Factors of Dynamic Shifts in Product and Process Architectures in Large Refrigerated Trucks

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Abstract **– In achieving sustainable growth, achieving originality, differentiation, and competitive advantage for its products is necessary for a company. Therefore, dynamic shifts in product and process architectures within the company are required in response to changes in the external environment. This study attempts a three-step analysis method to quantitatively measure the integrality of product and process architectures and evaluate the source of competitive advantage. Consequently, it was found that the factors of dynamic shifts in product and process architectures were technological changes and organizational capability changes, and the status of architecture changes could be evaluated.**

Keywords **– competitive advantage, organizational capability, product architecture, process architecture.**

1. Introduction

Companies are required to create innovations to achieve sustainable growth. While promoting business expansion in existing business fields, a major question entails how to orient the growth strategy toward new markets and products, as it is indicated by Ansoff's growth matrix [1]. In considering these growth strategies, understanding the company's status, that is, the external and internal environments, is essential. There are two perspectives: the market/customer axis and the product/technology axis. Correctly forecasting technology trends to understand the status of the external environment concerning the product/ technology axis, which is important. One of the methods is patent information analysis [2], [3]. For example, to visualize the technology S-curve prospectively, classifying patent information into product and process inventions in advance [4] has been proposed. Moreover, identifying the company's core technologies to understand the status of the internal environment is necessary, and a method that modifies the quality function deployment (QFD) method has been reported [5]. Moreover, recognizing the architecture of the company's products is useful.

Architecture refers to the basic concept when designing an artificial system. In the case of a product system, product architecture refers to the basic design concept of the product, such as how to relate the product functions with the product structures and how to design the interface between structures. Similarly, when applied to a process system that produces a product, the basic concept regarding the correspondence between the product structures, production processes, and interface design between the processes is referred to as process architecture [6], [7]. It is stated that product architecture is particularly related to a company's research and development (R&D) function, and the architecture is determined in the early stage of the innovation creation process where R&D plays an advanced role [6]. It is also pointed out that product architecture plays a decisive role in developing and promoting a new product as a business that integrates product strategy, technology, operations, and supply chain [8].

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Furthermore, as one of the innovation categories, it has been proposed that an architectural innovation reconfigures the existing system by connecting the existing components in a new way [9]. This implies that innovation should be viewed from an architectural perspective. It is suggested that architecture is not necessarily given to a company, but there is a room for the company itself to define it strategically [10]. As pointed out by these previous studies, architecture has to be an indispensable perspective when considering the direction of R&D and product strategies to continuously generate innovation.

Moreover, product architecture is a framework that discusses the mutual relationship between an organization and product design/technology. In other words, it has been pointed out that the product architecture perspective provides new insights when the relationship between the organization and product design/technology is the subject of analysis [11]. As products and technologies are not static, it is known that product architecture evolves from an integral to modular type and cycles back after that [12].

Several studies have analyzed the relationship between architecture and technology and between architecture and organizational capability as process product case study; the organizational capabilities of Asahi Breweries, Ltd. were analyzed on beer products with integral process architecture according to the multi-layered structure of competitiveness in previous study. Consequently, cyclical cause-and-effect relationships between the layers were observed, and it was found that this was the source of competitiveness [13]. As a case study discussing the cyclic change in product architecture with technological change, the change in product architecture of FANUC's NC system, an assembly product, was qualitatively analyzed. The architecture changed from the integral type in the early stage of the product to modular type. After that, with the introduction of the epoch-making technology, the microprocessor, the architecture returned to integral type again [14]. Thus, it can be said that there are technological changes and organizational capability changes that cause dynamic shifts in product and process architectures because the dynamic shift factor of product architecture entails the introduction of technology from outside. There are organizational capabilities that support process architecture.

However, there are merely a few case studies that have quantitatively analyzed dynamic shifts in product and process architectures. Therefore, a case study that comprehensively analyzes product and process architectures, technology, and organizational capability will be attempted.

