Review

"The 4th Industrial Revolution and Economies of System"

The need for industrial system innovation in Japan from the perspective of paradigm shift

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Abstract—The 4th Industrial Revolution (I4.0) and Digital Transformation (DX) require concurrent transformation in various aspects of the industrial system and its surrounding social systems. These various aspects are business models, the architecture and coordination mechanisms of the industrial system, the methods of product and solution development, the competitive environment, industrial and science/technology policy, adult education, approaches to work, etc. These transformations are being driven by a paradigm shift.

In many cases, Japanese companies' approaches to I4.0 and DX have been based on functional silos, produced changes that are too slow and small, and have rarely led to full-scale investment. The reason is that it is not easy for Japanese companies to adapt to the new paradigm, because the new paradigm is different from the paradigm that has supported the past success of Japanese manufacturing companies. It is essential that Japanese companies and the government work from a comprehensive and long-term perspective to design systemic transformations under a change management methodology for industrial and social systems based on "economies of system".

Keywords—The 4th Industrial Revolution, Digital transformation, industrial and science and technology policies, paradigm shift, open innovation, open service innovation, the power of modularity, systems engineering, system transformation, economies of system.

1 Introduction

At the "Study Group on the 4th Industrial Revolution and Systematization" conducted four years ago by the Transdisciplinary Federation of Science and Technology (Hidenori Kimura, Chair) [1], 12 participants including the chair held a wide-ranging discussion on the group's theme and made proposals that contained bold hypotheses.

The Study Group analyzed "Japanese weaknesses caused by lagging systematization" and "the background of the lag in systematization."

The keyword "Digital Transformation (DX)" established itself as a phenomenon for observation after the Study Group; although there have been many forays into cutting-edge technology utilization (proof of concept (POC)), particularly at major corporations, these have not reliably resulted in full-scale investment. Meanwhile, foreign institutional investors have shown interest in medium-to-small-scale manufacturers based on expectations for open innovation, but have proceeded into agreements in only few cases. (For convenience, this article treats I4.0 and DX as synonyms.)

Behind these phenomena lies the issue of inadequate explicit knowledge utilization and organizational knowledge utilization among management, and of lagging "systematization".

But if systematization is lagging among Japanese corporations, what are the factors behind this?

The following three points warrant consideration as such factors. (1) I4.0 and DX require revolutionizing the structures and regulatory mechanisms of the industrial system. As a result, it may not be sufficiently acknowledged that society is living through a paradigm shift which will require systemic reforms – in other words, simultaneous and parallel reforms – of our basic thinking about a wide range of industrial and social-systemic fields, specifically our approach to business models and securing competitive advantages, to target markets, value creation and corporate strategy, to performance evaluation, to product and solution development, to fundamental industrial policy and science and technology policy, and to work and adult education.

(2) The new paradigm will use "economies of system", which achieves economic efficiency by improving the long-, medium- and short-term environmental adaptability of the entire industrial system including users (see "dynamic capability" below).

A representative business model in this regard is the "product service system" (PSS), which achieves scaling-out by utilizing "cloud software", a price-destroying and zero-marginal-cost management resource; the structure of the industrial system is shifting to a horizontal network structure (ecosystem) in which PSS will be linked in an open and flexible manner.

(3) The new structure for business models and industrial

systems will be very different from the product sale business model centered on ((product) spot) markets that supported the past successes of Japanese corporations, in which companies compete over quality and cost within vertical chain pyramid structures of high-volume production and hierarchical subcontracting, developing products through self-sufficient, fine-tune integration [*suriawase*] (within corporate groups) in pursuit of so-called "economies of scale".

I believe that designing "systemic transformations of industry and society" from a comprehensive and long-term perspective will be essential to our response to this paradigm shift.

The structure of the article is as follows.

- Obstructed State of Japanese Corporations vis a vis I4.0 and DX
- Understanding I4.0 and DX from the Perspective of Systematization
- The 4th Industrial Revolution Reconsidered
- The Various Phases of the Paradigm Shift Demanded by Systematization
- Research on the Required Systemic Reforms, and Methodology Therefor

2 Obstructed State of Japanese Corporations vis a vis I4.0 and DX

Prof. Michael Porter of Harvard Business School recently commented on the challenges facing the Japanese economy and corporations [2].

"When you think about economics and corporations in Japan, what grabs your attention is the low growth rate and low productivity. Japan has excellent craftsmanship as well as high educational standards and technical prowess that has been built up over a long time. It should surprise us that growth and productivity are low in spite of these strengths.

"One of the biggest problems I see in the background is the relative lack of enthusiasm for DX. Companies today need to be using digital technology in production and distribution so they can measure and analyze data. If Japanese companies did this their productivity would rise, but you don't actually see it happening. Compared to companies in other countries, Japanese corporations do not emphasize the role of the CIO (chief information officer). In Japan, even CIOs themselves don't appear see the importance of their roles, and don't really understand what it is they should be doing."

Many top managers respond to Prof. Porter's observations by saying something to the effect of, "The challenges facing Japanese corporations can be explained to a large degree in terms of the macroeconomic environment and macroeconomic policy, and are therefore not problems that can be resolved through corporate managerial effort. Because of this, Professor Porter's observations are not appropriate to our situation." However, we cannot simply ignore the refined sentiments and candid views of a world-renowned scholar. Also, there seems to be no denying that many corporations are hesitant to make full-scale investments in DX, despite holding large amounts of cash in their internal reserves.

Below, I introduce multiple recent phenomena that I have observed around me – albeit with little statistical support.

2.1 Efforts and Problems for DX at Large Corporations

(1) Lots of POC but Little Real Investment

Society 5.0 and DX have been widely discussed, and at Japanese corporations as well, for component technologies there have been many forays into cutting-edge technology utilization (POC), including IOT, Big Data and AI, and these have been covered in newspapers, business magazines, and other mass media outlets. However, at Japanese corporations, much of this POC has been evaluated as individually successful without necessarily resulting in full-scale investment in/by the overall company. The purposes of DX for corporate management overall are just beginning to be examined anew.

