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JFMRA

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Greetings to Our Readers on the Eleventh Issue of
the *Journal of Japanese Management*

Japan Federation of Management related Academies (hereafter referred to as JFMRA) was established on November 23, 2006 with the membership of 57 academic societies in the fields of management, accounting and commerce. The objectives of JFMRA, as stipulated in Article 2 of its constitution, are to develop and disseminate research related to management, contribute to society through management-related research and education, promote exchanges between related academic societies and researchers, promote cooperation with overseas researchers, and promote collaboration with the Science Council of Japan. In short, I understand that the mission of JFMRA is to make efforts to ensure that "business administration" in a broad sense is recognized by society as a field that forms a part of academia and to achieve further development.

As for the academic characteristics of "business administration" in a broad sense, it is not necessary to say so here, but I believe that it is characterized by the fact that it is approached from various backgrounds and methodologies in the respective fields of management, accounting, commerce, and information, and that each field develops new knowledge and concepts and continues to develop at a high level under the so-called academic division of labor.

Methodologically, the unique characteristic of business administration is that researchers from various backgrounds, including economics, sociology, psychology, engineering, history, and humanities, as well as business administration, cooperate with each other to comprehensively elucidate complex management phenomena. This is a unique characteristic of business administration. As is well known, as many as 57 individual academic societies are members of JFMRA, and even including other fields such as natural sciences, an unprecedented number of academic societies cooperate to form a council.

This comprehensiveness of business administration and the diversity of its sub-disciplines show the complexity of the subject matter and the diversity of disciplines in that each discipline has discovered and developed its own unique knowledge, and this can be seen as having the potential for further development in the future. However, on the other hand, these unique characteristics of business administration tend to lack unity and systematicity of "business administration" as an academic discipline as a whole, as well as closeness among sub-disciplines, and tend to be developed in a closed form within each discipline. This also suggests that it is difficult to disseminate information on the significance of business administration as an academic discipline.

In order for "business administration" to be recognized by society as an important part of academia, rather than a mere collection of knowledge in each individual field, it will be essential for the management-related sciences as a whole to act as a whole, including the establishment of close relationships among lower-level fields, interaction with society as a whole, and cooperation with the Science Council of Japan, which is deeply involved in academic policy in Japan. In addition to building closer relationships among the various fields of business administration, it will be essential for business administration as a whole to interact with society and cooperate with the Science Council of Japan, which is deeply involved in academic policy in Japan. I believe that the *Journal of Japanese Management* (JJM) plays an extremely important role in making these activities fruitful.

I rejoice at the release of the eleventh issue (Vol.6, No.1) and would like to thank the members of the JJM editorial board, especially Professor Yasushi Ueda, the Vice-President of JFMRA and Editor-in-Chief, and Professor Kiyoshi Murata, the Assistant Vice President. I am confident that this issue will stimulate the readers intellectually. JFMRA, with editorial board members, I sincerely wish this journal will become beyond the expected levels of many academic researchers at home and abroad.

Prof. Norio Kambayashi
President, Japan Federation of Management Related Academies
Professor, Graduate School of Business Administration, Kobe University, Japan

From the Editorial Board:

The Journal of Japanese Management (JJM) was first published in 2000 as an international journal in the field of management, publishing only English papers. In order to start this journal, significant contributions were made by Dr. Fangqi Xu, the first Editor-in-Chief, former professor of Kindai University, as well as directors of the Japan Federation of Management related Academies (JFMA); their contributions have been well-recognized and deeply appreciated.

We acknowledge that the publication of English journals is crucial and almost unavoidable to communicate with the academic community across the world. Over the long history of management studies in Japan, many papers would have made more extensive contributions toward developing management theories worldwide if they had been published in English. However, no matter how exceptional the papers are, the academic community outside Japan would have very few opportunities to access them if they are available only in Japanese.

Although some academic societies affiliated to the JFMA periodically allow their members to submit English papers, others have continued to publish papers only in Japanese, since they face certain challenges in establishing an appropriate review system. Therefore, this international journal is crucial for such academic societies, and accordingly, it has been positioned as one of the essential activities of JFMA.

This journal includes papers submitted by members of academic societies participating in JFMA or papers recommended by these societies. Although the submission process is somewhat different, both types of papers are accepted through a rigorous review process, and their quality is ensured.

The contributions of authors and reviewers of papers are indispensable for any academic journal. Specifically, a steady review process is made possible only with the dedicated support of anonymous reviewers. The outstanding contribution of these reviewers is greatly appreciated.

Finally, we hope that all the papers in this journal offer intellectual stimuli to our readers and contribute to developing various fields of management theory.

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Contents

Strategic Reconfiguration of Transactions in the Japanese Manufacturing Industry: A Case Study of Quantifying the Processing Designed by a Supplier

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Abstract

This study investigates the reconfiguration of transactions that occurred due to criteria and measurement devices designed by a supplier in the Japanese manufacturing industry[1]. Assemblers played a significant role in the development of this industry by providing financial and technical support. Other industry participants also contributed to this development. Previous research mainly focused on transactions between assemblers and suppliers with the assembler-led control mechanism. In contrast, this study focuses on transactions with multiple types of companies, such as assembler, supplier, material manufacturer, and tool distributor, and investigates changes of control mechanism. The proposed framework is grounded in the sociology of markets and the new institutionalism of organization studies, and it addresses calculative devices as a control mechanism of transactions involving diverse interests. The case study describes how Yamamoto Metal Technos Co. Ltd., a typical secondary supplier, quantified cutting processing based on its own technology achieved through considerable business experiences, for making better negotiations with assemblers. Once the newly designed criteria and measurement devices worked as calculative devices that withdrew companies' interests had piled up under assembler-led transactions, reconfiguration of transactions began based on those interests. This study's results suggest that the design of calculative devices is critical in strategic reconfiguration for attaining advantageous and important positions in transactions.

Keywords
Reconfiguration, calculative device, calculative agency, rules of thumb, quantify

(1) Introduction

In the past, in the context of transactions between assemblers and suppliers in the Japanese manufacturing industry, the assemblers primarily gave orders to the suppliers and provided funds

[1] This study focuses specifically on the transactions occurring in the automobile and electric appliances sectors in the Japanese manufacturing industry.

and technology to them. In contrast, suppliers focused on the subcontracting business. By the late 1980s, this assembler-led mechanism featured traits such as "commission as a bundle," "lump-sum subcontract," "effective competition among a few suppliers," and "a long-term and stable continuous transaction" (Fujimoto, 2001). It also enabled cost reduction and quality improvement and became the most efficient transaction-control mechanism until changes in the Japanese manufacturing industry's social, economic, and technical conditions in the 2000s.

After these changes, we could observe new transaction styles appear and developed new theoretical viewpoints to analyze those transactions, such as globalization in the Japanese manufacturing industry due to overseas relocation of the production base (e.g., Shimokawa, 2002, 2004; Sei, 2016), the concept of modular architecture (e.g., Baldwin and Clark, 2000; Sako, 2003) and the concept of networks loosely connecting independent companies (e.g., Fujimoto et al., 1998; Seki, 2011). Related studies carefully examined new transactions in detail, through the assembler-led control mechanism. Some studies focused on suppliers which sought to develop their own technology or goods to survive. Seki (2011) described supplier effort that does not depend on assemblers as "autonomy" and introduced such cases in his book. The studies focused on suppliers; however, they mainly used the same viewpoint or framework as in other studies (e.g., Ueda, 2006; Seki, 2011). That is, the previous studies have mainly focused on the transactions with assembler-led control mechanism even though there exists a greater number of new transaction styles with diverse interests than before. For example, assemblers, material manufacturers, machine tool manufacturers, and wholesalers have recently begun to negotiate and directly conduct transactions with suppliers. However, little attempt has been made to understand these new and alternative control mechanisms of diverse interests, which were not observed in previous transactions[2].

In contrast, this study focuses on diverse interests and transactions with multiple types of companies, such as supplier, assembler, material manufacturer, and tool distributor, and investigates changes caused by a supplier's actions to make advantageous negotiations to receive stable orders from assemblers. The advent of new transaction styles can also lead to newer control mechanisms. Rather than focusing only on the assembler-led control mechanism, studies need to explore the control mechanisms targeted toward transactional relationships in which multiple interests are intertwined. This implies that there is still scope for building a strong ground to

[2] For more details of the reviews of previous studies on the historical and theoretical considerations of the assembler-led control mechanism, see Uenishi (2016, 2017).

study new events that did not occur under the assembler-led control mechanism of transactions and examine how suppliers can design a control mechanism strategically.