2. Objectives

The quantitative dynamic shifts in product and process architectures are focused on in this section. Furthermore, the relationship between changes in the internal environment, such as technology and organizational capability, and profitability, that is, the competitiveness to generate sustainable growth, will be clarified. Finally, the specific changes in technology and organizational capability will be clarified, and the status of dynamic shifts in the architecture will be evaluated.

A new analysis method is proposed in this study, and a case study is attempted to clarify those as mentioned earlier. In Section 3, the framework of the analysis method and the specific analysis method is explained, and Section 4 presents the results of the proposed method analysis. In Section 5, the sources of competitiveness that generate sustainable growth are discussed based on the results of the analysis. Finally, a summary and a future research topic are presented in Section 6.

3. Methods

Figure 1 shows the three-step analysis method: the first step is the selection of target companies and products and the extraction of change points in the company's growth; the second step is the quantitative analysis of the dynamic shifts in product and process architectures before and after the change points; and the third step is the analysis of the technological changes and organizational capability changes in the time domain before and after the change points.

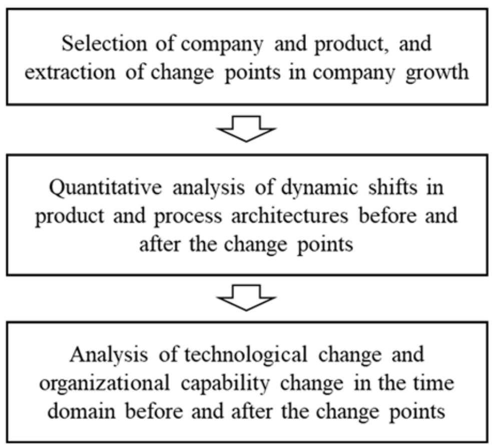


Figure 1. There-step analysis method

The methods shown in each step of Figure 1 are explained in detail. First, in subsection 3.1, it is explained what kind of company and product to select and what type of change point to focus on. Next, in subsection 3.2, integrality is defined as a quantitative indicator of the product and process architectures before and after the change points, and the analysis method of integrality is explained. Furthermore, in subsection 3.3, the analysis method of core technologies is explained. Based on the technology transition information of the target product, the presence or absence of key technologies that play a significant role in providing value to customers, so-called core technologies, is focused on. Finally, in subsection 3.4, the perspective of competitiveness analysis is explained. In analysing organizational capabilities, the analysis will be conducted from the perspective of competitiveness based on examples of activities of companies and organizations.

3.1. Selection of Company and Product, and Extraction of Change Points

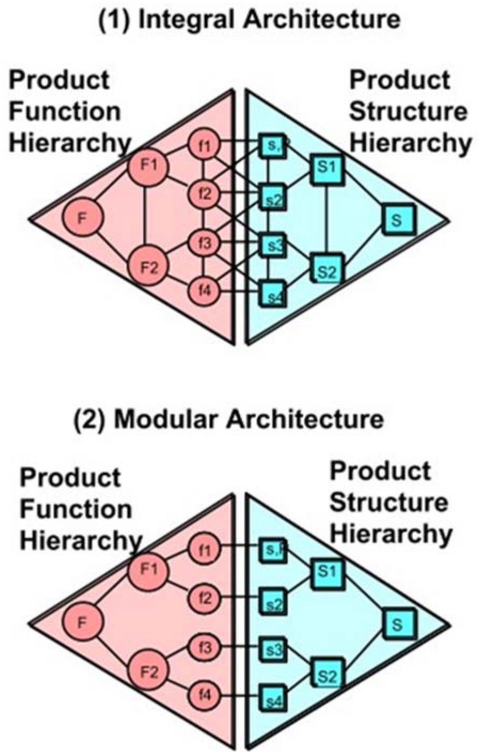
There is a social demand for companies to achieve sustainable growth. From this perspective, the target companies have developed their business with a competitive advantage and have continued to grow for a certain period. Therefore, as the target products, the main products that significantly impact the company's performance are selected. Even if a company is growing continuously in the big picture, it is assumed that its growth is changing locally, either increasing or decreasing; thus, the change points are focused on. To extract the change points, having information on the change in performance at the product level rather than at the company level is necessary. Therefore, obtaining information on the performance trends of the target products is important; however, this information is often not disclosed to the general public.

