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Growth of the Custom-made Market in the Metal and Machining Sectors in the DX Era and Startups and Small and Medium-sized Enterprises as Engines of Innovation

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Abstract

In the manufacturing sector, the shift from large scale mass production to small lot production or special-order production is increasing. While custom-made products tend to increase costs, they are also what Hobday (1998) calls a Complex Product System (CoPS), a process of knowledge creation toward an efficient production system. The progress of digitalization has realized economies of scope in the world of low-volume, high-variety and custom-made production, while servitization serves as a platform for expanding business domains.

The cloud is not only a user service, but also a system that collects and multiplies various data generated by machines and equipment existing onsite and make that data intellectual assets. It is an open CPS in the sense that it is widely shared and utilized across the entire site.

In this research, we analyze cases of (1) online estimation and ordering service of design data by cloud computing, (2) service bureaus and new service businesses for additive manufacturing (AM), (3) a consortium aiming to realize smart factories as well as a company that supports the construction of smart factories through processing programming that pursues full automation using AI.

The cases are analyzed from the viewpoint of business ecosystems and intermediary organizations. In each case, startups and relatively small businesses are leading innovators.

Keywords: *custom-made products, cloud engineering service, platform strategy, smart factory, AI (artificial intelligence)*

1. INTRODUCTION

Many of the transformations taking place in the business world are not due to innovative technologies in specific industries, but rather due to the deployment of a broad set of technologies (bundles) in the business world, as symbolized by digital transformation (DX). In the industrial world, technological innovation is required in various fields as well as the digitalization of factories and manufacturing sites, such as cloud computing which will improve the reliance function of manufacturing.

In other words, digitalization is a major enabler of innovation diffusion. Diffusion here is the process by which an innovation is communicated through certain channels over time among the members of a social system and communication is a process in which participants create and share information with one another in order to reach a mutual understanding (Rogers, 1983) [1)].

On the other hand, the manufacturing sector has shifted its emphasis from mass production to small lot production, and recently, the demand for custom-made products has been further increasing, requiring prototyping and single-product production.

Custom-made products are what Hobday (1998) calls CoPS (Complex Products and Systems) which are highly engineering-intensive goods and service. The dynamics of innovation in CoPS are likely to differ from mass produced commodity goods. Complexity reflects the number of customized components, the range of knowledge and skills required to develop, and the degree of new knowledge involved in making them.

The shift from a traditional product-centric approach to a digital-based, service-oriented approach is forcing the creation of entirely new business models (Paiolaa & Gebauer, 2020).

The proliferation of cloud systems has led to an increase in services that support online ordering, including machining, which is bringing about significant changes in the supply chain. On the other hand, the field of custom-made production, which had previously been regarded as an inefficient field, is now regarded as a process of knowledge creation toward efficient production systems because of the development of cloud computing, AI (artificial intelligence), and DB (data base).

In addition, cloud-based systems make it easy to collect, store, update, and retrieve information, and the digitization of design documents can lead to the creation of intellectual assets that generate value from past drawings. Digitization reduces the number of design man-hours and parts by utilizing diverted drawings, and automatic analysis of drawings dramatically improves productivity.

Modern firms operate within a loose network of suppliers, distributor outsourcers, manufacturers of related products and services, providers of related technologies, and other organizations that influence or are influenced by the production and provision of their products, the so-called ecosystem (Iansiti & Levien 2004). Tatsumoto (2017) states that business ecosystem-type industries are characterized by (1) the existence of firms with different roles (firm types), (2) multiple firms forming a network with direct and indirect relationships, and (3) the emergence of very specific firm types that have influence on industry evolution. New boundaries and dynamic combinations are organized, and business models based on complexes are generated, but there are intermediary organizations that serve as bearers. The new boundaries and dynamic combinations created are organized to generate business models based on complexes, and there are intermediary organizations that serve as bearers.

In this paper, the following three emerging industry sectors are highlighted, focusing on the business ecosystem and the intermediary organizations that connect suppliers and end-users. First the market trend of online quotation and ordering services for design data by cloud computing and online ordering platform companies are discussed. Second, service bureaus and new service businesses that are responsible for the formation of the additive manufacturing (AM) market, known as 3D printing are examined, and third, companies that are working to realize smart factories through consortiums and processing programming that pursues full automation by making full use of AI are discussed.

The methods used in this study were literature and material survey, previous research review, participation in lectures and seminars, and interviews with survey targets.

2. TRENDS IN THE DIGITALIZATION OF THE MANUFACTURING SUPPLY CHAIN

2.1. Custom-made demand market

Since many companies are involved in the design, production, and procurement of custom-made parts, a large amount of time is required for procedures as well as other transactions and for secure communication to ensure the confidentiality of product information. In the world of small lot production, which accounts for about one-third of the entire manufacturing industry, or in the world of custom-made parts manufacturing (in large transportation equipment, industrial machinery, medical equipment, and other industries), various social issues exist in both ordering and receiving, such as unstable ordering and receiving platforms, the length time and amount of effort required for ordering and estimation, procurement costs, and high loss ratios on the manufacturing side.

Increasing labor productivity is essential to meet the market's demand for custom orders. As various operations in the manufacturing industry become more remote, services that support on-demand ordering of machining parts are increasing. In the global market, Protolabs (U.S.) and Xometry (U.S.) are getting a lot of attention. In addition, the internet-enabled custom-made machining service market is growing rapidly at an annual rate of 20%, and is expected to reach 800 billion JPY globally by 2025 (Fuji Keizai, 2018, Stasia (n.d.), Straine (n.d.)).

