Fujitsu's Monozukuri Strategy

● Akira Ito ● Ken Takizawa ● Akihiko Miyazawa

Fujitsu has expanded its activities to the development department and other supporting departments in the form of the Fujitsu Production System (FJPS) since the introduction of the Toyota Production System (TPS) in the production department in 2003. These activities are firmly based on the principle of using Fujitsu's own information and communications technology (ICT). The digitization of human activities and things is progressing in parallel with advances in ICT and the Internet of Things (IoT), and the analysis and prediction of conditions in the near future using such a wide variety of data is becoming a reality. These developments point to a major transformation in the entire Monozukuri (Japanese way of manufacturing) process. Fujitsu envisions smart Monozukuri as a higher order of Monozukuri that interconnects departments and plants as well as suppliers, partners, and customers via a virtual environment. This paper describes the current state of Fujitsu's Monozukuri platform based on ICT activities that have come to support the evolution of Monozukuri and a next-generation smart Monozukuri platform.

1. Introduction

Starting out as a manufacturer of telecommunications equipment, Fujitsu has grown to become a Monozukuri (Japanese style of manufacturing) enterprise as well as an information and communications technology (ICT) solutions vendor. Fujitsu has advanced its Monozukuri by utilizing its own ICT. Creating a virtuous cycle between Monozukuri processes and solutions has been a major strength of Fujitsu. At the same time, Fujitsu has come to offer its customers Monozukuri ICT solutions using as reference the environments, tools, and know-how that it has fostered through the effective use of ICT.

This special issue introduces Fujitsu's approach to constructing a smart Monozukuri platform, advanced technologies supporting that platform, and practical cases of innovative Monozukuri. In this paper, we survey the current state of Monozukuri at Fujitsu, describe Fujitsu's activities toward smart Monozukuri, and discuss the future outlook for Monozukuri.

2. Monozukuri in the Fujitsu Group

In this section, we describe the Monozukuri platform that has come to support the evolution of the Fujitsu Production System (FJPS) while touching upon Monozukuri in the Fujitsu Group.

Since establishing the Monozukuri Development Unit in 2003 to enhance Monozukuri processes, Fujitsu has been expanding activities promoting innovation in Monozukuri based on FJPS (**Figure 1**). In addition to "evolution of development, production, and manufacturing technology," we have been working on three themes: "production process innovation," "supply chain process innovation," and "development process innovation."

These activities promoting comprehensive innovation in Monozukuri including human-machine harmonized production have been a driving force behind the ongoing development of FJPS. The following describes each of the above activities.

2.1 Production process innovation

Fujitsu is promoting innovation activities with "just-in-time" and "*jidoka* (automation with a human

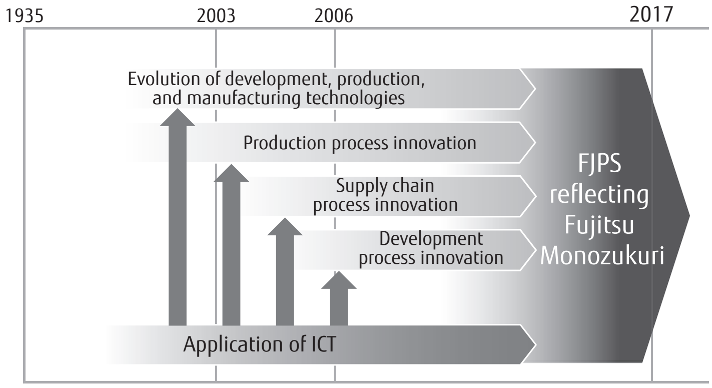


Figure 1
Expansion of activities promoting innovation in Monozukuri.

touch)" as two main preconditions of the leveling process described later. In the area of *jidoka*, the idea is not simply to save on labor but to create techniques and mechanisms that can respond to changes in product types and volumes in an agile manner.

1) Just-in-time production

Streamlining, single-piece flow, and the pull system are being achieved on the Fujitsu production line. These changes are helping to prevent stagnation in the production process and wasteful overproduction and to improve just-in-time production. In addition, thorough implementation of standardized operations makes it easier to visualize and correct anomalies and to expand the range of mixed production. This, in turn, enables the construction of a production line capable of responding to fluctuations in production volumes without drops in efficiency. This approach to shortening lead times and reducing costs is progressing daily in FJPS.

2) *Jidoka*

Fujitsu is promoting *jidoka* based on the concept of a "production line enabling human-machine harmonization." The following measures are needed to deal efficiently with changes in the types and volumes of products through human-machine harmonization.

- Simplification of setup operations at time of product switching (versatility)

This measure includes automatic generation of robot operations, autonomous judgment of work status, automatic generation of work plans, and human-machine communication.

- Greater degree of freedom in dividing up work between human and machines

This means expanding the range of *jidoka* targets such as the handling of flexible objects, connector joining, soldering, and 3D picking.

These measures include the detection of changes such as fluctuation in lot characteristics and gradual degradation of equipment, that is, the autonomous absorption of changes and fluctuations. They also include the absorption by machines (robot systems) of fluctuations in production volumes that have traditionally been dealt with by changing the number of production personnel.

In the above way, Fujitsu has come to place importance on two key axes: expansion of the domain capable of being automated by robot systems and improvement in the level of autonomy on the production line. One successful example of this approach is Fujitsu's multi-function assembly robot system, which can automatically change between six types of tools and perform multiple types of assembly without a switching setup.