The change points in the company′s growth are either such whereby the company's performance has once declined but has rapidly recovered or where the company's performance has significantly increased.

Based on the aforementioned, target companies are selected and information on the performance trends of their main products is obtained. After that, the local points of change are extracted from the information while the company is growing in the big picture.

3.2. Quantitative Analysis of Product and Process Architectures

The product and process architectures are quantitatively analyzed before and after the change points extracted in subsection 3.1. Figure 2 shows the hierarchical representation of integral and modular product architectures [7]. In terms of product architecture, the case where functional elements (f1–f4) and structural elements (s1–s4) are in many-to-many correspondence is referred to as integral architecture. They are in a one-to-one correspondence that is termed modular architecture. Similarly, process architecture is defined by whether the structural and process elements that produce the product are either in a many-to-many or one-to-one correspondence. This classification of architectures into two categories is conceptually easy to understand but too unrobust for detailed discussion. If the degree of change is to be expressed concretely, expressing how much the architecture is integral or modular by a single point on a one-dimensional axis defined by a single index. Herein, integrality is adopted as this index.



F=product Function as a whole, S=Product Structure as a whole, F1-F2=Sub-functions of the Product, f1-f4=Sub-sub-functions of the Product, S1-S2=Large Modules, s1-s4=Small Modules.

Figure 2. Integral and modular architecture [7]

Three kinds of ideas have been proposed to measure integrality [7,15]. The first method is to measure it by the number of correspondences between functional and structural elements and between structural and process elements, according to the definition of architecture, and the second method is to measure it by the degree of commonality of interface design between structures and processes according to the definition. The first and second methods are time-consuming because the target company needs to collect detailed technical information to measure the correspondence and interface design accurately. Conversely, the third method is a subjective approach, also called the simplified method. Several events that are likely to be observed when the architecture is integral presented, and whether they are observed or not is measured based on subjective judgment. As it can be conducted in a questionnaire, numerous data can be collected due to its simplicity [15].

However, because it is a subjective approach, the reliability of the third method may be lower than that of the first and second methods based on the detailed technical information collection results.

To explain in more detail, compared to the first method, the second method is more complicated because it involves many procedures and judgment criteria, and the measurement results may vary depending on the judgment criteria. Therefore, this study adopts the first method, which is more reliable and less affected by the judgment criteria.

A matrix representation of the architecture is used to quantify the number of correspondences. Figure 3 shows a matrix representation of the correspondence between functional and structural elements of product architecture. For example, in the case of a matrix with four rows and four columns, the structural elements (s1–s4) are listed in the rows and the functional elements (f1–f4) in the columns. If there is a correspondence between the rows and columns, a circle is entered in the cell. The number of circles is divided by the number of cells to define the integrality. For example, in case (1) in Figure 2, the integrality is 10/16, and in case (2), the integrality is 4/16.

The integrality of (1) = 10/16

		Product Function			
		f1	f2	f3	f4
Product Structure	s1	○	○		
	s2	○	○	○	
	s3		○	○	○
	s4			○	○

The integrality of (2) = 4/16

		Product Function			
		f1	f2	f3	f4
Product Structure	s1	○			
	s2		○		
	s3			○	
	s4				○

Figure 3. Matrix representation of product architecture

In discussing the architecture, the granularity issue of which layer of the hierarchy to choose exists [7], which needs to be considered.

From those as mentioned above, the integrality of the product architecture is measured by the number of correspondences between functional and structural elements before and after the change points extracted in the previous subsection. Likewise, the integrality of the process architecture is measured by the number of correspondences between structural and process elements. While considering the granularity issue, functional, structural, and process elements are defined, and detailed technical information is collected from the target company to determine the correspondence among them. Thus, the change in the integrality of the architecture can be measured quantitatively.