On-demand manufacturing of prototypes and small lot manufacturing using injection molding and machining via a proprietary digital manufacturing system that allows customers to upload 3D CAD data and receive a quote with manufacturability analysis in several hours, and manufacture injection molded and CNC machined parts in days is growing. Injection molding and CNC machined parts are manufactured in a few days.

2.2. Online Contract Service

MISUMI Group Inc. (MISUMI 3D2M), a trading company for the manufacture of die stamped components, has been promoting standards that eliminates the need for "drawing" and "estimation" since its first published "catalog" in 1977. In other words, customers select specifications such as shape, material, surface treatment, and dimensions from a catalog and order by catalog number. 'Meviy,' a parts procurement platform released in 2016, enables customers to upload 3D CAD data on the web to receive immediate quotes and provides one-day shipping at the earliest. In addition to the manufacture and sale of "standard items" that can be ordered from their catalogs, which is the main business, the platform also supports "drawing items," which are manufactured from drawings. Design scenarios and items consist of three divisions such as "FA mechanical parts" (sheet metal parts and machined plates) for equipment and device design, "rapid prototyping" (prototyping) for development and product design, and "die parts" for die and mold design. The company has global operations with a set of sales offices, distribution centers, and production facilities in Asia, the Americas, Europe, and other parts of the world.

Kabuku Connect is a service that supports process innovation and business innovation by making full use of software development capabilities and manufacturing technologies. Kabuku Connect offers an immediate quotation service, a batch procurement service for machined parts intended for equipment, a service in which manufacturing professionals provide VE proposals for optimal QCD, and services from planning and design to prototyping, as well as a simple design and procurement service in which plates made of 6-sided milling material can be procured through machining.

Factory Agent Corporation (established in 2020), a JTEKT Group company, uses a unique network and program to match "clients" who are looking for designs and machined products with "clients" who have machining technology. Zero-Four Corporation, founded in 2007, has been providing 3D data analysis software "iQ35-Web," which can be operated on the internet, as part of the "iQ series" which provide automated 3D data cost estimation for the fabrication of metal parts and manufacturing since 2021. Orizuru 3D, a pseudo-AI search tool for 3D models provided by Core Concept Technologies Inc. and Terminal Q provided by TERMINALQ Inc. has also been created.

Sumitomo Corporation, a general trading company, developed and is operating "SynApp," a platform for matching parts processing. Initially, the platform targeted sheet metal and cutting work, and allows users to request work starting with just a single process. When an ordering company registers a project, the AI automatically matches it with a processing company that has the appropriate capabilities. Kanamori Industries Ltd. has also launched the PlaQuick service that specializes in plastic materials.

Table 1 summarizes the online ordering

Table 1: Online ordering platform

Online platform	Service offered
Meviy	A platform for accepting orders for machine parts over the Internet. Customers upload 3D CAD data for the machined parts they have designed, and MISUMI provides immediate quotations and parts procurement information.
CADDi	The ordering side enters drawings and specifications, and an estimate is automatically calculated. CADDi accepts bulk orders for inspection and delivery of finished products, as well as parts production and assembly of equipment.
Kabuku Connect	An on-demand manufacturing platform, consisting of "instant quotation service," where users upload 2D/3D design files to receive quotations and place manufacturing orders, etc.
Factory Agent	A platform that matches customers with factories selected by the JTEKT Group to help solve problems related to parts procurement in terms of price, delivery time, quality, and man-hours.
Zero-Four	An estimating software for sheet metal and can manufacturing processes provides cost calculation and immediate quotation services. "Gokou" is a platform that connects manufacturing companies and metalworking businesses.
SynApp	Processing companies can register their processing capabilities, standards, and certifications in advance, and when an ordering company registers a project, the AI automatically matches it with a preregistered processing company.
PlaQuick	Kanamori Industries provides "PlaBase" (plabase.com), a database of plastic molding materials, and "PlaQuick" (plaquick.com), which supports plastic molding prototyping issues with short delivery times, small lots, and low costs.

Source: Created by authors based on each company's website

platforms for presenting design data in Japan.

The following section 2.3 discusses the case of Kabuku Inc. and CADDi Inc. that operate an order and supply platform that is specialized for the manufacturing industry. Both are relatively young firms that are in the process of growing and also attracting attention from the public sector.

2.3. Cases of Online Contract Service Companies

2.3.1. Kabuku Inc.

Kabuku Connect is an on-demand manufacturing platform for prototypes and custom-made products that has been operated since 2016 by Kabuku Corporation (established in 2013), a Futaba Electronics Group company. Kabuku Connect and other initiatives were the first companies certified using the Small and Medium Enterprise Agency's newly established certification system for businesses that create opportunities for small and medium-sized subcontractors[2)].

The company is also developing "Drawing Communication," an online drawing sharing service, and "Cost PRO," a cloud-based processing cost estimation service, as services that improve the efficiency and flexibility of the entire manufacturing industry. In 2020, the company's "Development of an on-demand supply chain platform for high-mix low-volume production" project was awarded a grant from the New Energy and Industrial Technology Development Organization (NEDO).

In relation to on-demand manufacturing platforms, a service that enables users to upload 3D models/ drawings, read the contents, calculate and issue quotations immediately, and place orders, a bulk procurement service for machined parts, to be used in equipment, can significantly reduce total costs.

