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著者	Shibata Tomoatsu
journal or publication title	DSSR Discussion Papers
number	52
page range	1-16
year	2016-01
URL	http://hdl.handle.net/10097/65027

DSSR

Discussion Paper No. 52

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Discussion Paper

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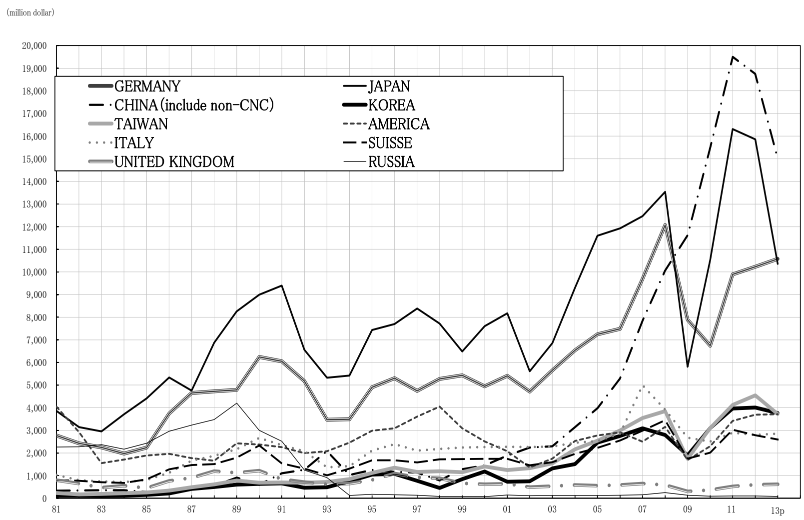
Introduction: in-depth longitudinal case study of Fanuc[1]

This case presents and analyzes the longitudinal process of Fanuc's growth from small business born as a venture within Fujitsu until becoming the world's leading factory automation (FA) company. It shows the mechanisms behind Fanuc's sustained growth past more than 40 years.

1. Overview of Fanuc and the machine tool industry

In the period of more than a quarter century since 1982, the Japanese production of machine tool kept its top position in the world, as depicted below in **Figure 1**. It is to be contrasted with the Japanese electronics industry including the LCD TV industry, which spectacularly emerged as the world top player in late 1980s, but whose dominance in the world market was short-lived in retrospect.



Source : American Machinist, Gardner Publications, Inc.'s data was used to make this graph by Japan machine tool builders' Association.
Footnotes:
1. Before 1990s,<Russia> means [Soviet Union], and <Germany> means [west Germany].
2. Modeling tool is not included.
3. The data of 2013 is estimated in February, 2014. And the data of 2012 is a revised edition.

Machine tools are often referred to as "mother machines" because they are machines that create other goods such as automobiles and electrical appliances. Automobile companies have a lot of machine tool to manufacture cars in their factory. Accordingly, competitiveness in the machine tool industry is intimately tied in with the competitiveness of other entire manufacturing industries.

The Japanese machine tool industry came to have such competitiveness because it was underpinned by the superior functionality of its NC machine tools, i.e., machine tools controlled with NC (Numerical Control) devices. In Japan, compared to Germany or America, the share of NC-type cutting machine tools was extremely large in the cutting machine market, and one of the chief factors that enabled Japan to produce many superior NC machine tools was the existence of NC device supplier Fanuc. Japanese machine tool manufacturers left the design and production of NC devices completely up to Fanuc, which enabled them to pour their efforts into innovating the machine tool itself other than NC devices.

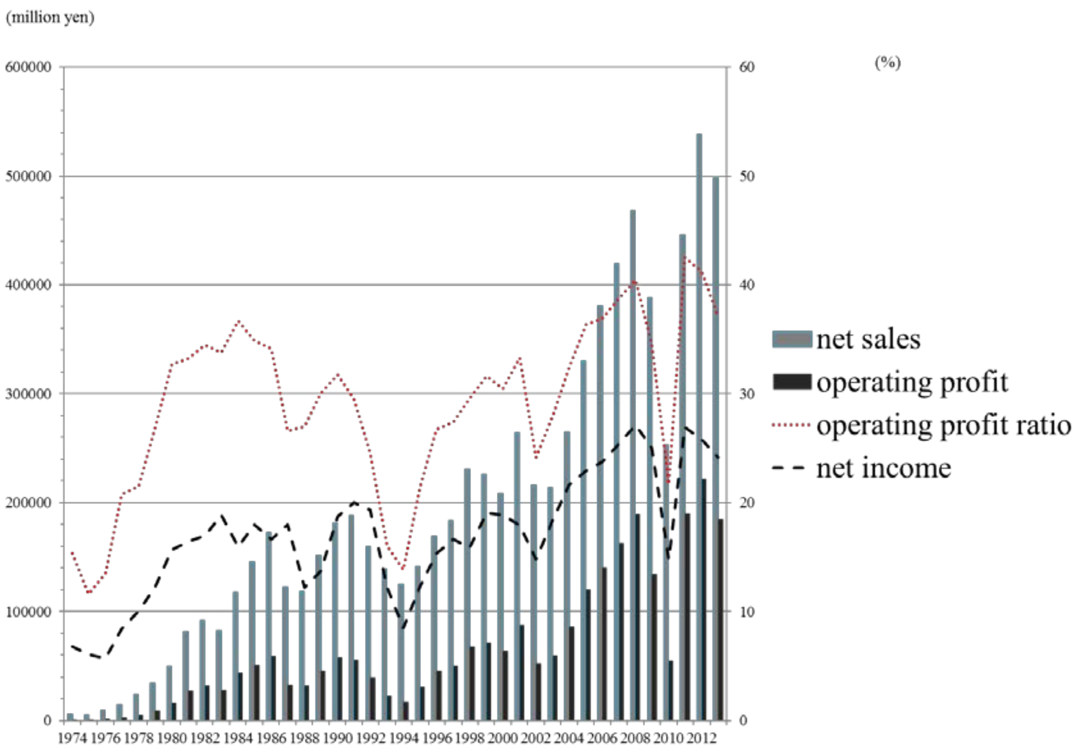
The "Made in America" report from the MIT Commission on Industrial Productivity survey states the following: (Dertouzos, 1990)

