

Innovation in Japanese Manufacturing: The Case of KOMATSU

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1. Introduction

Headquartered in Minato-ku, Tokyo, Komatsu is one of the leading global companies in the Japanese manufacturing industry. In terms of construction equipment market share in 2022, Komatsu is Japan's No. 1 and the world's No. 2 comprehensive construction equipment manufacturer. At Komatsu, the driving force behind sustainable corporate growth is the promotion of "Dantotsu Management".

The concept of Dantotsu management is a management strategy that provides Dantotsu solutions by having Dantotsu products as a manufacturing industry and Dantotsu services. In addition, one of the important perspectives that support Dantotsu management is the active strategic use of ICT (Information and Communication Technology). Komatsu has been promoting the ICTization of construction sites for about 30 years, ahead of other companies in the industry.

Development of the KOMTRAX (Komatsu Machine Tracking System) started in 1998, operation started in 2001, and it is currently installed as standard on Komatsu construction machinery. KOMTRAX is a construction machinery operation management system that allows you to remotely

check the location and operating status of vehicles, such as which construction machinery is in which location, whether the machinery is being used efficiently, and whether there is fuel remaining.

In 2015, we provided an integrated solution through "Smart Construction", making it the "DX-Gateway" of the construction industry's DX (Digital Transformation). In Komatsu's ICT strategy, the most representative ICT utilization after KOMTRAX is the promotion of DX through Smart Construction. In 2017, we are building an "open platform" by providing various services based on construction machinery data. An open platform is a construction machinery infrastructure that is literally open, anyone can freely participate, and can be used by any company.

On the open platform, for example, it is possible to upload Caterpillar construction machine data and analyze it with Hitachi Construction Machinery's application. Komatsu's open platform construction aims not only to increase sales of its own construction equipment, but also to DX in the construction industry involving other companies.

In 2020, in order to accelerate the development of DX at construction sites, we are implementing a DX renewal with Smart Construction, which started in 2015. In 2021, KOMTRAX will be significantly revamped, using digitized construction machinery data to improve convenience so that various applications can be used. Komatsu does not define only the ICTization and digitalization of each step of the construction site process as "DX at construction sites" for DX of Smart Construction.

"Construction site DX" that Komatsu is aiming for means replacing all processes at construction sites with digital data and bringing about "major reform" when the data is connected. Komatsu's "major reforms" include the installation of "ICT retrofit kits" on its own and competitors' older construction machines. The use of ICT in construction equipment enables the collection of more construction equipment data, enabling highly accurate data analysis and evaluation. Komatsu is providing an open platform in which all companies can participate in order to promote DX in the construction industry.

This paper examines Komatsu's corporate management and ICT strategy based on published research papers and books, securities reports, annual reports, Internet information, and other academic literature. In this study, we will also conduct an interview survey with Komatsu's CTO (Chief Technical Officer) and CIO (Chief Information Officer). Conduct research to clarify the relationship between Komatsu's corporate management and ICT strategy, and the genealogy of Komatsu's ICT strategy.

2. Dantotsu Management and Trends in Academic Literature, Methodology

2.1 Dantotsu Management of Komatsu

As of 2022, Japan's Komatsu is the number one construction machinery manufacturer in Japan and the world's second largest manufacturer. In the global construction machinery industry, the share ratio in 2020 is such that the world market will be influenced by two strong companies, Caterpillar

(U.S.) (27.8 percent) in first place and Komatsu (12.4 percent) in second place (C'Lab, 2022).

Komatsu is a world-class manufacturing company, and the source of its sustainable corporate growth is its advanced initiatives based on its management strategy slogan of "Dantotsu management." Dantotsu management provides Dantotsu value to customers and agents, which establishes an overwhelming competitive advantage over competitors.

Dantotsu Value in Dantotsu Management is provided to customers and agents from three axes: Dantotsu Products, Dantotsu Services, and Dantotsu Solutions (Sakane, 2011). Dantotsu products are construction machinery that introduces the latest technologies and functions that competitors cannot catch up to in several years. Examples include hybrid hydraulic excavators in 2008, ICT construction equipment in 2013, and human detection and collision mitigation systems in 2019.

Dantotsu Service is a measure to ensure that construction machinery that was Dantotsu at the time of shipment from the factory continues to be used by customers for many years, while continuing to maintain quality and to remain Dantotsu for customers. Dantotsu Solution uses the latest ICT to collect and analyze construction data from construction sites such as civil engineering and mining. It is also a business model that provides solutions to problems at construction sites by realizing "visualization of construction".

In Dantotsu management, through the technological strength and experience of manufacturing that we own, "in-house development and in-house production of main parts," and through the integration of "development, production, and suppliers" to create construction machinery, we provide cutting-edge products, services, and solutions that lead the construction industry (Sakane, 2009).

2.2 Trends in Academic Literature and Methodology

What supports Komatsu's Dantotsu management in terms of structure is the proactive promotion of ICT strategies. Komatsu has been proactively developing its ICT strategy for about 30 years, ahead of its competitors in Japan and overseas. KOMTRAX is one of Komatsu's representative ICTization applications for construction machinery. KOMTRAX started development in 1998 and started operation in 2001.

There has not been much systematic, overall discussion in research to date regarding a series of genealogy of ICT strategies such as Komatsu's use of ICT, promotion of DX, and construction of an open platform. In addition, individual research (including technical) on Komatsu's ICT strategy has been reported in magazines and news in Japan, as well as numerous papers, reports, and books both in Japan and overseas.