This study investigates how suppliers can strategically change the transaction-control mechanism to their advantage by considering diverse interests and reconfiguring the transactions. In other words, there was an opportunity to see the appearance of the supplier-led control mechanism of transactions rather than the assembler-led control mechanism. Specifically, this study discusses how suppliers can develop and design new criteria and measurement device as transaction-control mechanisms and take advantage in transactions. To discuss it, this study used the case of Yamamoto Metal Technos Co. Ltd. (Yamamoto Metal, henceforth). This company is a typical secondary supplier for metal cutting processing. It receives blueprints and orders from assemblers and processes the orders through basic techniques. However, it expanded its business, more than typical suppliers usually do, by developing the criteria and measurement devices designed with quantified processing data; this can help in the construction of a more efficient method of processing and solve problems that occurred under the previous transaction-control mechanism.

(2) Theoretical framework: Reconfiguration through designing rules and tools

This section proposes a framework to develop a transaction-control mechanism that represents, demonstrates, and configures diverse interests. As mentioned above, different transaction styles have begun to appear in Japanese companies. Direct negotiations with suppliers have begun to appear with assemblers, material manufacturers, machine tool manufacturers, and wholesalers. This stream is counter-current compared to the previous control mechanism. Previous studies mainly focused on the assembler-led and supplier-follow control mechanism of transactions. They did not pay much attention to the control of diverse interests, even though the marketplace is a place for various companies having different interests. To understand the transaction-control mechanism of diverse interests like the marketplace, the concepts of tools and rules in the study of the sociology of markets would help. The sociology of markets investigates the mechanism of market formation by describing how problems that arise due to conflicts of interests are addressed and how relationships are formed (Fligstein and Dauter, 2007). Callon (2004) investigated tools and rules that may serve as calculative devices and act as an anchor in adjusting conflicts of interests and relationship formation.

In Callon's discussion, economic activities are described as calculative processes involving non-human elements, such as technologies and artifacts. A calculation is not innately performed as assumed in economics but becomes possible when "distributed calculative agency" (Callon and Muniesa, 2005, p. 1237), which we can find in every actor, is associated with each other. This association is handled by calculative devices that provide logic and consistency for calculations, such as double-entry bookkeeping and calculators (Callon and Muniesa, 2005). In other words, distributed calculative agency (henceforth, calculative agency) becomes visible through calculative devices that appear as tools and rules and makes association possible; it creates relationships that involve both non-humans and humans. This socio-technical arrangement or formation with non-humans and humans is called a configuration (Callon, 2004; Callon and Muniesa, 2005). In other words, a configuration is collected and associated with calculative agencies and "what they want, think or feel depends on the configuration of their socio-technical environment" (Callon, 2004, p. 4).

Therefore, the key to configuration is the calculative device; depending on the calculative device design, it will control how calculative agencies are formed and influence configurations. Callon (2004) points out that "We must be aware that when designing ICTs, what is at stake is the type of human agency, of human being we want to develop" (p. 9). At the same time, Callon (2004) also notes that discussion on the desirable design configuration is insufficient; therefore, various configurations will be formed and experimented upon in the future. This means that configurations will keep changing because the calculative agency is not an internal attribute but rather a relational effect formed by a configuration. The calculative agencies change as the configuration varies (Ueno and Tsuchibashi, 2006, p. 236). While calculative agencies and configurations continue to change, designing calculative devices means participating in the shaping of new calculative agencies or reconfiguring existing ones; it does not only mean responding to demands or satisfying needs (Callon, 2004, p. 9).

This raises the question of the direction in which a calculative device is being designed without concrete calculative agencies and configuration. In Callon (2004), it was considered that various rules and tools support the calculation as devices and focus was on the devices for formalization. It has not much explained why others include those calculative devices for calculation and the direction of designing them. Why formalization is important has been explained by the new institutionalism in organization studies, developed based on Max Weber's modernization theory (1920). According to the theory, rationality represents an ultimate value used as a reference in the search for appropriateness of behaviors (e.g., Clegg, 2005; Lounsbury and Carberry, 2005), and the ultimate modern value is formal rationality, indicating the technical rationality of an instrumental process (e.g., Kanno, 1971). Therefore, being efficient or following efficiency is taken-for-granted in the modern times; behaviors can be justified as technically rational by following efficiency and others with different interests can be convinced through displaying the efficiency of behavior.

However, there is one thing that must be remembered. Even though our behavior can technically justify and determine, formal rationality quantifies values as well. Each society's unique values qualify through relativization; as a result, formal rationality unavoidably embraces these various unique values (Kanno, 1971; Clegg and Lounsbury, 2009). It means that when we observe and follow the efficiency in numbers, quantified unique values are implied in those numbers. Therefore, companies trying to be more efficient is taken for granted. At the same time, being efficient can bring conflicts between companies because formal rationality embraced a variety of distinct values, and the contradiction between them manifests as a conflict (Meyer and Rowan, 1977).

Here I would like to emphasize that this framework does not focus on the efficiency itself. Efficiency is just a modern ultimate value that shows better or worse in numbers and every company justifies their actions by referring to it. However, efficiency can be different for every company. Efficiency can be different for assembler and supplier because they have different interests and unique values. All efficiency can be shown in numbers and when that happens, those unique values and interests would be hidden in numbers. A Calculative device is just a device that hides those interests or unique values in a black box and shows formal rationality like efficiency in numbers.

Considering the above discussion, a theoretical framework that is as follows, will be used to analyze the control mechanism and reconfiguration of transactions in this study. A company forms its calculative agency using existing calculative devices and configuration. By archiving its calculative agency, the company can design a new calculative device that displays the more efficient ways of other companies. Therefore, the calculative device designed by one company will be used in other companies' calculations, and they will depend on it. Simultaneously, the other companies will also attach the unique value of their company, which is implied, in those devices through the design. When companies begin to calculate their actions based on these new devices, the existing control mechanism of transactions changes to the new calculative devices and the transactions start to reconfigure.

In the next section, these research steps, archiving the calculative agency through existing calculative devices and configuration, designing calculative devices such as tools and rules, other companies depending on those devices and the initiation of reconfiguration of transactions, are described empirically using the case study of Yamamoto Metal. In the case study, data were collected mainly via semi-structured interviews with the president of Yamamoto Metal between 2008 and 2016 and additional interviews conducted on the material manufacturer, tool manufacturer, and cutting oil manufacturer who had transactions with the company, in 2010; further information was added from internal documents and company websites.

(3) Case Study: Design of calculative devices and reconfiguration of transactions[3]

1. Calculative agency of Yamamoto Metal

Yamamoto Metal has been in the metal cutting processing business as a secondary supplier in Osaka since 1965. Today, the company also operates a measurement and assessment service for processing. At the time of its founding, the company experienced instability of transactions as it catered to the assemblers' demands, such as extremely short deadlines and seasonally changing volume of orders. These demands brought the company to a situation wherein there were terms with no orders, a mismatch between volumes of orders and the number of machines to use. To solve the instability and these problems, Yamamoto Metal tried the typical method-increasing the volume of orders received from specific customers, at first. However, this created more imbalance in the availability of machines. The machines needed for those orders alone were in operation while the other machines were unused. Playing along with the assembler-led control mechanism destabilized its business even at that time.

To find a solution to this problem, Yamamoto Metal started analyzing the processing system using the knowledge of management engineering of its president. As a result of the analysis, the company found that the current method of operation was not worth the cost and the cause of destabilization was the way of receiving orders. Therefore, Yamamoto Metal changed its approach from increasing specific orders received from specific customers, mostly relying on their relational skills and specializing in specific processing, to increasing various orders from different customers. As a result, the company began diversifying the orders received from a broad range of customers. Even when the volume of orders was small, machines could operate in a balanced way by coordinating the same processing of orders, and a stable production system was developed. Additionally, this change enabled Yamamoto Metal to accumulate large and diverse processing data that could not have been obtained if the company was specializing in specific orders received from specific customers.

This experience led Yamamoto Metal to search and build a full-fledged system to measure processing and collect various data. For example, the company had small-scale factories that were not suited for mass production. One of the factories turned into a factory specialized for stainless steel processing that could not be processed together with iron. Another factory turned into a factory specialized for same-order spans. Other small factories also specialized by taking advantage of their small size, measuring various processes, and collecting more various data.

[3] For further details and the extended version of this case study, see Uenishi (2017).

More varied data were collected, Yamamoto Metal was able to analyze the processing and find problems and solutions by using those data. It allowed Yamamoto Metal to exhibit more efficient ways of processing to its clients in order to solve their problems. This assessment service began to attract companies that struggled with various issues under assembler-led control mechanism of transactions.