"NC and NC machine tools give businesses the flexibility and automation needed to provide small amounts of, and a wide range of parts for the automotive, electronics and machine industries etc., just-in-time."

"NC design and production for NC machine tools in Japan is all done by Fanuc, a single company. This is not so that Japan can gain an economic advantage of scale, but to solve the problem of compatibility that has troubled American machine tool users."

Since gaining independence from Fujitsu in 1972, to date Fanuc has achieved close to 50% of the global market share, and has sustained an extremely high business profitability of around 30%.

Figure 2 Fanuc History in Performance Indicators

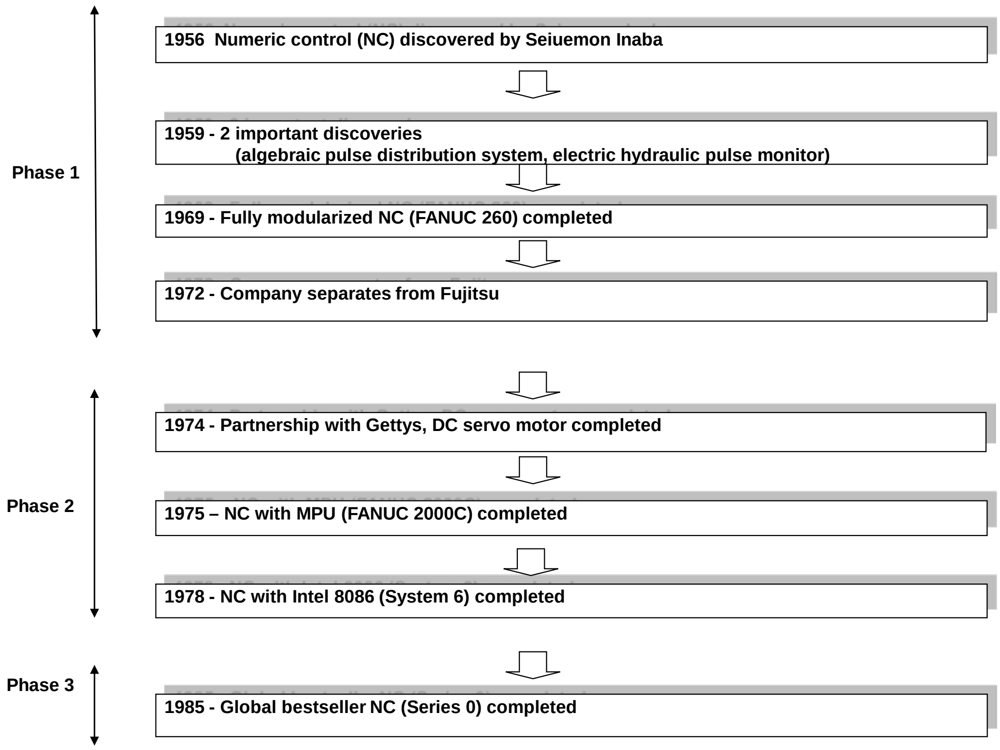


2 Tracing the growth of Fanuc

It's possible to conceptualize Fanuc's growth as 3 historical phases (see Figure 3). Phase 1, from 1956 to 1972, is the phase beginning with the company's inauguration as a venture within Fujitsu to its separation from Fujitsu. Phase 2 corresponds to the successful technological transformations the company achieved with implementation of DC servo motors and MPU (microprocessor unit), leading to the establishment of its present-day technological systems. This meant the establishment of dominant design of NC device (Anderson and Tushman, 1990) corresponding to the period up to 1980. Phase 3 is then the following period of dramatic market expansion in which the company brought about bestselling NC device, called series 0.

Following, we described each phase of Fanuc's growth trajectory in sequence.

Figure 3 Stages of Growth at Fanuc



2.1. Phase 1 (1956 to 1972)

(1) Creation of an internal venture business

To understand Fanuc's history, we have to look back as far as 1956. Technical director at Fujitsu at the time, Hanzo Omi, made the decision to break into the new field of computers and controllers beyond communications, and appointed Toshio Ikeda and Seiuemon Inaba as those respective project leaders. At the time, Fujitsu was only involved in communications equipment, and Ikeda and Inaba were simply instructed to find out what could be done in the new fields.

