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Industry 4.0 and Significance for Japanese Manufacturing

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In 2015, Industry 4.0 triggered a situation that can best be described as a boom. While Industry 4.0 remains a hot topic, the year 2016 should be the time to calmly discuss this new industrial trend as part of a company's long-term strategy. Many company executives say "I think I understand the concept of Industry 4.0, but I just don't know where to start." To answer this question, it must be noted that the direction of specific actions that a company should take in order to adopt this industrial change differs depending on the type of industry and the company's position. Therefore, this paper considers the type of industry and the difference in company size in attempting to show the broad directions that a company should follow.

Industry 4.0, a vision proposed by the German government, aims to bring about innovations in the production equipment industry, and promote the design of the modular architecture of this industry and the development of international standards for interfaces between modules. Changes in the industrial structure, as well as changes in players, that have taken place in other industries such as PCs, liquid-crystal-display televisions and semiconductor manufacturing equipment, are highly likely to occur in the production equipment industry as well.

Two trends of overseas companies in relation to Industry 4.0 ---"a smart mother factory" and "manufacturing platform service business" --- are noteworthy as pioneering examples.

It is risky for Japanese companies to disregard these trends. The reason comes from the outlook for management environments over the next several years, which consists of the following two possibilities: (1) in the product market, competition with emerging market manufacturers that are equipped with the manufacturing know-how of developed countries will intensify, and (2) in the capital market (M&A, etc.), competition with manufacturers in developed countries that have incorporated the growth of emerging economies and thus expanded their market capitalization will increase.

I What is Industry 4.0?

1 "Responding to the fast-growing global market" and Germany's strong sense of crisis

(1) Industry 4.0 is a strategy to "respond to the fast-growing global market"

After experiencing various occasions such as conversations with the executives of European and U.S. companies, the authors have come to feel that what lies behind the Industry 4.0 initiative is Germany's greater awareness of the issue of adapting to the global market that is growing at a fast pace in a long-term perspective than of the issue of simply making the most of the technological advancements related to the Internet of Things (IoT).

In Japan, immediately after the collapse of Lehman Brothers, the importance of a long-term strategy was a hot topic of conversations. At that time, it was predicted that the size of the global market for consumer durables would increase from about 600 million in 2007 to about 5 billion in 2025. It was also predicted that failure to successfully develop business in rapidly emerging economies would result in decreased market share and entail high risks of being lost in mergers and acquisitions (M&A) competition in the capital market. Be that as it may, in order to develop business in the product markets of emerging economies, it is no easy matter for manufacturers in developed countries to build a business structure that enables them to generate profits because low-end products often constitute mainstream markets in emerging economies.

Industry 4.0 is the proposal originated by Germany as to how best to respond to the fast-growing global market in terms of methodology. It is more sensible to accept this proposal as one that attempts to redefine the rules of a game rather than proposing a challenge to a new game.

(2) Germany's strong sense of crisis lying behind Industry 4.0

An in-depth look at Industry 4.0 makes us feel that Germany has a strong sense of crisis behind this strategic initiative. This sense of crisis comes from the following: (1) with high market cap, the new Big 4 of the U.S. (Apple, Google, Amazon and Facebook) are revving up their activities to enter new industrial fields such as self-driving cars and (2) engineering skills are rapidly becoming sophisticated in China and India. In recent years, not to mention the development of software, more and more companies than we can imagine have been outsourcing highly sophisticated engineering work. Engineering services outsourcing (ESO) has expanded beyond product design and development, and now encompasses the development of software that underpins the realization of factory IoT and digital simulation.

The authors often strongly feel a healthy sense of crisis that Germany has in that considering the pace at which the technological capabilities of emerging economies are being sophisticated, "if the situation is left as it is now, no one knows whether Germany will be able to maintain its competitive advantage in the manufacturing sector for the next ten years."

2 Cyber-Physical Systems (CPS) and decentralization with the high level of integration in three key aspects

(1) CPS

1) The concept of Industry 4.0 indicated in the report published by Germany's National Academy of Science and Engineering (acatech)

The "Final Report of the Industrie 4.0 Working Group" published by the National Academy of Science and Engineering (acatech) provided the definition of Industry 4.0. According to this report, the second industrial revolution involved the division of labor and mass production with the help of electrical energy, and the third industrial revolution employed robots to achieve increased automation of manufacturing processes. In particular, during the third revolution, robots were controlled through the integration of Programmable Logic Controllers (PLCs) into manufacturing technology. This means that if we are simply discussing robots alone, such discussions are within the realm of the third revolution and outside the realm of the fourth revolution (Industry 4.0). Instead, Industry 4.0 involves the implementation of cyber-physical systems (CPS).