For example, at the National Diet Library (as of September 7, 2022), which has the largest collection of books in Japan, 290 documents can be found by searching with the keywords "Komatsu" and "construction machinery". In addition, searching the library with the keyword "dantotsu" yields

1,370 hits, and searching with the keywords "dantotsu" and "management" yields 135 hits.

From the early 2010s to recent years, there are many books and papers on Komatsu's Dantotsu management. For example, Sakane (2011) in the book "Dantotsu Management" and Kuromoto (2012) in the academic paper "Komatsu's Global Growth Strategy" etc. In addition, academic papers on Komatsu's construction machinery and KOMTRAX include, for example, Nojiri (2012) "Komatsu Mini Construction Machinery" and Orisaka (2014) "Maintenance Management Utilizing KOMTRAX" etc.

With google scholar (as of September 7, 2022), which allows you to search a wide range of academic literature regardless of field or country of publication, searching for the keywords "komatsu" and "KOMTRAX" will find 390 publications. In addition, 170 documents can be found by searching the keyword "Dantotsu" on google scholar.

From the about 2010s to recent years, there are many foreign academic papers on Komatsu construction equipment and KOMTRAX. For example, Szadziul and Słowiński (2008) "Telematic System for Monitoring the Operation of Machines and Vehicles in a Transport-Equipment Enterprise" and Basu and Ahmed (2012) "The Employee Perspective in Lean Environment".

However, the research content so far has focused on research on individual items of ICT strategies such as Komatsu's ICT implementation, digitization, smart construction, DX, and open platform construction. Therefore, not only research on individual items related to these ICT strategies, but overall research on ICT strategies that systematizes each item is rarely done.

The slogan of Komatsu's management strategy, "Dantotsu Management," is based on research into ICT strategy, which has the function of its source and support. This research on there is also great involvement and interest from an innovative point of view. Therefore, in this paper, we have collected published academic literature, asset securities reports, annual reports, Internet information, and interview surveys with Komatsu's CTO and CIO.

A case study will be conducted on the relationship between Komatsu's corporate management and ICT strategy, and on the genealogy of Komatsu's ICT strategy. In the following chapters, Komatsu's individual research on ICT strategies will focus on examples of innovative smart construction, and consider the implications of those examples.

3. Lineage of Komatsu's Corporate Management and ICT Strategy

3.1 Komatsu's Corporate Management and ICT Strategy

Komatsu was founded on May 13, 1921, and mainly engages in the manufacturing and sales of construction machinery, utilities, forestry machinery, and industrial machinery (FSA, 2022). Komatsu has been expanding overseas since around the 1950s, and is a manufacturing industry that has been actively expanding globally from an earlier time than automobile manufacturers. Komatsu's base

network (as of March 31, 2022) consists of 76 production bases (overseas production ratio of 61 percent), 54 sales bases, 211 service agents in 148 countries, and 62,774 employees (consolidated) (FSA, 2022).

Komatsu's construction machinery division has a network of 208 bases worldwide. They are roughly divided into (1) 76 production bases, (2) 54 sales bases, (3) 42 parts centers, (4) 21 training centers, and (5) 15 reman centers. Komatsu's industrial machinery division has a network of 43 bases worldwide. The division is roughly divided into 9 production bases and 34 sales bases.

Komatsu is facing a financial crisis in 2001, posting an operating loss of about 13 billion yen for the first time since its founding. However, the current business situation has escaped from the financial crisis, and in terms of market share among construction equipment manufacturers, it is overwhelmingly the top in Japan. In terms of global market share, Komatsu is second only to Caterpillar Inc. (U.S.), which is the number one company.

In Komatsu's corporate management, sustainable corporate growth to date has the following two major characteristics.

The first characteristic is that more than 80 percent of Komatsu's sales are made up of the construction machinery. Komatsu is one of the few Japanese companies that has secured a competitive advantage in the global market through manufacturing, sales, and service development centered on a single product group based on construction machinery. In the 1960s, we began selling construction machinery overseas, and now overseas sales account for more than 80 percent of our sales (as of March 31, 2022).

The second characteristic is that most of Komatsu's business is developed in overseas markets. This is because Japan has a small land area and a small population, so the number and scale of construction sites are small, and domestic projects alone are highly risky. For this reason, Komatsu was one of the first companies in the Japanese manufacturing industry to enter the global market, and more than half of the approximately about 62,000 employees (as of March 31, 2022) worldwide are already foreigners.

At Komatsu, the slogan of the management strategy after the management structural reform is the promotion of "Dantotsu management" that demonstrates outstanding strengths in a certain priority field (Sakane, 2011). In the product development method based on "Dantotsu management," we provide products with overwhelming technology and functions, various services, and integrated solutions based on our strengths in construction machinery (Dantotsu value). However, Komatsu does not aim for "Dantotsu management" in all business fields. Sacrifice business areas where you can afford to lose to your competitors, or business areas that are on par with your competitors. Then, we will concentrate our management resources on our strengths (construction machinery) and promote a management strategy that focuses on our strengths.