What this reveals is a tendency to design POC from a bottom-up partial organizational standpoint, and a lack of clarity as to the effectiveness of DX investment for management as a whole. Furthermore, the reason for this is that business operations for overall management are not being treated as a system, and that "system structures" and business operations – in other words, "system regulatory mechanisms" – are not being analyzed or designed. It appears to be that organizations responsible for business operations have not been put in place from the perspective of companies as a whole. In leading corporations overseas, it is commonplace for there to be organizations responsible for these areas.

(2) Weak Technology Transfer Power for Scaling-Out

A still-unresolved challenge that is receiving more attention as an issue confronting Japanese corporations is weak technological transfer power for overseas expansion, M&A, and PMI. Achieving sophisticated technology transferability by turning manufacturing technologies and manufacturing management technologies into explicit and organizational knowledge is a major aim of I4.0 and DX efforts overseas; in Japan, by contrast, this is rarely taken up as a relevant topic, and in most cases, the focus appears to be on utilizing component technologies.

(3) Importance of Dynamic Capability

Furthermore, recently, responding to geopolitical risks, such as U.S.-China tensions and the global pandemic, has become a major issue. In corporate management, it is becoming more and more important to achieve "dynamic capability", in which various manufacturing technologies and manufacturing management/operations technologies are converted into explicit and organizational knowledge, and into cloud services using software, thus making it possible to adapt nimbly to environmental changes.

As in (2) above, this paradigm has become a major objective of I4.0 and DX overseas, but seldom seems to be taken up as a relevant topic in Japan.

2.2 Efforts and Challenges for DX at Medium-to-Small-Scale Manufacturers

(1) Rising Interest and then Disillusionment from Foreign Institutional Investors

Foreign institutional investors are beginning to show strong interest in Japan's medium-to-small-scale manufacturers, but this curiosity rarely develops into full-scale investment. Below, I consider a prototypical case study involving a Southeast Asian investment bank and a local bank in Japan.

Suppose that the investment bank has met with multiple local banks, indicating a desire to invest in medium-to-small-scale Japanese manufacturers and expand business in partnership with a Southeast Asian manufacturer, and requesting introductions. The investment bank indicates that its interest is based on the extremely strong product workmanship precision, manufacturing technology, and quality control capabilities of Japanese manufacturers. The local bank provides a one-week tour, introducing ten medium-to-small-scale manufacturers in the area. (The local bank expects that it can secure a deal worth tens of billions of yen.)

However, the investment bank's remarks on the last day of the tour come as a total surprise to bankers at the local bank. "This is difficult for us to say, but unfortunately, not one of these companies satisfies our eligibility requirements for investment. Their manufacturing management technologies or business management technologies rely on personal efforts and have not been systematized or converted to explicit or organizational knowledge; scheduling is conducted at white board meetings; quality control is based on the experience and intuitions of senior managers; and estimated costs are calculated on Excel spreadsheets. Neither the standard cost accounting nor the cost variance analysis recommended by the WTO are being conducted, and the companies aren't even utilizing low-cost ERP. What is going on here? To be honest, we almost can't believe what we're seeing. Even if we partnered with these companies, we wouldn't be able to exchange technology with them. Can you show us a more normal company?"

This is evidence that the rate of IT adoption at Japanese local medium-to-small-scale manufacturers is lower than the IT adoption level at some medium-to-small-scale Southeast Asian companies – or perhaps, that the Japanese companies see little value in IT adoption and have no enthusiasm for it.

(2) Weak Technology Handover, Technological Transferability

One challenge facing medium-to-small scale manufacturers is the need to "eliminate labor shortages and weak technological transferability at times of technology handover, business handover, or overseas expansion." In this case, I believe the problem is that these issues with management systems are not being debated in connection with I4.0 and DX. The problem of labor shortages is not one that you can solve just by introducing robots.

2.3 Is Lagging Systematization a Factor Behind the Obstruction?

(1) Concerns Facing User Companies and IT Vendors

The further expansion of cloud services has made it possible to utilize low-cost business applications, AI, and computer resources. However, it seems to me that this phenomenon is spreading much more slowly in Japan than in other countries.

From upper management one often hears the candid acknowledgement that "I don't understand how, or for what, we should be utilizing this." At the same time, there are many IT vendors saying that "there's no point in our making a proposal if they don't decide the requirements for where things will be utilized."

(2) Frank Questions from Overseas Vendors

As a result, the mysterious English-letter phrase "JIREI [example]" has appeared on the scene. Overseas vendors will say with amazement, "We've heard that, for Japanese corporations, it's effective to just use a competitors' JIREI that can be immediately imitated as-is; that can't really be true, can it? On the contrary, in the U.S., people ask if we can work with them to create new ideas that other companies still aren't doing." The contrast is almost comical, but it's true.

(3) Japanese Companies' Uniquely Dismissive View of Systematization

As was noted in the Study Group Report, the value in Japanese companies is placed on IT technology itself and its implementation methods. In many cases, with regard to the design of required specifications and the definition of requirements as to what will be utilized how and in what field, the prevailing attitude is for vendors to regard such issues as problems for client company management, and for users to assume that the venue where the IT will be utilized should determine such specifications.

Nonetheless, no matter how great such a venue is, its approach will be structurally "fragmented" and will not address "overall" management. The sum total of fragmented optimization does not necessarily add up to overall optimization. Thus, it is essential to understand overall management as a system and utilize the "cross-functional operations management structures" that are becoming ever more sophisticated.

It is also necessary to create industrywide system regulatory mechanisms, such as intercompany or inter-organizational regulatory mechanisms for the sharing of planning information, risk sharing, and the like. Although this is not well known in Japan, in Southeast Asia and other foreign countries, international standardization organizations have been busy designing intercompany regulatory mechanisms such as efficient consumer response (ECR) structures, which focus on distributors, and Global Standard One (GS1). These developments bear noting as well.