However, there were many options for control related technologies, and the NC development theme eventually put forth by Inaba was not a simple discovery. In particular, Inaba, a mechanical engineer who had graduated from the school of precision engineering at Tokyo University, had to search for a field dealing with machine controllers that was not the same as the process control field which already had an established market at the time. In the midst of trial and error in which a development theme had been difficult to determine, Inaba discovered the NC theme when looking at a copy of the MIT report (Dertouzos, 1990).

The first time that Inaba had heard of the MIT report was in October of 1956 at a conference held on automatic control at Waseda University. At the conference, the then California University Professor, Yasuto Takahashi, showed Inaba a copy of the Scientific American featuring an article about NC milling machines. Inaba said the following about his sentiments when he first saw the MIT report.

“Since my background are in the mechanical engineering, I remember a sense of strong interest in servo mechanisms the moment I first heard about the MIT report, and I immediately got consent from my boss, Director Omi, to set the R&D theme as NC for the machine control team.…Then, the MIT report introduced to me by Professor Yasuto Takahashi became like a bible for our research for sometime…[2].”

In this way, Inaba discovered the new field of NC, finished his trial-and-error efforts to find out what could be done, and went on to execute a new business strategy. At that time, Inaba’s development project team was a completely separate organization within Fujitsu from the company's existing communications equipment departments, and top management at Fujitsu had given the team a certain level of autonomy and freedom.

(2) The invention of the algebraic electric hydraulic pulse motor

Numeric control began at the Fujitsu Nakahara Factory laboratory with a project team consisting of four or five engineers from both the electric and mechanical fields. At the time, Inaba, a team leader who had only just reached his 30s, pushed forward with development. The first prototype was then achieved in 1957. As previously stated, the critical areas in NC are the computing and servo mechanisms. This prototype adopted a new element called the Parametron invented by Eiichi Goto of Tokyo University, and was an NC system that employed electric servo motors for its servo mechanisms[3].

In 1958, Makino Milling Machine Co and Fujitsu jointly exhibited an NC milling machine at the Osaka International Trade Fair, however it wasn't a machine that could withstand practical application. Then in 1959, Hitachi Seiki and Fujitsu delivered an NC milling machine to Mitsubishi Heavy Industries’ Nagoya Aircraft Works. This could have been said to be the first commercialized NC product, but it had a problem in that it blew an average of 1 electronic vacuum tube every day.

In this trial-and-error process, Inaba brought together his own knowledge of mechanical engineering, and Fujitsu's know-how about digital circuitry with the knowledge in the MIT report, and through repeated prototyping experiments with NC machine tools, all of this knowledge accumulated and became embodied as the tacit knowledge of the Inaba team.

All of this came to fruition with the following epoch-making invention. In 1959, Inaba and his team invented the revolutionary “algebraic pulse distribution system” and the “electric hydraulic pulse motor.” These two technological innovations enabled dramatic improvement in NC performance which was recognized both in Japan and internationally with a number of awards. The organization responsible for this invention was the project team in Fujitsu that the company referred to as “Inaba’s NC Brigade” or the “Inaba Family.” The algebraic pulse distribution system was brought about through joint research with University. Inaba said the following:

“Aiming for devices that can be put to practical use, we would like to produce stability and reliability in both the circuitry and the servos. We were fortunate to have been greatly inspired by electrical engineering Assistant professor Tatsu Motooka of Tokyo University Engineering Department, and his assistant, currently Tokyo University Institute of Industrial Science Professor Kusuo Yamaguchi. We dispatched an engineer from the Automatic Control Department as it was called at the time, which effectively became the brains of the development from where we received guidance[4].”

As a result of this joint research, the invention of the “algebraic pulse distribution circuit” -

technology that could calculate the combinations of arcs and straight lines that make up the forms of mechanical parts - came into being. Since its establishment, Fanuc has been extremely proactive in bringing in knowledge from universities .

Fanuc's adoption of open loop electric/hydraulic pulse motors was opposite to the closed-loop DC motors adopted in the United States[5]. Electric hydraulic pulse motors consist of an electric pulse motor and a hydraulic servo, in which the output from the electric pulse motor is amplified by hydraulics enabling significant power. Later on, when Fanuc was established, this technology was invented and patented by Inaba himself, although he got the idea from the automatic exchange equipment that were being built by Fujitsu at the time. Inaba reminisced on those times as follows:

"I couldn't ask the professors about the servo, so I had to think up something myself, but then I recalled the automatic exchange equipment that Fujitsu had been manufacturing[6]."

From that idea, Inaba imagined driving a motor by inputting pulses, and went on to prototype the electric pulse motor. However, this pulse motor alone was unsatisfactory in that was not able to deliver much torque, so Inaba imagined amplifying the torque by combining the pulse motor with a hydraulic motor. This was the bones of Inaba's invention. Inaba commented as follows:

"The department of precision engineering from which I graduated was known as the school of armory before the war, and as the name suggests, it was artillery that I studied. The gun turrets on warships were driven by hydraulic motors. Using these hydraulic motors with NC servo mechanisms, I tried controlling flow with the electric pulse motor[7]".