In addition, the essential condition for achieving "Dantotsu management" is to reduce the cost of

the company's products by 10 percent or more. As a result, the company has devoted its surplus management resources to the realization of Dantotsu solutions in the field of construction machinery, creating Dantotsu products that are far ahead of its competitors. This Dantotsu management of management strategy has realized a change in the mindset of all employees, including development, production, and sales etc. In June 2008, the world's first hybrid hydraulic excavator was born as a Dantotsu product. However, despite the high price range (approximately 30 million yen per unit), which is about 1.5 times the price of conventional models, it has led to high sales volume and increased sales overseas.

Dantotsu management implements "visualization of construction sites," "visualization of business," and "visualization of construction" in the construction industry, standardizes operations and processes, and develops management efficiency. Generally, in the construction machinery industry, competitors sell similar products three to four years after the introduction of a new product. In other words, Komatsu's competitors are also constantly conducting research and development, so when considering the product life cycle, they will always catch up with the best products.

With Komatsu's comprehensive strength, even if we cannot temporarily determine the superiority or inferiority of construction machinery products, we have more than 20 years of experience and achievements with KOMTRAX, and the type and amount of accumulated data is overwhelmingly superior to other companies. Therefore, in Dantotsu management, there is Dantotsu product manufacturing as a manufacturing industry, Dantotsu service is born from data collection, and this leads to a management strategy that provides integrated Dantotsu solutions through data processing and analysis.

Here, Komatsu's definitions of terms in the ICT field, ICT strategies, and their relationships are organized. Apart from the size of their use, modern companies have an ICT strategy that utilizes ICTization, digitalization, IoT (Internet of Things), CPS (Cyber-Physical System), Digital Twin, DX, open platforms, etc. is deployed.

Komatsu, which represents Japan's manufacturing industry, is also promoting an aggressive ICT strategy in the development of "Dantotsu management" to establish a competitive advantage. Komatsu handles the following definitions and relationships for a series of terms (functions) in the ICT field.

At Komatsu, the functions (tools) for realizing smart construction are "ICTization" and "digitalization." Komatsu's ICTization implementation organically connects the data of all "things" throughout the construction process. By linking various types of construction site various data, we are able to "visualize construction" in all construction processes. Visualization at construction sites realizes visualization of operations in four fields based on each work process (Table 1).

Table 1: Visualization of Main Operations at Construction Sites (Visualize each work process and each worker at the construction site)

Visualization of Operations	Overview
(1) Business Process	In the visualization of business processes, all employees can share information about the company's business processes by creating a business flow using words, diagrams, and charts for each worker's work procedure manual and work content.
(2) Business Knowledge	In the visualization of business knowledge, by accumulating knowledge such as experience, expertise, and the skills of each worker, all the workers involved can share business information.
(3) Time Management	In the visualization of time management, all employees can share work-time information by understanding the schedule of each employee's work and whereabouts.
(4) Work Progress	In the visualization of business progress, all employees can share work progress information by grasping the progress of each employee's tasks.

(Source) Prepared by author.

Komatsu's digitization accumulates data for all construction processes, from construction site surveys to inspections. Based on the various data, the progress status and construction plans of construction sites are visualized in real time.

KOMTRAX, which Komatsu has been operating since 2001, connects approximately 650,000 construction machines (as of 2021) at construction sites around the world with IoT functions (tools).

"IoT" realizes constant monitoring and remote control of construction machinery. With Komatsu's IoT, the location of each construction machine is individually recognized by the GPS (Global Positioning System) installed on the construction machine at the construction site. In addition, it prevents the occurrence of troubles such as theft and runaway of construction machines, and theft prevention such as immediate engine cut-off by remote control.

With Komatsu's digital twin, information on construction sites in real (physical) space is collected using IoT and organically connected, and based on that data, construction sites in cyber (virtual) space are reproduced. In other words, Smart Construction makes full use of IoT and digital twins to visualize construction management, operational efficiency, and progress confirmation at construction sites.

On the other hand, Komatsu's CPS provides services aimed at realizing a more advanced information society by integrating construction sites in real space and cyber space. Therefore, CPS is a more comprehensive concept than IoT, starting with real-world data collection in real space and including data analysis and feedback of results in cyberspace.

Komatsu regards CPS and digital twins as the same concept, and does not clearly classify, distinguish, or use them properly. This Komatsu concept is not particularly unique, but is generally regarded as a synonym in the actual ICT field. Also, if we dare to distinguish between CPS and digital twins, CPS shows the cycle of data utilization in more individual indicators. A digital twin is a physical model that reproduces a collection of construction site data in real space in cyberspace.

By the way, Smart Construction, which Komatsu started in February 2015, provides integrated solution services as a construction machinery manufacturer, and is positioned as a "DX-Gateway" at the entrance to DX in the construction industry. The introduction of Smart Construction can provide various benefits and convenience by utilizing cutting-edge at construction sites. In July 2017, Komatsu established LANDLOG with four companies (including Komatsu) to build an open platform

(foundation) that can provide various services from construction machinery.

An open platform can provide solution functions that can be freely used by any company by cutting out only the functions of the base part of Smart Construction. In April 2020, Komatsu is renewing Smart Construction to further accelerate the development of DX at construction sites. The new Smart Construction targets all construction site processes and can provide overwhelming safety and productivity improvements.

And, in 2021, Komatsu will significantly revamp and improve KOMTRAX for the first time in 20 years, implementing real-time data, high speed, and large capacity. Construction equipment data from KOMTRAX is available for operation data in five fields (Table 2) (Kazusa, 2021).