2.4 A State of Obstruction Specific to Japanese Corporations

The question of whether lagging adaptation to I4.0 and DX can be linked to the recent macro performance problems in the Japanese economy is outside the scope of this paper. However, from my perspective after operating in an environment with a relatively large number of opportunities for contact with many companies, my sense is that while there are some exceptions, in most cases so far, initiatives for I4.0 and DX at Japanese corporations have not been truly effective.

If Japanese companies have a closed attitude toward promoting I4.0 and DX even though it is the managerially correct decision, there must be factors specific to Japanese companies that account for this.

3 Understanding I4.0 and DX from the Perspective of Systematization

How should we understand I4.0 and DX? I will now provide a commentary based on the Study Group Report, with some supplementation.

3.1 Systematization is What will Drive Innovation (Section 1 of Source No. [1])

Another important issue is utilization for streamlining of the "AI, data collection, accumulation and analysis, and other new tools and technologies" that are being introduced in connection with I4.0 and DX. However, even more important is for corporate management to seek broader industrial systematization so that the zero-marginal-cost resource of software can be utilized on a wider scale for business growth.

3.2 I4.0 is a "Systematization Revolution" (Section 2 of Source No. [1])

I4.0 is defined in the Proposal [10] as "cyber physical systems" (CPS), and thus self-evidently signifies the "systematization" of industry and society.

In Japan, however, my sense is that the interpretation of the term is more along the lines of "utilizing cutting-edge component technologies such as IoT, AI, and clouds to realize 'something' immediately effective." It therefore seems essential to emphasize the concept of "systematization" of overall corporate management and of industry.

In this paper, I have tried, in assessing the economic phenomena occurring in conjunction with I4.0 and DX, to set out the concept of industrial systematization from the two perspectives of the "structures" and "regulatory mechanisms" of systems.

3.3 Changing "System Structures"

(1) From "Vertical Structure Product Business Model" to "Multilevel Service Business Model"

I4.0 and DX are creating a revolution in industrial system structures by utilizing the computer resources that continue to destroy price paradigms and bring marginal costs closer to zero. This structural change can be understood as a transition from a "vertical pyramid product manufacture/sale business model" to a "PSS (product service system) business model with an open and flexible horizontal network structure."

The "vertical pyramid product manufacture/sale business model" places manufacturers responsible for the manufacture of final products at the top of the pyramid, and procures components, materials and the like in a hierarchical subcontracting structure on the basis of the top manufacturer's design specifications. For any changes in the top manufacturer's specifications, the details are worked out flexibly in a "fine-tune integration" approach based on tacit knowledge within the corporate group. In many cases, transactions are confined within the corporate group and they are willing to invest in relevant special assets. In this vertical chain structure, responsibility for the operational functions of materials, processing, components, and assembly/sale, which can be considered direct services for the final product, is borne by the subsidiary companies from an "economy of scale and economy of scope" perspective.

In contrast, the new industrial system structure is a "service business model" in which various indirect operational functions are commercialized as operational function services for outside parties. At this time, new territories are being opened which can be scaled out in the form of software services utilizing low-cost cloud services.

Indirect operational functions include "various operational functions", such as: product service planning/marketing functions; product service design functions; production technology/manufacturing equipment (including software) design functions; manufacturing supply chain design functions; planning functions; manufacturing management (quality, cost) functions; manufacture execution functions; manufacturing history management functions including quality; use history management functions at time of product usage; maintenance/operation service functions; and financial functions.

Up to now, we have seen a phenomenon where "outsourcing" has become a buzzword in distribution, IT, accounting, manufacturing, and other such fields. This has happened because, in recent years, it has become relatively easy to develop "cloud-type operational software service business" by utilizing "computer resource cloud services", such as AWS, GCP, and Azure.

This "cloud-type operational software service business" is entering a rapid-growth phase through network effects resulting from: the formation of an open and flexible horizontal network ecosystem through international standardization of the interfaces between operational function modules; the expansion of the number of participating companies through so-called multi-sided (supply-demand) utilization; and the continuing growth of the number of participating companies beyond a certain threshold. In addition, a service business model that combines multiple "cloud-type operation software service businesses" and targets emerging markets having ample room for growth, has also emerged. These phenomena may be more understandable if we refer to them, collectively, as "platform service businesses".

In particular, for I4.0, an idea has been advanced in which manufacturers provide PSS (product/service systems) as comprehensive services for overall life cycle management, including the operation and maintenance work that has conventionally been handled by indirect divisions of client companies; this concept has already begun commercialization. The idea of having manufacturers, who are the most knowledgeable about products and equipment, draw on their knowledge to provide associated operation and maintenance services, is a topic that was being studied even before I4.0 as "manufacturer servitization" [3].

(2) Diverse Platform Businesses on the Rise

In addition to GAFAM, multiple "computer resource cloud services", and "business infrastructure platform services" which utilize international interface standards, have already come on the scene and achieved success in many industries.

In the background of this is the advancing internationalization of inter-module interfaces (IF) to ensure interoperability, including the internationalization of intercompany EDI. As a result, international trade/distribution industries and international labor division systems have been rapidly assembled, and there are examples of successful platform businesses in the apparel industry, where an internationally standard IF has been established. Some examples of this are as follows.

i) Apparel procurement/production/distribution agent platform (LI-FUNG)
ii) International container terminal operation contract service (PSA, HIT)
iii) International consigned freight platform service (Cargo Wise)
iv) Social infrastructure life cycle management integration platform (Bentley Systems)
v) Global small loan (financing, payment, purchase support, cross-border EC, investment) service (Ant Finance)
vi) Oil/chemical plant planning/development, operation/maintenance service (Schneider)
vii) Manufacturing knowhow cloud service business (BOSCH)

These non-GAFAM operational infrastructure platform businesses in individual industries have not attracted much interest in Japan. Moreover, it looks as though almost no Japanese companies are developing business in these areas.

This may be due to the fact that the environment for utilization of global EDI and other international standard intermodule interfaces is poor in Japan, and that as a result, platform service businesses that are based on international standards and have their eye on the global market from the beginning, which are becoming commonplace in Europe and U.S., are barely making themselves felt in Japan and are not readily imagined by companies there.