As described above, Inaba did not only start out with closed innovation R&D initiatives in an organization within Fujitsu, but also made concerted efforts to bring in technical know-how from outside the company (Tokyo University and the MIT report) and thus promoted open innovation (Chesbrough, 2003).

(3) Creating the NC market

In 1959, through the process of prototyping, experimenting and assessing the 2 inventions, the performance of NC was dramatically improved, however market demand did not increase with speed and uncertainty of NC market continued. It was not until 1965 that the NC Department got profitable. In other words, it took nine years from Inaba's discovery of the NC technology in 1956 until the NC business turned a profit, but from then on, Fanuc's shipments of NC products rose dramatically from 388 units in 1965, 483 units in 1968, 1184 units in 1969, to 1684 units in 1970.Following is the process of creating NC market.

With the two inventions in 1959, the standard had already been set for NC performance and stability to meet the demands of practical application. Inaba said the following the circumstances at the time:

"We had great confidence in the NC technology, but unfortunately the NC machine tool market was still quite small, and it wasn't easy to achieve sales. Therefore, our huge efforts went unrewarded and our monthly accounts remained in the red[8]."

The NC machine tool market had not yet matured, but Inaba understood the nature of the market well. In other words, there is some critical point in a market, and until that critical point is reached, demand does not rise very much, but when it is, market demand expands rapidly. Inaba had the following to say about the growth of new market.

"At a certain time, markets grow explosively. There are many companies that can't wait for that and give up, ending in failure. We endured that period patiently, and once 1966 came around the market for Japanese NC machine tools suddenly took off… (abbreviated)… That means we waited 10 years from 1956 when we first embarked on the development. That explosive growth continued afterwards, but those kinds of issues are things that a company must face[9]."

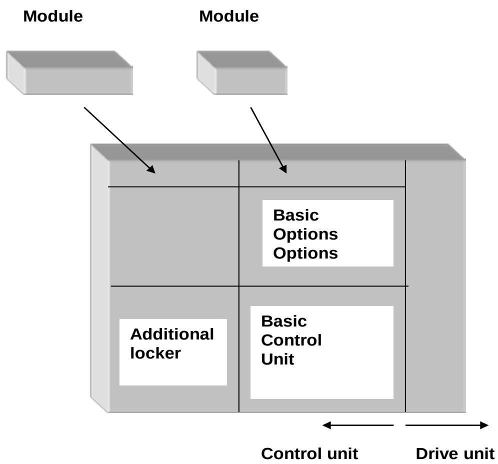
Even though he was unable to see growth in the market initially, Inaba continued with the NC development and proactively brought in new technologies. In actual fact, Fanuc shipped FANUC 220 using transistors in 1962, FANUC 260 with total integrated circuitry, and by 1969 had succeeded with complete modularization, which accelerated growth in the NC machine tool market - the number of completely modularized units shipped in 1969 was three times that of the previous year. Fully modularized NC meant that the company could respond to a wide range of customer demands at low cost.

The main reason for the losses the company experienced up to 1965 was custom orders. Custom orders grew vigorously as the sales department took any orders to extend order volume[10]. However, custom-made products cost more than standardized products, and when the company investigated they found all of these orders were making a loss. To bring costs down, companies have to make a wide range of standardized parts, but to respond to the diverse demands of the market, custom-made items are also required, and the way to combine and overcome these contradictory aspects is full modularization. In other words, all the modules that Fanuc produces are standardized, but combining them as required enables the company to respond to various market demands.

For example, the FANUC 260 is a range of functional modules created by analyzing the details of specifications demanded for a variety of machine tools. By mass-producing and stocking these, modules can be assembled to build an NC device to meet the specific needs of individual users. The modules are electronic circuits with specific functions created by combining a range of logical elements such as transistors and memory elements, which are mounted on separate printed circuits and units. See Figure 4 for an example of the FANUC 260 configuration.

FANUC 260 has three types of basic control units, about nine basic options, and about 20 additional options, which means that more than 60 million combinations are possible. Moreover, modules can be connected with screws and cable connectors, enabling completely solder-free assembly using only screwdrivers and spanners. This makes it extremely easy to add functions. Thus, required functions can be added easily without having to do any rewiring on-site with the user. By adopting this completely modularized NC product architecture, Fanuc can respond to a wide range of market demands at low-cost, which in turn greatly contributes to further market expansion.

Figure 4 Structure of fully modularized NC (FANUC 260) (Phase 1)