Yamamoto Metal formed its calculative agency, the measurement and data accumulation techniques based on its production system, while struggling with the prevailing issues under assembler-led transactions. The company noticed how its calculative agency helped make processing more efficient and, in turn, how it could solve the problems that occurred in assembler-led transactions. This means that the impact of its calculative agency was not limited just to assemblers, but also other companies involved in processing, such as material manufacturers, machine tool manufacturers, and cutting oil manufacturers. These companies also recognized that the rules of thumb, such as "see the processing with the blade of the tool" and "best measurements should be taken here," could not solve problems anymore and they needed to measure and quantify processing. Each company made local optimizations, and the differences caused by them were complemented by the rules of thumb. However, the gap between theoretical numbers in simulations and actual numbers in the processing have widened as the performance of materials and machines improved. Filling this gap with the rules of thumb became an increasingly difficult task, but no one had an alternative solution. This gave Yamamoto Metal an opportunity to present a way to fill the gap and solve the problems. Accordingly, the company designed criteria (rules) and measurement devices (tools) by using its calculative agency.

2. Criteria designed as rules

The gap starts from the company closest to the origin of processing. That is, a material manufacturer is the first target to design rules and tools. For Yamamoto Metal, it could create an environment of less competition with other suppliers because if the material manufacturer would depend on its data and technology and use them to produce new raw material, Yamamoto Metal was the only supplier that knew how to process it with best effort. For the material manufacturer, the data that Yamamoto Metal had already collected from various materials processing operations were needed desperately. Material manufacturer used to receive material drawings developed by assembler from processing supplier and then developed and manufactured materials according to the drawings. However, material manufacturer recently received fewer material drawings and developed and manufactured material through direct consultations with processing supplier via processing drawings. In addition, the assembler demanded shorter R&D period and cost reduction, owing to which the material manufacturer began to face the challenge of developing high-quality, high-performance materials under such difficult conditions.

Sumikei Techno Co. (Sumikei Techno, henceforth) was a material manufacturer facing such a challenge; it mainly developed, manufactured, and sold over 300 different types of aluminum extrusion materials and processed components of different qualities. The company often received inquiries on the materials and processing methods that suited certain materials from both processing suppliers and assemblers, and began receiving more complaints about cracks in the material. This was the case for "Material X," which had been developed as a new product in 2006. The cause of cracks was the use of an inappropriate processing method. Material X was developed to avoid the use of lead, which is essential for the formation of alloys, after introducing a regulation to reduce the use of lead due to environmental issues. Tin was employed instead of lead, and a relatively more environment-friendly material like Material X was developed. Still, the cutting ability and strength of the material were inferior compared to those of a lead alloy. Therefore, a processing method suited to Material X was required, but processing suppliers handled Material X using a conventional processing method and this caused cracks in the material. To avoid the formation of cracks, the processing method had to be revised to accommodate the characteristics of tin, whose melting point is lower than that of lead. However, the biggest issue was that neither processing suppliers, or Sumikei Techno knew the appropriate processing method for Material X. Processing suppliers had no prior experience with this new material, and Sumikei Techno was neither specialized in assessing materials in the processing stage, nor presented the right conditions for processing. None of the material manufacturers in Japan owned a technical team that could assess the processing stage, and the cracks that occurred upon processing lead-free materials became common. To solve the problem of cracks, Sumikei Techno began looking for a company able to assess processing and develop a method suited for Material X. Research laboratories of material manufacturers could only assess the material itself, while processing suppliers only had rules of thumb to prevent cracking. Still, the method could not be translated into data or transformed into a general processing method. Searching for this partner company was difficult and took approximately two years.

At that time, Yamamoto Metal was not just measuring the processing and collecting data but also began analyzing data accumulated through its production system at its own technical development center, a rare facility for supplier, and providing consulting services such as assessing processing, analyzing processing data, and identifying processing conditions suited to materials. Customers for its services were assemblers and companies with problems with assembler-led transactions. Yamamoto Metal assessed their processing, provided proposals for solving problems, and proposed more efficient processing conditions. Sumikei

Techno initiated a business partnership with Yamamoto Metal in May 2008.

The first step in solving the problem of cracks was to measure the machinability of Material X. Machinability is a criterion of material that shows the ease of grinding during processing by cutting. Machinability used to be covered by rules of thumbs; however, Material X utilized tin instead of lead, and its machinability was reduced under the conventional processing method, such that it could no longer be covered by the rules of thumb. Therefore, Yamamoto Metal measured the machinability of Material X under various conditions and analyzed the differences in the degree of machinability compared to conventional materials and conditions that could guarantee a satisfactory outcome. As a result, Yamamoto Metal successfully showed the cause of the cracking and proposed suitable processing conditions for Material X. In other words, Yamamoto Metal defined a new set of conditions for processing, rather than changing the processing method itself, by focusing on machinability.

Machinability was covered by the rules of thumb until now; however, it could now be measured, assessed, and showed in numbers. Companies could now desire and request a greater production of Material X, rather than just reducing its cracking. The improved process needed a setup for machinability and other conditions, and Yamamoto Metal could provide these services to those companies. This led Yamamoto Metal to work on more measurement criteria to assess a variety of processing conditions. In particular, metal fatigue is another important criterion for processing, which was found to be another primary cause of cracks in Material X; it was also covered by the rules of thumb. If the metal is fatigued, its strength declines and, by continuing the processing, the metal eventually fails to bear the stress, and cracks arise. Machinability is a crucial attribute, but it fails to pursue its original purpose if quality issues such as cracking occur as a result of pursuing a greater machinability. The treatment of metal fatigue requires simultaneously addressing the machinability and the cause of cracking.

3. Measurement devices designed as tools

Through a business partnership with Sumikei Techno, Yamamoto Metal began to design measurement devices to utilize the accumulated processing data beyond just measuring and assessing, with criteria such as machinability and metal fatigue. Material X was measured using machines and tools owned by Yamamoto Metal and assessed by combining these results with the accumulated processing data. To assess more various processes and set up suitable processing conditions, an enormous amount of processing data regarding the machinability and metal fatigue of materials and the tools for processing are required. Accordingly, Yamamoto Metal needed to design a measurement device that was suitable to its processing technology for collecting the data on various objects. In 2007, Yamamoto Metal designed its proprietary measurement device for machinability, "MULTI INTELLIGENCE®."

At the same time, a measurement device for metal fatigue (called fatigue testing machine), which was equally important, was designed. The alternative to existing testing machines was produced based on either the rules of thumb or theoretical figures. These machines also were too expensive to purchase only for testing metal fatigue for Yamamoto Metal, and therefore, the company outsourced this task without purchasing the machine. However, Yamamoto Metal could not obtain and offer an accurate assessment by combining machinability measures with outsourced measurements of metal fatigue using different techniques. This affected the extent of processing consulting provided to clients using the processing data and technologies. In 2008, Yamamoto Metal began developing a proprietary fatigue testing machine and designed "GIGA QUAD®," a quadruple-type rotating bending fatigue testing machine.

These measurement devices were specially designed to accumulate processing data along with the processing technology of Yamamoto Metal. The company was now able to collect a large amount of more accurate data and assess both machinability and metal fatigue by using the devices; therefore, combining them was not a problem. There were companies that individually measured machinability and metal fatigue in the past; however, no company had ever succeeded in measuring machinability and metal fatigue, assessing processing, and proposing more efficient methods in the same package by utilizing their own processing technology.

4. Initiation of the reconfiguration via newly designed criteria and measurement devices

As a result of the criteria and measurement devices designed, the configuration of transactions at Yamamoto Metal began to change. Assembler and material manufacturer which had never conducted transactions with the company before began to inquire about its business. Assembler always looked for suppliers that enabled higher cost reduction; this could be offered by the business that used Yamamoto Metal's devices. In addition, the partnership between Sumikei Techno and Yamamoto Metal could provide material development and guarantee processing with no cracking problem to assemblers, all in a bundle. GIGA QUAD® could also provide quality assurance regarding the material to assemblers.

Since processing could be visualized in numbers only with those devices, it became a black box and invisible to the client. Therefore, the companies that employed the devices must also use assessing and consulting services and continue using the devices and services to accumulate their data for more accurate analysis. By providing better processing and more efficient transaction using the devices and services, no one would be concerned about the fact they always needed to use the devices and services. For example, companies that used Material X needed to ask Yamamoto Metal to set up the processing conditions, based on the assessment of their processing. Requests for this assessment increased as the number of companies that used Material X was augmented. This was based on a practice unique to Yamamoto Metal, which searched for suitable processing methods and tools every time the material changed. As a result, Yamamoto Metal could receive orders using its own technology; this helped the company to solve its prior problem of instability in orders by replacing the assembler-led control mechanism of transactions.