3) Use of ICT at production sites

The use of ICT at production sites has been progressing with the aim of shortening the production preparation period. For example, the digital environment of FUJITSU Manufacturing Industry Solution Virtual Product Simulator (VPS), a digital tool using 3D modeling, can be used to evaluate the ease of assembly and maintainability of products and to perform process design, prepare work instruction manuals, etc. In addition, the digital environment of Global Protocol for Manufacturing (GP4), which enables production-line simulation, can be used to design product production lines. Production equipment and products that have been digitized using model-based development techniques are also being used to test production equipment and equipment-control software.

2.2 Supply chain process innovation

In the supply chain, Fujitsu is promoting activities that can suppress fluctuation in materials and facilitate efficient Monozukuri through a two-stage process of leveling off the receipt of orders and shipments by sales and operations planning (S&OP) in the sales department and leveling off the submittal of orders in the production department.

1) S&OP activities

Originating as production innovation in the production department, S&OP activities are aimed at improving Monozukuri by expanding the FJPS concept to suppliers and customers and the supply chain itself. These activities are driving improvements in the operations department and sales department with the aim of leveling off the receipt of orders. Promoting innovation with the sales department is helping to eliminate the stagnation of information transmission through S&OP activities. Constructing a mechanism that can link up with the sales department—even in relation to information on business negotiations that have yet to produce an order—and updating that information as needed and thereby obtaining an understanding beforehand of large-scale negotiations, sets a foundation for achieving production leveling while meeting delivery dates.

2) Promotion of production leveling

Production-leveling activities in the production department are progressing through coordination between the operation and manufacturing departments, and we have been promoting several measures such as production of fixed orders ahead of schedule.

For example, the operations department executes a plan-do-check-act (PDCA) cycle with the aim of meeting targets in agreement with the manufacturing department by constructing leveling logic that takes into account the production line configuration (as in mixed production of various types of products on one production line) and by visualizing the level of leveling. The manufacturing department, in turn, works to reduce production-related factors that hinder leveling off in processes that perform lot-based production because of equipment-related constraints, such as by making lot sizes smaller through improvements in setup operations. In this way, improvements are being sought on a daily basis so that Monozukuri can be performed without a drop in production efficiency even in the event of fluctuating production volumes.

2.3 Development process innovation

The Flexible Technical Computing Platform (FTCP) supports development work in the Fujitsu Group from product planning to product design and analysis.

1) Integration and sharing of design know-how (FTCP 1.0)

Fujitsu set up the FTCP (**Figure 2**) in 2007 as a development environment for company-wide integration. It provides a mechanism for interconnecting a variety of tools and in-house systems essential for product development, and in this capacity, it has produced significant effects in cost reduction, quality improvement, and greater design efficiencies. In short, FTCP integrates design technologies that are needed from design to production (such as computer-aided design [CAD], computer-aided engineering [CAE], product data management [PDM], design rules, and parts information), and promoting the use of these technologies within the Fujitsu Group has accelerated the consolidation and sharing of design know-how. The early introduction and in-house use of advanced technologies via FTCP has given birth to a virtuous cycle that enhances the technologies available for use and facilitates the consolidation of new forms of know-how.

2) Extensive testing functions

Testing functions include design rule checks (DRCs) based on design standards and a variety of simulation techniques for electromagnetic field analysis and other purposes. There are about 300 DRC testing functions that include a design for manufacturability (DFM) function for evaluating productivity plus know-how for making design work more efficient. Checks at the design stage can be executed in real time, and design errors can be corrected on the spot, which has the effect of greatly reducing the amount of reworking. Simulation, meanwhile, can be used to verify whether designs are meeting standards. The FTCP enables effective operation of DRC and simulation functions.

3) Development and application of an engineering cloud

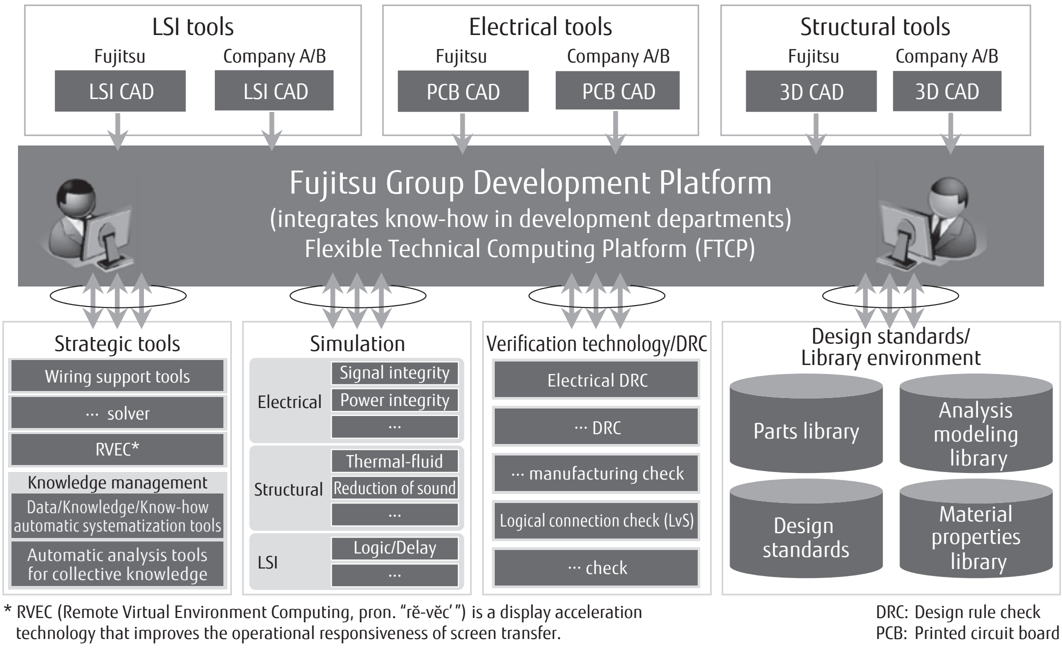


Figure 2
FTCP development platform.