The new KOMTRAX is designed to improve convenience, enabling data collection from daily units to real time, and high-speed, large-capacity data exchange. Since then, we have been promoting an open platform strategy that creates a variety of services as an infrastructure platform that anyone can freely participate in and that can be used by any company.

Table 2: Main Operation Data of Construction Machines by KOMTRAX

Operation Data	Overview
(1) Maintenance Management	Caution information and replacement time information for construction machinery can be displayed.
(2) Vehicle Management	A list of construction machines equipped with KOMTRAX can be displayed.
(3) Operation Management	Detailed information on operation, monthly operation status, and annual operation status can be displayed.
(4) Vehicle Position	It is possible to check the map screen, position history, fuel consumption, driving support, and document creation.
(5) Driving Support	Energy-saving driving can be proposed based on the machine operation data from KOMTRAX.

(Source) Based on Kazusa, 2021.

3.2 Genealogy of Komatsu's ICT Strategy

One of the important perspectives of Komatsu's management strategy based on Dantotsu management is the active use of ICT. In this paper, Komatsu's ICT utilization, DX promotion, open platform construction, and a series of genealogy and initiatives in the ICT field are again treated as Komatsu's "ICT strategy". In addition, here, we will review the genealogy of Komatsu's ICT strategy in chronological order.

According to Komatsu's ICT strategy, the most representative ICT utilization after KOMTRAX is the introduction of Smart Construction. However, the major features of Komatsu's ICT strategy are not limited to KOMTRAX and Smart Construction, which are front office divisions that directly generate revenue. The idea of ICT investment is also a major feature in the back-office department, which provides back-up support for the sales department.

In the back-office department, the basic policy of "ready-made clothes should be worn for the introduction of ICT in office work" is thoroughly adhered to. And depending on the necessary business processing within the company, external package software is selectively used. The back-

office department customizes the existing software or creates a new system and uses only the processing that is absolutely necessary for the execution of internal business.

This is because in the global expansion of companies, there is a limit to adapting to overseas bases with an in-house production system that is all in-house development in its ICT strategy. Especially in the back-office department, the language, currency, laws, etc. differ depending on the target country for business processing that does not generate direct profit, such as human resources, general affairs, accounting, finance, and legal affairs. However, even if the response of the target country is different, there are many cases where the work content, processing procedure, processing method, work flow, etc. to be processed do not change.

In this case, the ICT strategy is to standardize back-office operations around the world, transform the business content according to the existing package software, or involve some (minimum) system modification, and adapt to the situation. At Komatsu, by "standardizing" and "ready-made clothes" in business processing, we have achieved a significant reduction in ICT investment costs and improved business efficiency (Yamamoto, 2014).

KOMTRAX is a construction machinery operation management system that enables remote monitoring and operation of vehicle locations and operating conditions, such as which construction machinery is in which location. By introducing KOMTRAX, significant effects are realized in seven fields (Table 3) (Numagami, 2016). In addition, Komatsu has been promoting the introduction of Smart Construction since 2015 with the aim of developing DX in the construction industry (Komatsu, H.I.S., Sugi Holdings, SENSHUKAI, SECOM, 2013; Sakane, 2015).

"DX of Smart Construction" organically connects various data in the entire construction production process (surveying, design, construction planning, construction, construction support, inspection, etc.) by visualizing the construction site. Construction managers can use devices such as PCs, smartphones, and tablets in remote locations to check the status of each construction process and the entire process based on organically connected data.

Table 3: Major Effects of Introducing KOMTRAX

Major Effects	Overview
(1) Anti-theft	Even if Komatsu's construction equipment is stolen, it can be remotely controlled by KOMTRAX so that the engine does not start. And when GPS is installed, its position can be tracked.
(2) Increased Operating Rate	By obtaining machine operation data from KOMTRAX, Komatsu's construction equipment can accurately predict the next maintenance and replacement timing based on the operation status and the previous replacement date of each part.
(3) Maintenance Service	Komatsu's construction machinery can obtain, analyze, and evaluate machine operation data from KOMTRAX in any location, of any scale, and any usage situation.
(4) Debt Collection	If the customer's loan repayments are repeatedly delayed, the operation of the construction equipment can be stopped by remote control using KOMTRAX after issuing a reminder or warning.
(5) Secondhand Market Value	With KOMTRAX, the maintenance history data can be saved, which increases the transparency of the condition of parts such as engines, starters, radiators, and mufflers.
(6) Build Supply Chain	By sharing machine information, production lead times can be shortened for parts procurement, product production, sales, and after-sales service.
(7) Global Market Forecast	Komatsu construction machinery operates all over the world, and with the data from KOMTRAX, it is possible to know what kind of construction work is being carried out in what country or region, on what scale, and in what time period.

(Source) Based on Numagami, 2016.

In the overall process, each process of construction can be checked from the perspective of such as "whether the work is stagnating", "checking the operation rate", and "is there any process that is prone to trouble?". In addition, in construction, it is easy to find bottlenecks from small changes in progress, and it is possible to immediately understand processes that have stopped due to trouble, and to raise the operating rate and availability rate.

Since June 2015, Komatsu has applied "visualization of construction sites" to manufacturing, and has started a new production innovation utilizing ICT technology. At Komatsu, construction machinery is produced by "connecting manufacturing" of the operation status of construction machinery production plants and "directly linking market information to the factory" to share the operation status of customers' construction machinery in real time.