Since Yamamoto Metal succeeded in designing criteria and measurement devices, the measurement and assessment of machinability that had been working since 2007 became a full-fledged machinability assessment testing procedure in 2010 and was formalized as a business in 2015. The measurement and assessment of metal fatigue started with R&D activities in 2008 and became a business in 2014. In 2016, the transactions between Yamamoto Metal and UACJ (formerly Sumikei Techno) were still carried out through the criteria and measurement devices. In addition, Yamamoto Metal won contracts to test a new material developed for an automobile manufacturer as commissioned research.

These measurement and assessment services are not restricted to testing materials. From materials and tools to cutting oil, everything associated with cutting processing could be subject to measurements and assessments. If the cutting tools and cutting oil optimal for processing could also be developed alongside materials, the materials could be sold in combination with the processing method, tools, and oils, as a complete package. Therefore, all the items at a processing site could be replaced with those included in the processing technology solutions of Yamamoto Metal. Thus, Yamamoto Metal approached the cutting tool and cutting oil manufacturers for potential joint development.

However, this joint development did not materialize because of conflicting interests. Yamamoto Metal aimed to design tools with a high cutting ability to accommodate the processing technology, while the tool manufacturer wanted to design tools with a high level of cutting ability and durability. Another reason for the mismatch of interests was that the criteria and measurement devices presented the durability of the cutting tools as numerical data. A number summarized the use of tools, but this indicator could become ambiguous when the material changed. In comparison, the number shown by the measurement devices was a compatibility index between various materials and cutting tools, which means that these numbers represented the performance of the tools for users. Revealing the performance of the tools would increase the number of competitors, which was something that tool manufacturers wanted to avoid. Likewise, the cutting oil manufacturer also wanted to avoid an increase in competition.

The assessment of cutting tools and

cutting oil was requested by client companies requiring processing conditions that matched the production site. However, as mentioned above, it was difficult to jointly develop cutting tools and cutting oils because the interests of companies did not match. Therefore, Yamamoto Metal decided to enhance its business and service based on the criteria and measurement devices designed instead of starting new joint developments.

(4) Discussion: Strategic reconfiguration via designed calculative devices

This section discusses what can be learned from the case study of Yamamoto Metal and helps see the beginning of the reconfiguration of transactions by establishing newly designed calculative devices from three perspectives. First, the calculative agency can be obtained under existing configuration of transactions and embodies newly designed calculative devices. As mentioned above, Yamamoto Metal was struggling with demands of assemblers. However, the company made progressive changes in its production system while responding to the demands of assemblers and developed measurement techniques and data accumulation using its production system as its calculative agency. Using its calculative agency, Yamamoto Metal solved not just its own problems, but also those of other companies which were a result of a similar assembler-led control mechanism as Yamamoto Metal. Solving problems had successfully satisfied assemblers' demands. The calculative agency that Yamamoto Metal archived provided stability to the company and solved problems caused by assembler-led control mechanism.

Calculative devices designed by Yamamoto Metal was embodied the calculative agency of Yamamoto Metal, as mentioned above, and made rules of thumb visible in numbers. Rules of thumb supported efficient processing and transactions in many ways for a long time. However, the invisibility of rules of thumb also created many problems because there were many different companies that had different interests in the process of manufacturing. To make the rules of thumb visible to solve problems, companies needed rules and tools such as criteria and measurement devices to quantify processing. Criteria and measurement devices enabled Yamamoto Metal to propose processing settings that suited the material properties and ensured the quality of materials and resulted in improving the production system. That is, criteria are the rules that clarify what should be visible as the data, while measurement devices are the tools for collecting data followed by criteria, and a larger volume of accurate data can be collected by criteria and devices that only one company could collect previously. The companies that purchased the measurement devices eventually collected the data by using them. Yamamoto Metal just needed to collect the data from those companies for free through providing their assessment and consulting services.

Second, the designed calculative devices triggered the reconfiguration of the existing transactions by making the latter align with them. Material manufacturer acquired the ability to sell directly instead of operating through wholesaler and began working on developing higher-quality materials by using the criteria and measurement devices. A distribution company used the criteria and measurement devices to assess equipment performance and display numeric results on their catalogs. Price was the only metric used to choose the equipment for client companies; however, the distribution company could now provide equipment performance as another metric for the selection of equipment. Additionally, the distribution company had worked on a database of equipment performance and planned to demonstrate this database to client companies. Machine tool manufacturers began collecting processing data by attaching measurement devices to their machine tools. This allowed them to develop machine tools to meet more client companies' needs by using the data collected. In this way, the criteria and measurement devices designed by Yamamoto Metal were gradually arranged in the existing configuration and triggered reconfiguration of transactions.

Third, the designed calculative devices showed a possibility of becoming pivotal in the future control mechanism and continuing reconfiguration of the manufacturing industry. MULTI INTELLIGENCE® did not sell much since the formalization of the business in 2015, but the main target of this device was Yamamoto Metal client companies, especially the research laboratories of assemblers and material manufacturers. Research laboratories conducted many measurements and analyses needed in product development and manufacturing, and MULTI INTELLIGENCE® connected these laboratories and Yamamoto Metal.

For example, several measurements were needed when an automobile manufacturer attempted to use a new material or a new processing technology for a new product. [4] The company performed assessment tests before establishing the technology for manufacturing the product. To do so, the research laboratory of the manufacturer would ask Yamamoto Metal for help in measuring, assessing, and accumulating data, carried out using MULTI INTELLIGENCE®; thus, it was employed to measure and assess the machinability in the research laboratory of the automobile manufacturer. The research laboratory collected the data obtained by MULTI INTELLIGENCE® and purchased the data (under the same conditions) from Yamamoto Metal, allowing it to reduce the time required for R&D as well as the time to respond to problems. New materials and processing

[4] The case of an automobile manufacturer was presented as an example of how an assembler's research laboratory functions, but the same applies to other companies who aim to shorten the R&D phase and the accuracy of equipment can also be improved by using MULTI INTELLIGENCE®, like medical equipment manufacturers.

technologies, including hybrids, electric vehicles, and fueled vehicles, are often applied in unknown fields such as next-generation vehicles. In these fields, accumulated data are scarce and valuable. Therefore, there is a high chance that Yamamoto Metal and MULTI INTELLIGENCE® would collaborate for new products, and after that, other companies would have to purchase and use MULTI INTELLIGENCE® with data from Yamamoto Metal if they wanted to use those materials or technology.

MULTI INTELLIGENCE® did not simply measure machinability; it played a significant role in creating a new blueprint for identifying the interests of other companies and reconstructing such interests. To be able to identify varied interests, Yamamoto Metal needed to find and solve more companies' problems which would become possible through the collection of a variety of accurate data. MULTI INTELLIGENCE® managed to be sold as a result of other companies' needs or interests to help Yamamoto Metal in deciding the direction of upgrading the device. More the problems that MULTI INTELLIGENCE® could solve, more the number of companies would use it. Then those companies would provide data to Yamamoto Metal. As such, Yamamoto Metal continues to design and enhance the measurement devices to understand other companies' interests by receiving orders of processing, ensuring that the measurement devices are used in the product development stage, and providing measurement and assessment solution services.

As more and more companies use the measurement devices, the transactions will get reconfigured around Yamamoto Metal. Being a part of the development stage of assemblers and the academic stage may have more effect of the reconfiguration. As the components in the rules of thumb have become measurable by the criteria and measurement devices, the need for composite measurements and assessment is being highlighted in academic conferences, such that the difference between simulations and actual measurements has become evident. In other words, the criteria and measurement devices visualized processing as actual values, which, in turn, formed the basis for reconfiguring transactions among diverse stakeholders. At the same time, it also meant that the criteria and measurement devices that Yamamoto Metal had strategically designed provided actual measurements in a manner that aligned with the processing carried on by the company.

As shown in the case of Yamamoto Metal, the design and arrangement of new calculative devices in the existing configuration is critical to reconfigure transactions strategically. Once new calculative devices become essential for controlling transactions, replacing or at least changing the assembler-led control mechanism, companies need to include calculative devices in their transactions. As discussed, the criteria and measurement devices designed by Yamamoto Metal influenced the reconfigurations of transactions among various types of companies. Developing these devices and offering services using them enabled a supplier like Yamamoto Metal to take advantage of the transactions that used to trigger a complete reconfiguration of transactions controlled with the rules and tools designed by assemblers. Therefore, Yamamoto Metal considers the total package for the measurement and assessment of the entire manufacturing process by including the designed criteria and measurement devices in the existing transactions.