In 2010, with the aim of compiling and managing development know-how within the Fujitsu Group in an integrated manner, Fujitsu began development of an engineering cloud ("Engineering Cloud") to place all design technologies (tools, standards, libraries, design data, etc.) in the cloud and promote a shift to a comprehensive design environment in the cloud rather than on the designer's terminal. Application of this cloud has been expanding in conjunction with usage trials. In general, desktop virtualization tools must deal with many issues including screen responsiveness since CAD and CAE require highly detailed line drawings and high picture quality. For this reason, Fujitsu Laboratories undertook the basic development of proprietary high-speed image compression and transfer technologies, which were then implemented by Fujitsu and applied to its in-house cloud environment.

4) Enhancement of design platform (FTCP 2.0)

As the use of simulation in design work came to be accepted, Fujitsu set out to expand its use and respond to an even higher level of needs. In the case of commercially available analysis software, calculation speed tends to saturate as the degree of parallelism in computational processing increases, which has been a major problem in terms of cost and performance. To solve this problem, Fujitsu developed solver software, FS-Solver, that prevents a reduction in calculation speed even with increasing model scale and then went on to construct an original analysis environment that can accommodate the development of all sorts of products from ubiquitous devices to large-scale servers. This made it possible to perform a wide range of model analysis from models of individual printed circuit boards (PCBs) to large-scale models of entire products. Additionally, in parallel with the above, Fujitsu developed preprocessing (creation of models) and post-processing (visualization of calculation results) techniques for improving efficiency in analysis work. In this way, Fujitsu has been able to contribute to making a whole series of analysis tasks more efficient from the incorporation of design data to model creation, highly parallel calculation, and results display (**Figure 3**).

3. Smart Monozukuri

Advances in ICT and the Internet of Things (IoT) combined with the digitization of human activities and things are enabling the use of diverse types of data as useful information. The analysis and prediction of conditions in the near future using such a wide variety of data are becoming a reality, and the possibility

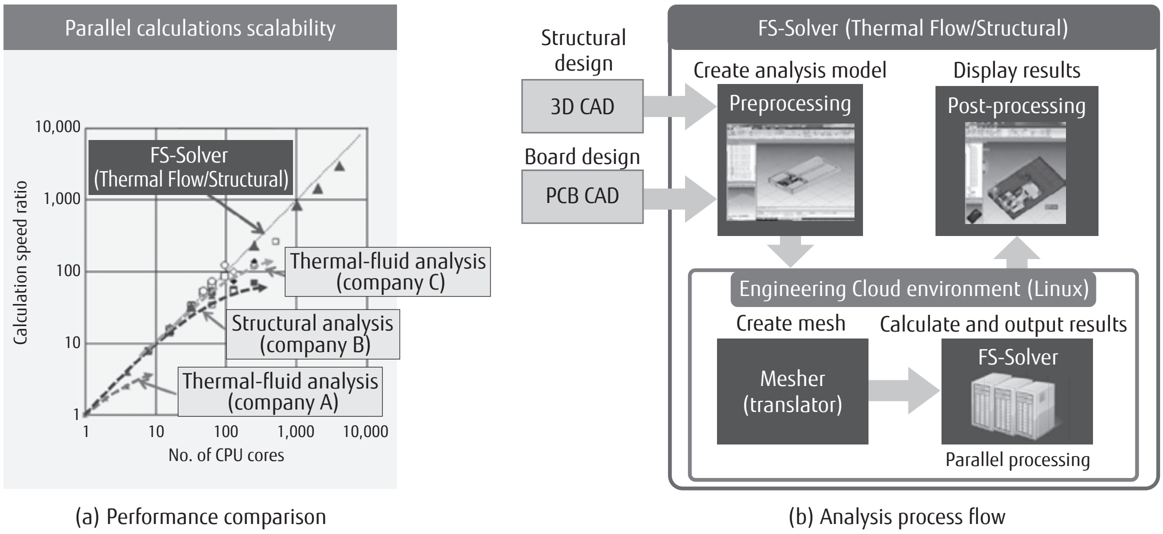


Figure 3
Massively parallel analysis solver supporting large-scale models.

of making radical changes to the entire Monozukuri process is coming into view. This is digital innovation targeting Monozukuri. Against the above background, we next describe the form of the next-generation smart Monozukuri conceived by Fujitsu.[1),2)]

3.1 What is possible with smart Monozukuri?

Fujitsu's objectives with smart Monozukuri from the viewpoints of customers, society, in-house development sites, and production sites are summarized in **Figure 4**.

- Customers: Make your dreams come true.
- Society: Contribute to the environment as a social mission.
- Development sites: Continuously pursue lower costs, higher quality, and greater value.
- Production sites: Use "only what is needed when needed."

In Figure 4, the "things" deemed necessary to achieve the form desired for these four objectives are defined on the layer labeled "Things," and the technologies for achieving these "things" are defined on the layer labeled "Technologies." Here, the core technologies for achieving this layer of technologies are digitization technologies.

3.2 Approach to achieving smart Monozukuri

Fujitsu's approach to achieving smart Monozukuri is shown in **Figure 5**. In the figure, "projection" and "connect (synchronize)" are keywords that best reflect this approach to achieving efficient, technology-based Monozukuri dictated by an appropriate level of quality. In this approach, development sites leverage common platform technologies including production and manufacturing technologies plus ICT to develop and test products and production in a digital environment in accordance with product attributes. Production sites use IoT to interconnect people and a variety of facilities and robots. This process "projects" the digital model created in a development site to a production site. Meanwhile, the state of production sites evolving with *genba-ryoku* (on-site competence) is immediately fed back into the digital model through IoT technology. With our smart Monozukuri, we aim to promote high-speed evolution in manufacturing through short-cycle verification in the digital environment, high-speed reflection at the production sites, and integration of *genba-ryoku* with digital technologies such as ICT and IoT.