(3) Accumulating Research Connected with Industry-Level "System Structure Revolution"

This "industrial system structure revolution" towards the platform service business model etc. was, in point of fact, not first proposed with the advent of I4.0 and DX.

The details cannot be provided here in their entirety, but to give a representative example, the fact that digital technology led to "a shift, with the decline in transaction costs, of the boundaries of corporate organization to the organizational side" [4] – in other words, an expansion of market procurement – has been the traditional story since the era of *Markets and Hierarchies* (Oliver E. Williamson), and has been robustly advanced ever since even in the 21st century, particularly in American business schools. The power of modularity [5], open innovation [6], open service innovation [7], strategic use of consensus-based standards [8], dynamic capability [9], manufacturer servitization [3], and other ideas that address the so-called structural revolution of systems by viewing products, corporations and industries in systemic terms, have been debated in business school strategy discussions and in the operations management (OM) field.

3.4 Changing "System Regulatory Mechanisms"

The I4.0 Proposal [10] presents the idea of eliminating complexity from operational instructions through direct communication between goods in process and production equipment at the factory field level. In addition, RAMI4.0 (discussed in 4.2 below) focuses on information exchange between companies and intercompany transactions, and thus can be considered to employ not only (spot) market price adjustment mechanisms (PQ adjustment) that requires a certain time for adjustments, but a transaction model that incorporates uncertainty. In such case, (medium-term) regulatory mechanisms, such as PQσT adjustment [9] for CPFR (collaborative planning, forecasting and replenishment) and the like in financial engineering and distribution, will also be necessary.

Further, recently, consideration has been given to intercompany information exchange and history management systems that require distributed ownership in which data is retained by owners (IDS [11], FI ware [12], AAS [13], blockchain).

This sort of transaction model that utilizes mathematical algorithms is essential (as a short-term regulatory mechanism) to make it easy to implement digitized "smart contracts" and achieve scaling-out.

Meanwhile, the emphasis on non-verbal mutual understanding typifying Japanese corporations has an inherent weakness in that it is resistant to digitalization and scaling-out. Unlike when dealing in products, contracts for dealing in services are inevitably more complex in contractual terms. This is an area that will require even more study going forward.

Furthermore, reform is also needed for the regulatory mechanisms of business divisions (SBU). The situation would appear to necessitate a transition from conventional hierarchical fiscal year budget management using finance KPIs to IBP/S&OP [15] or other management processes capable of flexibly adjusting overall structures to improve adaptability to changes in the business environment. I believe that the concepts of IBP/S&OP and the above-described CPFR were modeled on the Japan-originating Toyota Production System (TPS), and are creating option value by improving flexible adaptability to uncertainties in the business environment. IBP/S&OP, CPFR and the like (long-term regulatory structures) seem to have already taken hold in cutting-edge companies overseas, not only in Europe and the U.S. but in China and Southeast Asia as well. However, adoption at Japanese corporations remains limited, and the focus is still on hierarchical annual budget management using finance KPIs.

It is interesting that in all of these methods, the design of management-level and intercompany-level regulatory mechanisms – and by extension, of regulatory/control mechanisms of the industrial system as a whole – which transcend the boundaries of departments (functional organizations) and companies to allow the industrial system to respond quickly to environmental changes as if it were a single "organism-like control mechanism", are constituted in the manner of the "Theory of Hierarchical, Multilevel Systems" proposed by Mesarovic.

This "industrial system control mechanism model" seems to be a new paradigm corresponding to the "market mechanism model" in earlier product transactions.

The product service systems (PSS) targeted in I4.0 do not necessarily apply to manufacturers only, and could also be applied to smart cities, transportation functions (MaaS), and a great many of the areas addressed by Society 5.0. This is the case because elevators, air conditions, energy control and the like are now handled by computer control using programmable logic controllers (PLC).

In Japan, detailed regulatory mechanism designs may not have been necessary in the past because the on-site environment was flexible, nimble and distinguished. This may be one of the reasons Japanese corporations undervalue new paradigms.

But meticulous regulatory mechanisms that scalably utilize digital technology are nonetheless needed. In fact, I believe there are great possibilities for converting this sort of on-site tacit knowhow around regulatory mechanisms into explicit knowledge, embodying it in software, and offering ground-breaking regulatory mechanism models from Japan to the entire world, as in the case of the Toyota production system (TPS).

4. The 4th Industrial Revolution Reconsidered

4.1 Three Basic Directions for CPS

The three basic directions for the CPS utilization proposed in the "I4.0 Proposal" [10] may be most easily understandable as a systematization of industry – in other words, "system structures", "system regulatory mechanisms", and the "shared infrastructures" that support them. Below, I provide the details of the "Study Group Report" [1] and lay out the correspondence relationships.

(1) Horizontal Integration of Value Chains (VC)

"Horizontal integration of value chains" means the construction of a "network for the realization of close international labor division systems transcending corporate and national borders." This means not merely product design activities, but the achievement of open innovation as needed and the construction of optimal international labor division systems in all business fields of all human engineering activity (from planning to disposal).

This concept can be understood as innovation of "system structures".

(2) Vertical Integration and Networking of Manufacturing Systems

Specifically, this means "achieving sophisticated operation/maintenance management services and maintaining capacity utilization ratio at global manufacturing hubs through smart mother factories and shared knowledge databases," and "having goods in process communicate with equipment by transmitting their own information, and better avoiding complexity through the use of autonomous distributed control mechanisms." This concept can be understood as a revolution in "system regulatory mechanisms" when the industry is understood as a system having a hierarchical structure.

(3) End-to-End Engineering Chains

This is a common infrastructure that manages information about not only products, but product service systems (PSS) and all other human engineering activities, in order to bring about (1) and (2) .

Here, "engineering activities" means all engineering activities for the entire life cycle of the artifact. Specific examples include product planning development, product design based on physical analysis (thermal conduction/vibration/stress analysis, etc.), production process design, production equipment design, production line design/simulation, manufacturing history information, product operation models and maintenance models, component usage load history information, and disposal process design.