At construction machinery production sites in Japan and overseas, we are working to strengthen the production system by linking information on "connected manufacturing" and the production process from production to sales in real time.

In recent years, Komatsu's ICT strategy is to build an open platform that transcends the boundaries of companies and industries, not just the construction industry. In October 2017, Komatsu established LANDLOG jointly with NTT DoCoMo, SAP Japan, and OPTiM to build the open platform "KomConnect" (LANDLOG, 2022). Komatsu's conventional approach to ICT strategy was a vertically oriented (in-house production) concept in which data collected from Komatsu-manufactured ICT construction equipment was used in Komatsu-developed applications.

However, with this concept, there were problems such as the inability to increase variations in order for the construction industry to speedily solve social problems and respond to business. Therefore, in order to develop the idea of horizontal orientation (openness), we adopted the concept of LANDLOG, an open platform (Ozaki, 2018).

Komatsu's ultimate goal is to create safe, efficient, and highly productive construction sites. Smart Construction to achieve this goal consists of two systems: the "base platform" and the "applications that run on it." However, although the functions of these two systems are closely related and produce great effects, their purposes are completely different. Therefore, we adopted the concept of LANDLOG, carved out a platform for only the base part of "DX of Smart Construction," and built an open platform that enables the provision of solutions that can be freely used by any company.

In other words, with the open platform, the concept is that it is possible to upload data from Caterpillar construction machinery, and that Hitachi Construction Machinery can provide applications. LANDLOG's "KomConnect" is a new open platform that connects all kinds of "things" such as soil, machinery, and materials related to the production process in construction work (SB Creative, 2015).

KomConnect is based on the data obtained from various construction machines developed by

Komatsu, and is a mechanism that allows you to connect, process and analyze various data. Literally any company can freely participate in the open platform, and participants can use various data. The functions of "KomConnect" realize operations in six fields in each work of the construction production process (Table 4) (Komatsu, 2020).

Table 4: Overview of typical functions of KomConnect

Functions of KomConnect	Overview
(1) High-precision surveying by drone	In topographical surveying, drones are flown to sites before construction to create 3D data. Conventional surveying takes two people and takes several days, but it can be completed in about 15 minutes. The accuracy of surveying is in units of a few centimeters, which is 100 times higher than when it is done manually, and the number of surveyed points is 10,000 times higher, which is several million.
(2) Accurately grasp the amount of cut and embankment	The construction completion drawing is converted to 3D data, and the "difference" is derived by superimposing it on the 3D data of the current situation. As a result, the area and shape to be constructed can be visualized on the display, and the amount of soil to be scraped or piled up can be accurately grasped.
(3) Investigation and analysis of fluctuation factors	Before proceeding with the construction, we will investigate, analyze and analyze the quality of the soil and underground buried objects that can be a variable factor.
(4) Creation of construction plan	Simulate multiple patterns of construction plans with ComConnect. The customer selects the most suitable plan for the construction conditions.
(5) Construction using highly intelligent ICT construction machinery	Based on the 3D data sent from ComConnect, construction is started with ICT construction equipment. The operation of the construction equipment is automatically controlled, so even inexperienced workers can work with the precision of an expert.
(6) Utilization of construction data after completion	Information after construction is completed is also accumulated in ComConnect, and is used for on-site maintenance and recovery from damage caused by natural disasters.

(Source) Based on Komatsu, 2020.

In 2021, KOMTRAX will undergo a major renovation for the first time in 20 years, and detailed operation data of construction machinery will be digitized to make it easier to use in various applications and further improve convenience.

For example, with the previous KOMTRAX mechanism, machine operation data was collected only once a day. However, with the new KOMTRAX, it is possible to acquire construction machine operation data almost in real time at intervals of several tens of seconds. In anticipation of the commercialization of 5G, the next-generation communication standard, it enables high-speed and large-capacity data exchange.

Also, as mentioned above, Komatsu's Smart Construction is realized through the use of ICTization in construction machinery and the digitization of construction site processes. Smart Construction has already been introduced at more than 10,000 construction sites in Japan domestic. However, Komatsu's Smart Construction does not define "DX of Construction Site" simply as the ICTization and digitalization for each construction site process.

DX of Smart Construction (DX of Construction Sites) is digitalization of construction with things "things (automation and sophistication of construction machinery) and things (optimization of construction operations)" and things "things (automation and sophistication of construction machinery)". We define DX at construction sites from both aspects (optimization of construction operations) and things (optimization of construction operations).

Therefore, the "DX of Construction Sites" that Komatsu is aiming for means the "major

transformation" that occurs when all processes at construction sites are replaced with digital data and the data is connected.

Smart Construction has already been introduced at more than 10,000 construction sites in Japan domestic. At Komatsu, Smart Construction does not define construction site DX simply as the realization of "ICTization" and "digitalization" for each step of the construction site process. In DX of Smart Construction, DX of construction sites is defined from the two aspects of sophistication of "products (automation and autonomy of construction machinery)" and "services (optimization of construction operations)".

For example, in the case of automobiles, it means self-driving, but in the case of Komatsu, it means the digitalization of the entire construction site. Therefore, the "DX of Construction Sites" that Komatsu is aiming for means the "major transformation" that occurs when all processes at construction sites are replaced with digital data and the data is connected.