Fujitsu is achieving the "things" shown in Figure 4 through smart Monozukuri by integrating the initiatives shown in **Figure 6** at these sites. In the following, we describe the current state of six of these initiatives.

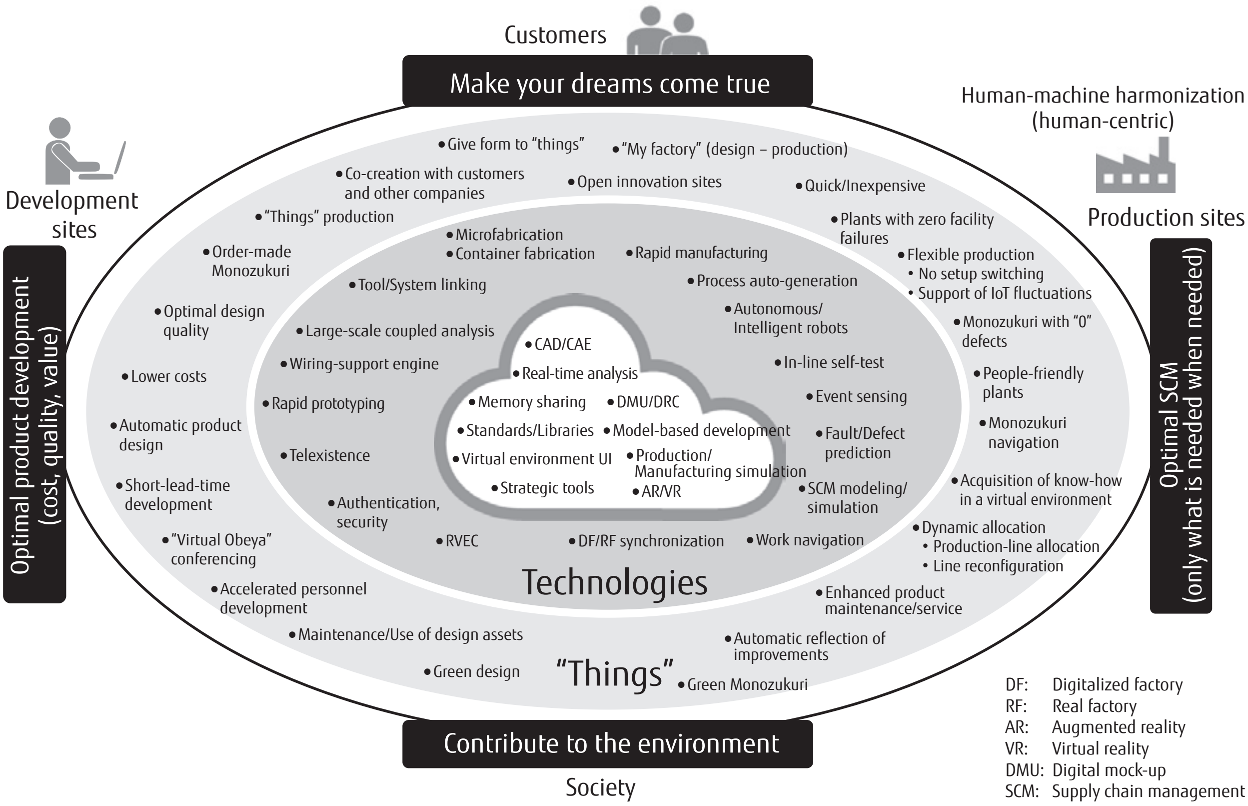


Figure 4
What is possible with smart Monozukuri?

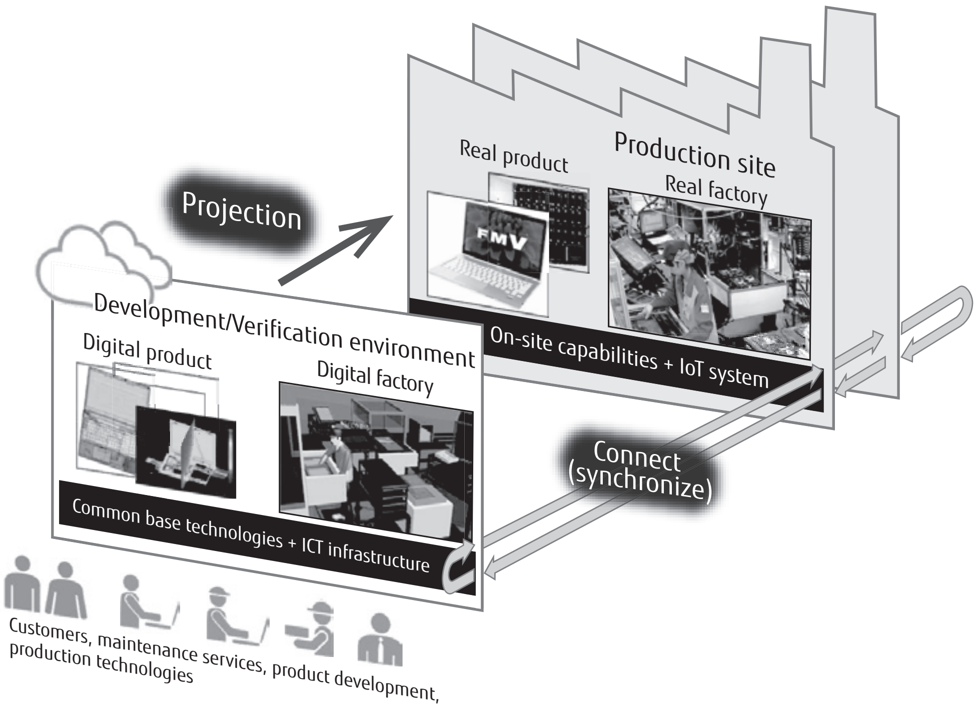


Figure 5
Approach to achieving smart Monozukuri.