This procedure, in which experts familiar with each manufacturing method utilize a network of domestic and overseas factories to provide quotes for a variety of manufacturing methods, including cutting, turning, sheet metal processing, can manufacturing, and procurement-related services. The company also offers a manufacturing consulting service that provides design, prototyping and procurement that significantly reduces the man-hours required for designing and procuring.

From 2019, Kabuku Connect added an instantaneous quotation function for metal 3D printing in addition to the previous function for resin 3D printing. Kabuku's 3D shape analysis and data mining technologies have made it possible to automate portions of the quotation process. After the customer uploads 3D data, the company responds in a few seconds with the lowest cost estimate from its factory network, and offers a 3D printer (compatible models: SLM, DMLS[3)]) additive manufacturing (AM) service.

2.3.2. CADDi Inc.

CADDi, Inc. is a startup established in 2017 and a developer of IT services that has been selected as a beneficiary company by J-Startup, a public-private startup support program led by the Ministry of Economy, Trade and Industry (hereinafter, METI) (2019 White Paper Small and Medium Enterprises in Japan, p.38). Since its establishment, the company has been committed to the mission of "Unleashing the potential of the manufacturing industry," providing the manufacturing order and supply platform "CADDi" and addressing structural issues that are latent in the entire value chain.

On the hardware side of their business, the company offers a fabricated parts manufacturing service that uses automated quotation technology to connect custom-order clients to fabrication companies nationwide. Using a proprietary pricing algorithm, optimal ordering, and a production management system, the company optimizes QCD and responds to capacity expansion and fluctuation. The system allows the "uploading 3D data of products (parts) to the cloud to calculate quotations and place orders." In fact, 3D data can be created for any part at the manufacturing site, and the system enables the manufacturing and prototyping of parts simply by uploading the 3D data. CADDi's business model is characterized by a detailed understanding of steel alloys, and the machining company's range of capabilities and strengths. The ordering and receiving platforms are linked to the respective systems for drawing analysis, cost accounting, production control, and partner factory coordination. The company guarantees the final manufacturing quality and takes responsibility for everything from quotation calculation and production management to final quality assurance and factory audits (CADDi, 2019).

The other part of their business focuses on software, which includes cloud software that automatically analyzes and manages drawings and the CADDi DRAWER program, a service that creates value by using past drawings and turns them into intellectual assets (Excite News, 2022). The software builds a data structure that facilitates the creation of value by aggregating the most important data (2D drawings) with peripheral information such as quotation history, order conditions, supplier information, quality defects, and delivery delays. This software is not just a simple "data storage" device, but is designed to improve the quality of judgment and decision-making for the purpose of cost reduction, order optimization, standard design, etc., and to make the data usable as an asset.

The total amount of funds raised in 2021 was over 8 billion JPY, which was invested in the human resource recruitment, the development of CADDi, and other new business ventures, including global recruitment. The funds were invested in new businesses. The company has also expanded overseas, establishing local subsidiaries in Vietnam, Thailand and the USA to promote the establishment of a supplier network.

Through these efforts, the company aims to become a global platform by accelerating the DX of the entire value chain from design to manufacturing, logistics, and sales, and by establishing a de facto standard in the digitalization of the manufacturing industry.

3. ADDITIVE MANUFACTURING (AM) BUSINESS TRENDS

3.1. Development of Additive Manufacturing (AM)

The global market size for metal 3D printing is projected to grow to approximately US$13.2 billion by 2030, registering a compound annual growth rate of 32.8% during the forecast period from 2021 to 2029 (Maximize Market research, n.d.). In Japan, sales of molding equipment and metal powder materials were 122.3 billion JPY and 11 billion JPY in 2017 respectively, and are expected to grow to 650 billion JPY and 2 trillion JPY, respectively, by 2030. In particular, the rapid growth of metal powder materials and metal fabricated products means that the number of metal fabricated products will increase. In the medical, aerospace, and automotive industries, the utilization rate of metal 3D printers is expected to grow especially rapidly. In particular, the use of metal 3D printers will increase drastically (TSC Foresight, 2019).

Metal Additive Manufacturing (AM)[4] technology, also known as 3D printing technology, is expected to be an innovative technology that will bring innovation not only to manufacturing processes but also to the fields of manufacturing and materials development, and could have a significant impact on the creation of new industries. It is also possible to control the microstructure of metal alloys during forming, and is expected to have potential as a process for controlling metallurgical structures that could only be obtained through processing using hot forging and heat treatment technologies.

AM is expected to significantly change the existing business model by eliminating the need for assembly of parts and components, enabling integrated structures, fast and uniform fabrication of complex shapes, reduced molding cycle time, improved yield, and improved product quality. The development of AM will depend not only on the progress of basic technology, but also on the ability to form new business models.

The three elements of metal AM technology are design, materials, and equipment. For materials, issues include powder modification technology, composite technology, granulation technology, powder manufacturing technology, powder bed fusion (PBF) technology (miniaturization to a few μm and faster), and safety technology, while for machines (molding method) the issues include molding speed, molding accuracy, surface roughness, optimal recipe development, and in-process monitoring technology.

AM is basically used for prototype and small lot product markets, but manufacturing methods have evolved and powder bed fusion (PBF) and binder jetting (BJT) have been put to practical use. In particular, the filament method for material supply has begun to expand into the mass production (medium volume production) market, although it is less precise than PBF and other methods.

3.2. Contract Fabrication Services and Changes in the Fabrication Market

In Japan, service bureaus that provide contract modeling services began to enter the market in earnest around 2013. Service bureaus are companies that provide business services for a fee.