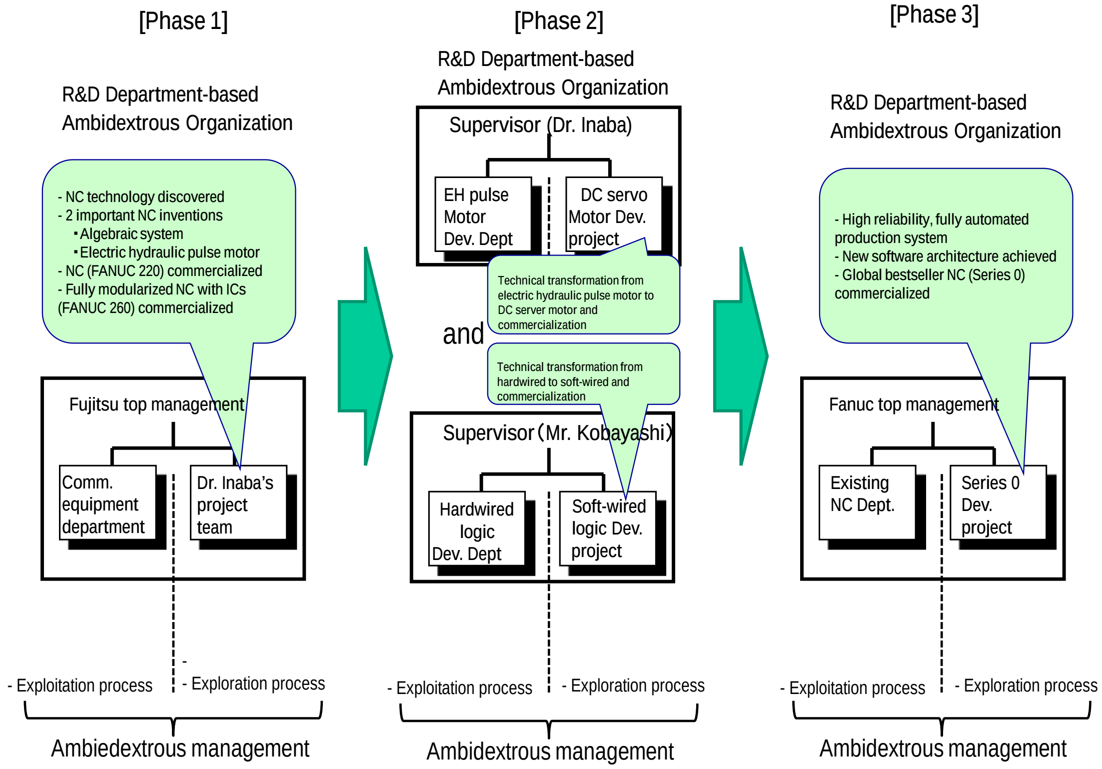


(4) Breaking away from Fujitsu

When the NC Department moved into the black in 1965, the number of NC units produced with the expansion of the NC market stabilized, and the department was growing as high earner within the company. In fact, Fujitsu's profit ratio in 1970 was 6%, although the NC Department had achieved more than 20%. It was at this point that the investments made into the NC Department over more than 10 years began to bear fruit.

However, in April of 1972, management at Fujitsu decided to separate the NC Department from the Fujitsu and form a new company, Fanuc. At the time, Fujitsu was facing enormous funding requirements needed to develop the Japanese-made computer. Therefore, since the long-term investments in NC had begun to bear fruit, it seemed like a rational judgment for Fujitsu to take the income from the NC Department and put it in the Computer Department. But Judging from the results past 40 years, it was obvious that separating Fanuc from Fujitsu would be right decision for business growth.

Figure 5 Organizational changes in each phase of Fanuc's transformation



2.2. Phase 2 (1973 to 1980)

(1) Technical change from electric hydraulic pulse motors to DC servo motors

The year after breaking away from Fujitsu in 1972, Fanuc was facing an unforeseen challenge. That was the first oil shock of 1973. As an opportunity, user assessment of the electric hydraulic pulse motors that Inaba had had absolute faith in began to change. There was a hydraulic pump was required to drive the electric hydraulic pulse motors, but the pump was extremely inefficient - for instance it took a 100 hp drive to get a 50 hp output. However, the electric hydraulic pulse monitor was the chief technology that had given Fanuc its unique position, and as mentioned, was invented by Inaba himself. For those reasons, in those circumstances, there was unusual attachment to Inaba's electric hydraulic pulse monitor. In fact, Inaba said the following to his friend at Siemens at the time.

"Taking the electric hydraulic pulse motor away would be the same as taking away my life[11]."

But at the same time however, Inaba had been carrying out various experiments to try to find a new type of motor, which he recalled as follows:

"At the time, I ordered two things, firstly I told Koyama to develop a new electric pulse motor in four months, and secondly I told Endo to investigate American company, Gettys motor[12]."

In other words, firstly Inaba ordered Koyama to develop an oil-free high-power electric pulse motor in January of 1974. The electric pulse motor uses the same open loop method as the electric hydraulic pulse motor, and even though it did not use oil, Inaba was still heavily committed towards the open loop-type pulse monitor. In addition to Koyama who was developing the electric pulse motor, Endo conducted a thorough survey of closed-loop DC servo motors as the alternative approach.

Inaba prepared, just in case, to negotiate for technological partnership on the closed-loop DC servo motor with Gettys. Then as instructed, Koyama completed the electric pulse motor development within the allotted 4 months, in May of 1974. However, because the noise of this motor was extreme, Inaba decided it couldn't be used practically, and decided to do away with the open-loop technology of the pulse motor and switch over to the closed-loop DC servo motor.