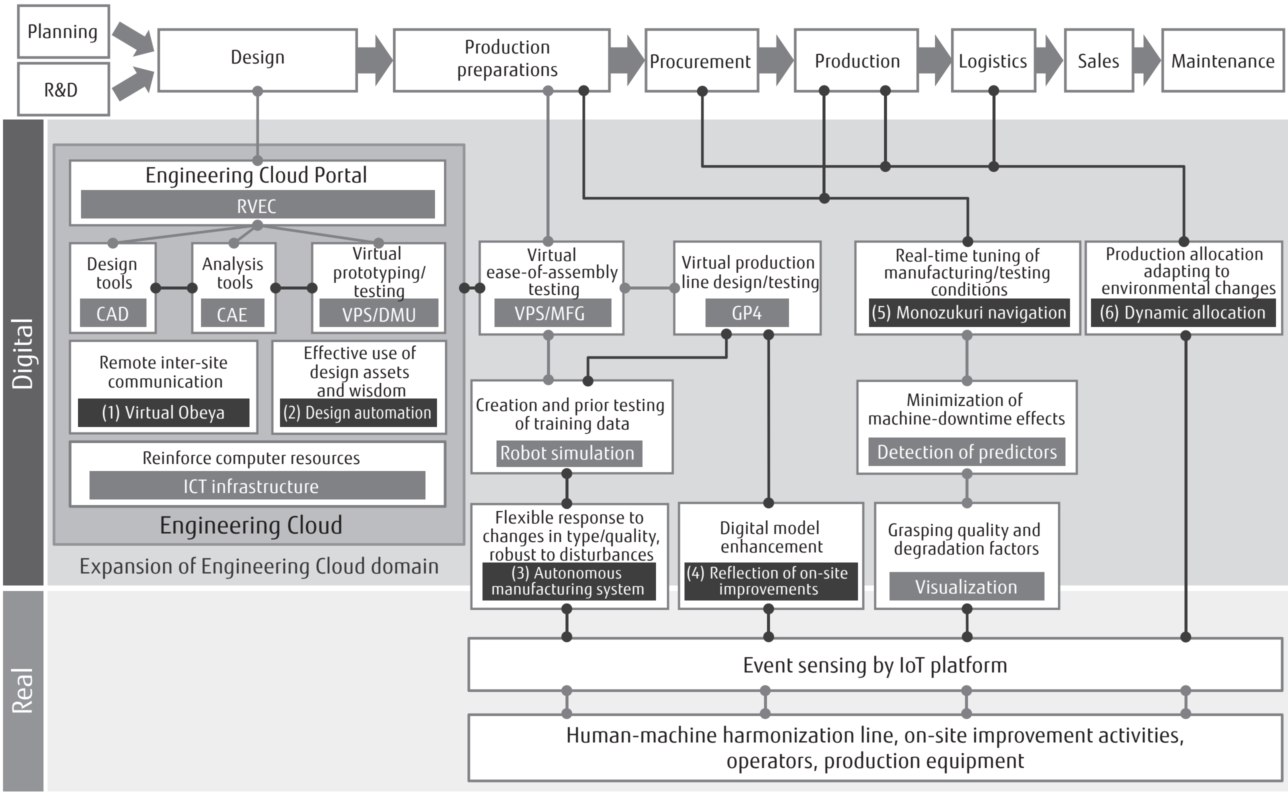


Figure 6
Map of smart Monozukuri initiatives.

1) Virtual Obeya

Virtual Obeya (where *obeya* means "large room" in Japanese) is a forum constructed in digital space to enable consumers, retired specialists, suppliers, vendors, etc. at sites around the world to communicate and participate in Monozukuri. It aims for a Monozukuri process that links design and production sites and that promotes the sharing of product development information without being limited by place and time.

2) Design automation

The functionality, performance, and quality required of products have become increasingly sophisticated, and a variety of issues such as heat generation, electromagnetic compatibility (EMC), enclosure design, low-voltage design, and noise have become increasingly intertwined. Fujitsu is working to solve these complex and composite issues through a One Platform concept that integrates the CAD/CAE tools used in electrical and structural systems and that achieves design automation (**Figure 7**). The following technologies related to this platform are also being developed.

- Composite analysis (coupled analysis)

The need for introducing coupled analysis techniques for simultaneously simulating the composite elements of heat, electricity, and structure has been recognized, and in-house trials have begun.

- System linking using web API

In addition to coordinating in-house systems related to product development such as FTCP and product data management (PDM), it will also become important to link up the systems of all product-related departments: marketing, design, manufacturing, logistics, and so on. To this end, the plan is to standardize the procedures for calling the database tools managed by each department as a Web API and to link up related departments so that each can create even more advanced and superior services.