4.2 The Purpose of RAMI4.0 is Promoting "Open Innovation as Policy"

The primary I4.0 activity is international standardization activity based on RAMI4.0 (Reference Architecture Model Industrie 4.0). [10] This is because, in order to instantiate the three trajectories described in 4.1, it is essential for system architecture design activities to occur in a PSS topological space comprising the three axes of "system structure" (spatial axis), "system regulatory mechanisms" (meaning axis), and "information infrastructure for sharing, operating and controlling engineering information" (temporal axis).

System architecture design activities include designing module structures in the topological space, international standardization of inter-module interfaces, and the creation of language systems, semantics, and reference architectures such as roadmaps.

But why is it important for these new industry system architecture design activities to be conducted through an international cooperative system? The answer is that system architecture design activities are themselves the "locus of open innovation as policy" that has enveloped both Germany and the entire world. In fact, Germany has already executed MOUs on pre-competitive collaboration activities for I4.0 standardization activities with major global countries including Japan.

I view I4.0, and specifically its core element of RAMI4.0, as the solution proposed by the German Academy of Science and Engineering, on the basis of the accumulated research and ideas detailed in 3.3 (3), for the objectives for realization of those ideas of "industrial module structure design that will serve a consensus standard" – in other words, a method for obtaining consensus for industrial system architecture.

In other words, the aim of RAMI4.0 can be considered to be "accelerating open service innovation in the PSS field by implementing as German industrial policy, in the new PSS industry which is a growth industry going forward, the 'system architecture design work' based on 'international standardization activity' at which Germany excels."

4.3 Approach to Research Themes Going Forward in the "Research Council of the Plattform Industrie 4.0 Proposal [Germany]" [16]

The most recent "Research Council of the Platform Industrie 4.0 Proposal [Germany]" [16] takes "value creation in PSS" as its theme and proposes creating value by transitioning to a PSS-centered business model in a digital ecosystem based on dynamic and flexible networks that transcend corporate boundaries. Reform methodology for corporations is mentioned as another research topic, and regulatory mechanisms for inter-module transaction agreements, such as smart contracts and digital ledger technologies (DLT), are also given as important research topics.

Notes: Future Research Topics in "Research Council of the Plattform Industrie 4.0 Proposal [Germany]" [16]

The research topics comprise the four areas indicated below. Here, I provide citations and summaries centered on value creation scenarios in a spatial relation. Please keep in mind that the focus here is not on technology alone.

- I4.0 Value Creation Scenario
- Future Technological Trends
- New Methods and Tools for I4.0
- Work and Society

I.40 Value Creation Scenario

(1) Providing Sustainable Value by Virtualizing Products and Services

- Make products and services into comprehensive service packages to develop, implement, and also virtualize PSS (Product service system)
- Continuously design diverse consumer benefits
- When providing services, attract customers by designing individual services while ensuring data sovereignty

(2) Data-Driven Business Models and Revenue Structure Innovation

- Construct flexible and dynamic revenue structures that cover the entire PSS life cycle
- Value assessments, market creation, activity scope approval method design, etc., for data subject to sale

(3) Further Development of Value Creation Architecture

- Development from current flexibility-poor value chains (VC; confined to corporate groups) to highly flexible and dynamic value networks (VN) that transcend company boundaries in the digital ecosystem
- Ensure that digital twins can be smoothly utilized in VN
- Strategically establish essential client interfaces
- Ensure business management that considers the entire PSS life cycle, and sustainability thereof
- Reform and reconstruct management structures to business models based on data-driven platforms

(4) Development and Implementation of Sustainable Management Strategies

- Optimal resource efficiency, sustainable management methods
- Automation, remote management, conveyance distance minimization, 3D printer utilization, etc.
- Elimination of physical prototypes through virtual-space prototyping
- Consider reuse options such as utilization in automobile battery fixing positions etc.

(5) Sustainability of Smart Contracts and Distributed Ledger Technologies (DLT)

- Smart contract automatic generation methods
- In addition to quality, economic value, and technical demonstrations, discussion from an institutional perspective is needed
- Discussion from a legislative standpoint of distributed ledger technologies (DLT) and smart contracts
- Analysis of impact of cryptocurrencies on digital business models

5. The Various Phases of the Paradigm Shift Demanded by Systematization

I4.0 and DX will bring about "systematization" – in other words, will redesign the structures and regulatory mechanisms of the industrial system – and therefore represent a paradigm shift that will demand, of the existing industrial system, simultaneous and parallel reform of all of the wide-ranging and diverse areas listed below.

- Product and solution development methods
- Transformation from product sale business model to PSS business model
- Changes to competitive environment for manufacturers
- Transformation of industrial policy and science/technology policy (academic-industrial collaboration)
- Revolutionizing work and education, particularly adult education

The "Research Study Report" analyzed "Japanese weaknesses caused by lagging systematization" and "the background of the lag in systematization." In this article, my aim is to further add to this analysis and, by setting out the various phases of the new paradigm demanded by I4.0 and DX, to call attention to the major differences that distinguish the new paradigm from the old paradigm that has been the backdrop of the success of Japanese corporations up to now.

As Japanese corporations and the government face pressure to respond to this paradigm shift, it is important for them to (1) adopt a comprehensive and long-term perspective, (2) recognize the structural problems with the industrial system and its surrounding social systems, and (3) instantiate and transform industrial systems under the new paradigm, including by designing analyses and solutions and solving any secondary problems that occur.

The new paradigm is expected to place increasing weight on so-called "system (control mechanism) economics" that go beyond conventional economies of scale and economies of scope. Industrial system reform for this new era is needed.

At the same time, the design of the methodology for reform under the changing environment is itself a major challenge.