Once Inaba had made that decision, Fanuc engineers obtained schematics for the DC servo motors from their now technological partner Gettys in the United States, and completed a DC servo motor in a mere two months. Then in September that year, the company exhibited an NC device using DC servo motors at a machine tool fair in Osaka. This was actually a very important decision for Fanuc. Switching from the pulse motor to the servo motor, and from the open-loop to the closed-loop systems means the change of basic design concepts. Looking back on those times, Inaba said the following:

"If my decision had been even just a little bit later, the share we now enjoy would probably have ended up with another company.… (abbreviated)… at the time, if I had stuck with the electric hydraulic pulse motor, the Fanuc we see today wouldn't have existed[13]."

Inaba recalls those times as difficult ones. As the inventor of the electric hydraulic pulse motor, Inaba had a strong attachment to the technology, but also as a manager, he was caught between a rock and a hard place of having to look squarely at the limitations of his own technology. And it was from that experience that Inaba began to think that "Technology does have a history. However from the engineers' point of view, there is no past, only creativity."

(2) Technical change from hard-wired to soft-wired by adopting MPU

Later in 1975, Fanuc developed the FANUC 2000C NC equipment with Intel's 3000 series MPU. This was the world's first NC equipment with built-in MPU. Adoption of the MPU meant a shift from control using circuitry built with transistors and diodes, to control using software. In other words, this was a huge shift in NC architecture from the hard-wired to the soft-wired. NC device using MPU is called computerized numerical control (CNC), and is often distinguished from conventional NC.

Technical issues that confronted the development of CNC were performance and reliability.

"The biggest issue was whether a computer running software could process interpolation. We performed various simulations and actually tried things to find out what was possible and what could be known, but the interpolation issue was the biggest issue.… (abbreviated)… we used semiconductor memory, but the technology hadn't been properly established, and the manufacturer couldn't provide us with the right advice. For example, when using ICs, but we were groping for answers because we had no idea whether ICs could be mounted on printed circuit boards and connected together by etching the copper on the board, and we weren't sure how to increase reliability in terms of noise[14]."

To deal with these technical uncertainties, the company formed a new computerized NC design section in addition to its existing hardwired NC design section, and operated both departments simultaneously. The hardwired NC section was involved in developing NC for mass production using technology that had already been established, and its aim was to develop highly reliable NC at a low cost. On the other hand, the goals of the computerized NC section was to pay attention to the trends in cutting-edge semiconductor technologies and whether they could be incorporated into NC systems, and whether performance and reliability could be improved. Thus the technological and design objectives of both departments were completely different, so the organizations were separated. Director Kurakake said the following about that situation.

"We completely split the organization into separate hardwired and computer sections. There was a manager overseeing the both sections at that time, and I was put in the computer section but had no lingering attachment at all to the hardwired section. I don't know what would have happened if we had tried to do it together. For my part I had absolutely no regrets about that, because we were able to do something new and get involved with the potential of computers [15]."

In this way both sections worked in completely different directions, but were overseen by one person, director Kobayashi, and organizational consistency was sustained by him.

"The manager oversaw both sections, so he knew the limitations of the current version of NC, and thus was able to see what needed to be done next, but there was a serious problem in trying to figure out how to develop beyond the current products which were creating revenue[16]."

Then around 1978, the NC systems using semiconductor technologies had improved to the point where they would surpass the hardwired NC in terms of performance and reliability, and so the hardwired NC design section was absorbed into the computer NC design section. Until that time, the two technological systems of hardwired and soft-wired had existed in parallel, but it was in 1978 when the company technologically integrated the two into the computerized NC only.

In 1978 Intel developed the MPU 8086, a single chip-type IC similar to those that we can still see today, and Fanuc developed its System 6 using the 8086 in 1979. The success of the System 6 made Fanuc the first company in the world to adopt the 8086 for mass produced goods. After that, Intel went headlong into the PC business. However, for Fanuc, the success of implementing the 8086 was a decisive moment for Fanuc's triumph in the NC market. Compared to Fanuc, American NC manufacturers were not as proactive about implementing semiconductor technologies such as MPUs, which was a fatal move on their part.

As described above, phase 2 did not only involve Fanuc maintaining business by sales activities and improvements and upgrades to existing NC systems with the total modularization of hardwired business that grew out of phase 1, but Fanuc also engaged in serious strategy change to deal with structural changes brought on by the oil shock and MPU.

2.3. Phase 3 (1981 to present)

(1) Developing Series 0, bestseller NC

By shifting technology from hardwired to soft-wired in the second phase, the new NC with product flexibility and expandability caused the market to grow significantly. This section will illustrate developing process of the Series 0, bestseller NC. The Series 0 went into mass production in September of 1985, and at the end of July 2004, 350,000 units had been shipped, becoming the #1 global bestseller computerized NC product.

The Series 0 failure rate is 0.008 per month per unit with its extremely reliable technology. When using industrial goods like NC, the importance of reliability is higher than consumables, since if industrial goods breakdown, for example in an automobile factory, the production line has to be stopped. The concept behind the Series 0 was to use technologies accumulated up to that time, and to optimally equip the product with the most compact NC possible. Rather than redesigning to produce cutting-edge technologies, that meant polishing existing products, and finding new ways to assemble them.