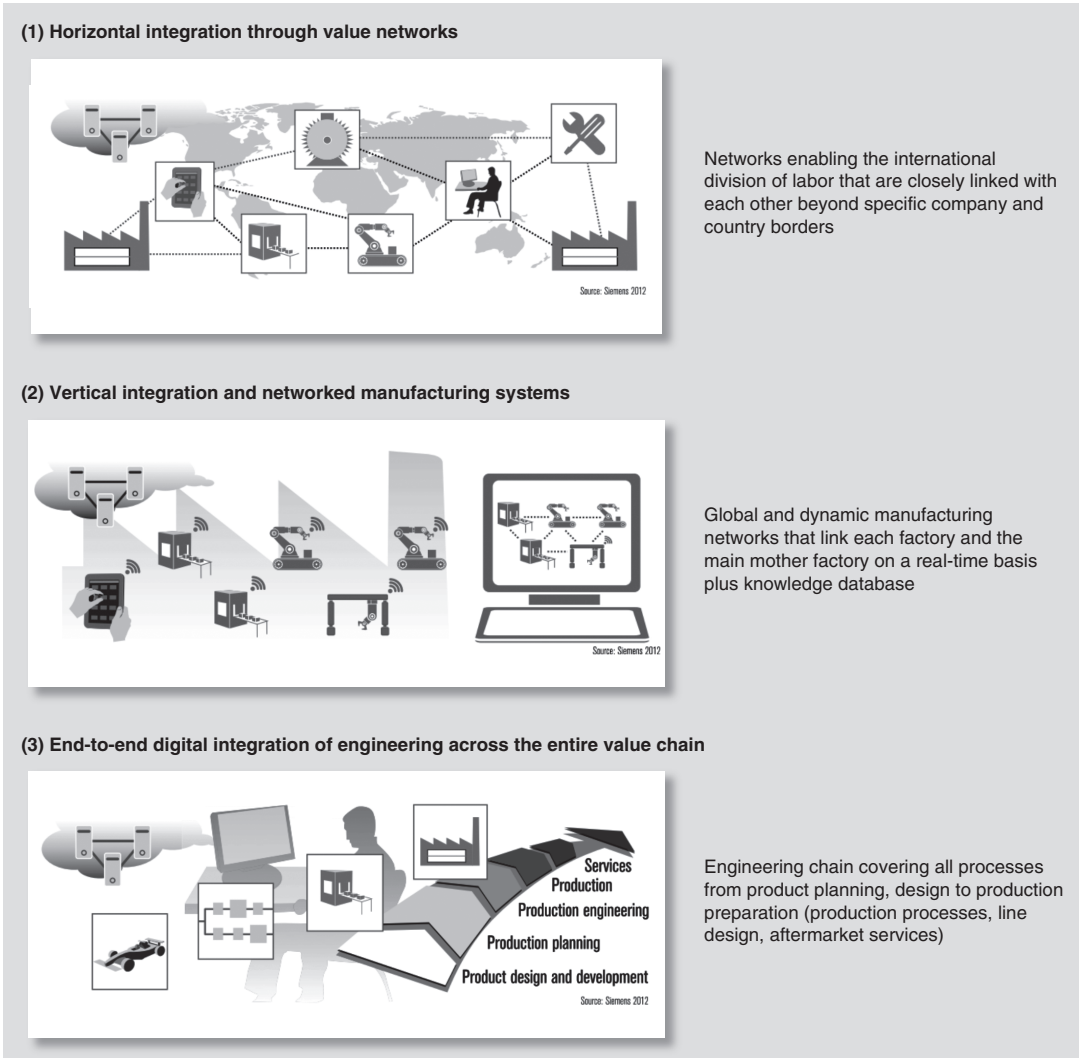
2) The basic idea of CPS

Then, what is the concept of cyber-physical systems (CPS) that is shaping a vision of Industry 4.0? As a matter of fact, CPS is not the term that was first defined by Germany's Industry 4.0. This concept was first proposed by the U.S. National Science Foundation (NSF). "Cyber" refers to a massive scale of digital space that the cloud provides, which we access through the internet. "Physical" refers to real-world space.

Specifically, model spaces (as a mathematical term, "isomorphic spaces;" as a slogan, "digital twin;" and as an easy-to-understand term, "copies") that correspond to physical spaces are created on cyberspaces. Then, models in physical spaces are created on cyberspaces. CPS aims at building a mechanism that enables not only the creation of the 3D design drawings of products and parts, but also the visualization of all corporate activities in the form of models as well as the simulation of such activities including corporate structures. It may be easier to understand the idea of CPS in such a way as that models in cyberspace are used to solve various work challenges occurring in physical space by utilizing a vast array of computer resources in digital space.

Here, work refers to a series of monodzukuri

Figure 1. CPS aims at establishing the "structure of decentralization with a high level of integration in three key aspects"



Source: Compiled based on acatech "Recommendations for implementing the strategic initiative INDUSTRIE 4.0; Final report of the Industrie 4.0 Working Group"

(manufacturing products) in the manufacturing industry and includes product planning, product design, physical analysis (heat conduction, oscillation, stress, etc.), manufacturing process planning, design of production facilities, design of production lines and simulation of production activities. CPS aims to build a mechanism whereby all such work can be done in digital space, and a variety of advanced sensor technologies are used to maintain links with physical space on a real-time basis.

Simply put, the concept of CSP is that simulation such as a popular role-playing game in a genre of video game becomes possible in overall corporate work.

(2) Decentralization with a high level of integration in three key aspects

To achieve the goals of the CPS strategy, the acatech report proposes the implementation of decentralization with a high level of integration in the following three key aspects (Figure 1).

1) Horizontal integration through value networks

"Horizontal integration through value networks" refers to the creation of "networks enabling the international division of labor that are closely linked with each other beyond company and country borders." Here, networks do not simply mean a supply chain of parts and semi-finished products. Rather, these division-of-labor networks also cover product design such as ESO, mentioned in Section 1, and maintenance work in the aftermarket following shipment to achieve close connections beyond company and country borders.

2) Vertical integration and networked manufacturing systems

"Vertical integration and networked manufacturing systems" is a concept that is somewhat difficult to understand. Putting it simply, it is a "smart mother factory." Suppose that your company is running a number of factories overseas. At each factory, various problems occur every day such as short-term breakdowns (instantaneous equipment failure). Basically, the factory experiencing a failure remains responsible for dealing with the problem. However, what is different from conventional factories is that in smart factories, the digital

knowledge database that was created by the mother factory detects the occurrence of the problem, indicates the cause of the problem (the cause is automatically identified based on an analysis of data from a number of sensors attached to equipment) and offers options for solving the problem. The system is so structured that factories throughout the world can access the constantly updated knowledge database.

If a new problem (one that did not occur in the past) occurs or if a problem that was once solved reappears at a certain interval, any factory across the world can make an inquiry to the main mother factory. Upon receiving the inquiry, the mother factory creates a mechanism to promptly resolve the reported problem. In this way, the problems solved and new effective solutions developed through the support of the mother factory are added to the knowledge database.

3) End-to-end digital integration of engineering across the entire value chain

It is reasonable to say that "end-to-end digital integration of engineering across the entire value chain" is a mechanism to achieve the above-mentioned smart factory functions.

Specifically, this means that all engineering information regarding a series of production processes in the manufacturing industry is managed as three-dimensional models, which are always updated to the latest status, for every factory and all equipment throughout the world in the form of CPS. Through such management, every factory can always access the latest information (maintenance history, past problems, etc.) on production facilities, not to mention products and parts, which is used to promptly solve a problem. This mechanism can always be used, even in the aftermarket (the post-shipment stage at which customers are using products), and the information made available through this mechanism is continuously updated.

Many people may have an impression that some Japanese companies have already implemented CPS. However, based on the experience of the authors, the number of Japanese companies that have actually been using such cyber-physical systems is extremely small.

3 Similarity between the concepts of GE and Industry 4.0

(1) General Electric's (GE's) concept

Figure 2 outlines the concept of the Industrial Internet indicated in GE's Industrial Internet Report, to which the idea of Germany's Industry 4.0 was added.

The authors feel that in recent years, under a clear strategy of becoming a company contributing to the development of social infrastructure in the world including emerging markets, GE has been transforming itself to become a company offering software service platforms that enable the optimization of social systems such as air transport and traffic networks, electric power networks and healthcare networks.