5.1 Reform of Product and Solution Development Methods

(1) From Self-Sufficiency Model to Open Innovation Model as Policy

Product and solution development methods are changing from a self-sufficiency model carried out only by engineers in specific companies to a model of open innovation as policy, in which reference architectures for the industrial system are designed in a consortium format and promulgated as international standards. This standardization is the result of the propulsive force of open innovation.

i) It is possible to design component technologies from system through a multilevel structure.

ii) Continuous innovation is carried out by module substitution.
iii) Therefore, standardization of inter-module interfaces is necessary.

The mindset that "standardization impedes innovation" is still particularly widespread in Japan, but it must be kept in mind that "standardization" in the sense used here does not mean standardization of technologies themselves, and instead refers to standardization of "inter-module interfaces", which are not patentable.

In the Study Group, an interview was conducted with a person with experience in the development departments of both European and Japanese manufacturers, who observed that "product development at Japanese corporations frequently involves a type of exchange called 'fine-tune integration [*suriawase*] adjustment' during the development process, and while this can appear lively at a glance, it seems to create a lot of friction.

"In contrast, in Europe, the underlying product architecture is designed first, and because everyone follows this, there isn't much reworking. It is unclear which of these approaches produces the best final result, but it does seem that product development would proceed more smoothly in Japanese corporations if those corporations adopted a method of designing the underlying product architecture first."

While it is unclear exactly what percentage of Japanese corporations can be described this way, in my experience, a great many corporations operate in the same manner. That is to say, it appears that the architecture design activities for achieving open innovation may be unfamiliar in and of themselves to Japanese corporations. If that is true, it means there are very few corporations able to understand the significance of the RAMI4.0 activities advocated under I4.0.

Likewise, the pre-competitive activity of the next section is most likely just the execution with outside corporations of activities already being conducted within corporations in Europe and the U.S.

(2) Pre-Competitive Activity and Competitive Activity

Industrial system architecture design activity means that user corporations and interested corporations (vendors) associated with the relevant industry form a consortium under the support of a standardization body or the like, and engage in pre-competitive activity as a united organization.

Pre-competitive activity comprises the following four activities.

i) Demand articulation for new industries [17]
  - External functions, specifications
ii) Modularity of constituent elements (design of internal structures)
iii) International standardization of inter-module interfaces
iv) Creation of overall roadmaps and reference architecture

Industrial system architecture design will involve updating inter-module interfaces and the functional components of individual modules, neither of which is patentable; such design is therefore outside the scope of application of antimonopoly law and can be treated as pre-competitive activity over which competing enterprises can gather and hold discussions.

Competitive activity thus involves (1) technology development/provision activities for functional modules (*i.e.*, constituent elements), and (2) coordination for combining modules and service provision activity as an integrated system.

(3) Superiority of Open Innovation as Policy

The open innovation as policy model is superior to the self-sufficiency model in the following four respects.

i) Marketing

In the self-sufficiency model, it can be difficult to ascertain customers' implicit needs in a clear and straightforward fashion, and time and cost are required for marketing (market development) activities. In addition, adopting designs tailored to the needs of specific customers can carry significant risk.

In the open innovation as policy model, multiple user industries form a consortium from the very beginning, thus quickly clarifying user needs to facilitate new industry external functional designs, and reducing the cost, time, and risk involved in marketing and sales activities (demand articulation [17]).

ii) Rapidity and Low Risk of Decision-Making for Technology Development

The more complex the industry, the more difficult it becomes to imagine the future of the technology and to define goals and points of emphasis for technological development. Many observers point out that the problem is less technological development itself than the fact that "investments get scattered because it isn't clear what should be developed." In particular, productivity is undermined by the lack of clarity around where there are ready-made technologies in the possession of other companies.

In the open innovation as policy model, both users and competing vendors participate in the consortium, thus making it possible for all parties, including competitor companies, to indicate where existing technologies can be applied, what new technical modules must be developed and by when, and what the extent of the demand will be. This makes it easier to identify the most important information, the so-called "missing links" (*i.e.*, areas requiring new technology development), in which there are no players with existing technologies, and makes it possible to narrow down the investment areas at an early stage.

iii) Finance

Investment decisions in the self-sufficiency model are frequently dependent on cash flow at the relevant time among top companies. Stable R&D investment is not easy to achieve.

The open innovation as policy model has the advantage of allowing injection of risk money. When missing links and areas with no ready-made technology are discovered under the clarified module structure, it is possible to invest risk money from venture capital, funds and other such capital markets for technologies whose development will involve risk. The effect of this is to make fundraising from capital markets significantly easier.

iv) Continuous Innovation

In the self-sufficiency model, because there is no modularization, it can be difficult to obtain provision of external technologies for continuous innovation of developed products and services.

In the “open innovation as policy” model, module recombination makes open innovation easy. Because the inter-module interfaces are public, it is easy to achieve continuous innovation globally and with the participation of other industry types. This is the option value [5] of module power.

5.2 Transformation into Product Service System (PSS) Business

(1) Transformation from “Product Sale Business Model” to “Product Service System Business Model Based on Horizontal Labor Division”

As competitive activities are divided and then recombined into (1) functional module provision activities and (2) “service provision as an integrated system,” not only for products but for entire industries serving as PSS, the business models of individual operators must also reform in accordance therewith.

As a result, manufacturer business models are shifting to a new service business model based on horizontal labor division, within a vertical chain structure. In I4.0, this phenomenon is called a “value network”.

Specifically, three types of service business model are expected to become prominent – namely, manufacturer servitization, platform business, and enabler business.

i) Manufacturer servitization [3]
ii) Platform business [7]
iii) Enabler (component module) business

(2) Manufacturer Servitization

Why is manufacturer servitization important? In my experience, the following five factors demand attention.

i) Possibility of Scaling-Out, High ROA

Manufacturer servitization represents a transition to a business model capable of scaling-out that utilizes zero-marginal-cost software – in other words, a transition to a service business placing substantial weight on zero-marginal-cost and high-ROA software. With cloud services as a foundation, black boxing is also easy.

ii) Business Growth

Entering the market as a service business providing manufacturing knowhow enables “early entry” to high-growth markets in emerging economies, even where it would not be easy to enter as a product business. In high-growth emerging economy nations, the GDP per capita standards are low, it is not always possible to sell products from advanced nations immediately, and the work of planning, designing, manufacturing and selling downgraded products can in fact involve significant costs. Because of this, the conventional wisdom among Japanese corporations seems to be that it is not easy for product sale businesses to enter these markets up to a certain economic standard.