On the other hand, in the major transformation of construction sites through DX, the introduction of Smart Construction will enable improved safety at construction sites and efficient placement of human resources, etc. In other words, at construction sites where experience and know-how has been required so far, all generations can handle the work without special knowledge. Furthermore, by optimizing the operation of construction machinery, CO₂ emissions can also be reduced, making it possible to adapt to global environmental measures.

The various data of ICT construction machinery that Komatsu has cultivated so far is published in a state that can be used by applications together with the processed data. This data provision mechanism is the construction of an open platform in which all companies can participate. Komatsu clearly distinguishes between "things that should be done internally" and "things that should be taken in from outside". By actively utilizing open platforms, the company incorporates necessary external resources, ideas and know-how possessed by other industries and companies, and knowledge such as technology, skills, and development from outside the company.

4. Smart Construction Case of Komatsu

4.1 Smart Construction Case

Smart Construction, which started in 2015, aims to eliminate the shortage of human resources in the construction industry, enhance safety, and improve productivity. Traditionally, at construction sites, humans have taken the lead in confirming and managing the entire construction production process (surveying, design, construction planning, construction, construction support, inspection, etc.).

For example, the surveying process is performed by multiple technical staff using dedicated machines. In the design/construction planning process, the person in charge of drawing draws the

design drawings, and the on-site supervisor creates the construction plan. After that, in the construction process, workers proceed with work using construction machines based on the completed drawings.

Komatsu's proactive ICT strategy deployment over the years has fruiting in April 2020's "DX of Smart Construction." In other words, "DX of Smart Construction" is realized with cutting-edge ICT technology.

Until now, Komatsu's proactive ICT strategy deployment for many years has come to fruition with "DX of Smart Construction" in April 2020. "DX of Smart Construction" will be realized with cutting-edge ICT and digital technology. For example, the surveying process uses drones to conduct surveys and surveys. Drone surveys and surveys enable speedy and highly accurate surveying by photographing construction sites from the air. In addition, in the design and construction planning process, not only design drawings but also construction plans can be created based on information obtained by drones.

After that, in the construction process, it is possible to use ICT construction machinery for work such as excavation, embankment, and soil transportation. In addition, there are cutting-edge technologies such as "cutting edge data" collected by sensors equipped with ICT construction equipment, and "terrain algorithms" that convert it into information that can be interpreted as topography. Various state-of-the-art technologies are used in ICT construction equipment, which is also useful in resolving the operator's lack of skill and experience.

The foundation (open platform) of Smart Construction is Microsoft's Microsoft Azure. In addition, this function is a cloud computing service provided through data centers managed by the company. Microsoft Azure was announced at the Microsoft developer conference in October 2008, and started service as "Windows Azure" in October 2010. After that, in 2014, the name was changed to "Microsoft Azure", and the service is still provided under the same name. The services provided by Microsoft Azure are generally called IaaS (Infrastructure as a Service) and PaaS (Platform as a Service). Smart Construction uses Microsoft Azure to provide a PaaS that provides the basic environment (open platform) required for the operation of applications.

Applications used in Smart Construction must be prepared in-house, but application development and operation itself can be done immediately on PaaS. In general, PaaS is easy to operate, but the degree of freedom in system construction is lower than IaaS. However, since PaaS provides a more flexible environment than SaaS (Software as a Service), which is software as a service, it is possible to make optimal choices for cloud computing services. In addition, the user by using PaaS, users can develop and operate their own applications while keeping initial and operating costs low.

Representative function implemented in "DX of Smart Construction" include (1) a hydraulic excavator equipped with a stereo camera, (2) 3D (Three Dimensions) survey using a drone, and (3) track vision, etc.

(1) A stereo camera-equipped hydraulic excavator is a service that allows the stereo camera to simultaneously photograph an object from multiple different directions and record the depth direction as well. The stereo camera KomEye equipped with ICT construction equipment can measure the terrain in front of the vehicle with a single touch, visualize progress differences, and improve the efficiency of progress confirmation. By using KomEye, speedy and highly accurate measurements are possible, data can be integrated with a dedicated application, and construction progress can be managed.

KomEye has a payload meter function that allows you to grasp the total load and amount of soil transported by the dump truck, and you can accurately check the weight of the soil with a smartphone or tablet. The payload meter can measure the weight of the soil loaded with the hydraulic excavator's bucket (attachment). In addition, the loading capacity can be maximized to match the maximum loading capacity of the dump truck, contributing to improved productivity at construction sites.

(2) In the 3D survey using a drone, it is a service that enables high-precision photography from the sky using a drone-mounted camera. In the conventional surveying process, even if the construction site was large, it was done manually by assigning multiple personnel. In addition, it was not rational because it took a lot of time for manual surveying and a considerable amount of time for moving the construction site.

By using drone surveying, it is much faster than surveying by human hands, and high-precision quality can be expected. Also, in conventional surveying, the survey location was sometimes in a dangerous area, but drone surveying can solve the dangerous problem.

(3) Truck Vision is a service that enables dump truck operation management using Microsoft Azure's cloud computing service. At construction sites, the operation status of dump trucks can be checked quickly, and the safety of construction sites can be improved by using the alert voice notification function. With Truck Vision, not only dump trucks, but also the location information of other construction machines can be centralized and managed. It also warns when a construction machine at a construction site is traveling over the speed limit or when it is too close to another construction machine.

