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MOT in transition: From technology fusion to technology-service convergence

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ABSTRACT

In the technical revolutions such as "mechatronics" and "optoelectronics," the concept of technology fusion, fusion among different kinds of technologies, had been critical in the management of technology. In this type of management, the joint research among different industries was the most important element.

In 1990s, however, modularization had progressed drastically and rapidly. To confirm this progression, a qualitative measurement in the Personal Computer and Automobile Industries is presented. When we entered into 2000s, however, the technology-service convergence phenomenon had become conspicuous. In this regards, two illustrative examples are presented from the Japanese experiences. Then, these examples are used to conduct a kind of thought experiment to draw a vision of the future.

By reviewing the transition in MOT (Management of Technology), from technology fusion to technology-service convergence via the age of modularity, we reach the conclusion that the essential nature of technology-service convergence is technical *evolution*, rather than technology *revolution*. In order to establish a method to view this convergence as an evolutionary process, therefore, we will bring in the argument on the design rule of modular structures.

Through the arguments described above, we will come to a conclusion that the "porting" operator is a critical element of this evolution. By applying the porting operator within the modular structures consisting of technology and service modules, we explore how the technology-service fusion may become a reality.

1. Introduction

In order to enhance the productivity as a nation, technology transfer from manufacturing to service sectors should be promoted. So far, this had been widely discussed as an important subject, but has not been fully realized, because technologies dominant in manufacturing were very different in nature from technologies supposed to be effective in increasing the productivity in service sectors.

However, we have now several technologies available more appropriate for this kind of technology transfer, such as RFID (Radio Frequency Identification) and GPS (Global Positioning System). As I will show later in this paper, these technologies will become major breakthroughs in the area of information and communication technologies (ICT), since RFID revolution differs from conventional information technologies in terms of data gathering and GPS differs from conventional communication technologies in terms of creating new business models for service industries. Therefore, we can say that the chance of technology transfer is high, but its realization is not automatic because a good management is necessary. To make it possible, we need to develop MOT (Management of Technology) beyond manufacturing.

In the service sectors, we need a different MOT from that which had worked well in manufacturing. The concept of technology fusion, fusion among different kinds of technologies, has been critical in the development of commercial technologies such as *mechatronics* and *optoelectronics*. However, in the area of technology-service convergence, which needs integration among different modular structures at different levels of hierarchy, the concept of fusion might be no longer so effective. We need to look into the process of integration in terms of socio-technical evolution rather than simple technology fusion.

In this paper, I will *review* the transition in nature of innovation from technology fusion to technology-service convergence via modularization, and demonstrate that the transition process involved several stages of trial and errors. In terms of managing the technology-service convergence, moreover, I will integrate issues related to design rules of modular structure into a new style of management. Finally, I will conclude that the current tools in MOT, which are based on the progressive nature of technology

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developments, should be enriched by accommodating the evolutionary nature of technology-service convergence.

2. Technology fusion (1975–1990)

The idea of "technology fusion" was proposed in order to characterize the then-emerging technologies such as mechatronics and optoelectronics (Kodama, 1986a, 1986b). And this conceptualization was identified as a unique Japanese capacity to innovate (Kodama, 1992a). Indeed, the innovation pattern was shifting from technical breakthrough to technology fusion, and the management implications of this shift were discussed (Kodama, 1992b).

It was argued that the difference between success and failure is not how much a company spends on research and development but how it defines it. There are two possible definitions. Either a company can invest in R&D that replaces an older generation of technology – the "breakthrough" approach – or it can focus on combining existing technologies into hybrid technologies—the "technology fusion" approach. The former is a linear, step-by-step strategy of substitution. Technology fusion, on the other hand, is nonlinear, complementary, and cooperative. It blends incremental technical improvements from several previously separate fields of technology to create products that revolutionize *markets*.

Technology fusion grows out of long-term R&D ties with a variety of companies across many different industries. Investment in research consortia, joint ventures and partnerships are important elements. It is both *reciprocal* and *substantial*—all participating companies are on more-or-less equal footing in terms of responsibility for and reward from the investment. *Substantiality* means management makes a commitment to the joint R&D project, from early exploratory research through to advanced product development. While substantiality is important, *reciprocity* is the essence of technology fusion. It means that all the participants in the joint research project enter as equals (mutual respect) and each assumes a responsibility for contributing a certain expertise (mutual responsibility). Reciprocity also means that all companies share in the success of the development (mutual benefit).

As more and more companies accepted and made fusion a part of their overall technology strategies, it played an increasingly important role in product development. This opened the door to even more cross-industry R&D. In the 1970s and 1980s, technology fusion was limited to manufacturing industries. In the future, it was predicted that fusion would go easily beyond manufacturing. Indeed, two Japanese electronics companies had taken the first steps toward fulfilling this prediction: Sony acquired Columbia Pictures Entertainment in 1989, and Matsushita (now it is called Panasonic) purchased MCA Inc. in 1990. As Michael Schulhof, vice chairman of Sony Corporation of America at that time, noted, "The acquisition of a major film studio extends Sony's long-term strategy of building a total entertainment business around the *synergy* of audio and video hardware and software." Akio Morita (Morita, 1992), the chairman of Sony at that time, confirmed Sony's strategy, by asserting that the possibilities and synergies created by the *merger* of Japanese hardware and American software were already yielding new products.