In other words, GE's aims are not limited to simply optimizing devices through mounting sensors onto devices that are located at the bottom of the production hierarchy, collecting big data from these sensors and analyzing these data. Instead, the company's overarching goals are to achieve the optimization of each aspect at each level, i.e., at the levels of intelligent devices, system machines, operation and overall systems. Optimization is pursued for the layers of equipment assets, design and maintenance of system machines, operation and social systems.

(2) Similarity between the idea of Industry 4.0 and GE's concept

If we consider Industry 4.0 in the context of the Industrial Internet, it can be said that Industry 4.0 aims at optimizing social systems in the realm of manufacturing. Specifically, the ultimate goal of Industry 4.0 is to optimize social systems through the optimization of not only robots but also of factory lines, factory operation and eventually of global factory management.

(3) "IoT, big data, artificial intelligence"

It appears that because of concern about whether the term "CPS" can be readily accepted as a Japanese term, the expression of "IoT, big data and artificial intelligence (AI)," instead of CPS, has started to be adopted in Japan. Discussions about IoT in Japan are generally based on a bottom-up approach starting from devices and give the impression that "something great could happen if data from device sensors are stored as big data and such data are analyzed by employing AI technologies that will be developed in the future." The reason behind such a tendency may be attributable to an underlying cause of abandoning the CPS concept too quickly.

(4) Flexibility and continuous innovation are keys in the design of social systems

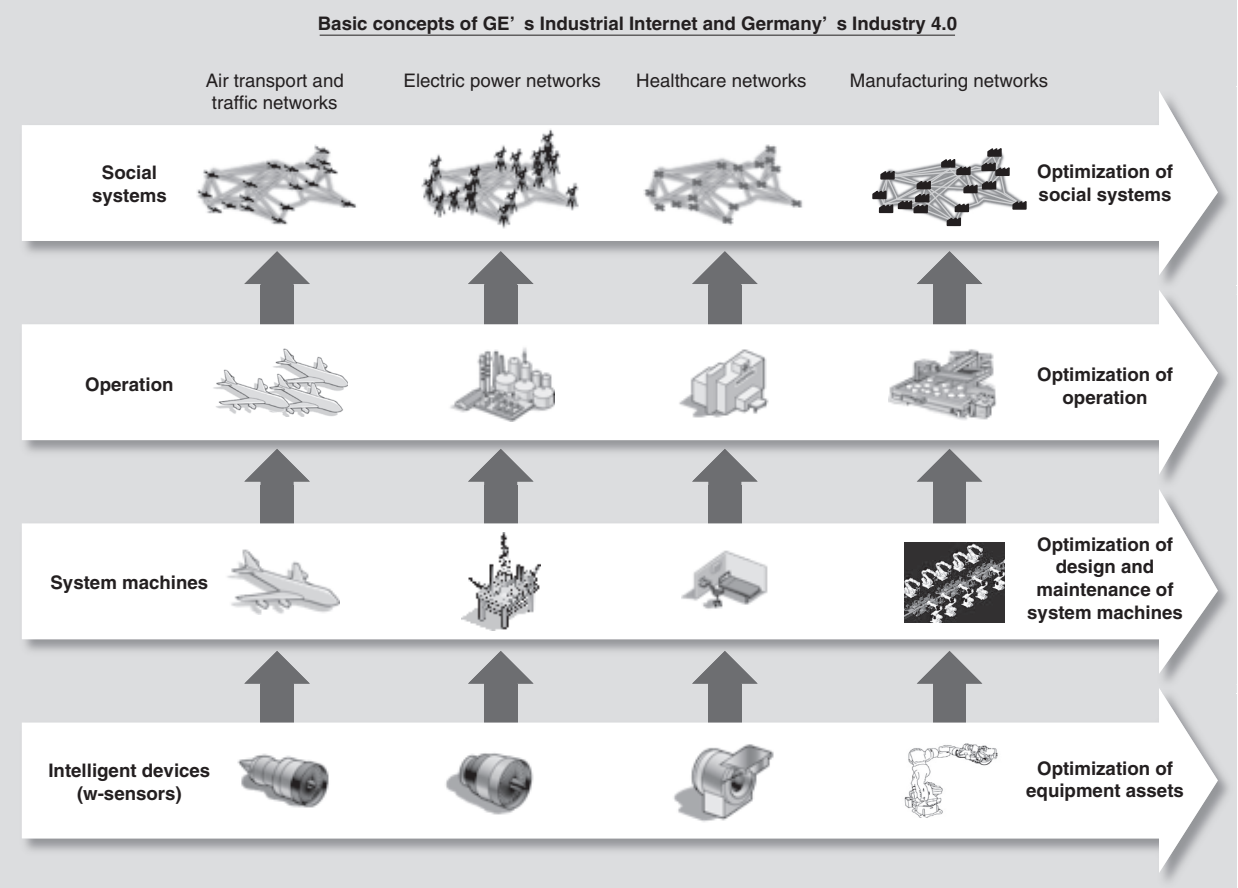
To design vast systems, a generally observed formula is to start from a broad perspective. Starting from the design of social systems and going through the hierarchical structure consisting of several layers will eventually enable the design of the value of devices in factories. Only after going through these processes, can the CPS that is worthy of the term "Industry 4.0" be implemented.

In order to continuously incorporate innovations in vast social systems, a mechanism is required whereby a modular architecture consisting of hierarchical layers is designed and innovations are integrated by replacing modules.

The development of international standards for interfaces between modules is an essential design requirement to incorporate open innovations into huge social systems.

Without the recognition that IoT is intended for

Figure 2. GE's strategy aimed at optimizing social systems and Industry 4.0



Source: Compiled based on GE's "Industrial Internet Report."

efforts to design vast social systems, it would not be possible to understand the importance of the design of a modular architecture having hierarchical layers and of the activities to develop international standards for interfaces between modules.

4 Design of modular architecture for open innovation

In its report, mentioned in Section 1, the German National Academy of Science and Engineering (acatech) asked the German government for "support for the promotion of standardization activities."

(1) Importance of "international standardization" activities, which tend to be misunderstood

The term "standardization," in particular, "international standardization," is one of the terms that tend to give wrong impressions, especially in Japan. Opinions that "if technology is standardized, innovation will not occur; standardization is inconsistent with innovation; and we should be careful about promoting international standardization" constitute no small part of Japanese impressions. However, the standardization we are talking about here is not the standardization of technology itself, but is the standardization of interfaces between modules.