High reliability can only be achieved by the continuous accumulation of technology, and will never be achieved in a short space of time. Making new functions and adding them to existing products is one way to go, but products that are highly reliable are not brought about by adding something new, but by unceasingly rethinking the entire product, and in some cases, adding new functions can cause misalignments in entire systems, thus reducing the reliability of a product.

It is also difficult to assess reliability. Functions and performance can be easily evaluated by actually trying them out. Similarly, the cutting speed and precision of NC machine tools can be easily measured by actually using them. However, malfunctions are often caused by on-site unplanned use of equipment, which is why it is difficult to evaluate product reliability.

To improve reliability of hardware, it is important to reduce the number of components, and reduce the interdependency between components. For that reason, a range of parts such as custom LSI, hybrid ICs, printed circuits, power sources and display technologies were rapidly developed for the Series 0. And by using a thin display, the depth required for the display was reduced to about one third of that required for a CRT. As a result of these measures, the Series 0 has twice the processing speeds of older equipment with about half as many parts. High reliability is the result of rethinking design based on accumulated technologies.

There are 2 main factors behind the success of Series 0, both of which are innovations in a sense, the first being the total automation of Fanuc's factory for high reliability, achieved by refined manufacturing and design, and the second being the development of new software architecture to promote "user innovation" (Hippel, 2009). We describe these 2 factors in sequence.

(2)Design for Manufacturing

One reason for the success of the Series 0 was the accomplishment of a fully automated factory. One of Fanuc's strengths is its ability to substantially reduce costs with factory automation. The Series 0 was the first time the company achieved full automation. For that reason, the Series 0 hardware design had to be reconsidered from the point of view of manufacturing. In short, to achieve fully automated manufacturing consideration must be given from the beginning at the design stage.

With NC manufacturing, firstly components have to be mounted onto printed circuit boards, which is a job done by automated machines. Then, once the components have been mounted onto printed circuit boards, each board must be tested, which is done automatically by a specialized testing machine to raise efficiency. Once testing is complete, several boards are assembled to create a single NC device, which is also done by a robot. Finally, the assembled NC devices are tested in another machine for overall performance. The Series 0 was the first product created with this type of full automation. Kurakake said the following:

“The new thing here was the automated mounting, and automated assembly. Whereas previously factory workers had mounted circuit board components by hand, this was the first time we have achieved 100% automated mounting. The boards are assembled automatically using robots. This was also a new idea [17].”

To achieve fully automated manufacturing like this, design concepts considering manufacturing are needed. Even with aligning components onto printed circuit board, design has to consider everything from component selection, how the robot can grab them, through to how to tighten screws. How big the screws need to be, where should the screw holes be… design has to consider everything down to the tiniest detail. That means right from the initial stages of design, the demands from manufacturing must be taken up, and meetings with manufacturing staff have to be held frequently. Kurakake had the following to say about design considerations.

“For a robot to grab an object, it is necessary to include a hole on the device for the robot to grab. It's only a little modification, but if time is not given over to consider how the robot can grab component in the design, and the robot can't pick things up once the equipment has been built, then you are already losing the race. That the type of equipment deployed was designed in consideration of how to make something[18].”

In this way, the success of the Series 0 was brought about by carefully accumulating technologies up to the time, improving reliability, and cooperation between design department and manufacturing department.

(3)Meeting customer needs by transforming software architecture

The second factor was the change of software architecture. The change in software architecture was to separate the area of user application software from basic software area controlled by Fanuc. Why this separation was useful? Because, this type of architecture enables both users and vendors to innovate independently of each other. This architecture enables users to satisfy their own demands by themselves, and concurrently vendors to satisfy their own needs independent of the user. In this sense, Fanuc changed software architecture from integral to modular. Here, we describe the background of this change of software architecture.

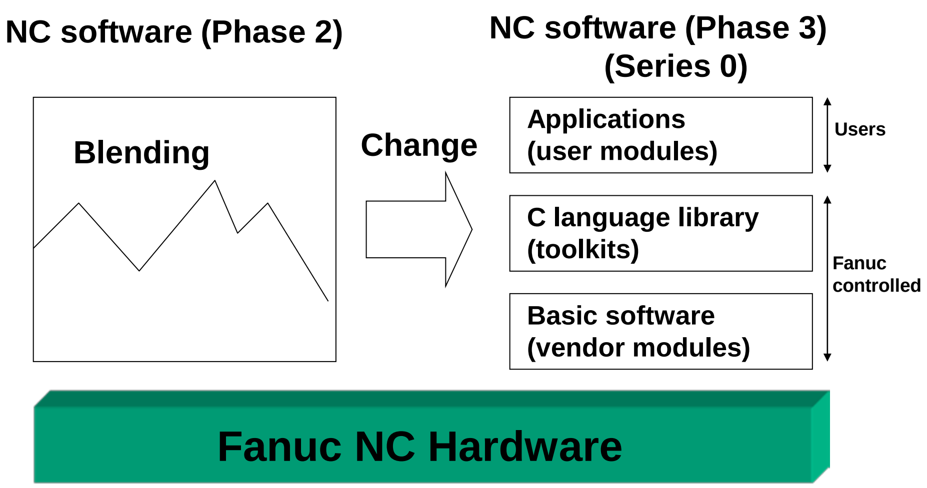
One of the drivers that brought about this bestselling computerized NC system was to provide customized functions called custom-made macros to meet the diverse needs of end users. Using these customizable functions, machine tool manufacturers, or end users could freely make necessary function independently from Fanuc, which was enabled by Fanuc rebuilding its software architecture.