Thus, it was a prevailing opinion that the technology-service fusion will be realized in 1990s without substantial difficulties as a mere extension of technology fusion. However, Panasonic sold MCA quite shortly after the purchase. In retrospect, Steve Jobs is quoted as saying: What's really interesting is if you look at the reason that the iPod exists…., it is because these really great Japanese consumer electronics companies who invented it and owned it, couldn't do the appropriate software (Cupertino Silicon Valley Press, 2011).

In summary, the fusion between manufacturing and service has turned out to be much more difficult than we had expected. Before we make a jump into service fusion, moreover, we had to go through the major structural changes within hardware technologies, which will be described in the next section.

3. Modularization (1990–2000)

As is well known, dramatic changes occurred in the computer industry. Around 1980, the computer industry was composed of vertically integrated firms. Hence, the industry had an extremely vertically integrated structure. Around 1995, however, the industry shifted to a horizontal competition. Drastic changes in the industrial structure occurred when computer manufacturers began to obtain various components and combine them (Grove, 1996).

Baldwin and Clark (1997) argued, the personal computer (PC) industry that has grown up around modularity, developed entirely new kinds of computer systems that have taken away share from the mainframe market. They assert: technical managers at the assemblers expect that the newly strengthened module suppliers are to take on most of the design responsibility. Therefore, we can assume that the technological responsibility and leadership has shifted from the assembler to the components supplier. Based on this observation, we can measure how much modularization had been developed. In Kodama (2004), we hypothesized that this shift should be reflected in *patenting* activities. For our measurement, we used a patent database called PATORIS (Patent Online Information System), a systematic online search system of patent information in Japan. The information in this database goes back to 1955 and contains about 40 million entries, as of around 2000. By taking modular innovations of PCs into account, we selected the following four *categories* of components: CPUs, memory, disks, and display. Then, we selected an appropriate combination of several *key words* to represent each of the four component areas. Our key words search was made on data of patent title and summary information about the patent.

We compiled the patent applications in every year from 1986 to 1997. Pertaining to CPUs, for example, 695 and 1595 patents are compiled in 1986 and 1997, respectively. In other areas of components, 2013 and 5316 memory-related patents, 111 and 5316 disks-related patents, 1415 and 5597 display-related patents were compiled for 1986 and 1997, respectively. Since our attempt is to measure the progression of modularization by means of the shift in patent application from the assembler to the supplier, we have to ascertain who filed the patent, assemblers or suppliers. For this purpose, 10 companies are identified as the PC assemblers in Japan: Sony, IBM, NEC, Matsushita, Fujitsu, Hitachi, Sharp, Mitsubishi Electric, Toshiba, and Epson. Then, we could measure the percentage of patent applications filed by PC assemblers in each of component areas. The changes from 1986 to 1997 are shown in Fig. 1.

As seen in the figure, the assemblers' shares in all the component areas stayed quite high with some fluctuations during the 1980s. Around 1990, however, all of these shares suddenly began falling and continued to drop consistently thereafter. This indicates, first of all, that the responsibility and *leadership* in technological development shifted from the assemblers to the individual module providers. Based on the assumption made at the beginning of this section, we can ascertain modularization has drastically progressed in the PC during the 1990s. We can also ascertain that modularization has driven the change in industrial structure of computer industry from a vertical to a horizontal structure.

In contrast, in the automotive industry it had been once argued that the modularization was not yet so visible during the 1980s.

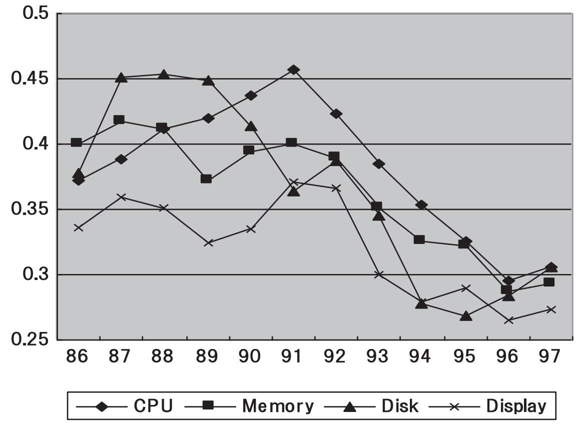

Fig. 1. Changes in share of PC assemblers of patent application. . *Source*: Kodama (2004)