(2) Standardization activities refer to the efforts made to design modular architecture for open innovation

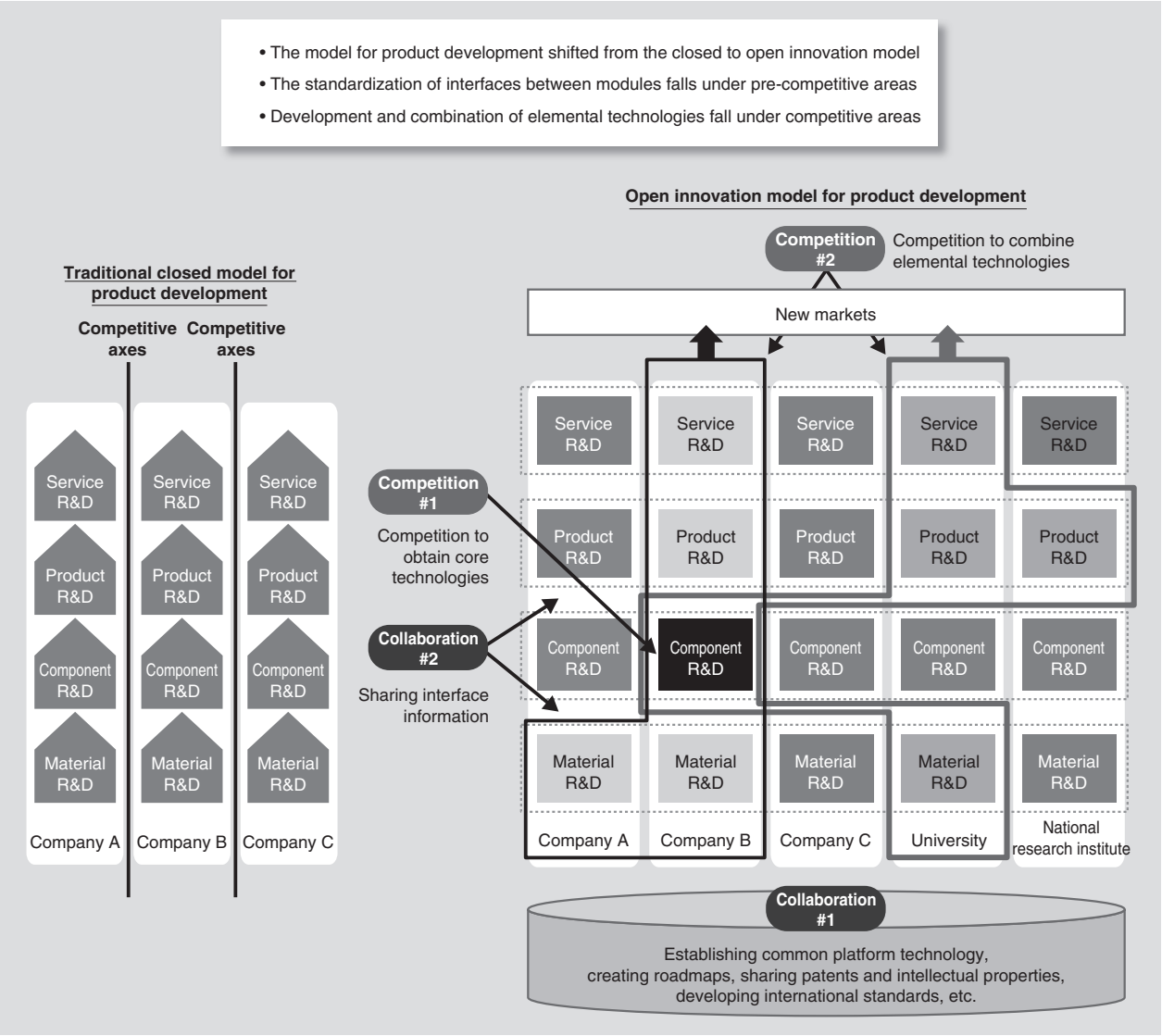
What is essential in understanding Industry 4.0 as an industrial policy is the recognition that Industry 4.0 is "the initiative aimed at 'activities to standardize interfaces between modules as an industrial policy' for the purpose of open innovation."

Figure 3 is a schematic diagram of an open innovation model for product development, which was created by Mr. Takeshi Okada (Director General of the New Energy and Industrial Technology Development Organization). In recent years, the methods of product development have shifted from those of the traditional closed innovation model to those of the policy-based open innovation model.

Specifically, to create a new industry, user companies and vendor companies offering element technologies, all of which are associated with this new area, form a consortium. The policy-based open innovation model refers to one in which this consortium systematically conducts so-called "pre-competitive" activities (as defined by the National Science Foundation (NSF)).

Pre-competitive activities include: (1) articulation of demand for a new industry, (2) modularization of components, (3) standardization of interfaces between modules and (4) creation of an overall roadmap

Figure 3. Design of modular architecture for open innovation



Source: Compiled based on material used in the January 2015 lecture by Takeshi Okada, Director General, Electronics, Materials Technology and Nanotechnology Department, the New Energy and Industrial Technology Development Organization (NEDO) at the "Monodzukuri Nippon Conference."

and reference architecture. In order to encourage open innovation as part of national policies, it is effective to design the modular architecture of a new industry as early as possible and make this architecture widely public.

Conversely, competitive activities include: (1) development and provision of technologies for individual module functions and (2) coordination to combine modules and provision of such coordination service. Item (2) lies behind the rise of an industry that comes under the category of "platform service business," which is described later in this paper.

To facilitate innovation for industries constituting huge systems, the policy-based open innovation model is more appropriate than the traditional closed model because of four reasons. These reasons are attributable to four weaknesses of the traditional closed model. The first weakness is that the more complex a high-tech industry is, the higher the level of difficulty in anticipating a vision of the future (it is difficult to determine the targets of technology development). The second weakness is that even if a product is developed, activities to tap the market (marketing and sales activities) require time and cost. The third weakness is that because of these uncertainties, which incur risk in terms of generating return on investment, it is difficult to collect investment funds within a company, prolonging the period of product development. This problem is symbolized by the recognition shared by many executives concerning R&D, which is "rather than the matter of investing in improving a company's technology development ability, we face a challenge in clearly determining the target of technology development, which results in dispersed investment." The fourth weakness relates to that even if a product is developed, a company must continuously develop and drive innovation on its own because the lack of modularization makes it difficult to accept technology developed by other companies.

The reason why affiliation-based transactions among partner companies and group companies worked effectively in the 1980s is that such business affiliations were relatively successful in dealing with the four weaknesses. On the other hand, Industry 4.0 aims to overcome the four weaknesses by organizing an open innovation platform based on national policies.