The majority of service bureaus are small to medium-sized companies that perform contract manufacturing for which they receive drawings and data, but sales of equipment and materials also account for a large portion of their business. Because compared to resin 3D printing, metal AM equipment is more expensive, and it is difficult for user companies to introduce it at once.

In addition, the removal of support materials in the post-process such as support removal[5] has been time-consuming and burdensome. The user created 3D data and handed it over to a service bureau due to the issue of boundary of responsibilities, and the user was limited to modeling existing products with AM. Many equipment manufactures forbid the use of third party metal powder materials, etc., and these were restrictive conditions.

The market has been led by service bureaus specializing in AM, but there are signs of change in the contract manufacturing market due to technological and software developments, including latticeization of support materials with the advancement of CAD/CAM/CAE software and CPS with the advancement of simulation technology, and the spread of Design for Additive Manufacturing (DfAM) is becoming more widespread. Also, third-party powder materials are becoming available. Furthermore, the emergence of low-cost equipment and lower production costs are reducing the hurdles for users to directly install equipment for themselves. Software-based companies are also entering the market by handling equipment.

A movement to introduce/promote AM through consortiums has also emerged. The members of the Japan AM Association, which was reorganized from the "Kansai-3D Practical Application Project," a consortium led by the private sector, includes equipment manufacturers, service bureaus, DfAM and CAD/CAM software manufacturers, post-processing (support removal, heat treatment, cutting, etc.), industrial gases (shield gas), third-party certification organizations, raw material trading

Table 2: Major Service Bureaus and Service Businesses

Service bureau	Market entry (establishment)	Founding and existing businesses
JAMPT	2017 (2017)	Casting (Koiwai) and general trading company (Sojitz)
SOLIZE	2013 (1990)	Optical fabrication systems, 3D modeling, prototype molds
Metal technology Co., Ltd.	2001 (1960)	Metal heat processing, engineering
ABIST Co.,Ltd	2017 (2006)	Machine design, Industrial Design Engineering Services
J.3D Corporation	2013 (2013)	Steel trading company, steel plate custom-made service
Ifuku Seimitsu Co., Ltd.	2016 (1980)	Rotor processing, precision parts processing, measurement
ORIX Rentec Corporation	2015 (1976)	Measuring equipment rental, measuring and commissioning services
Kabuku Inc.	2013 (2013)	On-demand manufacturing platform
tsukulus Co., Ltd.	2007 (2007)	Software/Hardware Sales, Service/Web Development
Data Design Co., Ltd.	2012 (1989)	Machining, Software development for manufacturing site
Japan 3D Printer Co., Ltd.	2013 (2013)	Equipment sales, contract modeling, consulting
FASOTECH Co., Ltd.	2013 (1983)	CAD/CAM/CAE Sales, Engineering
Marubeni Information Systems Co., Ltd.	1992 (1965)	Machinery trading company, System integrator
Melta Inc.	2014 (2014)	Contract modeling, 3D data creation
Yamaichi Special Steel Co., Ltd.	2016 (1927)	Sales of steel products, contract processing
Ricoh Company Ltd.	2014 (1936)	Manufacturing and sales of MFPs and printers
DMM.com LLC	2014 (1999)	On-demand manufacturing platform
JMC Corporation	1999 (1992)	Sales of industrial CT, inspection and measurement services
NTT Data XAM Technologies Corporation	2020 (2020)	Equipment sales, contract molding

Source: Created by authors based on Japan Society of Additive Manufacturing and each company's website

companies, machine tool manufacturers, trading companies and distributors, and agents etc., as well as a cross section of AM, peripheral technologies, and related fields.

Service bureaus specializing in AM have established a service structure that crosses technologies from various sectors, such as equipment, powder materials, and fabrication processes. Although it does not provide a completely open platform, it has grown into a semi-open ecosystem with dynamically changing players.

On the other hand, a case has emerged in which a company is assuming a new function in a different form from that of a service bureau. Ifuku Seimitsu Co., Ltd. with 34 employees, whose core business is lathe turning, is developing a digital warehouse service that creates 3D CAD data from existing products, manages a shared cloud, and processes, restores, and manufactures products according to customer needs, in addition to reverse engineering that uses high-precision 3D measuring instruments and 3D scanners to measure actual products and faithfully reproduce them (J-Net 21, 2020). Furthermore, the company is building a supply system that shortens delivery times and reduces logistics costs by utilizing its network of trading companies to output (modeling) products at locations close to customers in Japan and overseas.

Data Design, Inc., a software vendor of small and medium-sized informatization support tools (e.g. CAD/CAM/CAE) for the manufacturing industry, is engaged in planning and proposing systems based on 3D digital technology, and providing materials and 3D-related application software (scanning, modeling, machining, printing, etc.), sales, and maintenance services as well as equipment, devices, and filament-type materials (binder materials and metal powder mixing materials). The company is working to develop applications and uses, and is pursuing generative design[6)] which adds optimization technology that makes full use of computational processing power within conventional design methods, with the aim of building a new business model.

Yamaichi Special Steel Co., Ltd, which entered the AM field as a medium-sized steel trading company, has accumulated know-how through joint ventures with overseas AM equipment manufacturers and alliances with software companies. It has also developed its own software that provides design methods and design guidelines to maximize the benefits of AM.