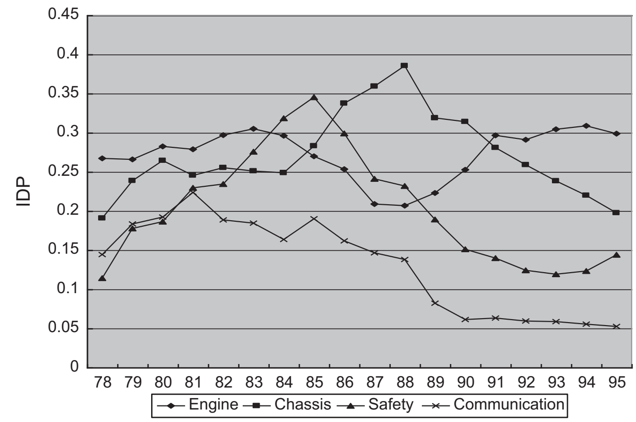

Fig. 2. Changes in shares of automotive assemblers in patent applications. . *Source*: Kodama (2004)

This was because the focus of competition was on the product integrity, especially on internal integrity—e.g., how well the parts fit, how components match and work well together, and whether the layout achieves maximum space efficiency (Clark and Fujimoto, 1991). When we entered into the 1990s, however, the big assemblers in automotive manufacturing have been moving away from tightly centralized design. Automotive designers and engineers are now looking for ways to parcel out the design of their complex *electromechanical* system (Baldwin and Clark, 1997).

For our study of modularization in the automotive industry, therefore, patent counting is applied to the following four categories of *control* systems: engine control, chassis control, safety control, and communication control systems. More specifically, engine control system includes that electronic control for fuel injection, vaporizer, and muffler. Chassis control system includes those electronic controls for automatic transmission, suspension, antilock breaking system, traction, four-wheel drive, and power steering. Safety control system includes such items as air bag, back sonar, automatic wiper, automatic air conditioner, cruise control, and keyless entry system. Communication control system includes such items as car navigation system, display meter, and optical communications system. This category is, as you may be aware, different substantially from those categories used for analyzing the *structural* modularity of the automobile. In a similar way as we did for the PC industry, we selected an appropriate combination of several key words to represent each of the four controls systems. As a result, we compiled the patent applications in every year from 1976 to 1998. For each control system, we measured the ratio of automotive assemblers in patent application, as shown in Fig. 2.

As seen clearly in the figure, the shares of automotive assemblers did not decrease so much in the 1980s and some of them increased in systems like chassis and safety control. In the 1990s, however, these shares began falling in chassis control, safety control, and communication control systems. In other words, the modularization proceeded rapidly when the automotive industry entered the 1990s. However, there is one obvious exception in this trend of modularization. The exception is in the *engine control* system. As can be seen in the figure, the share of automotive assemblers in engine control system increased in 1990s, that is, the modularization did not proceed. This is different from the case of PC in which the modularization proceeded in all the components. Now, we are interested in analyzing why the modularization in the engine control system did not proceed in the 1990s, while the modularization is visible in other automotive control systems.

We can postulate that the differences in modularization have something to do with the differences in *digitalization* of the automotive components. Thus, we tried to measure the *degree* of digitalization in terms of the relative value of ECUs (electronic control units) built in each control system. Specifically, the production value of ECUs for each control system is divided by the total value of automotive parts production. In other words, the relative economic weight of ECUs built in each control system is used for the index of digitalization. Results of this measurement show that digitization in engine control systems has not advanced, or rather there is a declining trend, while digitalization has advanced drastically in the other three control systems, as seen in Fig. 3.

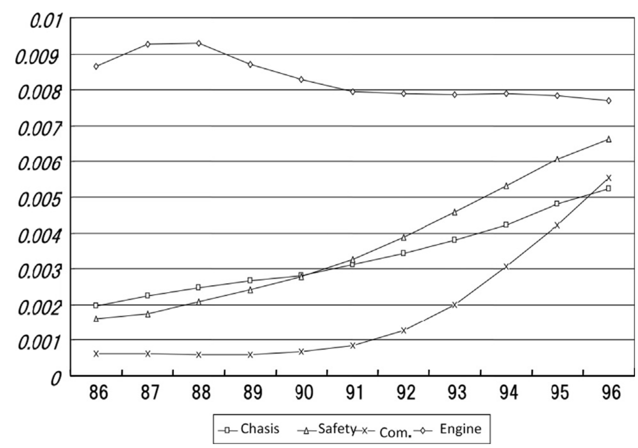

Fig. 3. The weight of ECU in each category of automobile control systems. . *Source*: Kodama (2004)

Based on this comparative measurement of modularization in PCs and automobiles, we can learn something about the relationship between the degree of modularization and the penetration of digital technologies. The deeper the penetration of digital technologies is, the further progressed is the modularization. Therefore, it is now clear that introduction of digital technologies makes the modularization possible and drives the industry towards horizontal competition. In an industry where not all the technologies are digital, as is found in the automobile industry, the technological leadership of assemblers remains strong as it was before.

This study indicates that we have to be very cautious about the arguments which emphasize the overall and excessive penetration of digital technology into a whole economy. Through quantitative analysis, we could confirm a positive relationship between the digitalization and modularization exists. By means of quantitative measurement, however, we could not look into the dynamic relationship in evolution between technology and service. In order to get some insights concerning this relationship, therefore, we will look into the illustrative examples drawn from Japanese experiences rather than attempting another quantification of this relationship.