By using the truck vision and payload meter together, it becomes easier to manage the soil loading and unloading performance, and it is possible to maximize the dump truck's soil loading capacity and prevent overloading. In addition, in dump truck operation management, the empty load amount of the vehicle can be managed as a truck scale of a large scale for measuring the weight of the cargo loaded on the vehicle.

By using these functions, "DX of Smart Construction" can improve construction site safety, visualize construction, manage construction site loading and unloading, dump truck load volume, and construction management in terms of loading and unloading of dump trucks. In terms of improving

safety at construction sites, it is possible to prevent traffic violations during construction machine operation by using the voice guidance function (alert voice notification) for traffic restrictions such as speed limits and temporary stops on site.

In the visualization of construction, it is possible to confirm the position of construction machines and arrange them efficiently by sharing location information among the contractors participating in the construction group by visualizing the moving places of the construction site. In loading and unloading management at construction sites, it is possible to manage each site by instructing the loading and unloading positions of dump trucks and sharing information. In addition, it is possible to change the loading and unloading positions and share information according to the progress of construction using smartphones, tablets, etc.

For dump truck loading, by sharing information such as truck loading and truck position information in real time, it is possible to optimize loading waiting times by moving to the loading location. When dump trucks are loaded and unloaded, it is possible to manage the amount of soil transported and traceability based on the information obtained from the truck scale, the information obtained from the payload meter of the hydraulic excavator, the position information obtained from the application, and the work registration information.

4.2 Discussion of Learnings from Smart Construction

In the progress of "DX of Smart Construction" in the construction industry, the use of ICT construction machinery has seen effects such as improved safety at construction sites and increased work efficiency. On the other hand, the labor shortage is a serious problem in the Japanese construction industry as a whole (MIAC, 2022).

Ideally, the labor force problem should be improved through self-help efforts within the construction industry. However, more than 90 percent of Japanese construction companies are micro enterprises with 10 or fewer employees. It is difficult for micro-enterprises to actively recruit young people, invest in ICT, introduce new technologies, and prepare for future business and risks, even if they want to increase labor productivity.

In Japan, due to the labor shortage in the construction industry, the use of ICT construction machinery enables people of all generations to easily undertake construction work that has traditionally required experience. In addition, by optimizing the operation of ICT construction equipment, it is possible to reduce CO₂ emissions, which are the cause of global warming, and to address global environmental issues.

These measures are a "big change" for the construction industry, and the future image of "DX of Smart Construction" that Komatsu is aiming for (Oyanagi, 2021).

In the promotion of "DX of Smart Construction" in the Japanese construction industry, there is a

high non-introduction rate of ICT construction machines at construction sites of 98 percent (end of 2020). At construction sites, there is a big problem that the introduction of ICT construction machines or construction machines equipped with ICT is very low.

In the Japanese construction industry, most construction companies use construction machinery made in Japan. Construction machinery made in Japan is of high quality, so there are few breakdowns, and it is durable and long-lasting, so it can be used for a long time. In addition, although the price of construction equipment is extremely high, the construction market in Japan is small in scale, so it is not possible to increase the operating rate of construction equipment and replace it with a new one.

On the other hand, in the construction industry in China, ASEAN (Association of South East Asian Nations), and other Asian countries, the construction market, which is driving the economies of each country, continues to expand, reflecting the high economic growth within the region. Therefore, the growth and expansion of the construction market in the Asian region is remarkable, making it easy to recover the cost of construction equipment, and it is a market where new purchases and replacement purchases can be expected even for high-priced ICT construction equipment.

However, in Japan, the reality is that the construction market cannot be expected to grow or expand due to the effects of the declining birthrate and aging population, slowing economic growth, and the significant depreciation of the yen. It is difficult for many Japanese construction companies and leasing companies to replace all conventional construction machines they already own with ICT construction machines.

Therefore, Komatsu conducted research and development to provide an "ICT retrofit kit", which is a "Dantotsu product". This is to apply ICT to construction equipment that is not equipped with ICT later. However, 3D controls (a function that controls the machine based on 3D data), which is possible (semi-automatically) with ICT construction machinery, cannot be used with construction machinery with an "ICT retrofit kit".

In the "DX of Smart Construction", it is absolutely necessary to convert construction machinery into ICT, which is the source of construction site data and digitization. However, the "ICT retrofit kit" that had been circulating in the construction industry up to that point were expensive products of about 10 million yen. In other words, if you buy a new construction machine (general price is about 20 million yen) or buy a used one (for example, 5 million yen), the installation of the 10 million yen "ICT retrofit kit" has a different meaning. Installing a used car with a lower market value than a new car does not justify the cost and profit.

In April 2020, Komatsu significantly reduced the development cost of the "ICT retrofit kit", making it possible to sell the market price of about 10 million yen for about 700,000 yen (excluding tax and expenses). Since Komatsu's "ICT retrofit kit" can be installed on construction machines of any manufacturer, there was concern that new models of Komatsu's ICT construction machines would

not sell well in the future.

However, Komatsu's ultimate goal is not to sell construction machinery, but to promote "DX of Smart Construction" at construction sites and to solve problems in the construction industry. By equipping a competitor's construction equipment with an ICT retrofit kit, it will be possible to collect more types and volumes of data, making it possible to analyze and evaluate even more precise data. This is one of the measures to realize "big change" at the construction site rather than selling ICT construction equipment.