- Advanced design/testing techniques using AI

Operating FTCP in the Engineering Cloud environment enables the history of design data and design processes to be stored as engineering chain management (ECM) information. In addition, an environment for extracting supply chain management (SCM) information stored in the production department by a web

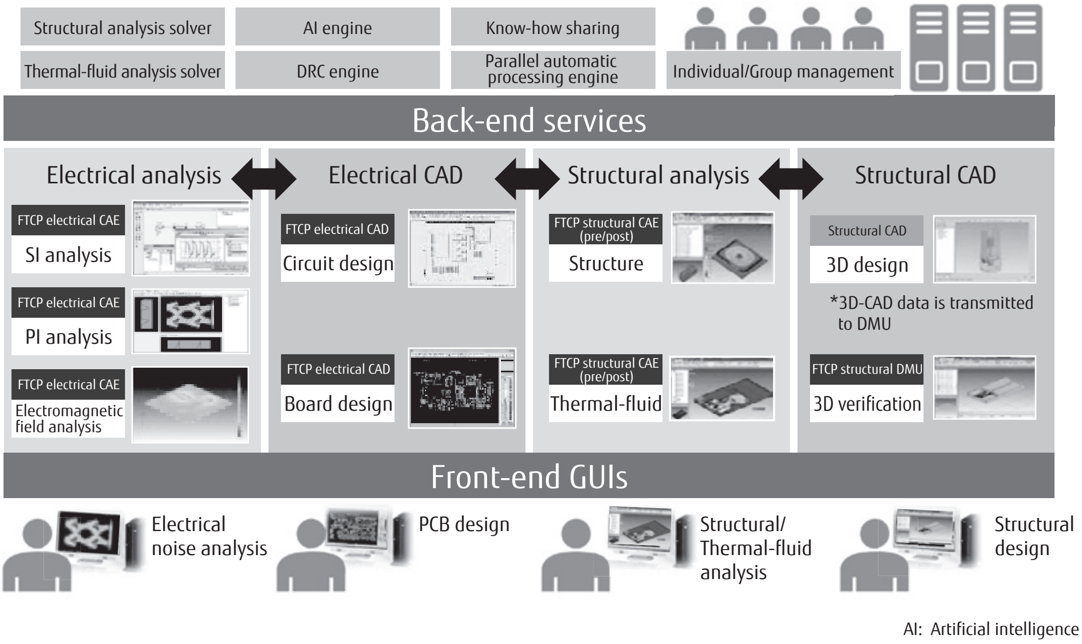


Figure 7
One Platform.

API can be constructed, and machine learning as one instance of practical artificial intelligence (AI) can be applied to design automation.

3) Autonomous manufacturing system

Fujitsu is developing autonomous/cooperative technologies to enable a robot system to "feel," "think," and "behave" on its own. This includes automatic tracking of variations in production lots and of aging deterioration of the robot system itself. An automatic generation system for robot programs and an automatic generation system for image-recognition programs[3] are also being developed. The automatic generation system for robot programs enables operators to specify robot actions with simple operations. It also can absorb differences in specifications among different types of robots so that operators can perform their work without having to worry about those differences.

This technology helps to minimize the labor associated with setup switching and work rearrangement and can lower the barriers to introducing robots.

4) Automatic reflection of on-site improvements made by people

This technology uses IoT to automatically and immediately reflect information such as operator movement, equipment operations, and operation timing in the corresponding digital factory. The digital factory can thus be brought increasingly closer to the real factory as the latter evolves (**Figure 8**).

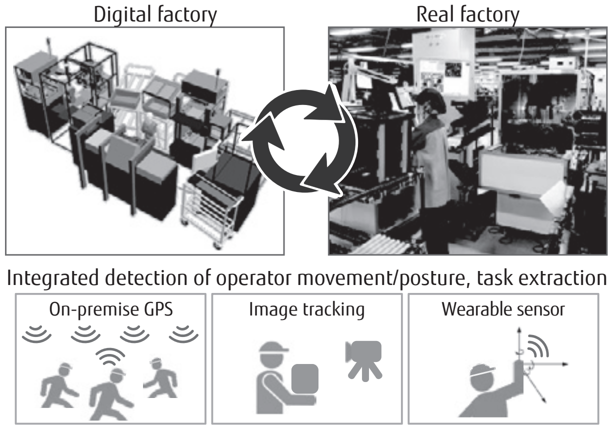


Figure 8
Automatic reflection of on-site improvements.

5) Monozukuri navigation

The idea of this initiative is to merge various types of information from the production site with the product design model, support the analysis of defects and their causes using data mining and statistical analysis, and construct a model for predicting the state of production.

This prediction model can then be used to tune production facilities in real time and provide improvement guidelines to the development and production sites (**Figure 9**).

6) Monozukuri dynamic allocation

The configuration of a smart supply chain is shown in **Figure 10**. In this process, information associated with each type of business is constructed as a data model in the corresponding business cloud, and links are formed between these clouds. All production information can therefore be shared even if some systems or facilities are not linked up. As a result, the stagnation of things and information can be eliminated, which enables not only a shortening of lead times and reduction of inventory but also the constant monitoring of differences with the prediction model. This information can be shared instantly among all the business clouds, which means that measures can be taken immediately on detecting situations that involve risk.

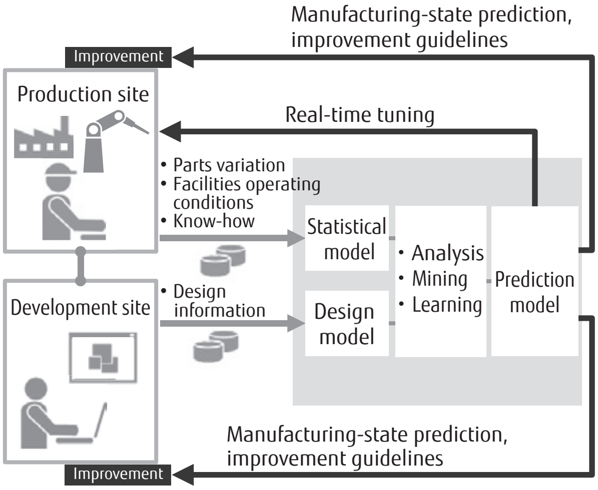


Figure 9
Monozukuri navigation.