4. Technology-service convergence (2000 beyond)

At the very end of the last century, Newsweek magazine (Newsweek, 1999) carried section, "Convergence: Embracing a millennium of change." In two short decades, they asserted, *digital* technology has reached critical mass. But the digital revolution is more than just a revolution of usefulness. They argued: the term that has come to encompass this revolution is "convergence"—the fruit of the digital *union* of telecommunications, information technology, and the Internet and consumer electronics. Its influence is manifested by an entirely new generation of products and services generated from the cross-pollination of all these *disparate* industries. The essence of convergence is also about *connecting* technologies in exciting new ways.

The idea of "convergence," however, is not necessarily a direct outcome of "digital" technology. Rosenberg (1978) argued that the 19th century industrialization was characterized by the introduction of a relatively small number of similar productive processes to a large number of industries. He finds a phenomenon which he calls "technological convergence." This convergence existed throughout the machinery and metal-using sectors of an industrial economy. More specifically, Rosenberg described, the use of machinery in the cutting of metal into precise shapes involves, a relatively small number of operations (and therefore machine types): turning, boring, drilling, milling, planing, grinding, polishing, etc. He argued, moreover, all machines performing such operations confront a similar collection of technical problems: power transmission, control devices, feed mechanisms, friction reduction, etc. Because these processes and problems became common to the production of a wide range of disparate commodities, he concluded, those industries such as firearms, sewing machines, and bicycles, became very closely related (technologically convergent) on a technological basis.

Reflecting upon the dubious relationship between digitalization and convergence, indeed, the Newsweek article also carried out the following comment by Dr. John Taylor (the director of Hewlett-Packard Labs Europe): "Convergence? It Means Turbulence. TV companies think they know. PC companies think they know. The Internet companies think they know. But no one really does."

In order to clarify a further progressive term of "technology-service convergence," therefore, we have to pay careful attention to what is going on both in technology and in service innovations (Chang and Yen, 2012). For this clarification, we will bring the following two illustrative examples drawn from recent Japanese experiences.

4.1. Illustration 1: Recent development of NC machine tools

The numerically controlled (NC) machine tools have a long history. However, NC machine tools controlled by personal computers (PCs) have only recently been realized, because NC machine tools and PCs are evolved independently along their own evolutionary paths (Shibata, 2009). The two systems have reached their modular *architectural structures* through their own evolutions. The PC reached "open" architecture, while the NC machine tools reached "closed" architecture. Therefore, it is difficult for those two systems to be integrated, although both of them have modular structure. Indeed, the PC controlled NC machine tools was realized only after the NC system obtained an open architecture in which three functions, *display*, calculation, and driving, were modularized and worked independently without interferences, as depicted in Fig. 4.

The integration of a PC function into the display unit of an NC machine tools, moreover, realized an NC system with flexible and enhanced PC functions such as database and networking. The database function, for example, enabled the NC operator to manage tool files, customize operation screens, and freely build human interfaces. The PC's networking function could also be used to operate the NC machine tools from a remote location within the factory via the Internet.

The combination of the PC's abundant information processing functions with control functions heralded innovations that turned the NC equipment into a product with diverse value at a more advanced level. I would argue that this combination will also open the door to the 'servitization' of the machine tool industry (Howells, 2004). In other words, value will be added by service activities in machine tool manufacturing sector. In terms of a technology-service fusion innovation matrix proposed by Chang and Yen (2012), I would argue, this illustration falls into the category of Quadrant II i.e., Technology-servitization innovation.

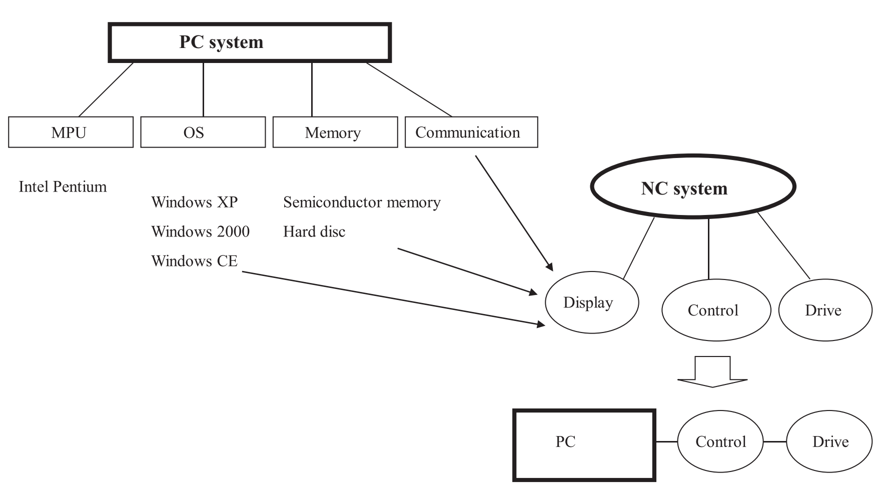

Fig. 4. Module integration of PC and NC. .
Source: Shibata (2009)