Komatsu aims to transform social value creation through an open platform of "solving social issues" from the conventional awareness of individual issues such as "visualizing construction sites" and "improving safety and productivity at construction sites". Regarding future construction sites, we are focusing on realizing "safe, secure, highly productive, efficient, and smart future construction sites" as soon as possible. Including the content discussed so far, Komatsu provides 4 IoT devices and 8 applications as functions (including renewal tools) that embody the new Smart Construction DX (Table 5).

Table 5: New ICT technology in Renewal Smart Construction

New ICT technology in Renewal Smart Construction	
(1) Smart Construction IoT Devices	
Smart Construction Drone (Old name: Everyday Drone)	This device is a drone for surveying the current terrain, creating 3D models, and grasping the daily construction volume. In addition, there is no need to install a GCP (Ground Control Point), making it easy to fly.
Smart Construction Edge	The device uses the latest edge computing technology to process drone photos at high speed on-site to generate orthorectified images and 3D point clouds with unwanted objects removed. In addition, we will be able to grasp the completed form and quantity of construction on a daily basis.
Smart Construction Retrofit	This device digitizes construction plans and construction processes based on Smart Construction for all construction machines placed on site, including existing construction machines that are not ICT-enabled.
Smart Construction Fleet (Old name: Tracking Management System)	This device centrally visualizes the location information of construction equipment and workers, and supports efficient and safe operation with approach notification and alert functions. In addition, soil carrying-in/carrying-in management is performed based on the obtained soil volume information and traceability information.
(2) Smart Construction Applications	
Smart Construction Dashboard	This application connects the digital site in 3D from construction study to construction completion. In addition to basic functions such as 3D terrain bird's-eye view and measurement viewer, comparison of current and completed terrain, soil volume calculation, etc., it will be linked with each application.
Smart Construction Simulation	This application applies the simulation technology and algorithms that Komatsu has cultivated as a manufacturer to construction sites, simulating the optimal soil movement procedure and direction, transportation route, size and required quantity of construction machinery and dump trucks.
Smart Construction Design	This application creates 3D data for construction based on the simulation results. In addition to ICT construction equipment, we also provide 3D drawing of temporary roads for transporting soil based on on-site issues and constraints.
Smart Construction AR	With this application, 3D models of completed terrain and target terrain during construction can be superimposed on the current terrain and checked on a tablet or smartphone to check the progress of construction and the amount of remaining work.
Smart Construction Fleet	This application monitors the operation of equipment such as construction machinery and dump trucks, analyzes forecast gaps, and determines optimal solutions. In addition, it supports the optimization of construction that rotates the PDCA cycle at high speed.
Smart Construction Field	This application can send digital tasks to people working in the field or digitize daily work by using a smartphone as a device. In addition, quantify labor and materials in construction site costs.
Smart Construction Remote	This application sends 3D construction data to ICT construction equipment, and remotely accesses the monitor when ICT construction equipment malfunctions or troubles occur for troubleshooting.
Smart Construction Insight	This application is software targeted at managers and management layers of multiple sites. In addition, this function supports accurate decision-making by digitally checking the site anytime, anywhere, regardless of the device.

(Source) Based on Komatsu, 2020.

5. Conclusion

Komatsu, which represents Japan's manufacturing industry, has been actively promoting the use of ICT as an ICT strategy in corporate management for about 30 years, earlier than its competitors. A typical successful example of Komatsu's ICT strategy is the "KOMTRAX" machine operation management system.

KOMTRAX is standard equipment on construction machinery and provides customers with services such as maintenance management and energy-saving operation by acquiring location information and vehicle information. Competitors also offer systems similar to KOMTRAX, but until recently they were merely optional equipment. By standardizing KOMTRAX and being ahead of competitors, Komatsu established a competitive advantage.

Since then, Komatsu has further accelerated its ICT strategy by providing "Smart Construction" and the open platform "KomConnect." Smart Construction is a service that realizes a safe and highly productive construction site by connecting all information on the construction site with ICT by ICTization construction machinery (including KOMTRAX). KOMTRAX is a customer-oriented construction machinery value chain.

In contrast to KOMTRAX's stock concept, Smart Construction provides value based on a flow concept centered on construction machinery. In other words, we are deeply involved in the customer's own closed value chain, such as customer-oriented construction plans and maintenance support.

KomConnect, on the other hand, is an "open platform" for realizing this smart construction. An open platform is a construction machinery infrastructure that is literally open, anyone can freely participate, and can be used by any company. Therefore, the concept is different from the function of providing value to customers in the value chain of KOMTRAX construction machinery.

An important part of Komatsu's ICT strategy is collecting, analyzing, and evaluating construction equipment data. What is important is what kind of value can be provided to the customer by linking each process data from the individual process data of the entire production process.

In addition, Komatsu's ICT strategy applies the "visualization of construction sites" to manufacturing production sites, and has started new production innovations using ICT technology. We are working to strengthen our production system by linking "connected manufacturing" information from construction machinery production sites in Japan and overseas and the production process from production to sales in real time.

Komatsu is actively promoting the use of ICTization and digitalization, and through the DX of Smart Construction, we are developing value creation through visualization of construction sites,

transformation of value chains, production revolution, and open platforms.

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