The purpose of dynamic allocation is to coordinate different production plants as demand fluctuates by linking production information from different production lines and by performing load adjustment and delivery-date negotiations through the help of simulations. Another purpose is to coordinate order receiving/placing information through the mutual exchange of parts-supplier process-status information and one's own production-planning information. In this way, a mechanism for linking production information between companies can be created so that production fluctuations that take into account a supplier's parts-production conditions can be absorbed, and parts procurement can be leveled out.

Improving the accuracy of demand prediction is one means of achieving dynamic allocation. To this end, Fujitsu has constructed a demand-prediction mechanism that uses not only past results and information on major business negotiations but also applies machine learning and big data analysis that combines

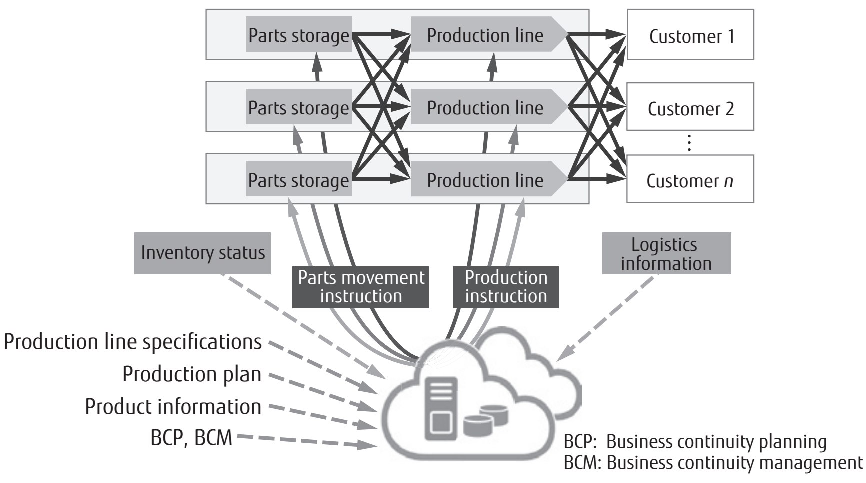


Figure 10
Dynamic allocation.

estimates from current negotiations and product configuration information. Compared with conventional techniques based on past results, this mechanism achieves high accuracy in demand prediction.

4. Future outlook

The Industrie 4.0 initiative in Germany and the Industrial Internet Consortium centered about the United States are well underway, and in Japan, the Robot Revolution Initiative (RRI) based on Japan's Robot Strategy and activities promoting manufacturing business reform through IoT have begun in earnest. Fujitsu has been contributing to these activities as well as to the Industrial Value Chain Initiative (IVI), a private-sector effort.

In step with these trends, Fujitsu will construct a "digital Monozukuri platform" to serve as a hub connecting the digital and real worlds through a next-generation Monozukuri infrastructure. A conceptual diagram and the configuration of this digital Monozukuri platform are shown in **Figures 11** and **12**, respectively. This platform interconnects all Monozukuri processes and the Monozukuri field, digital field, and market/customers. In this way, it facilitates links with suppliers and partners and enables immediate feedback from customers.[4] Going forward, Fujitsu seeks to promote this digital Monozukuri platform as a de facto standard through the IVI and RRI and to eventually establish it as an international standard.

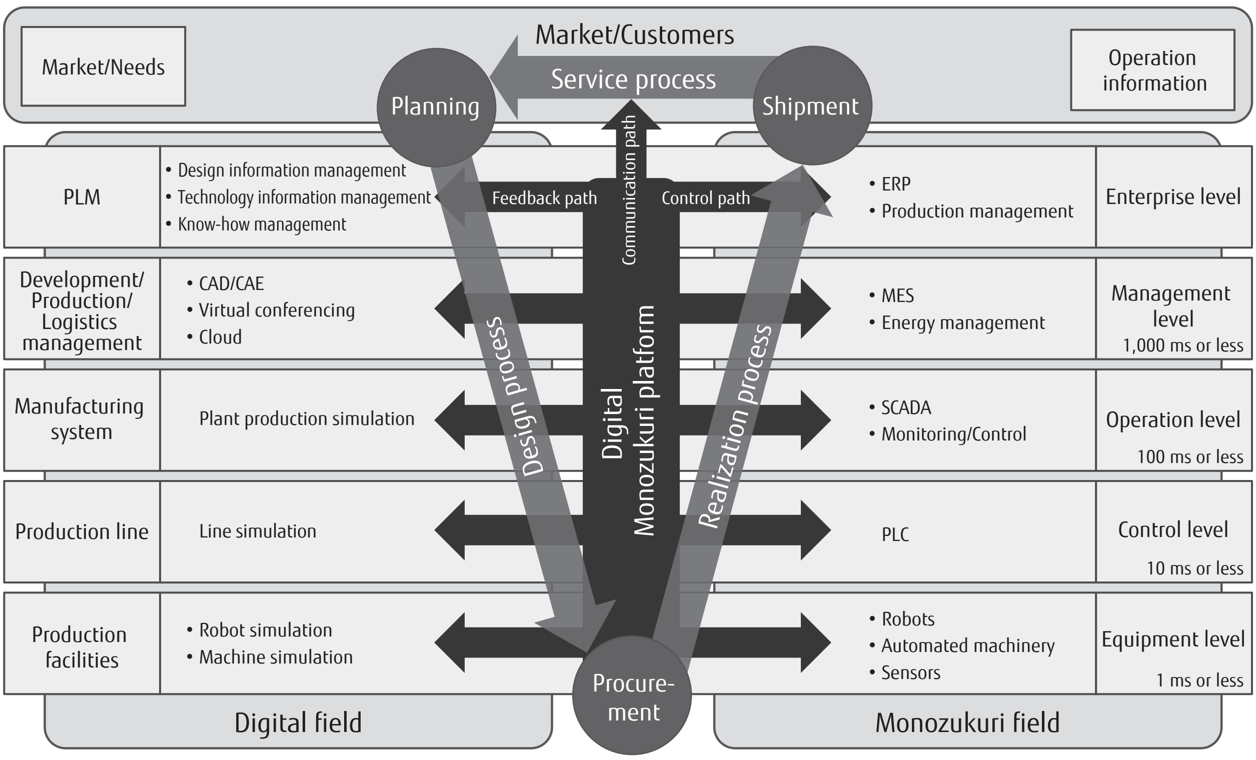
The following measures can be viewed as keys to achieving a digital Monozukuri platform.