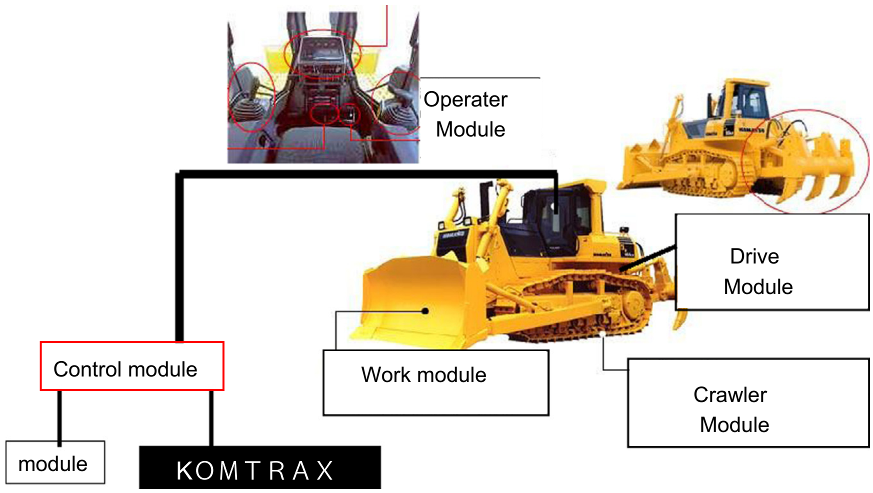

Fig. 5. KOMTRX system. .
Source: Nikkei Business (2007)

4.2. Illustration 2: Management information system of construction company

A Japanese construction machinery supplier, Komatsu Co. Ltd., turned out to be the first company which introduced disruptive technologies such as RFID (Radio Frequency Identification) and GPS (Global Positioning System) for development of building lots, and now is a market leader in construction businesses (Nikkei Business, 2007). As shown in Fig. 5, RFID sensors are inserted inside their machines operating all over the world and all the data about their operating conditions are sent to Komatsu headquarters in Tokyo via satellite communication. The system Komatsu developed is called "KOMTRAX" system. They started its operation in 2001.

Having KOMTRAX developed, Komatsu could enhance customer service drastically by providing them with timely exchange and repair of parts and also with *theft* prevention. Generally speaking, the running cost of construction machinery is three times as high as the purchase cost. The elimination of wasted activities and the out-of-order situations that are made possible by using the operation data collected by KOMTRAX, therefore, is very advantageous to customers. The sales agents located around the world can also benefit by reducing their inventory. In summary, the use of the RFIDs and GPS enabled or facilitated delivery of various customer services by the construction machinery providers (Walker et al., 2002), such as timely exchange and repair of parts, theft prevention etc. Indeed, Komatsu used these technologies to reduce labor costs and create value-added services, improve service quality, and enhance customer satisfaction (Zhu et al., 2002). In terms of the technology-service fusion matrix, therefore, this case illustration seems to fall into the Quadrant III, i.e., Technology-enabled services.

By establishing the KOMTRAX system, Komatsu headquarters has obtained and access to all the data about operation conditions of all the Komatsu machines installed all over the world. In fact, these collected data are effectively utilized for discussion on demand forecasting being conducted at the headquarters. Based on this demand estimate, headquarters formulates production schedules and equipment investment plans at each factory. In 2004, for example, the Chinese economy was in downturn, due to the financial policy then implemented by the government. The collected data by KOMTRAX system showed clearly that the operating ratios of their machines were abnormally low in China. Komatsu halted production three months before the demand reduction was officially announced by a Chinese government agency. This gave Komatsu an enormous advantage over competitors.

If we make a retrospective observation about the development and sophisticated utilization of the Komtrax system, this case history can be interpreted as a service integration innovation that arises when an existing service innovation is fused with a new *corporate management* innovation. Therefore, it falls into Quadrant IV, i.e., Service integration innovation (Chang and Yen, 2012). The current debates on 'Service Innovation,' however, are focused around the cases in which manufacturers are modifying their business strategies to incorporate more service/downstream offerings (Howells, 2004). It is also widely argued that a competitive manufacturing strategy may consider the going-downstream business models, owing to the abundant knowledge of products and markets owned by the manufacturers (Wise and Baumgartner, 1999). I would argue, therefore, what Komtrax system has made possible in corporate management goes far beyond these current debates.

This development is, indeed, encapsulating a core part of corporate management including investment planning (Howells, 2004). In order to comprehend these phenomena in a broader context, therefore, we need to bring a more evolutionary perspective, which will be proposed in the next section.

5. Proposing an evolutionary view of technology-service convergence

In the 1970s and 1980s, corporate R&D activities had been the major driving forces behind industrial diversification, at least, in Japanese industries (Kodama, 1986c). And it is also ascertained that the drastic growth of an industry can be fostered only by downstream diversification within manufacturing (Kodama, 1995).

In the 1990s, however, most large manufacturers have struggled, despite their own focus on improving productivity and quality (Wise and Baumgartner, 1999). The combination of stagnant product demand and an expanding installed base, indeed, has pushed economic value downstream, away from manufacturing and toward providing services required to operate and maintain products.