Fanuc holds a 70% share of Japanese NC equipment. Therefore, for machine tool manufacturers, the big challenge is how to bring about product differentiation while using Fanuc's virtually ubiquitous NC equipment. Conventionally, in order to give machine tool manufactures customized characteristics, they have to ask Fanuc to develop new functions. With this method, machine tool manufacturers would often demand further modifications, additional functions and once again ask Fanuc to make corrections or developments, which meant that all of the work ended up back at Fanuc. In short, machine tool manufacturers could not modify or add functions by themselves. Not only was this a huge inconvenience for both the machine tool manufacturers and Fanuc, but it also cost money. Regarding this situation, Kishi (Executive Director, November 1996), said the following:

"Trying to get individual characteristics like that, machine tool manufacturers asked Fanuc to develop functions to certain specifications, and when those requests came we had to provide quotes for them, including how much time it would take. It meant that if the machine tool manufacturer wanted to add or modify a function to create their own features, there was no way that they could do it without us helping them[19]."

The main reason for this was that the basic software involved with control hardware and application software involved with the user were blended together in the conventional NC software, which meant that basic software and application software both had to be modified to meet customization requests.

Figure 6 Evolution of software architecture



To overcome this, Fanuc divided NC software as a whole into application sections that could be controlled by the user, and basic software section that could be controlled by the vendor as shown in Figure 6, and set up a C language library between them. The C language library is a software toolkit that for instance contains functions to display characters on screen or read keystrokes, and a range of internal NC input-output control functions for parameters and current cutting tool position and so forth. Machine tool manufacturers were thus able to freely assemble functions with the C language library to create their own screens, and display their own unique information. Without having to rely on Fanuc, they became able to add functions as they pleased.

Reconfiguring architecture this way enables the machine tool manufacturers as NC users and Fanuc as the NC vendor to independently innovate in parallel with each other. Fanuc was released from the diverse demands of machine tool manufacturers and end users, and was able to focus on improving its core technologies such as hardware and basic software. While on the other hand, machine tool manufacturers and end users were no longer affected by hardware and basic software changes made by Fanuc, and gained the ability to create unique functionality themselves.

As described above, in phase 3, Fanuc achieved change of software architecture as well as full automation in its factories, and successfully made Series 0 bestseller CNC.

3. Conclusion: searching for New Growth Opportunities with global partner

In 1986, GE and Fanuc set up a full equality joint-venture, each with 50% capital investment to work on CNC and PLC called GE Fanuc Automation Corporation (GE Fanuc). Headquartered in Charlottesville, Virginia in the United States, the company oversees 3 subsidiaries in North America, Europe and Asia. The extremely broad scope of this partnership extends across cooperation in development, manufacturing and marketing. To make it known that this was a partnership of full equality, Inaba suggested that the company should be called “GE Fanuc,” for “GEF” would not have sufficed. For this he gained understanding from GE. Anybody could easily guess what the initials GE stand for, but the F for Fanuc would be completely unknown. Obviously, personnel would come equally from both companies, and one person from GE and Fanuc each was sent to preside over the new company in a joint chairmanship system.

Fanuc's globalization concepts are clearly apparent in this partnership with GE. Rather than relying purely on the company's own resources, its partnerships with trusted local companies for R&D, manufacture and marketing are horizontal cooperative relationships. For such relationships to be enabled, partners must be fully equal. Accordingly, mergers with local companies must on principle be based on 50-50 capital expenditure, regardless of whether they're in the West or in Asia. In building a cooperative relationship through a fully equal partnership with another company, Fanuc is able to help out with local production training, and aims to go beyond simple exporting as part of its globalization concepts.

Notes

[1] This case study was created with reference to interviews with persons involved, books, papers and published materials. In particular, we received a lot of help in the form of information and interviews provided to us by Fanuc. We would like to express our gratitude here.

[2] Refer to Inaba (2003). The yellow robot, *Japan Industrial Journal*, (in Japanese).

[3] Inaba (2003)

[4] Inaba (2003)

[5] The pulse monitor is characterized as follows: Firstly, it has applications in a wide range of

areas including large-size machine tools, and a diversity of NC control applications. Secondly, the electric hydraulic pulse monitor can be combined with machine tools by cogs and feed screws to create NC machine tools extremely easily.

[6] Inaba (2003)

[7] Inaba (2003)

[8] Inaba (2003)

[9] Inaba (2003)

[10] Inaba (2003)

[11] Inaba (2003)

[12] Inaba (2003)

[13] Inaba (2003)

[14] Interview with Mitsuo Kurakake on 7 December 2000 (Executive Director at that time)

[15] Interview with Mitsuo Kurakake on 7 December 2000

[16] Interview with Mitsuo Kurakake on 7 December 2000

[17] Interview with Mitsuo Kurakake on 7 December 2000

[18] Interview with Mitsuo Kurakake on 7 December 2000

[19] Interview with Hajimu Kishi on 7 December 2000