(5) Concluding remarks

This study described the potential reconfiguration of transactions by arranging calculative devices designed by a supplier into existing transactions. In the case of Yamamoto Metal, the criteria and measurement devices were designed as calculative devices while considering other companies' problems or interests. The calculative devices were designed via a calculative agency, measuring processing and accumulating data, while solving Yamamoto Metal's own problems and responding to the demands of assemblers. This allowed the company to show others how calculative devices can make their processing more efficient and solve their problems. Ensuring that processing and transactions are efficient is more important than following the assembler-led control mechanism, which was considered as the ideal method in the past. As a result, reconfigurations of transactions began by arranging these devices as a control mechanism for transactions instead of assembler-led control mechanisms.

Furthermore, the criteria and measurement devices showed different patterns of reconfiguration. These criteria became the point of reference for corporate activities. For example, Yamamoto Metal's measurement and assessment solution service formulated new criteria based on the processing data. As explained before, Yamamoto Metal defined a criterion that served as a point of reference for the purchase of tools on behalf of distribution company that sought to differentiate by means other than price. In addition, measurement devices not only performed measurements but also collected data. For example, MULTI INTELLIGENCE® was designed to be attached to a machine tool, as explained before. In this way, companies could easily measure processing by simply attaching the device to their machine tools, while Yamamoto Metal could collect a large amount of data to use them for its business.

Even a typical secondary supplier can have a chance to analyze other companies' interest and design calculative devices that can become a possible control mechanism of transactions for the whole industry. It does not require advanced technology, but a calculative agency archived in the existing configurations to design calculative devices in order to process other companies' interests and make them depend on its calculative devices. However, this study is limited to the case of Yamamoto Metal and its client companies during a certain time period. It is necessary to study various calculative agencies and their calculative devices and reconfigurations to analyze the pattern or category of calculative devices to arrive at more specific conclusions. Furthermore, continuing the observations will provide an overall perspective on reconfiguration and its effect over the whole industry. However, as discussed, the framework for investigating transaction-control mechanisms from the perspective of calculative devices has yielded enough evidence, making it possible to apply the study's results to other transactions or industry reconfigurations.

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The Effect of Feedback Control and Feedforward Control on Organizational Performance: A Simulation Analysis Using NK Model

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Abstract

This study examines the effect of feedback control and feedforward control on organizational performance by using computer simulations. Feedback control and feedforward control in management accounting have been studied since the late 1960s; however, findings on the effects of these controls have been inconsistent in existing research. The limitations of observing feedforward control without feedback control can be one reason for these inconsistencies. This study uses computer simulation and the NK model to analyze the effects of controls without limitations of observation. I add three factors—memory, environmental change, and control structures to the basic NK model—to analyze the effects of control. The simulation results indicate that effective control differs, according to the variability of the environment and the degree of interdependency among organizational decision factors. Additionally, simulation results show that the simultaneous use of feedback control and feedforward control is effective at high environmental variability and high interdependence among decision factors.

Keywords

Feedback control, Feedforward control, Management control, Simulation, NK model

(1) Introduction

This study uses computer simulations to analyze how feedback control, feedforward control, and the joint use of these controls influence organizational performance under different conditions.

Demski (1969) introduced the concepts of feedback control and feedforward control in the discipline of management accounting. Since then, many researchers have used these concepts to understand management accounting. Using feedback control enables the discovery of problems that occur and advances the exploitation of existing capabilities to solve problems (Ferreira and Otley, 2009; Grafton et al., 2010). It also enables discovering new potential opportunities and advancing the exploration of new capabilities (Grafton et al., 2010).

Although feedback and feedforward controls have been shown to have these advantages, the influence of these controls on organizational performance is inconsistent, as reported in existing studies (Grafton et al., 2010; Ismail, 2013; Lerch and Harter, 2001). These inconsistencies can emerge from differences in environments faced by organizations, such as variability and complexity (Fowler, 1999; Lerch and Harter, 2001).

Measuring the state of these environments requires detailed investigation and considerable costs. Additionally, organizations using effective feedforward control will simultaneously use effective feedback control, as feedforward control requires information obtained using feedback control (Demski, 1969). Acquiring empirical data on organizations that use feedforward control without feedback control has been difficult.

Thus, this study uses computer simulations to analyze how feedback control and feedforward control influence organizational performance. Computer simulation allows for the acquisition of virtual data on the environments faced by organizations and the influence of only feedforward control on organizational performance.

The remainder of this study is organized as follows. In the next section, I discuss the concepts of feedback control and feedforward control. Section 3 introduces the NK model as the base model. In Section 4, the NK model is developed to express feedback control and feedforward control. In Section 5, I present the results of the simulation analysis, while Section 6 concludes this study.

(2) Feedback control and feedforward control

1. Definition

Demski (1969) introduced the concept of feedforward control in management accounting research by presenting a "decision-performance control" framework. This framework contains not only feedback control, which uses feedback information such as past results to control the implemented decision, but also feedforward control, which uses feedforward information such as environmental information to develop the best strategy. In the decision-performance control framework, feedback control is defined as the control that uses information that results from the physical process, as well as further environmental information to control decision making; feedforward control, however, is defined as the control that uses forecast information based on internal and environmental information.

Maruta (2005) compared the computation structure of feedback control with that of feedforward control and demonstrated the difference between these controls from two perspectives: a time structure and a relationship between standards and objects. Feedback control is the process through which a controller makes actual outputs closer to standards of control, while feedforward control is the process through which a controller makes the forecast outputs closer to standards of control. For example, traditional budgetary control is a feedback control that uses the difference between the actual profit and forecasted profit to manage an organization. Thus, this control uses actual profit as the object of control and forecasted profit as the control standard. Budgeting is a feedforward control that uses differences between forecasted profit and target profit to manage an organization. Budgeting therefore uses forecasted profit as the object of control and target profit as control standards. The difference between traditional budgetary control and budgeting is whether the objects of control are actual values or forecasted values.

Both Demski (1969) and Maruta (2005) emphasize that feedback control uses results or output information after implementation, while feedforward control uses future forecast information before implementation. Additionally, Maruta (2005) shows that research in various disciplines states that the major difference between the concepts of feedback and feedforward is the perspective of after implementation or before implementation. This study focuses on this basic difference in modeling and analyzing feedback control and feedforward control[1].

Demski's (1969) framework considers feedback control and feedforward control as a series of processes. An organization's manager or decision maker usually requires past information acquired by feedback control to perform feedforward control. However, analyzing the influence of only feedforward control on organizational performance requires separating these controls; thus, I conceptually separate these controls in the analysis model .

2. Relationships among feedback control, feedforward control, and decision-making environments.

This subsection discusses the relationship between feedback control, feedforward control, the variability of decision-making environments, and the interdependency among decision variables.

Using feedback control enables organizations to discover problems and solve them, modify action, advance organizational learning, and exploit existing capabilities to solve problems (Ferreira and Otley, 2009; Grafton et al., 2010). These functions can only improve actions after strategies decided in the past are implemented. Feedback control is useless for organizations to take advantage of new potential opportunity (Nørreklit, 2000). Additionally, this control has shortcomings, in that recognizing occurring problems takes time (Maruta, 2005).

Using feedforward control enables organizations to discover new potential opportunities, advance the exploration of new capabilities, and to act before problems occur (Grafton et al., 2010). This indicates that feedforward control enables organizations to explore a new decision

[1] I discuss whether controlling lagging indicators by using a leading indicator is feedback control or feedforward control; this study treats such a control as feedforward control. Control requires clear objects of control (Maruta, 2005). If lagging indicators become objects, a leading indicator enables forecasting of the future states of objects (Demski, 1969).

option, based on the extant decision, at the complex interdependency among decision variables. However, the use of forecast information requires a precise forecast model and the observing information about the change in the input variable for the forecast model (Fowler, 1999). Thus, the use of feedforward control can be inefficient when the environment significantly changes. Additionally, using only feedforward control limits organizations' ability to modify the extant action when the forecast is wrong.

Lerch and Harter (2001) investigated the effects of feedback and feedforward control. Their findings indicate that using only feedforward control has negative effects on performance, while using only feedback control or even no control can gradually improve performance. Their study also shows that using either both controls or no controls affects performance more than using only feedback or feedforward control. Lerch and Harter (2001) explain the reason for their result from the perspective of interdependency among decision variables. For the small number of interdependencies among decision variables, using only feedforward control results in relatively low performance. A few interdependencies enable the efficient exploration of alternatives without feedforward control. Thus, feedforward control leads to unnecessary cost increases and negative effects on performance at a few interdependencies.