When we entered into 2000s, we went further beyond downstream diversification, as exemplified by the two Japanese experiences described in the preceding section. In the case of PC controlled NC machine tools, the impacts might go far beyond the simple synergy between the two major industries, i.e., the computer industry and the machine tool industry. As stated above by Rosenberg, the technological convergence that occurred in the machine tool industry had been a driving force behind a whole of the 19th century industrialization. He also suggested that the machine tool industry may be regarded as a center for the acquisition and diffusion of new skills and techniques in a machinofacture type of economy (Rosenberg, 1978). Its chief importance, therefore, lay in its strategic role in the learning process associated with industrialization. Rosenberg asserted that this role is a dual one: (1) new skills and techniques were developed or perfected here in response to the demands of specific customers; and (2) once they were acquired, the machine tool industry was the main transmission center for the transfer of new skills and techniques to the entire machine-using sector of the economy. Since the machine tool industry will still remain as the core of industrialization, the combination of ICTs with machine tools is expected to play a strategic role in the learning process associated with emerging post-industrialized society.

In the case of the Komtrax system in the construction industry, the introduction of ICTs provides the machinery suppliers with drastic widening in the range of service activities and also enhances service quality. A qualitative leap in business activities was attained by utilization of big-data provided by the Komtrax system in corporate decision-making. This had not been originally intended nor planned since it is obvious that the Komtrax system was developed mainly for the improvement of after-sales activities by construction machinery providers. This prototypical case of the enhanced use of big-data available through the one-line and world-wide aggregation of operation data, however, might trigger improvements in the quality of corporate decision-making countrywide, because the potential demand for this type of utilization of big operation data does exist in any company in any industrial sector.

This type of thought experiment on the future vision of those Japanese examples of technology-service convergence, leads us eventually to propose a new analytical framework which covers more than the current debates on servitization and/or going-upstream of manufacturing. The essence of technology-service convergence, as described above, is that the two systems which had been evolving by following quite different trajectories, and which had reached quite different architectures, are now integrated with each other.

The idea of convergence, furthermore, should not necessarily be confined only within the technological aspects such as technological trajectories and architectural designs. In the Newsweek article mentioned above (Newsweek, 1999), "convergence" revolution is characterized by "the fruit of the digital *union* of telecommunications, information technology, and the Internet and consumer electronics."

Here again, Steve Jobs is quoted as saying (Cupertino Silicon Valley Press, 2011): "We do not think that televisions and personal computers are going to *merge*. We think basically you watch television to turn brain *off* and you work on your computer when you want to turn your brain *on*." I interpret that he is essentially talking about the evolutionary process even in terms of how and under which environments these digital technologies are and will be used by consumers.

By viewing the technology-service convergence as an evolutional process, therefore, we can suggest establishment of a new framework of analysis of this convergence. Baldwin and Clark (2000) looked at the dynamic possibilities that are inherent in modular structures. They argue that the changes that can be imagined in a modular structure are spanned by *six*, relatively simple modular operators. These operators, applied at various points and in different combinations, can generate all possible *evolutionary* paths for the structure. They define and describe the six modular operators: splitting, substituting, augmenting, excluding, inverting, and porting. According to Baldwin and Clark (1997), designers achieve modularity by partitioning information into *visible* design rules and *hidden* design parameters. The operator "inversion" describes the action of taking previously hidden information "moving it up" the design hierarchy so that it is visible to a group of modules.

The "porting" operator, as the name suggests, *ports* modules to other systems, and is the only operator that operates on other systems. The other five operators only work within their respective system. Porting occurs when a hidden module "breaks loose" and is able to *function* in more than one system. In the case of the PC-controlled NC machine tools, a PC function is ported into the display module, as shown in Fig. 6. As seen in the figure, in the second module partition, only after the display module is parceled out from the whole NC system of close architecture, does the porting of the PC display module into NC system become possible. This porting took much longer than everyone had expected.

In the early stage of KOMTRAX development, on the other hand, its function was hidden in the Control Module, as was depicted earlier at the right-bottom corner of the preceding Fig. 5. Then, this module was ported to Komatsu's corporate management system. The porting process of the KOMTRAX module is described in Fig. 7, by following the format suggested by Baldwin and Clark.

These analyses described above have shown us how an evolutionary framework can be applied to the emerging pattern of technology-service convergence. They also indicate that the technology-service convergence is made possible by applying the

