services with a short timeframe of construction have been successfully developed in the CO_2 capture business. When it comes to the utilization of generative AI, early adoption of advancements in AI and digital technologies for in-house operations is encouraged. In gathering production equipment data, various types of data are centrally collected in the cloud, thereby helping to improve equipment availability, optimize manufacturing conditions, and reduce energy consumption.

The goals of these are to make all of MHI Group's products autonomous and intelligent. The promotion of this goal is in progress under the banner of ΣSynX through collaboration and cooperation between MHI's Shared Technology Framework and related business domains. In the future, we will contribute to our business by incorporating AI and digital technologies into our products, solutions, and services for a decarbonized society, and we look to play a key role in changing the working style of those involved thus gradually leading to social transformation.

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