Maruta (2005) considered the process of budget updating as a feedforward control. Budget updating is the process of renewing forecasted values before recognizing the actual value output, when recognizing environmental change. This process requires recognizing environmental changes before performing feedforward control. Recognizing environmental change requires feedback control that becomes clear due to the difference between past and current information. These requirements show that feedback control is more important than feedforward control in managing environmental change, and that feedforward control provides an additional effect.

The findings on the relationship between feedback control, feedforward control, and organizational performance is inconsistent in existing studies. One reason for this inconsistency is that the effectiveness of both feedback control and feedforward control vary, depending on the decision-making environment. Existing research indicates the variability of decision-making environments (Fowler, 1999; Maruta, 2005) and that the interdependency among decision variables (Lech and Harter, 2001) influence the effectiveness of feedback control and feedforward control; however, research examining this relationship is limited.

From the next section, I examine how the variability of decision-making environments and the interdependency among decision variables influence the effectiveness of feedback control and feedforward control by using computer simulation.

(3) NK model

This section explains the NK model, the base model used in this study.

The NK model was introduced by Kauffman and Levin (1987) as a model in the evolutionary biology field. This model allowed biologists to analyze the evolutionary process in cases for which characteristics or genes are interdependent on each other (Kauffman, 1995; Kauffman and Levin, 1987). The model has been used in management discipline since Levinthal (1997) used it to analyze the cause of diversity in organizational forms. Researchers have also studied issues relating to "exploration and exploitation" (March, 1991) or "differentiation and integration" (Lawrence and Lorsch, 1967) by using the NK model.

The NK model aims to express situations in which managers try to improve decisions gradually, to thereby improve organizational or departmental performance. The decision in the NK model has N decision variables that have only two states. For example, whether the firm buys equipment A or B, or whether the firm makes a component itself or buys it. These variables do not directly affect performance. The performance of a variable depends on the states of the other variables. A variable's performance can depend not only on one other variable but also on multiple other variables; thus, the number of dependences per variable is expressed as parameter K. Changing K enables us to express the complexity of decision making.

Combinations of decision variable states increase exponentially as N increases; however, managers have insufficient capacity to consider all variables simultaneously.

This insufficient capacity limits the number of decisions that the manager can consider simultaneously; it also limits the number of variables that the manager can use to forecast performance change that can change at once. These limitations enable the model to express real managerial situations wherein decisions are made adaptively.

I formulate these situations as follows: The simplest model has a single agent that can make a decision. This single agent is generally interpreted as an executive manager who makes decisions at every time-step.

First, I define decision making. N decision variables are binary decisions, that is, $d_i \in \{0,1\}$, ($i = 1, \ldots, N$). Feasible decision is defined as N-dimensional binary vectors $\boldsymbol{d} = (d_1, d_2, \ldots, d_N)$. Therefore, the number of decision patterns is 2^N. Existing studies mainly set N from 6 to 10 (e.g., Siggelkow and Levinthal, 2003; Siggelkow and Rivkin, 2006; Wall, 2016). Such a small N still allows us to express sufficiently complex situations.

Second, I define the performance obtained through the decision. Each of the decision variables makes a certain contribution c_i, (i=1, …, N). The value of the contribution function c_i depends not only on decision variable d_i but also on other K decision variables. Thus, the contribution function has K + 1 variables; that is, $c_i\left(d_i \mid d_{i(1)}, d_{i(2)}, \ldots, d_{i(K)}\right)$, where i (k) is the function that returns the number of the k-th decision variable that influences the contribution of d_i. At the beginning of the simulation, a random value from a uniform distribution is allotted to each of input vector $\left(d_i, d_{i(1)}, d_{i(2)}, \ldots, d_{i(K)}\right)$ as the return value of contribution function. The performance of decision ***d*** is defined as the average of the values returned by the N contribution function:

$$V(\boldsymbol{d})=\frac{1}{N}\sum_{i=1}^{N} c_i\left(d_i \,/\, d_{i(1)}, d_{i(2)}, \ldots, d_{i(K)}\right). \quad (1)$$

When K is larger, the influence of changing a decision variable spreads to other decision variables more, and decision-making is more complex. The smallest value of K (K = 0) achieves the highest performance by changing the decision variable one by one, because all decision variables are independent of each other and the graph of $V(\mathrm{d})$—that is, the fitness landscape—has a single peak. In contrast, the largest value K (K = N − 1) limits the improvement of the decision. In this situation, changing certain decision variables to increase contributions can lower global performance, as all decision variables are interdependent and the fitness landscape has many local peaks. Thus, improving global performance requires simultaneous consideration of multiple decision variables at the same time.

In these environments, a single agent, an executive manager, make decisions repeatedly, following "hill-climbing method" algorithm. The manager has insufficient cognitive capacity to survey all alternatives at once; therefore, the manager searches for a fixed number of alternatives that is sufficiently close to the decision implemented in the previous time-step at one time-step. The number of alternatives and the distance form decisions implemented in the previous time-step are the parameters under this manager capacity assumption.

Distance was calculated using the concept of the "Hamming distance." This concept defines distance as the number of different components between two vectors. For example, the distance between vector (0, 1, 1, 0) and vector (0, 0, 1, 1) is two, because these vectors have two different components: the second and fourth components. Thus, selecting a decision sufficiently close to the decision implemented in the previous time-step means that the manager can only change a limited number of decision variables at once.

Subsequently, I explain the concrete algorithm of hill-climbing:

1. The decision implemented at time-step 0 is decided at random.
2. Let recent time-step be t. The manager searches decisions at random from alternatives that are sufficiently close to decisions implemented at time-step $t-1$.
3. The manager adopts the decision that produces the highest V(d) from alternatives searched at step 2 and the decision is implemented at time-step $t-1$.
4. Step 2 and step 3 is repeated until termination conditions are fulfilled.

In the simplest NK model, a single agent reaches a local peak that is nearest to the initial decision. This agent stays at this local peak because of its capacity limit, although the other decision, which is producing higher performance, exists far from the current decision (Kauffman, 1995). This indicates a limitation of gradual improvement in organizations that face complex environments and the dependency of the current state of organizations on the initial state of the organizations.

(4) Expansion of NK model

Analyzing the relationships among feedback control, feedforward control, and organizational performance using the NK model requires the introduction of the structure of feedback control and feedforward control into the NK model. Introducing the memory structure of an agent (Wall, 2016) and environmental change (Levinthal, 1997) allows the NK model to express both feedback control and feedforward control.

In my model, an agent is interpreted as an organization or a manager who represents an organization. Thus, agent memory indicates organizational memory and the searching process indicates the organizational search of decisions.

1. Memory structure

In the basic NK model, an agent chooses a current decision by comparing the performance obtained through decision implemented in the previous time-step and the forecasted performances which could obtained by implementing feasible decisions. This setting is limited, in that it is difficult to manage past information and future information. In my model, an agent stores information in memory. Feedback control allows an agent to memorize the combinations of decisions implemented in several previous time-steps, and their performance; feedforward control allows an agent to memorize the combinations of decisions that are feasible in several future time-steps and the forecasts of their performance. An agent can use memorized information as an alternative way of making a decision at each time-step. However, when environmental changes occur, memorized information can lose its relevance to the current environment. The capacity of memory has no upper limit, and thus, memorized information remains until the feedback or feedforward control process reveals that the information is incorrect.

2. Environmental changes

Examining the influence of feedback and feedforward control on organizational performance requires us to consider environmental changes. My model uses a structure in which the contribution functions change on a regular basis. This structure is also used in Levinthal's (1997) model, but unlike their model, the degree of environmental change varies in my model, depending on the variability, ranging from 0 to 1.

When environmental change occurs, each return value of the contribution function changes to a random value from a uniform distribution that has an upper limit and a lower limit, as expressed in the equation below.

$$\textit{upper limit} = \textit{value before change} + (1 - \textit{value before change}) \times \textit{variability}.$$

$$\textit{lower limit} = \textit{value before change} - \textit{value before change} \times \textit{variability}.$$

No environmental change occurred when the variability was zero. The contribution function values reset independently of their values before environmental change when the variability is one.

3. Feedback and feedforward structures of the relationships between decisions and performance

This study mainly uses the concept proposed by Demski (1969) to address feedback control and feedforward control. In my model, feedback control is treated as the process in which a manager uses past performance information to control current decision making, while feedforward control is treated as the process in which the manager forecasts the relationships between feasible decisions and performance, and uses the forecast information to make the best decisions possible. Feedback control enables managers to obtain information on the results of past decisions, whereas feedforward control enables forecast information to be obtained before implementing a decision.