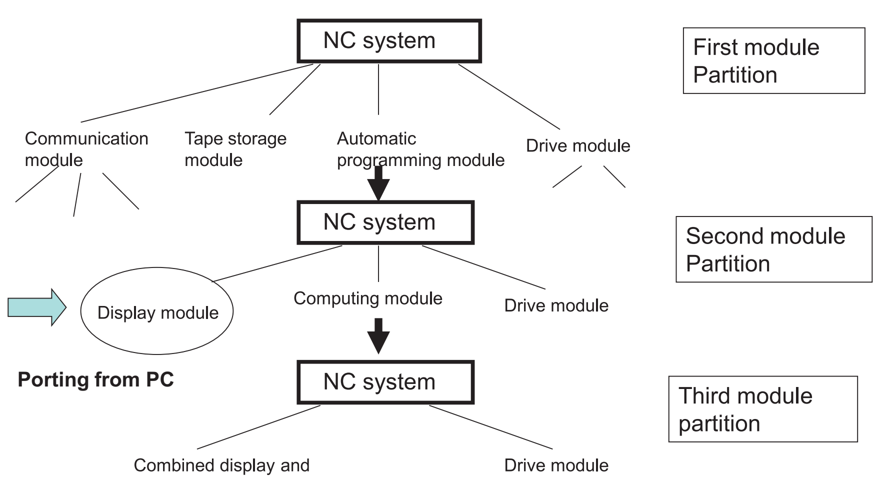

Fig. 6. Porting a PC function in the PC controlled NC. .
Source: Shibata (2009)

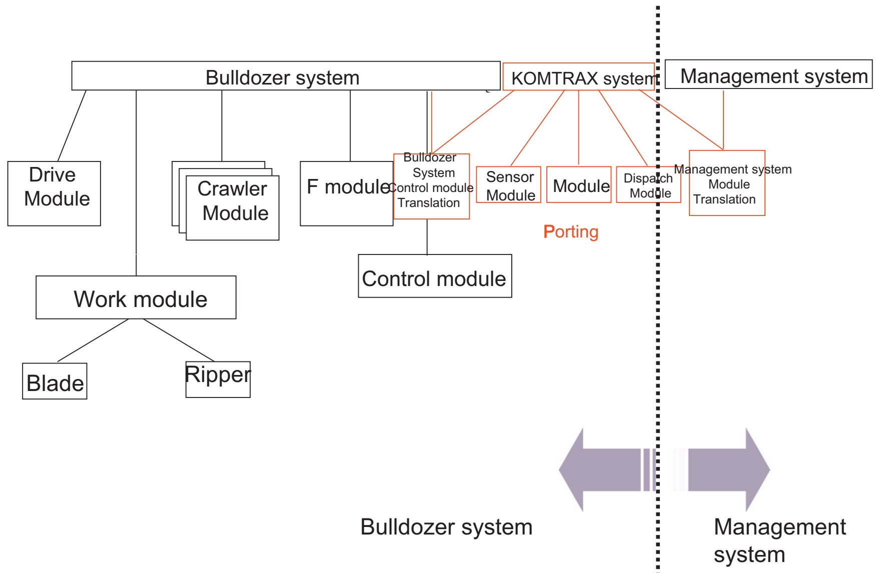

Fig. 7. Porting of KOMTRAX to management system.

porting operator within the modular structures consisting of technology and service modules. As illuminated by the thought experiment conducted on the foreseeable evolution of the two Japanese experiences, I postulate that the technology-service convergence will be widely diffused into a whole society in the post-industrialized era. In order to build a new societal platform, however, one porting is not enough. We need porting after porting (World Economic Forum, 2008). In the technology-service convergence of tomorrow, therefore, evolution will proceed through *multiple* porting.

Although it is needless to say that this analysis is far from providing us with comprehensive evidence, we can at least suggest that porting becomes a trigger that facilitates technology-service convergence. In this regards, a further investigation involving several case studies is an absolute necessity.

6. Concluding remarks

In this paper, I reviewed the transition in the nature of innovation from technology fusion to technology-service convergence via modularization, and demonstrated that the transition process involved several stages of the progression.

Based on the Japanese illustrative cases, we ascertained that the "porting" operator is critical to the evolution of technology-service convergence. This finding should be contrasted with the importance of "integration," or "fusion," which had received most attention until now. These wordings are, however, "engineering" wordings, reflecting the fact that engineering aspect used to be a critical part of the problem in the past. In the coming post-industrialized society, I also postulated that technology-service convergence will evolve through *multiple* application of porting operators. In this context, management of technology becomes critical, i.e., how to manage the process of multiple porting becomes upmost important (Kodama, 2008).

The evolutionary nature of technology-service convergence innovation described in this paper, calls for upgrading typical MOT concepts and tools such as technology strategy, technology forecasting, technology road-mapping, and technology project portfolio (Cetindamar et al., 2010). These concepts and tools have so far been based on the assumption that technology development and utilization progress in a more or less sequential manner. In technology-service convergence, however, technology and utilization are going in apparel through various evolutionary paths. We therefore should enrich the basic understanding of MOT so that this evolution can be properly analyzed, predicted and managed in optimally.

Our specific recommendations are as follows. The first is related to emergence of big-data businesses. In order for suppliers to exploit the opportunities brought about by the technology-service convergence, they have to enhance the capability to deal with the big-data processing, both in the collection and the utilization capability. This recommendation also applies to the capability-building of service providers. Since the big-data are collected automatically by manufacturers in the process of providing maintenance services to customers, it can be a critical resource for the manufacturers' diversification into the service sector.