1) Construct a data distribution infrastructure

This means constructing an environment that enables uniform access to data and information from the upstream to the downstream.

2) Provide a plug-in method for diverse services and establish data formats

To further accelerate design work, there is a need for a plug-in method for using services in the data distribution infrastructure and for data formats to



PLM: Product lifecycle management
ERP: Enterprise resource planning
MES: Manufacturing execution system
SCADA: Supervisory control and data acquisition
PLC: Programmable logic controller

Figure 11
Conceptual diagram of digital Monozukuri platform.

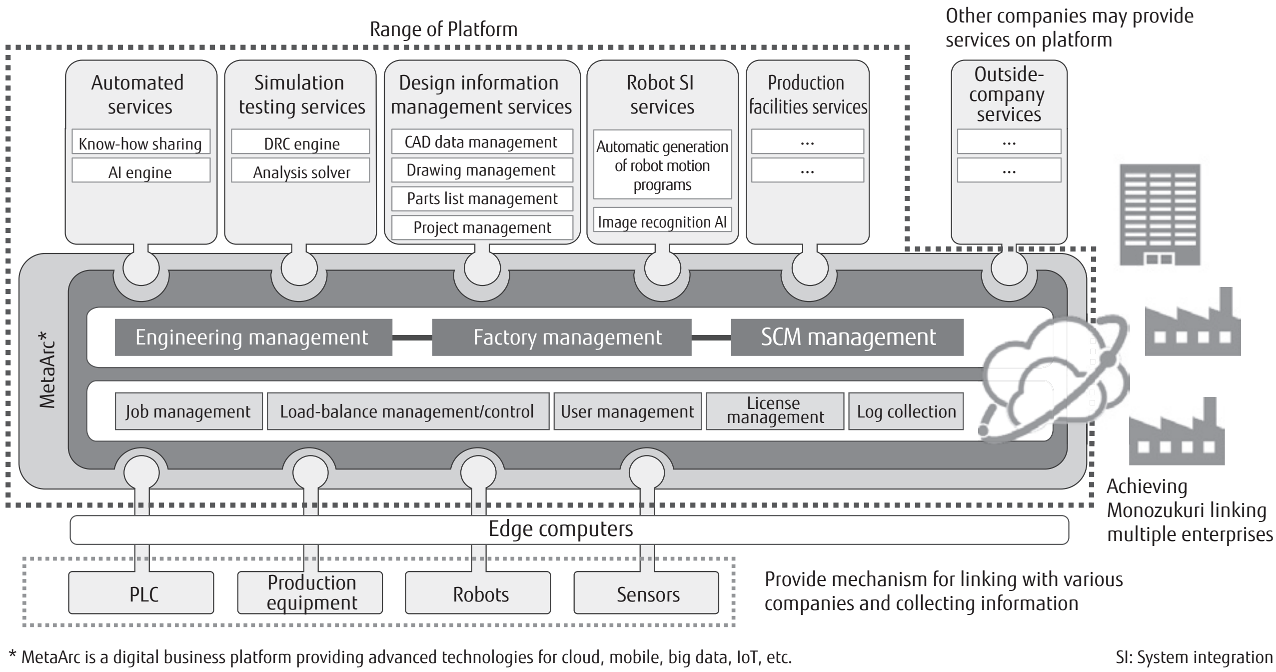


Figure 12
Configuration of digital Monozukuri platform.

enable efficient data exchange among different types of services.

3) Perform real-layer control from the digital layer

This will require the formation of control paths from the digital world to the real world and feedback paths from the real world to the digital world to support in real time the different requirements of each level in Figure 11, from PLM to production facilities. In terms of feedback paths, there will be a need not only for feedback on each level but also feedback from upper and lower levels.

4) Form communication paths with the field

This measure involves the formation of paths for accessing outside information and communicating with customers, suppliers, and partners as well as communication paths on the digital layer to enable secure connections with the platforms of other companies.

5. Conclusion

In this paper, we examined the evolution of Monozukuri in the Fujitsu Group, described the current state of Fujitsu's Monozukuri platform that has supported that growth, and discussed the future outlook for Monozukuri at Fujitsu. Going forward, the plan is to make "smart Monozukuri" a reality through a next-generation Monozukuri platform and to promote digital innovation in Monozukuri. Fujitsu aims to realize its vision of a Human Centric Intelligent Society in the field of Monozukuri and to make far-reaching contributions to the advancement and expansion of the manufacturing industry.

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Akira Ito
Fujitsu Ltd.
Mr. Ito directs advanced technology development and the Monozukuri integrated development environment in Fujitsu's Service Platform Business.

Ken Takizawa
Fujitsu Ltd.
Mr. Takizawa directs production/manufacturing technology development and the promotion of Monozukuri innovation activities.

Akihiko Miyazawa
Fujitsu Advanced Technologies Limited
Mr. Miyazawa directs integrated development environments and advanced technology development.