In my model, the variable T indicates the time distance between the current time-step, information obtained at that time-step, and the interval of information acquisition [2]. First, I define the no-control situation as $T = 0$. A no-control situation allows an agent to search only decisions feasible in the next time-step but not to memorize those decisions. This represents a situation in which an agent lets its actions take its own course.

A T-value smaller than zero indicates existing feedback control. For example, at $T = -5$, an agent acquires and memorizes information about decisions implemented during the past five time-steps and the performance related to these decisions.

At this stage, past information about decisions and performance is inserted into the agent's memory. Extracting past performance information from memory enables the selection of decisions that produce higher performance. Demski (1969) treats the concept of feedback control as a control, with a comparison between current states and standards or assumptions. This model expresses only a comparison between the current states and assumptions. For example, if memory states that implementing decision (0, 0, 0, 0) produces a performance of 0.6, but implementing decision (0, 0, 0, 0) produces only 0.4 in actuality, an agent modifies that statement in the memory to a new one. If memory has no information about implementing decisions (0, 0, 0, 0), the statement that implementing decision (0, 0, 0, 0) produces 0.4 is inserted into memory.

If T is larger than zero, it indicates existing feedforward control. For example, at $T = 3$, the agent acquires and memorizes the forecast information about several decisions that are feasible during the next three time-steps and the performance

[2] I define the interval of information acquisition as the other variable. For example, the model can contain rolling forecast structures that the information of several future time-steps is obtained at every time-step. This study excludes this structure from the analysis to simplify the model; this point will be examined in future research.

obtained from these decisions per three time-steps. In the NK model, the relationships between decisions and performance are decided randomly at the beginning of the simulation. The memory in which information about such a relationship is stored is the decision model, which is referred to by Demski (1969). In my model, the feedforward process searches for new relationships between decisions and performance. This expresses the advantages of feedforward control: paying attention to new potential opportunities and advancing the exploration of new capabilities. An agent has limited capability to make optimal decisions, and thus, they can only forecast decisions that are feasible in the near future; thus, feedforward in my model is conceptualized differently from that in Demski (1969) who treats it as an optimization.

When using feedforward control, the forecast processes are as follows: First, an agent searches for a decision that is feasible at the current time-step and acquires information about the relationship between the decision and performance produced by implementing it. Second, the agent searches for a decision that is feasible at the next time-step and the information, on the assumption that the agent implements the decision searched by the agent in the previous step. If T is larger than three, the second step is repeated recursively. The decisions searched after the second step are distant from the decision implemented at the last time-step; therefore, implementing those decisions requires several time-steps.

The forecast uses contribution function values before environmental change, although the forecast period contains the time-step at which change will occur. The observer (researcher) knows this time-step, because the change interval is fixed; however, an agent in the computer model does not know this. This condition setting reflects the shortcoming of using only feedforward control has a limited ability to cope with environmental change. In reality, managers can acquire several actual performance indicators without feedback control and evaluate the validity of information from the feedforward process. However, limiting the acquisition of actual performance information without feedback control enables the clarification of the characteristics of feedforward control. Thus, in my model, only feedback control verifies the information acquired by the feedforward process after implementation.

4. Flowchart of analysis model

This subsection presents a flowchart of analysis model (Figure 1). Initially, the decision implemented at time-step 0 is decided by randomly allotting each decision variable to zero or one. Simultaneously, the return values of the contribution function are set at random values from a uniform distribution $U(0, 1)$ for any decision vectors. These values change every 50 time-steps, depending on the variability.

Based on the absolute value of T time-steps, information acquisition by feedback and feedforward process occurs.

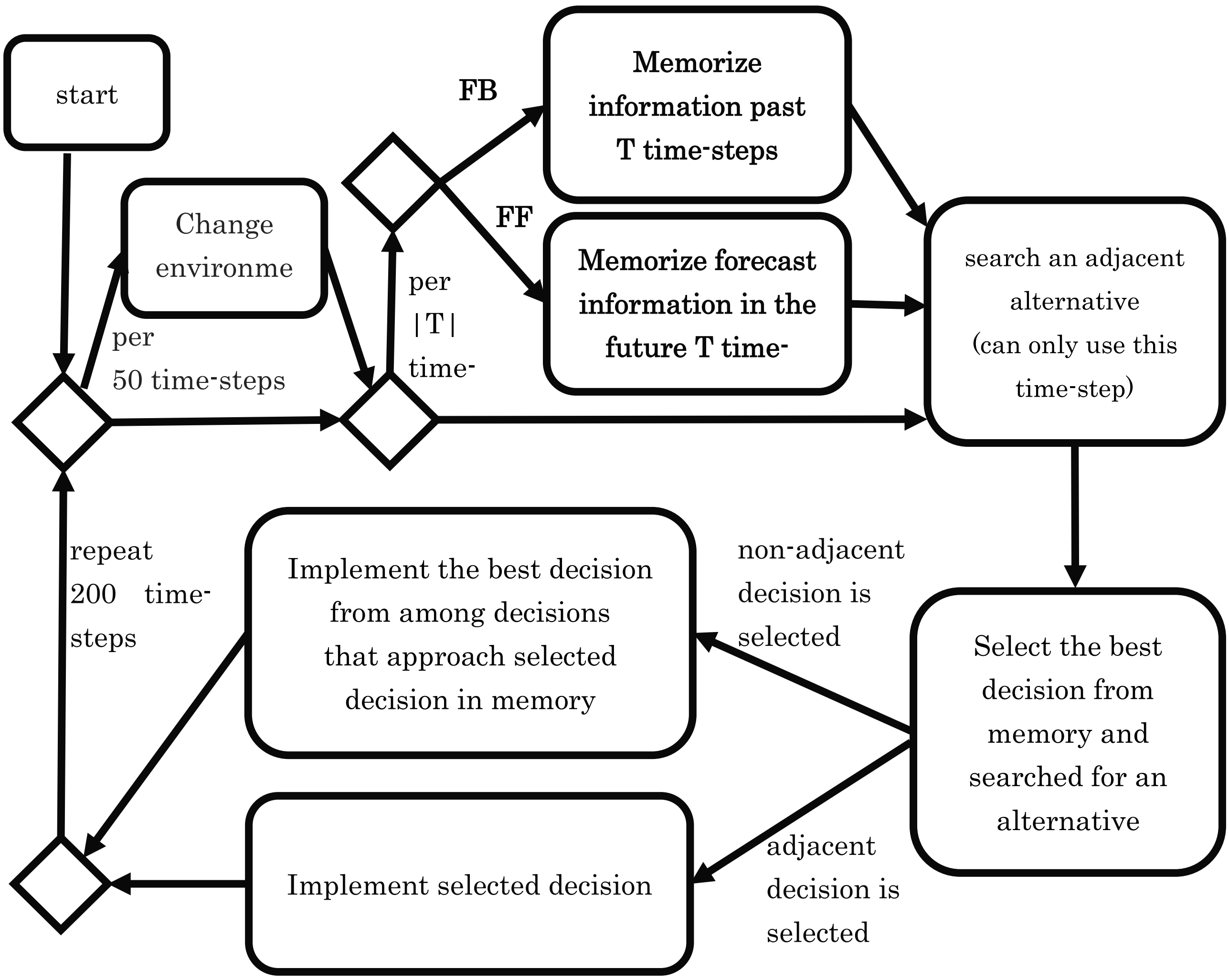

Figure 1: Flow Chart of Simulation Model

Using feedback control allows an agent to memorize the relationships between decisions and performance that actually occurred in the past T time-steps. Using feedforward control allows an agent to search and memorize forecasted relationships between decisions and performance that will occur in future T time-steps.

Next, regardless of the feedback or feedforward process, an agent searches for an alternative. This alternative is made by replacing one randomly-chosen decision variable in the decision implemented in the last time-step. The agent uses this alternative only in this time-step. After this search process, the agent selects the best decision from among the decisions in the memory and searches for an alternative. If the selected decision is accessible at the current time-step, the agent implements this decision. If the selected decision is not accessible at the current time-step, the agent implements the best decision from among decisions that approach the selected decision in memory.

The agent repeats this process 200 time-steps. I treated these 200 repetitions as one trial and analyzed them using this model.

(5) Simulation results and discussion

1. Method and variable settings

This section presents and discusses the results of the simulation.

The control structures were the main parameters in this analysis. The control structures had four patterns. "NO" is in the state of $T = 0$, meaning that no control exists. "FB" is the state of $T = -3$, meaning that feedback control only exists. "FF" is the state of $T = 3$, or feedforward control only exists. "FB&FF" is the state in which both feedback control ($T = -3$) and feedforward control ($T = 3$) are used simultaneously[3].