3D printers, coating machines, and laser equipment have been installed in a spacious factory lined with cutting machines. The company develops and manufactures filaments for 3D printers, and engineers changing task support through various highly specialized software that make up the design area.

In their AM section, material platforms that have been monopolized by overseas equipment manufacturers are being released, and third-party material products are expanding, leading to the formation of more open platforms. These changes are expected to promote the reorganization and sharing of upstream/downstream know-how and knowledge fixed at each layer in the ecosystem.

3.3. Case of Yamaichi Special Steel Co., Ltd.

Yamaichi Special Steel Co., Ltd.'s involvement in the AM business began in 2016. In 2018, Yamaichi established Weare Pacific as a joint venture with Weare Aerospace of France with the goal of accelerating its aircraft parts business through an AM business.

This joint venture was intended to take advantage of the mutual benefits of the Yamaichi's expertise in supporting mass-produced products, such as automobiles, as a professional manufacturer of special steel. The Yamaichi had the intention of using the AM business as an opportunity to accelerate its aircraft parts business, which it had already entered. However, due to the low productivity of metal AM and the lack of expansion in the domestic market, Yamaichi decided to stop the contract manufacturing of metal AM in 2019 and concentrate on resin and composite materials.

On the other hand, the company established its own "AM-optimized design workflow" based on the 3D model data diagnostic software "Cognitive Additive," the optimization simulation tool "Optibot," which was developed in-house, and the 3D CAD engineering software "nTopology" developed by the US company nTopology. "Cognitive Additive" was originally developed as a data diagnostic software and used as an in-house system to shorten the time required to prepare quotations for customers in the course of processing special steel. In partnership with an overseas company, the company compiled a large amount of AM data into a library and began selling it to external customers in 2020.

"nTopology" is a design software with AM characteristics including lattice design and topology optimization in conjunction with existing CAD/CAE. nTopology signed a distributor agreement with Yamaichi in 2020 to become a user of "nTopology" in 2018. Furthermore, Optibot, a tool that automatically creates a large number of models from items designed with "nTopology," can automatically derive thousands of optimization results from multiple parameters based on the concept of design experiments (DOE)[7].

In their contract modeling business, the company provides a one-stop service that leverages the technology and expertise it has cultivated from its existing business, including the development and manufacture of raw materials, optimization design, and the steps from modeling to finishing and inspection processes.

In addition, the series of work flows combining "Cognitive Additive," "nTopology," and "Optibot" is the greatest strength of the company's AM business, as many companies have installed AM fabrication equipment but have not been able to utilize it to its full potential due to a lack of specific applications. "Cognitive Additive" enables the diagnosis of whether or not a product being considered for production is suitable for AM.

The AM workflow for computational design proposed by the company is shown in Figure 1.

The Yamaichi is a trading company specializing in steel products, but it also engages in the resin bureau business with an integrated in-house system that includes molding equipment, materials, software, and post-processing. The company also proposes essential solutions that approach the original purpose of AM and the solved issues through its unique workflow. The company's ability to respond to the production of custom-made

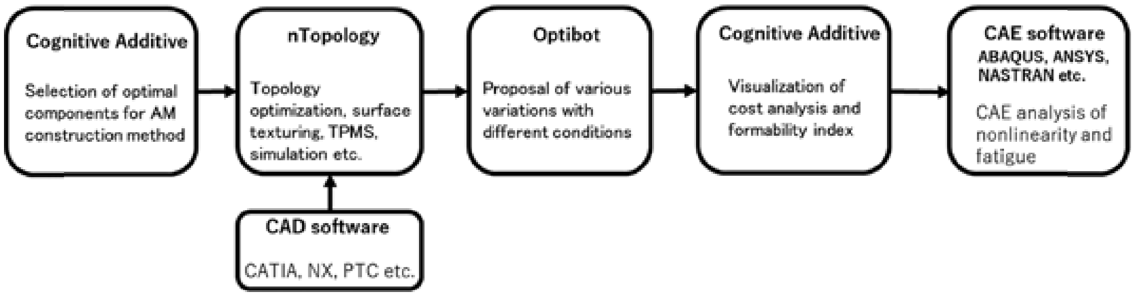

Figure 1: The AM workflow for computational design

Source: Japan AM Association seminar and the presentation materials https://jsam.or.jp/event/2022-03-17-467/

products, which it has acquired through its existing special steel processing business, is thought to be one of the factors that makes this possible, as well as its partnerships with overseas companies.

4. MANUFACTURING AI AND AUTOMATION

4.1. Smart Factory and AI

A smart factory refers to an advanced factory in the form of the Industry4.0 protocol proposed by the German government. It is a CPS in which all devices in a factory, including sensors and equipment, are connected to the IoT to visualize various information on quality and conditions, achieve a "clarification of cause-and-effect relationships" among information, and allow equipment to work in cooperation with each other or with equipment and people. It is not limited to individual factories, but aims to network a group of factories and manufacturing companies.

In Japan, major machine tool manufacturers are using IoT technology to connect all machines and equipment in a factory to a network, share information in real time, and achieve automatic optimal control of production lines through production support systems. (Enomoto, 2018).

Industrial Value Chain Initiative (IVI) (established in 2015), the leading smart factory consortium in Japan, Nishioka (2022) presents an overview of the IVI ontology obtained through many demonstration experiments with respect to architecture and schematics for smart manufacturing in Japan. The IVI includes: convenience factories, where manufacturing is performed at the location closest to the final consumption point; sharing factories, where advanced or rare manufacturing technologies are aggregated to increase efficiency and generate economies of scale; rapidly changing technological domains; and in areas where market uncertainty is high, they advocate connected factories, in which businesses specializing in elemental technologies, rather than finished products, form a network to meet diverse needs.