1) Being able to quickly identify the target technologies to be developed

Creation of a new industry does not necessarily involve new technologies alone. By designing modular architecture, a company will be able to distinguish the areas where existing technologies can be used from those where new technology modules must be developed. In addition, the company will be able to know when new modules will be required and the size of demand for new services (demand articulation). Such demand articulation enables the company to promptly focus on the target technologies to be developed. As a result, the company will be able to identify the areas at a relatively early stage where it is easy or difficult for the company to develop technology, enabling the company to limit the areas of investment.

2) Being able to articulate user needs at an early stage

Because a consortium in which user industries participate from the beginning of development conducts the design of external functions of a new industry, the risk associated with marketing and sales activities can be greatly minimized.

3) Risk money becomes available

Because the areas of new technology development (missing links) can be defined under the created modular architecture, risk money becomes available from capital markets such as venture capital and hedge funds for technology development involving risks. The effect of being able to raise funds easily from capital markets is immeasurably valuable.

4) Achieving open economy innovation by replacing modules

For less complex compact products, master craftsmanship in a factory may better achieve agile innovation. However, in order to continuously incorporate innovations into products having complex systems, albeit compact, such as smartphones, to say nothing of huge systems such as social system solutions, products/systems must have a structure that is open and is designed to always accept new technologies by means of replacing modules. To enable the continual introduction of new technologies, modular architecture must be clear and interfaces between modules must be made public.

Progress in modularization will accelerate competition in developing individual modules. The market share of a company owning the technology that has become a de facto standard for a successful module will increase, resulting in overall cost reduction. Cost reduction will then lead to further expansion of demand. In this way, growth of the relevant new industry can be further accelerated.

In contrast, when a huge system is created based on the closed model, even if the system is successfully created, a company will face the risk of being in a restricted situation in that a series of subsequent innovations must be designed and incorporated into the system on its own.

The effects of the open innovation model described in 1) to 4) above may shake the very foundation of traditional competition rules in the manufacturing sector. Traditional competition rules relied on competitive advantage and differentiation achieved in terms of both product technology and manufacturing technology. As suggested by the law of entropy in physics, these effects could be seen as the mechanism whereby modules that determine competitive advantage are distinguished based on structured industrial technologies, and an on-off valve is attached to each module for the purpose of information disclosure. It is no exaggeration to say that the open model presents the mechanism that can dramatically transform the industrial structure.

For manufacturers that have overwhelming technological advantages in the early days of a relevant market and are extremely proud of their ability to supply superior products that conform to their strict quality standards that are subsequently established on a progressive basis, the greater their pride, the more likely they are fated to confront difficulties in controlling the entropy generated by their pride. In other words, the open model could be seen as the one that requires an aggressive approach.

II The Essence of Industry 4.0 and Case Studies

1 Deployment of a “smart mother factory” and “manufacturing platform service business”

Industry 4.0 encompasses a wide range of activities. Because of this, many experts tend to point to individual business cases introduced by the acatech report mentioned in Chapter I as examples of Industry 4.0. These cases include an autonomous distributed control system and mass customization as one element of applied cases. Nevertheless, the authors consider that particular attention should be given to two major cases where new approaches are adopted. They involve the deployment of a “smart mother factory” and “manufacturing platform service business,” which are introduced in the report in a form that integrates individual business cases.

2 Case of "smart mother factory:" Bosch's Blaichach plant

A well-known example of a smart mother factory is Bosch's Blaichach plant. In Blaichach, Bosch operates a smart mother factory that heads a group of 11 plants worldwide, which produce the same kinds of automotive parts and components; 5,000 standard equipment items have already been networked.

In this plant, a common knowledge database was created that contains on-site experiences such as the causes of instantaneous equipment failures, and is utilized at the same type of plant throughout the world. For a new problem that did not occur in the past, the plant experiencing the problem calls the system center, which then provides advice based on advanced engineering analysis. After the problem is resolved, the solution is entered in the database.

The reason why Bosch was able to develop this mechanism is that its Blaichach plant and 11 plants that produce the same products worldwide all use machine tools produced by Bosch. If those plants were to use different machine tools and different control systems such as PLC, it would be no easy task for a company to realize a "smart mother factory" at present.

However, if progress is made in the modularization and standardization of module interfaces, which are ongoing under Industry 4.0, machine tools that conform to specific standards, not necessarily those produced by Bosch, are all able to be connected via networks. It is expected that by doing so, smart mother factories can be developed and operated for a much wider range of factory groups.

3 Case of "manufacturing platform service business:" Siemens service

Since 2007, Siemens has acquired multiple groups of software products through M&A at the cost of about 1 trillion yen. These products are managed under the concept of Product Lifecycle Management (PLM) in the fields of product design and production equipment design. Interoperability among these products is ensured by the platform of Totally Integrated Automation (TIA) in the fields of production processing design and manufacturing execution management. By so doing, Siemens has been building a structure in which end-to-end integration of engineering across the entire value chain is achieved by a single group of connected applications.

Furthermore, Siemens has started to offer a so-called "manufacturing platform service." In this service, Siemens performs the functions of a customer company's production engineering department. On behalf of a customer company, Siemens conducts overall work such as work in the production preparation process (design, procurement and development of production equipment), continuous productivity improvement activities, analysis of a cause of an instantaneous failure and predictive maintenance.

A specific example of this service is that offered for a joint venture of BMW Group and Brilliance China Automotive Holdings in China. The service for a plant of this joint venture has the following four features. First, Siemens provided full turnkey service in which all work ranging from design, procurement of equipment, materials and services, construction to trial operation was collectively contracted. Second, factory floor workers only conduct simple control and are not required to have proficiency in related skills. Third, even without proficiency, the plant produces all of BMW's specific models using a single production line (multiproduct, variable quantity production). Last, Siemens was able to achieve a very high operating rate of more than 99 percent and implement high-quality production.

In the December 2014 committee meeting of the Study Group for Creating Japan's Earning Power, which was established by the Ministry of Economy, Trade and Industry (METI), Siemens's full turnkey service, mentioned above, was one of the topics discussed. A production system under the Industry 4.0 landscape does not require factory floor workers to have proficient skills, whereas the style of multiproduct, variable quantity production adopted in Japan requires workers to have proficiency. Nevertheless, employees who finally reached the stage of sufficient skills tend to switch jobs. Even though a Japanese company intends to expand its scale of production, it is often short of human resources. Frequent job hopping would entail the risk of know-how leakage. More than anything, the fact that Japan's system takes several years to get used to is a fundamental problem. It merits consideration that the METI committee meeting warned that "an Industry 4.0 production system is likely to have competitive advantage" [Note].