However, if we can change our thinking and provide, in the form of cloud-based solution service businesses, manufacturer technology and knowhow for which there is already strong demand in the developing world, rapid market entry will be possible.

iii) Business Stability

Service businesses involving 10-20-year long-term contracts can be expected to deliver stable earnings even if their short-term sales volume is ostensibly low, and thus can have significant impact on corporate value. A major concern among equipment manufacturers has always been the impact of business fluctuations, but the service business is a stable business boasting continuity not dependent on facility investments, and is not significantly impacted by business fluctuations. Putting a service business in place under a holdings umbrella makes it possible to stabilize one’s overall business portfolio.

iv) Internalization of Innovation

Adopting RAMI4.0 for PSS as an international standard and establishing the industrial architecture will allow for the rapid development of open innovation in CPS areas. Many platforms and enablers will be utilizable. By executing long-term service agreements with customers and maintaining a customer-front perspective, it is possible to internalize platform business and enabler innovation within your own revenue structure.

v) The Goal is Enhancing Total Share Market Value

The goal of manufacturer servitization is not found in current or future PL. It is, in fact, investors who highly value that a business (1) have scaling-out potential and high ROA, (2) have growth potential, (3) have stability, and (4) be capable of internalizing innovation. The result of this servitization is to make it possible to increase total share market value.

In Japan, it appears to be rare for manufacturer servitization to attract the interest of management. From the perspective of performance evaluations by top management, because servitization has no connection to current-term sales or profits, it is not considered attractive. This pitfall of evaluating performance from a short-term orientation is emblematic of the product business paradigm.

5.3 Approaches to the Changing Competitive Environment and to Corporate Strategy

As manufacturer servitization expands, the competitive environment in both manufacturer product markets and capital markets will undergo fundamental changes. It is expected that multiple manufacturers in advanced nations will provide manufacturer knowhow cloud service businesses to manufacturers in emerging economies. The speed of this change is rapid because software is driving it.

As a result, the competitive environment for Japanese manufacturers in the old product markets and capital markets is expected to undergo radical change.

(1) Changes to Product Markets

Fierce competition with manufacturers in developing countries is expected. These manufacturers will utilize manufacturer knowhow cloud services provided by European and American manufacturers, and thus will be able to utilize sophisticated manufacturing technologies. It is possible that the technologies of manufacturers in emerging economies will in fact experience rapid advancement, and is likely that low-cost manufacturers benefiting from the low labor costs will emerge.

(2) Changes to Capital Markets

Competition with manufacturers in advanced countries will be intense, because any such manufacturers that have undergone servitization will be able to increase their total share market value.

If Japanese manufacturers continue pursuing only product businesses that cannot be scaled out, they will run a major risk of trapping themselves more and more between emerging economy manufacturers in product markets and advanced economy manufacturers in capital markets.

5.4 Transformation of Approaches to Industrial Policy, Science/Technology Policy, and Academic-Industrial Collaboration

Approaches to industrial policy, science/technology policy, and academic-industrial collaboration have already experienced significant changes reflecting movements of the new paradigm. In addition to ERC in the U.S., which was introduced in the Study Group Report, the Fraunhofer Society ("FH") in Germany and the Palo Alto Research Center are significant players. Foundational research at these centers explores and utilizes worldwide technologies openly. In product and solution development, these organizations carry out contracted research to ascertain company needs around the world.

(1) ERC, U.S. ("Study Group Report", Chapter 5 [1])

ERC (U.S.) has achieved success in promoting research projects that integrate foundational, applied, and practical approaches over the relative long term. ERC operates under an NSF funding scheme, and has established itself in project form at many universities for the purpose of promoting need-driven interdisciplinary research. Of particular interest in this regard is the use of three-level architecture to "systematize" research activities. Coordination between research and societal applications allows long-term research activities to be planned, conducted, evaluated and publicized on a rolling basis in accordance with the three tiers of "system", "enabler", and "component technology". Under this paradigm, the three levels are always considered simultaneously, and individual research topics are evaluated from the perspective of the system as a whole.

(2) Fraunhofer (FH) Society

The FH Society is a leading European applied research organization with 72 research labs and units throughout Germany. The following three points warrant special attention as essential aspects of the Society from a functional standpoint.

i) Open Contract Services for Need-Driven Research and Development

FH accepts contracts from federal and state governments, and contracted technical research and development from the private sector accounts for the majority of its revenue. This contracting also includes SMEs and startups. As a result, FH is able to accurately ascertain the R&D needs of private-sector enterprises and promote need-driven research. The feature of conducting not joint research, but contracted research that carries certain responsibilities for deadlines and research deliverables, is important here. Fundamental to the FH Society's activity is the construction of close relationships with the business community through the advisory board. FH's client companies are diverse and open, and are not limited to German enterprises. For example, the Society has made significant inroads and undertaken multiple research projects in South America, and many Japanese companies are among its clients as well. The dynamism of the FH Society is rooted in its open approach to contracted research activities.

ii) Formation of Open Network with Global COEs

The FH Society adopts a stance of utilizing global foundational research deliverables as needed, and has formed a network with global COE (centers of excellence), including Germany's renowned Max Planck Society. Japan is no exception to this outreach either, as an FH research hub has been established in Sendai.

iii) Achieving Linkages Between Foundational, Applied, and Practical Research

The FH Society has institutes affiliated with universities, and all of its directors serve concurrently as university professors. Many directors also serve as CEOs of product development startups. In other words, FH is an organization whose leaders are equipped to serve as university professors, research institute directors, and heads of startups. This seems to be an effective method of conducting foundational, applied, and practical research in a closely coordinated fashion.