In April 2022, IVI launched CIOF Partners, an organization that promotes the Connected Industries Open Framework (CIOF) as a mechanism for open collaboration to connect companies digitally. CIOF Partners is an initiative consisting of companies that lead inter-company collaboration in the carbon neutral (CN) era, companies that promote DX involving their business partners using valuable data within their companies, and companies that provide products and services that realize such DX.

The large amount of data collected in real time by IoT technology is analyzed by AI using machine learning domains to optimally control manufacturing lines, etc., and has become commoditized for use in demand forecasting, work automation, defective product sorting, predictive maintenance, supply chain optimization, and other fields. On the other hand, the essence of deep learning, which eliminates the bottleneck of feature extraction, is that it automatically learns which features to focus on based on large amounts of data (unsupervised learning).

There are two main types of AI, edge AI and cloud AI, depending on where AI functions are placed in cyberspace. Edge AI refers to AI learning and reasoning functions that are embedded at the edge, i.e., in products and machines, or placed on nearby servers, etc., where they analyze and make decisions on real-world data collected there (Shibata, 2022).

4.2. Manufacturing AI and the pursuit of full automation

ARUM Inc. pursuing manufacturing AI, founded in 2006 is a small and medium-sized enterprise with about 40 employees. Initially, the company worked on automation, robotization, and AI for manufacturing processes as a mechatronics and electronics business based on contracting. The company's original business was Original Design Manufacturing (ODM) development of automation equipment and software, and its manufacturing AI software, called "ARUMCODE," which automatically generates NC programs from 3D CAD data using AI, was released in 2021.

Many custom-order companies do not reproduce the same parts for each individual order, and only machining the part is automated, while most of the other parts are done by human operators. The manufacturing AI program automates all six processes, including shape analysis, determination of the type of machining required, tool selection, cutting condition setting, machining path generation, and program creation.

In 2014, the company launched a concept plan for software that would automatically create NC programming to run machining centers (MCs) by inputting drawing data. OSE Corporation, which is engaged in cutting, electrical discharge/ wire machining, and grinding operations, was acquired through M&A[8]. The OSE was originally Arum's largest outsourcing partner, and the company was taken over by the OSE's aging management at the time. During this period the concept of manufacturing using AI and automation programs was solidified.

The ARUM designed and manufactured production line automation, robot systems, and AI software, while OSE engaged in three businesses. The three businesses were: a parts business, including mold press die parts, equipment parts, and jigs and tools; a mechatronics business, including design and development of automation lines, assembly, automatic operation adjustment, and maintenance; and a control systems business, including PC control, system control, and control systems for processing machines and facilities. After the merger, the company spent several years developing a database containing OSE's onsite expertise and is now offering software that realizes full automation of NC programming by utilizing AI technology as a new service. The ARUM's facility designs and manufactures automation equipment and software, while the OSE's facility manufactures ultra-precision machined parts to verify development results.

The manufacturing AI program, analyzes the shape of machined part, selects optimal tools, sets machining conditions and toolpaths automatically, as well as displays material and tool set instructions instantly by simply loading CAD data. The system automatically selects the optimum tool for each process based on machining allocation data and tool information registered when the software was installed, and also automatically displays the material and tool set instructions. The program calculates the optimum machining conditions quickly according to a proprietary algorithm.

Based on the set machining conditions, the program automatically calculates efficient machining paths and draws machining simulations. The number of vices and the gripping allowance (in mm) can be registered in advance and can be checked in the model viewer. A machining program is automatically created based on the information gathered up to this point, and at the same time, work instructions and quotation information describing the tools to be used and the machining conditions are also created. Users upload diverse information to the cloud and the system is designed to store a variety of data within the company. The company is developing the system while conducting design reviews, which is a priority for the company.

The AI-based automation program and cloud system enable users' data to be incorporated into the in-house system, and the data-utilizing platform networked with output devices such as internal and external machine tools aims to create a smart factory. The program plays the role of a data-utilizing platform that expands the business domain by connecting directly with customers' equipment and machines.

In August 2022, ARUM Inc.'s proposal for "R&D on building a variable supply chain for the cutting

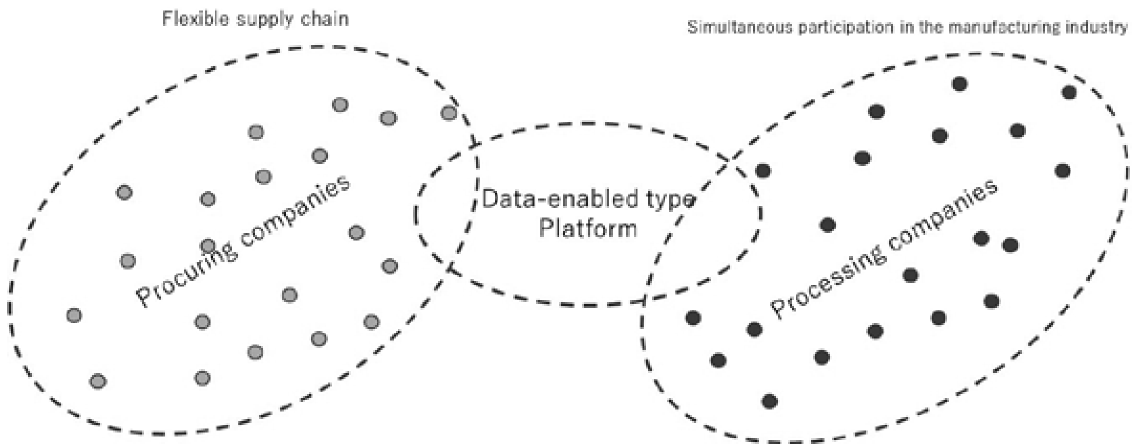

Figure 2: Data-enabled platform deployed by ARUM

Source: Authors

industry through full automation and remote operations" was adopted as a major NEDO project[9]. With an eye on both edge AI and cloud AI, a consortium is being formed with major telecommunications, security, and cloud service providers to develop machines, AI engines, and new control methods in-house both edge AI and cloud AI.