III Impact on Corporate Management

1 Importance of converting tacit knowledge to explicit knowledge, creating organizational knowledge and digitizing data

Statistical surveys on the number of companies that converted tacit manufacturing know-how to explicit knowledge in the Japanese manufacturing sector are still few in number. As such, based on our experience, the authors assume that many Japanese manufacturers have production engineering departments that are extremely busy because of delays in the development of explicit knowledge.

For example, the authors suppose that many companies have been experiencing the following situation as an everyday affair. "An engineer in the production

engineering department was assigned to start up an overseas factory. The engineer planned to stabilize quality in six months and return to Japan. However, it actually took twelve months to stabilize quality, after which the engineer returned home. After less than one month had elapsed, the local factory asked the engineer to revisit the factory because quality had become unstable. Therefore, the engineer had to again travel to another part of the world."

Considering this situation, even before the Industry 4.0 concept was proposed, companies should have addressed themes such as converting tacit manufacturing know-how to explicit knowledge, creating organizational knowledge and digitizing data in production engineering departments.

2 Importance of a smart mother factory

Considering the rapidly growing global market, it is vitally important in terms of not only corporate strategy but also of business strategy to establish the functions of a "smart mother factory" (the idea of creating an integrated control center and a knowledge database containing manufacturing know-how and of not necessarily requiring many skilled workers in local factories), which is pursued by Industry 4.0, and to develop a company's ability to deploy these functions anywhere and at any time along with an IT platform.

A "smart mother factory" could be called a systematized box of knowledge. It could also be called a virtual conference room where all workers in local factories throughout the world can discuss the next generation of best-possible monodzukuri (manufacturing) based on their handiwork and experiences.

3 Deployment of a "manufacturing platform service business"

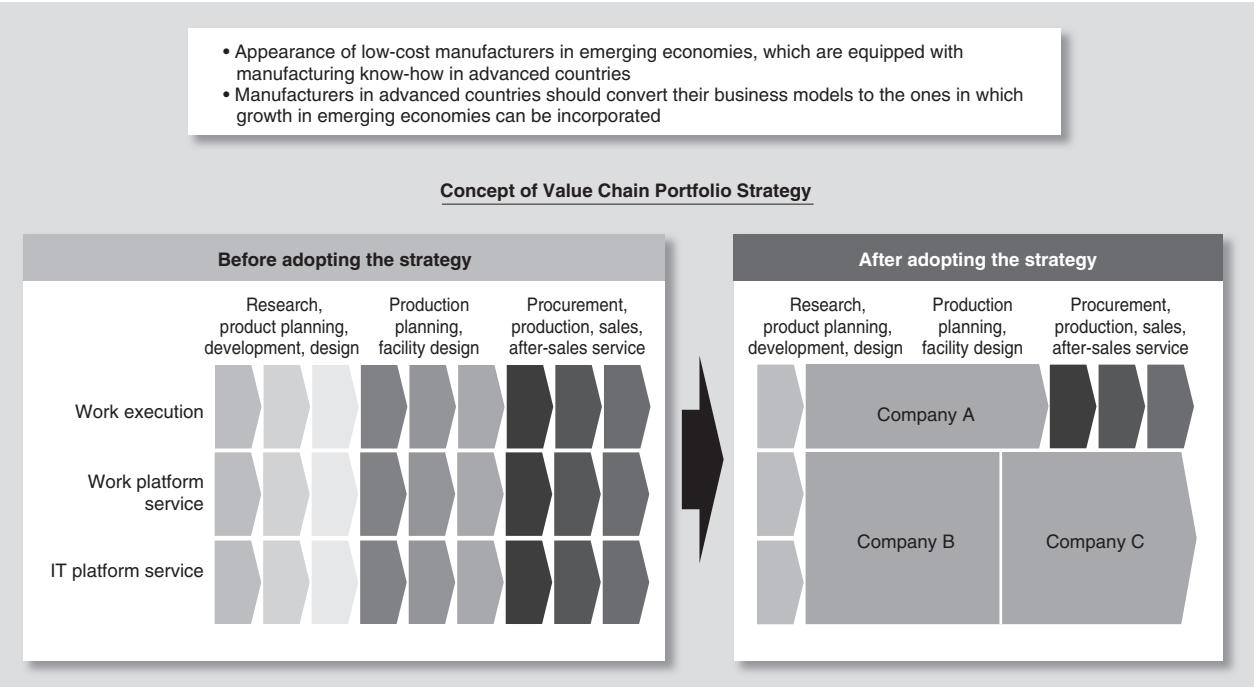
Once the business know-how of a smart mother factory is established and a related IT platform is developed, it is considered relatively easy to deploy a "manufacturing platform service business." Establishing management resources requiring zero marginal cost by building an IT platform and using the cloud to conserve technologies by turning them into a black box would be effective and essential.

In particular, if the problems inherent in the production equipment industry, which include: (1) the industry is significantly affected by the ups and downs of business cycles, resulting in large fluctuations in earnings and (2) this tendency makes it difficult for a company to make "bold" investments in internal resources, are considered, it would be highly significant to add a company engaged in a service business, which generates relatively stable earnings and requires only a relatively small number of fixed assets, to the portfolio of companies under the umbrella of the holding company.

Such being the case, it would be important for a manufacturer to seriously consider the deployment of a "manufacturing platform service business," which some European companies have already launched, even though trial and error learning would be unavoidable to a certain extent.

Manufacturers, who put enormous time and effort into monodzukuri, would probably want to achieve the development of a smart mother factory and IT platform on their own. In addition, they would probably not want to easily convert tacit factory floor know-how into explicit knowledge, and they may feel strong resistance to

Figure 4. Using outside platform services to quickly respond to rapidly growing markets



digitization because they might consider that digitization could easily lead to increased risks of data leakage. Especially because manufacturers have these concerns, the authors believe that studying the deployment of a service that caters to the needs of other companies would paradoxically become the key to creating measures to protect a company's own competitive advantage.

4 Need for "value chain portfolio strategy"

If building an IT platform takes time and if it is difficult for a company alone to convert tacit mass production know-how to explicit knowledge, create organizational knowledge and digitize data, it would be sensible to quickly acquire the ability to deploy business at a fast pace in a scalable manner through the use of outside platform services.

To adopt this approach, a company should first identify its core competencies (competitive advantages) across the entire value chain. For the areas of core competency, if proprietary technologies can be turned into a black box through the use of IT, a company should further improve such technologies until outside services become available. For other areas, a company should buy time through the use of the world's leading outside platform services. Full consideration should be given to this strategy (i.e., value chain portfolio strategy) (Figure 4).

IV Basic Concept of the Adoption of Industry 4.0 by Japanese Companies

The concept of the adoption of Industry 4.0 by Japanese companies varies significantly by industry type and company size. The concepts for five major business types are introduced in the following sections.