The other important parameters were N that is the number of decision variables, K that is the number of dependencies per decision variable, and variability. In this analysis, N is fixed at 10, while K varies between 0, 5, and 9. Variability varies from 0 (no change) to 0.2, 0.5, and 1.0. Therefore, the combinations of the parameters become 48 patterns. this research conducted 1,000 trials per combination of parameters, changing random number seeds, and used average values to analyze the simulation results.

In the basic NK model, performance $V(d)$ is the average value of the contribution that can take any value from 0 to 1 at random. Therefore, the maximum value of $V(d)$ differed among the different trials. This makes comparison among trials difficult, and therefore, I use relative performance—the value dividing $V(d)$ by the maximum of $V(d)$—in each trial.

I used Repast Simphony 2.6 software, a tool for agent-based modeling, to conduct the simulation.

2. Independent influence of feedback control and feedforward control on performance

This subsection discusses the influence of the use of only feedback or only feedforward control on organizational performance. To accomplish this, I used the average of the relative performances from 1 to 200 time-steps (Table 1).

Figure 2 shows the difference between the relative performances of FB and NO (FB in Figure 2) and the difference between that of FF and that of NO (FF in Figure 2). The relative performances were clearly different for low variabilities (0 or 0.2) and for high variabilities (0.5 or 1.0).

For low variabilities, the performance of FB showed few differences from that of a case at K = 0. As K increased, FF had a greater advantage than FB. Additionally, at K = 9, the difference was greater than at K = 5. This indicated that a larger K value caused a greater advantage of FF at low variabilities.

The reasons for these results are clear. Using feedforward control allows an agent to search for decisions that are unreachable directly but that could lead to high performance in the future. This prevents the

[3] I use three as the absolute value of T because other values (1–5) do not change the relationship that this study aims to analyze; thus, I adopt a median value between 1 and 5.

agent from adopting a decision that is easily available but can only reach low peaks; therefore, the agent can adopt a decision that enables performance to reach a high peak. This tendency is more obvious at a higher K value, because the fitness landscape has more low peaks at higher K. This is consistent with the function of feedforward control referred to by Grafton et al. (2010), which advances the exploration of new actions.

Variability	K	FB	FF	FB& FF	NO
0	0	0.985	0.987	0.991	0.750
0	5	0.881	0.919	0.922	0.643
0	9	0.835	0.895	0.900	0.639
0.2	0	0.978	0.976	0.977	0.798
0.2	5	0.900	0.910	0.927	0.701
0.2	9	0.865	0.891	0.901	0.696
0.5	0	0.950	0.923	0.939	0.810
0.5	5	0.884	0.838	0.896	0.713
0.5	9	0.858	0.826	0.878	0.708
1.0	0	0.893	0.822	0.861	0.751
1.0	5	0.829	0.730	0.842	0.643
1.0	9	0.811	0.729	0.835	0.638
Average		0.889	0.871	0.906	0.707

Table 1: Average performance 1 – 200 time-steps (confidential intervals are from ±0.001 to ±0.010)

For high variabilities, the relative performance of FB was higher than that of FF, contrary to low variabilities. When not using feedback control, recognizing the change in performance caused by environmental changes is difficult. Using feedback control enables the recognition of such changes by acquiring information about actual performance after environmental changes. In other words, using feedback control enables quick learning from mistakes and therefore quick recoveries after environmental changes.

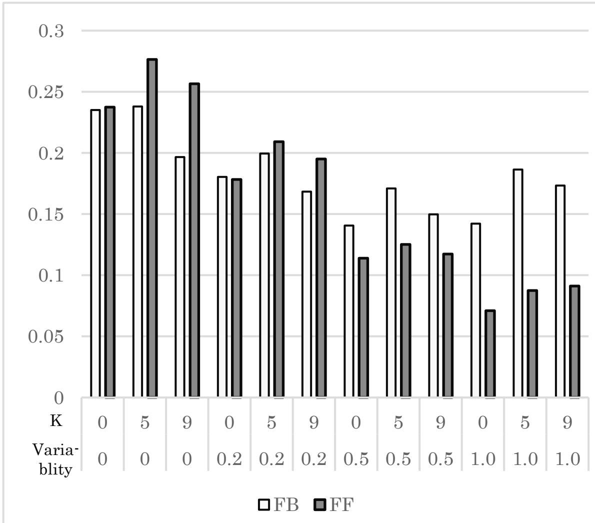

Figure 2: Relative performance of FB and FF

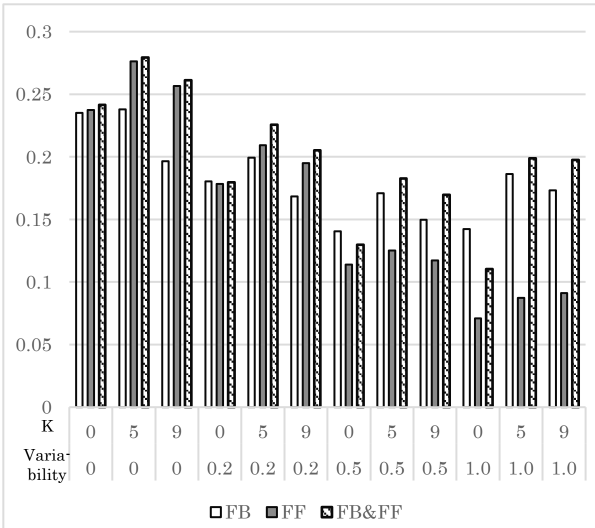

Figure 3: Relative performance of FB&FF

3. The influence of simultaneous use of feedback and feedforward control on performance

This subsection discusses the influence of the simultaneous use of feedback and feedforward control on organizational performance. Existing studies show that such simultaneous use is more effective than other patterns. This study obtains different results in some variable patterns.

I add the difference between the relative performances of FB&FF and that of NO to Figure 2 (shown in Figure 3).

For low variabilities, the relative performances of FB&FF were on the same level as the relative performances of FF.

For high variabilities and K = 0, the relative performance of FB&FF was lower than that of FB. Forecast information by feedforward control becomes incorrect information after changing the environment; therefore, feedforward control prevents an agent from making sound decisions at high variabilities and low interdependence among decision variables.

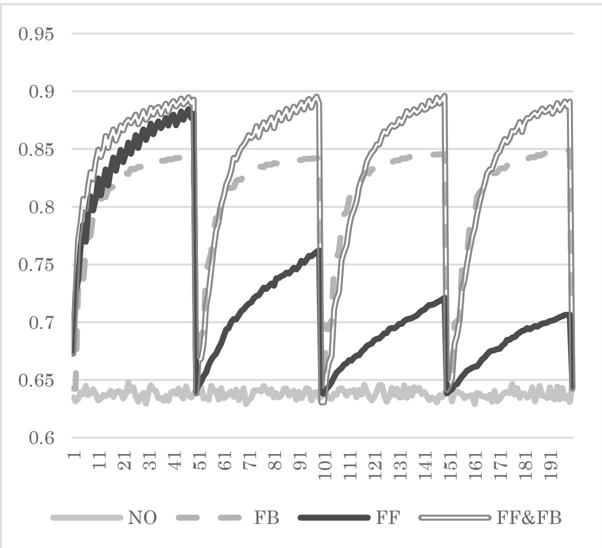

Figure 4: Transition of performances for K = 9 and variability is 1.0

For high variabilities and high K, however, the relative performance of FB&FF was higher than that of FB. To analyze these results, I show the transition of relative performance from 1 to 200 time-steps (Figure 4). Although Using only feedback control enabled quick improvement of decisions, once the local peak was reached, improvement was paused until the next environmental change. Thus, in the case of FB, the relative performance was not very high. Feedforward control compensates for this shortcoming of feedback control. Feedforward control enables the agent to leave the local peak that was reached at once and search for distant but better decisions; therefore, the simultaneous use of feedback control and feedforward control enables the continuous improvement of decisions.

(6) Conclusions

This study examines the effects of feedback control, feedforward control, and the simultaneous use of these controls on organizational performance using a computer simulation.

This study makes two contributions to the literature. First, I have shown that the influence of feedback and feedforward control on performance varies according to the degree of interdependence among decision factors or the variability of the environment. Second, this study demonstrates that the simultaneous use of feedback control and feedforward control is effective at high environmental variability and high interdependence among decision factors, and suggests the reason for these results.

In this study, I was unable to address the accuracy of feedback and feedforward control to model. Although this factor influences organizational performance, it was not used in this study to keep the complexity of the model as low as possible and to simplify the analysis (Labro, 2015).

Our future work will address the accuracy of the control and examine the influence of accuracy.

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