The consortium is promoting the construction of a smart factory that aims for fully automated online production with variable and simultaneous participation by multiple entities with a variable and simultaneous ecosystem.

In December 2022, the company received the chairman & CEO's Award of the Small and Medium Enterprise (SME) Support Japan at the 22nd JAPAN VENTURE AWARDS (JVA).

5. DISCUSSION

The three areas discussed in this paper, online contract services, AM service business, and smart factories and manufacturing AI, are all emerging industries and can be considered business ecosystem industries. In addition to manufacturing companies, there are also extended service companies and software companies, aiming for innovation through business ecosystems. Indirect influence (i.e., network effect) exists, and platform companies exist in the middle.

Platforms create value by associating and coordinating constituent entities that can innovate and compete, or by creating and exploiting economies of scope in supply or demand (Gawer 2014). Online ordering systems such as Mevy, Kabuku Connect, and CADDi are two-sided platforms that create optimal matching between customers and suppliers (Figure 3). All of these companies have global operations. The business model requires expertise, as the company is responsible for inspecting the products before they are shipped. The consulting function is also important.

Additive manufacturing (AM) is a technological process based on custom-made demand and small-lot, high-mix production, and has been introduced to the market by service bureaus that handle contract modeling as a contact point. While equipment, materials, software, etc. have evolved, new service providers have emerged with the spread of DfAM.

Mai et al. (2015) propose a framework for a 3D printing service platform for cloud manufacturing (CMfg) and analyze online integration of 3D printing services and 3D model library construction. A case study of a small and medium-sized company (Ifuku Seimitsu Co., Ltd.) that has partnered with a factory that installed a 3D printer as an output device near the user, has established a system to output, and delivers the product onsite has also been created.

According to Heising et al. (2020), the AM business ecosystem is shown in Figure 4. Service bureaus are located between suppliers and end