1 Major manufacturers (OEM, major automotive parts and components, etc.)

In the case of major manufacturers, especially leading automotive parts and components manufacturers, the concept is relatively clear. By pursuing the goal of firmly retaining mid- and long-term competitiveness, these manufacturers should continue to maintain optimal production systems from a global perspective. In this context, modularization serves as a spur in the production equipment industry.

In this type of industry, the share of sales and production activities conducted in Japan is already less than 50 percent in many companies. Depending on the level of technological sophistication available in overseas offices, local factories will no longer have a reason to follow the intention of the head office in Japan, that is, all production equipment and software must be made in Japan.

Rather, a company should build a mechanism in advance that always enables the selection of optimal tools through the replacement of existing ones, which creates a means of hedging against risks. Relying on technologies particular to a specific group is not necessarily meaningful in terms of risk management.

Challenges facing major manufacturers include "redesigning global operations and rebuilding production technology management functions." To keep abreast of the fast pace at which global markets grow, they must start up factories across the world in a timely manner, and engage in optimal mass production and quality management. Engaging in all of these functions/activities in the current framework of "local factory plus support from the head-office factory" (that is, a limited number of employees in human resources available in the current production engineering organization) has already met limits.

In particular, one of Japan's weaknesses that is being uncovered is that "there is a limit with respect to the procurement of engineering resources in the production engineering department" in that engineers dispatched by the head office in Japan must travel all over the world to support overseas factories. From a mid- to long-term perspective, having production bases in Japan, in and of itself, is likely to put a company in a position that is inferior to its competitors in terms of increasing the number of engineers.

Of course, the training and education of local staff is important. Also important are converting tacit manufacturing knowledge particular to a company into explicit knowledge, creating organizational knowledge and creating a common "production technology multi-language database." A mechanism must be built to synchronize on-site problem-solving activities to continuously update this database.

In addition, a hierarchical structure must be created for a group of factories that manufacture the same types of products. A smart mother factory should be developed to help these factories when they have difficulties in resolving a problem.

For this purpose, investments are needed in systems such as product lifecycle management (PLM) and manufacturing execution system (MES), which manage not only product design information but also manufacturing process information on a global scale. Japanese manufacturers have lagged behind their counterparts in other countries in terms of introducing these systems on a full-scale basis.

2 Small and medium-sized manufacturers

For supplier selection in Europe and the U.S., there is a growing tendency among customers (major manufacturers) of small and medium-sized manufacturers to include

local vendors in their choices. It is obvious that, from a long-term perspective, being unable to keep pace with customers' overseas deployment will eventually result in fewer transactions, even in the Japanese market. However, most small and medium-sized manufacturers have a relatively weak production engineering department in terms of size, and by no means have sufficient human resources for global deployment.

For these reasons, one sensible option for small and medium-sized manufacturers is to make good use of the "manufacturing platform industry," which is expected to grow in the future, whereby the latest software and replaceable production facilities are used as a service. By so doing, they will become able to deploy stable production bases quickly at a relatively small risk.

There is no need for them to solely invest in the construction of information systems and operational infrastructure for production facilities from scratch. Rather, a combination of various manufacturing platform services should be used, and efforts should be made to retain a company's competitive advantage by making investments focused on enhancing its particular know-how. The rise of a wide variety of manufacturing platform services is good news for small and medium-sized manufacturers.

3 Major companies offering production equipment and related products

In the past, the basis for the competitive advantage of major companies offering production equipment and related products was to build and provide "production equipment plus control software, etc." in an integrated manner. Because these companies developed all resources at their own expense, their current technological capabilities and organizing abilities are high in extensive areas.

However, the moves of Industry 4.0 aim to modularize the structure of this production equipment industry and give rise to innovations that are destructive to this industry. While these attempts will not necessarily be successful, there is no denying that changes in the industrial structure similar to those that occurred in the PC industry could happen in this industry.

Because of such risk, companies in this industry should, at least, consider the creation of a portfolio of strategies. That is, for the time being, companies should maintain the current, high-quality, vertically integrated business. At the same time, they should consider the development of new strategies and businesses for the European and U.S. markets where it was not necessarily easy for them to participate in the past.

In other words, it would be effective for them to launch the following new businesses: (1) adopting a sales strategy of selling their own core technologies in units of modules by drawing on the predominance of such technologies, (2) coordinating (line building) business to combine modules including those made by other companies to tailor to customer needs, and (3) business to continue to provide total maintenance service for equipment and offer continuous kaizen (improvement) activity service.

By standing in the customer's position, companies can put themselves in a position where the real challenges facing customers that were difficult to identify in the past can be solved together with customers. It would be effective to reflect these solutions in the development of new products.

Even so, from the short-term perspective, there is a risk of a conflict of interest between the product development business and the service business, which takes the part of customers. To avoid such a conflict, it would be even more effective to start a service business as a separate company.

4 Small and medium-sized production equipment manufacturers (including related control software)

The small and medium-sized equipment manufacturers that own "brightly shining" production technology have thus far grown primarily through transactions within a major company group. The moves towards modularization and international standardization that are taking place as part of Industry 4.0 are highly likely to bring big business opportunities to these manufacturers.

A company's own technology that provides it with competitive advantage has thus far been utilized only within a group's umbrella companies. However, in the future, by making their interfaces compatible with international standards, a company can make a big jump to deploy business in the global market. It is highly likely that these companies will be able to engage in technological tie-ups, alliances and mergers and acquisitions (M&A) on a global scale.

Actually, small and medium-sized European companies have already entered the Chinese and Japanese markets and have been expanding their businesses. There are plenty of business models. One of the aims of Industry 4.0 is the acceleration of global deployment by small and medium-sized companies.

5 Production equipment line builders (companies providing equipment)

While there are many line builders in Europe, Japan also has prominent line builders, albeit small in number.

Industry 4.0 also provides new heaven-sent business opportunities to line builders. Line builders have already been offering "coordinating (line building) services whereby a company's own modules and those of other companies are combined and tailored to customer needs." Any further progress in modularization and standardization of interfaces between modules will

expand the range of choices and increase the value of optimization. The ability to evaluate new technologies constitutes the essence of line builders.

Furthermore, the aim of globally deploying a "business to continue to provide total maintenance service for equipment and offer continuous kaizen (improvement) activity service" can be relatively easily achieved by making use of a "production line operation software platform," which is expected to be offered in the future. Indeed, many small and medium-sized manufacturers already have relatively high needs for such services.