(3) Palo Alto Research Center (PARC)

The PARC Research Center in the U.S. has once again attracted attention in recent years as an open contract research lab. As the R&D division of Xerox, PARC is a pure private-sector research organization, and in recent years has expanded its externally contracted research. CEO Tolga Kurtoglu notes that "we have accelerated our research activities by openly accepting R&D projects from external sources. More than anything else, there is immeasurable value in being able to form a network for needs and seeds with companies around the world."

Unfortunately, if there are any organizations with similar functions in Japan, their activities only occur within corporations or other organizationally closed environments, and appear incapable of exerting the leverage of open network effects for both needs and seeds.

5.5 Revolutionizing Work and Adult Education

It has been noted that discussion of reforming work and adult education will be essential in I4.0. In response, the German Labor Ministry has held discussions and released the results as the White Paper on Work 4.0 [17]. Jörg Hofmann of IG Metall, a representative of Germany's leading labor unions, visited Japan last year, and his visit provided an opportunity for an exchange of views at a symposium on Work 4.0. A summary of this conversation is provided below.

i) The procuring of outside talent will increase going forward, and it is highly probable that the organizational form of corporations will change radically. This will happen because it will not be easy to provide adequate internal education in a wide range of cutting-edge technologies.

ii) Operations that can be conducted by telework will expand, due to growth of high-added-value operations conducted in digital space.

iii) AI utilization will enable large-scale task and skill matching.

iv) Employees will gradually become crowd workers. The trend will be towards freelancing conducted by telework under project agreements, and work will be characterized not by man-month work hours, but by output agreements and the ability to contract with multiple companies at the same time.

v) Employees will need to be engaged in continuous study in response to technological innovations. A system must be created which allows employees themselves to manage their educational investments with public funds. For example, the government has proposed publicly bearing approximately two million yen per year in education costs.

vi) To increase productivity, it will be important to set out staff experience and skill information, such as past work experience and educational history, in granular detail. This is because barriers to participation in crowdsourcing intermediation services will be reduced.

vii) IG Metall (Germany's leading industrial labor union) operates Fair Crowd Work, a public evaluation site for crowdsourcing operators.

viii) For example, the code of conduct policy for crowd work sourcing businesses comprises the following items.

- Legality of tasks; clear indication of legal status of both parties; fair pay; motivation and good-quality work style; business operations respectful of relevant parties (workers and users); clear definition of tasks and adequate time planning; temporal and locational "freedom and flexibility" for work tasks (*i.e.*, projects) (long-term fixing not permitted); constructive feedback and open communication; task output receiving processes and recovery in accordance with predefined rules; data protection and privacy

At the symposium, I commented to Mr. Hofmann that "Creating adult education opportunities by awarding two million yen in public funds per worker is a wonderful idea." Mr. Hofmann replied, "I'm opposed to it. It is wrong to assign a maximum amount to workers with the will to learn. It should all be free, and universities should always be doing R&D to develop effective curricula. The budget for this should be abundantly secured as well." Was I the only person there who found himself wishing that Japanese labor unions would make demands like this?

6. Study of the Required Systemic Reforms and Reform Methodologies

I4.0 and DX by their nature require a shift (reform) from the existing paradigm (convention) to a new paradigm. Simultaneous and parallel reforms are needed across a wide range of fields in industry and its surrounding social systems, including system structures and regulatory mechanisms, the methods of product and solution development, and our approaches to securing competitive advantages, to target markets, value creation and corporate strategy, to performance evaluation, to fundamental industrial policy and science/technology policy, and work and adult education, and other various related fields.

In addition, I4.0 and DX will demand not only merely individual problems as fragmentary problems and exploring solutions in POC, but designing methods of reforming the industrial system with an understanding of the large-scale paradigm shift surrounding these problems.

Martin [19] has proposed a "7-SAMURAI" approach to systemic reform. When interpreting this in the context of I4.0 and DX, what seems essential is (1) not simply conducting bottom-up POC aimed at solving fragmentary problems from a symptom treatment mindset, and instead (2) imagining the entire post-reform system (new industrial system), and then completing a detailed design of this entire system with individual solutions in their respective places, while simultaneously (3) transforming and establishing infrastructural systems to make the new industrial system sustainable.

In this context, "infrastructural system" seems to mean, in a broad sense, a mechanism for formulating research, education and policy for innovation (reform) of industrial/social systems, in order to redesign and revolutionize industrial policy, science/technology policy, work and adult education, and ultimately, to create a new social system.

7. Conclusion

I4.0 and DX can only be achieved as a long-term and comprehensive paradigm shift in the social system.

No small number of observers have noted that Japan's response to this shift is lagging. If those observations are correct, the reason is most likely the substantial difference between the "'product transaction market mechanism model' paradigm which supported the past successes of Japanese corporations, in which companies mainly compete over quality and cost in a mass production model within a pyramidal industry structure of hierarchical subcontracting, developing products self-sufficiently within their corporate groups in pursuit of economies of scale and economies of scope," and the "'industrywide system control mechanism model' paradigm comprising 'product service system businesses (PSS)', in which companies compete over speed, scale and dynamic capability, utilizing open innovation and zero-marginal-cost cloud software, in pursuit of the economies of system underlying the emergence of such phenomena as manufacturer servitization and platform businesses."

It will not be easy for Japan to achieve systemic reforms appropriate to this paradigm shift, because such reforms will require deviation from the model of Japan's past successes.

Nonetheless, I am optimistic. Once, not long ago, the U.S. found itself shocked by the high performance of JIT and TPS in Toyota Motor's American factories, and after much research, established new POMS courses in business schools and came to regard operations management (OM) as indispensable. Furthermore, the importance of this area was emphatically conveyed to the White House, and today, OM is common knowledge among top managers, and the POMS researcher community in the U.S. is home to a faculty of 10,000 instructors, and has realized dynamic research activities and a sophisticated body of knowledge. How to utilize digital technology is a research topic for this OM field. What will happen when the Japanese scholarly community takes the now-obstructed Japan as a model, and makes the country's presence felt in the world by designing and proposing methodologies for the coming transformation to a new social system?

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