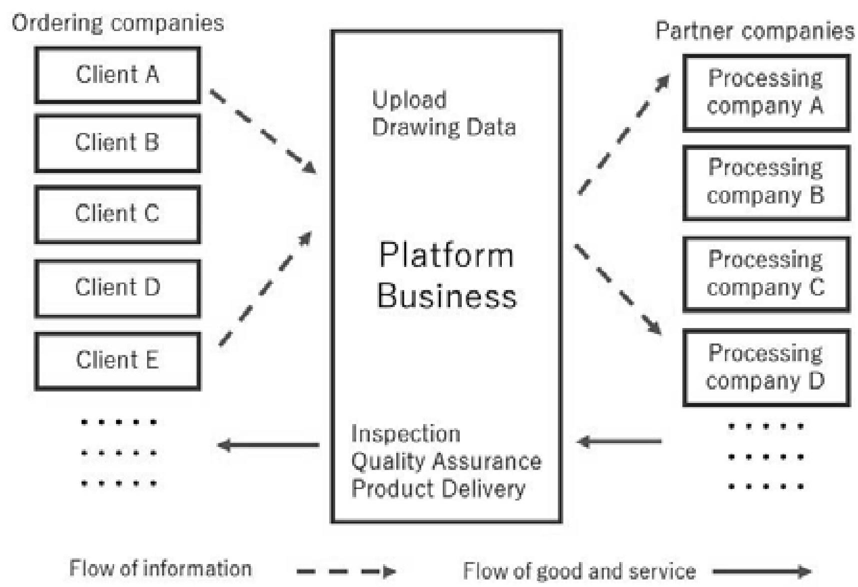

Figure 3: Platformer business model

Source: Authors

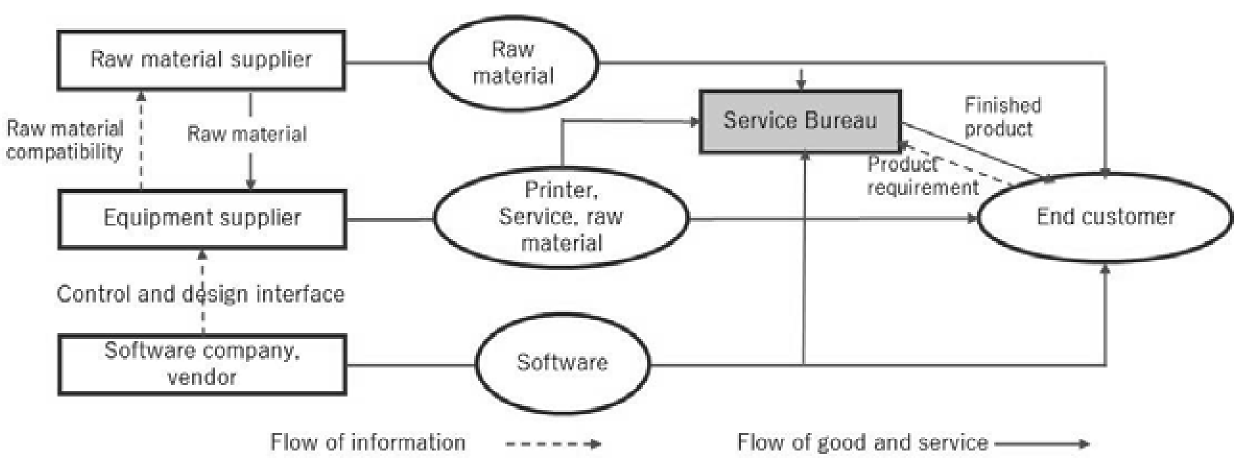

Figure 4: AM service bureau ecosystem

Source: Heising et al. (2020)

customers. It plays a role of an integrator that provides design and engineering functions, as well as consulting functions such as advice on design and modeling.

A manufacturing site is a system in which various machines are interconnected and organically interlocked. To increase the productivity of the entire site, it is necessary to collect various data generated not just by individual machines but by all the machines and equipment present on the site, share and analyze them, and increase overall productivity (Shibata, 2022).

It is an open CPS and a data-utilizing platform in the sense that individual data collected from the field, including not only the company's own factories but also those of other companies, is widely shared and utilized across the entire field against a backdrop of the commoditization of AI. The key point is the fusion of the manufacturing site department and the information processing department, which generates superior data.

The basis of DX is the repetition of value creation through the accumulation, capitalization, analysis, and utilization of data, as well as the creation of intellectual assets through a cloud-based data storage system for user input and design work. If the design is done in Japan and the output device is located near the user, the product can be provided anywhere in the world with short delivery times and without incurring excessive distribution costs.

The players in these efforts are IT-enabled, relatively small intermediary organizations, integrators and keystone companies[10)] with design and engineering functions, often with consulting capabilities.

6. CONCLUSION

Efforts to develop efficient production systems are progressing amid the increase in custom-made production, small lot production. Digitalization efforts are achieving economies of scope in the world of such kind of production, while servitization functions as a platform for expanding business domains.

Cloud systems are becoming popular, and services that support online ordering, including machining, are increasing. The cloud is an open CPS in the sense that it is a user service, a system that collects and multiplies various data generated by machines and equipment on site, makes them into intellectual assets, and is widely shared and utilized throughout the entire site.

This is occurring not only in the AM and machining fields, but also in the local cloud manufacturing system field (design at headquarters and output at a remote site), in which production data and the control parameters of the equipment are centrally managed via the cloud by locating output devices near the user has been progressing.

In the manufacturing industry, the evolution of on-demand engineering services using the cloud is impacting the IoT ecosystem. To create smart factories, it is a prerequisite to have both open and secure systems.

Many of the actors driving the DX of the industry are intermediary organizations such as startups and small and midsize companies. One of their strategies for competitive advantage is a business ecosystem, which requires the formation of various partnerships, including strategic alliances, with the ability to conceive and produce business models will play an important role. The source of added value is on the business model provider side.

NOTES

1) Rogers (1983) lists four factors involved in the diffusion of innovation: innovation (technology), communication channels, time, and social systems.
2) The 2019 Manufacturing White Paper by the Small and Medium Enterprise Agency focuses on on-demand supply chain platforms (2019 Manufacturing White Paper, Chapter 1, Section 2, p. 30).
3) SLM (Selective Laser Melting) and DMLS (Direct Metal Laser Sintering) are both a type of Powder Bed Fusion (PBF) using metal powder as the material.
4) Additive manufacturing (AM) is defined by the ISO/ASTM 52900 terminology standard: the process of joining materials to make parts from 3D model data. Usually, the material is joined layer upon layer, as opposed to subtractive and formative methods of manufacturing. Other terms for AM include 3D printing, additive fabrication, direct digital manufacturing, freeform fabrication, solid freeform fabrication, rapid manufacturing, and rapid prototyping.
5) When 3D printers produce hollow structures or overhanging parts, support materials are produced at the same time to prevent deformation or collapse. The support material is removed after modeling, but the removal process is time-consuming and labor-intensive, so it is possible to design lattice structures for the part to significantly reduce the removal time.
6) Generative design is a technology that allows designers to create optimal product designs from scratch by inputting certain information into computer software. The computer will propose multiple designs in response to the input conditions.
7) The company has developed topology

optimization, digital texturing, and the design of TPMS (Triply Periodic Minimal Surface) structures, which are key elements of DfAM (Design for Additive Manufacturing). "Optibot," which derives thousands of optimization results from multiple parameters using nTopology and add-ons; and "Part Selector," which analyzes the best cost and AM from the many 3D data presented to the user. "Cognitive Additive," a parts selector that analyzes the best parts for cost and AM from a large number of presented 3D data, is provided as self-developed software.

8) O.S.E. Inc. was ARUM Inc's largest customer, but there were concerns about the company's longevity due to the aging of its management.

9) NEDO (2022) "Research and Development for Strengthening Dynamic Capability of Manufacturing Industry by Utilizing 5G, etc. (FY2022)" (2022.8.22) "Research and Development for Establishing Variable Supply Chain in Cutting Industry through Full Automation and Remote"

10) Keystone companies build platforms and services that can be used by ecosystem participants to promote collaboration and value creation among companies in the system, and share the value created with other members.

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