The major concerns of line builders include sharp demand fluctuations caused by the fact that capital investment is influenced by business cycles and product lifecycles. Because of these fluctuations, it is often difficult for them to secure human resources to meet peak demand, making it difficult for them to achieve continuous business growth. Such being the case, by using a platform service and by increasing the extent of the continuous service portion within the entire business, business stability will be enhanced and the securing of human resources will become relatively easy. By so doing, companies can reduce risk, enabling them to expect accelerated growth.

V Positioning Industry 4.0 in the Management Strategies of Japanese Companies

1 Industry 4.0 is an inevitable theme for Japanese companies; companies should start studying their long-term strategies (5 to 10 years)

The authors do not believe that there is a high probability that the current Industry 4.0 trend will have a crucial impact on Japanese companies within the next three years. However, if a span of five to ten years is considered, it will certainly become an essential theme for their management strategies. It is risky for them to ignore this trend and do nothing.

The reason comes from the outlook for management environments over the next several years. Specifically, the outlook consists of the following possibilities: (1) in the product market, competition with emerging market manufacturers that are equipped with the manufacturing know-how of developed countries will intensify, and (2) in the capital market (M&A, etc.), competition with manufacturers in developed countries that have incorporated the growth of emerging economies and thus expanded their market capitalization will increase.

To effectively cope with these possibilities, companies should develop long-term strategies covering the next five years or more, which are different from an ordinary management plan, based on scenario writing that considers destructive innovations. Moreover, the activities of staff members who engage in planning these long-term strategies must be included in continuously conducted organizational activities.

In planning these strategies, focus should be given to "value chain portfolio strategies" in addition to product/service portfolio strategies. Specifically, the following issues should be addressed: clearly defining a company's core modules and determining the modules and layers on which a company creates value; considering the methods of conserving core modules in a black box by means of IT; determining a business model in which the resources of emerging economies can be used as leverage; and exploring the possibility of expanding business through the use of IT platforms. On top of these issues, it is important to develop measures to cope with various scenarios such as that involving the appearance of a rival company that sets out to compete by making maximum use of the latest platform.

2 Choosing effective study team members is important

A careful approach should be taken in choosing study team members who engage in planning strategy discussed above. Generally speaking, many companies do not have employees who consider strategy for a span of five or more years. Moreover, the IT department employees may not necessarily be good at addressing these themes, which involve a high degree of freedom. In addition, study activities may not necessarily be completed in a short period of time, and could require continued efforts.

Considering these aspects, a company's next-generation "ace" employees should be assigned to this study team. Furthermore, this team should be a diverse team consisting of employees from organizations responsible for many different areas such as product strategy, technology strategy, financial strategy, IT strategy and marketing. It is also important to gather wisdom from around the world.

3 Values unique to Japan should be identified, thereby proposing new initiatives for global manufacturing

U.S. companies have an overwhelming presence in the IT industry. While U.S. presence poses a threat to German and French companies, these companies consider themselves as leading players in developing new production systems in the field of the Internet of Things (IoT) in manufacturing. Even under circumstances in which the concepts that European and U.S. companies tend to lead (e.g., systematization, converting tacit knowledge to explicit knowledge and modularization) are highly likely to prevail, revolutionary mechanisms

that do not rely on database structure began to function in the world of IT systems. Nevertheless, the essence of the most vital information and knowledge in manufacturing lies in "factory floor information (things)," which is accumulated based on work having more of a human nature.

In the field of IoT in manufacturing, one question is whether it is possible to redesign the vital roles of human beings and design new systems that enable maximum use of such roles. The global leaders in next-generation manufacturing would be none other than those companies that can successfully incorporate experience values and inference methods in terms of failures and successes involving factory floors and workers into new systems. Creators of such systems would not be limited to developers and white-collar workers. Because workers on factory floors who have worked together with the developers and white-collar workers have accumulated a wealth of intuition, skills and experience through their handiwork, the participation of these engineers and workers is essential.

Success cannot be achieved by copying European and U.S. companies. To pursue the IoT in manufacturing, we should humbly learn their positive aspects and make the most of the results of such learning. At the same time, we should discover something that cannot be achieved in extension of their thinking, develop the idea of involving all employees including factory workers, and find out the value derived from such involvement. This way of thinking would lay the foundation for the concept of a new social system in the manufacturing sector.

VI Key Requirements for Industry 4.0

The key requirements for Industry 4.0 include the ability to re-establish global manufacturing operations and engineering ability. Even though not discussed in this paper, it is also important to design and implement work activities and functions in the following six areas on a global scale. These areas of activities and functions have nearly become commonplace in overseas companies. As a matter of fact, the concept of a smart mother factory is only one part of these activities/functions.

- Introduction of an organizational decision-making model for global marketing, determining the time to launch new products, capital investments and M&A (S&OP)
- Activities to plan, design and develop products/services (business models) (global product development functions: PLM)
- Design and operation of supply chains for materials, parts, assemblies, etc. (global SCM functions)
- Activities to design, operate and maintain production equipment/line control systems (production engineering center functions)
- Production activities, equipment maintenance and factory operation (creation of knowledge database on manufacturing know-how: MES)
- Attempting to realize a manufacturing servitization revolution and business model innovations

Furthermore, a manufacturer needs to develop a new organization that performs the above-mentioned functions in the capacity of a global head-office organization. Naturally, the effective use of IT is essential. This is because a company cannot "fight with its bare hands or bamboo spears" in its organization-wide efforts to acquire the abilities to quickly deploy business in a scalable manner in the fast-growing markets.

Incidentally, many people think that Industry 4.0 is a trend that is only occurring in the automotive industry and automotive-related industries, and has nothing or little to do with other industries. However, the authors consider that its actual status is different. Because the automotive industry requires high quality management standards, sophisticated division-of-labor systems and advanced production management abilities, the business model in which "an extremely large number of entities smoothly conduct work by using open cloud services and in the framework of an international division of labor" has at last become a reality. Many companies in other industries such as apparel fashion, social infrastructure (civil engineering, construction, maintenance, etc.) and international logistics have already adopted similar business models. The "fourth industrial revolution" is already a reality in many other industries.

Notes:

Siemens provided full turnkey solutions to BMW's assembly plants in China. A production system under the Industry 4.0 landscape only requires factory floor workers to conduct simple control (know-how on complex control is conserved in a black box) and does not require high proficiency.

In contrast, the style of multiproduct, variable quantity production adopted in Japan requires factory floor workers to have proficiency in many aspects. This style tends to entail the risk of know-how leakage. For these reasons, an Industry 4.0 production system is likely to have competitive advantage (excerpt from material of the December 2014 committee meeting of the Study Group for Creating Japan's Earning Power, the Ministry of Economy, Trade and Industry).

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