The second recommendation is related to MOT tools. As our illustrative examples have clearly demonstrated, the realization of the technology-service convergence cannot be achieved without developing some kind of new business models. Indeed, the recent innovation pattern involves simultaneous development of a technology and a business model. It is, therefore, recommended to include "business model" development as part of MOT research and teaching. This might possibly result in a comprehensive reorganization of the MOT research agenda and teaching curriculum.

Last but not least, I will give some thoughts on the management of national economy, a topic now widely discussed in advanced countries. In particular, the discussion often concerns the impacts of financial policy measures implemented by central banks on the depression and/or deflation of the national economy. Without the timely collection of accurate information about ongoing economic activities, it is not feasible to plan and implement adequate financial policies to bring the national economy back to normal and stimulate growth. In this context, those big-data automatically collected through the daily operation of firms are growing importance and relevance to the decision-making by financial institutions. For example, information about the level of manufacturing activities is contained in the big-data collected by machine tool suppliers for purposes of customer service. The big-data collected by construction machinery providers contains information about how these machines installed are actually being utilized, and thus this can provide financial institutions with real-time, accurate data about the overall economic activity, including those of how far public work projects have been executed.

In conclusion, the impacts of the technology-service convergence will not be confined to the corporate management, but will have wider implications for the management by the government. This is not feasible, however, unless we can discover ways to share the big-data collected by individual firms, moderating conflicts of interests by finding the appropriate level of data aggregation and by devising effective schemes for safeguarding proprietary information.

References

Baldwin, C., Clark, K., 1997. Managing in an age of modularity. Harvard Business Review. (September/October), 84–93.
Baldwin, C., Clark, K., 2000. Design Rules: The Power of Modularity. MIT Press, Cambridge.
Cupertino Silicon Valley Press, 2011. iPod as Software. Steve Jobs: His Own Words and Wisdom (Steve Jobs Biography): Remarkable Quotations by Steve Jobs, Cupertino Silicon Valley Press.
Chang, Y.C., Yen, H.R., 2012. Introduction to the special cluster on managing technology-service fusion innovation. Technovation 32 (7–8), 415–418.
Cetindamar, D., Phaal, R., Probert, D., 2010. Technology Management. Palgrave Macmillan, Hampshire.
Clark, K., Fujimoto, T., 1991. Product Development Performance: Strategy, Organization, and Management in the World Auto Industry. Harvard Business Scholl Press, Boston.
Grove, A., 1996. Only the Paranoid Survive: How to Exploit the Crisis Points that Challenge every Company and Career. Doubleday, New York.
Howells, J., 2004. Innovation, consumption and services: encapsulation and the combinatorial role of services. The Service Industries Journal 24 (1), 19–36.
Kodama, F., 1986a. Technology fusion as a new pattern of innovation and its analysis (in Japanese). Bulletin of Japanese Society for Mechanical Engineers 89 (80), 44–49.
Kodama, F., 1986b. Inter-disciplinary research: Japanese innovation in mechatronics technology. Science and Public Policy 13 (1), 44–51.
Kodama, F., 1986c. Technological diversification of Japanese industry. Science 233, 291–296.
Kodama, F., 1992a. Japan's unique capability to innovate: technology fusion and its international implications. In: Arrison, T., Bergsten, C., Graham, E., Harris, M.S. (Eds.), Japan's Growing Technological Capability: Implications for the U.S. Economy. National Academy Press, Washington D.C., pp. 149–164.
Kodama, F., 1992b. Technology fusion and the new R&D. Harvard Business Review 70 (4), 72–75.
Kodama, F., 2004. Measuring emerging categories of innovation: modularity and business model. Technological Forecasting & Social Change 71, 623–633.
Kodama, F., 1995. Emerging Patterns of Innovation: Sources of Japan's Technological Edge. Harvard Business School Press, Boston.
Kodama, F., 2008. Keynote speech III: MOT beyond manufacturing. In: Proceedings of First International Conference on Technology Management: New Directions of Technology Management, Official Conference of The IEEE Technology Management Council, October 12, 2008, Tokyo.
Morita, A., 1992. Partnering for competitiveness: the role of Japanese business. Harvard Business Review 70 (3), 82 3.
Newsweek, 1999. June 21 issue.
Nikkei Business, 2007. June 4 Issue (in Japanese), 28–31.
Rosenberg, N., 1978. Perspectives on Technology. Cambridge University Press, Cambridge15–18.
Shibata, T., 2009. Product innovation through module dynamics. Journal of Engineering and Technology Management 26, 46–56.
Walker, R.H., Craig-Lees, M., Hecker, R., Francis, H., 2002. Technology-enabled service delivery: an investigation of reasons affecting customer adoption and rejection. International Journal of Service Industry Management 13 (1), 91–106.
Wise, R., Baumgartner, P., 1999. Go downstream: the new profit imperative in manufacturing. Harvard Business Review 77 (5), 133–141.
World Economic Forum, 2008. World Scenario Series: Engineering & Construction: Scenarios to 2020. Switzerland.
Zhu, F.X., Wymer, W., Chen, I., 2002. IT-based services and service quality in consumer banking. International Journal of Service Industry Management 13 (1), 69–90.