3.3. Survey of Technological Transition and Analysis of Core Technologies

Before and after the change point extracted in subsection 3.1, the transition of the technologies installed in the target product is investigated in the time domain. What are the major technologies that play a significant role in providing value? The so-called core technologies are analyzed, and the transition of these technologies is focused on.

A method to identify core technologies has been proposed in a previous study [5], and this method will be adopted in this study. In the previous study, the core technologies were derived from the quantitative analysis by collecting detailed information from the target companies based on the quality function deployment (QFD) method. The QFD method is employed to determine customer requirements and derives the technological requirements to create a product that achieves customer satisfaction. The technological requirements are then deployed to functions, mechanisms, and parts. As the analysis requires a wide range of information from ″Voice of Customer‶ to technology in detail, several staff members are interviewed in the previous study.

In the time domain extracted in subsection 3.1, extensive information is collected from the target company to obtain the transition of major technologies related to the target product and the customer and technological requirements needed for the QFD method. Then, the core technologies can be derived based on the quantitative analysis.

3.4. Survey of Activities of Companies and Organizations and Analysis of Competitiveness

In the time domain described above, actual activities of companies and organizations are investigated. In collecting information from the target companies, particular attention is paid to the cases related to competitiveness to find out why the companies continue to grow sustainably, that is, why they continue to have a competitive advantage over other companies. The multi-layered structure of competitiveness proposed in the previous work [16] can be used as a guide to collect information for this purpose.

Figure 4 shows the multi-layered structure of competitiveness constructed concerning the previous work, which argues that understanding the competitiveness of manufacturing companies in terms of four layers, organizational capability, deep performance, surface performance, and profitability, is important. This multi-layered structure of competitiveness is organizational capability, which means the ability to realize efficient operations stably, especially in manufacturing, for example, standardisation of work, just-in-time, total quality control, and other activities. Deep performance within a company is not visible to customers, that is, the competitiveness behind the scenes. These indicators include productivity, lead time, quality, etc., and are directly influenced by organizational capabilities. Surface performance is based on customers' evaluation in the market, that is, the competitiveness on the surface. Specifically, its indicators are price, market share, brand, service, etc., which appear as results of deep performance. The top layer is profitability, including operating profit margin and cash flow ratio, etc. Accumulating the results of each of these layers in a balanced manner is important.

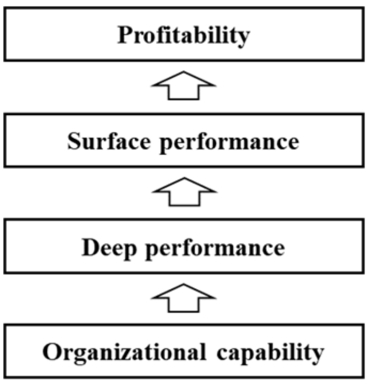


Figure 4. Multi-layered structure of competitiveness

Therefore, detailed information will be collected from the target companies to obtain actual activities related to competitiveness conducted by the companies and organizations in the time domain extracted in subsection 3.1. In particular, the specific activities of companies and organizations that are not visible to the market and customers but are related to manufacturing organizational capabilities and deep performance will be focused on. Thus, the organizational capabilities that are the source of competitiveness will be analyzed.

4. Results

The analysis results according to the method proposed in Section 5 are presented in the following subsections.

4.1. Large Refrigerated Trucks

In subsection 3.1, it is shown that a target product is selected in the target company, and local change points in the company's growth can be analyzed from the performance trend information of the product. It is assumed that the target company is developing its business with a competitive advantage and is growing continuously. To extract the change points, disclosing the performance trend information of the target products is necessary. Therefore, while many companies do not disclose performance information at the product level, cooperative companies in disclosing information are preferred.

One of the companies with a competitive advantage and sustained growth is Japanese small- and medium-sized enterprise (SME) Y. SMEs are one of the important elements of national economic development [17]. Figure 5 shows the sales trend of Company Y. Company Y has been growing continuously for more than 40 years. However, in the 1990s, Company Y was hit by Japan’s economic recession, and its sales dropped temporarily in 1998, but quickly recovered. The main products of Company Y are large refrigerated trucks, which have the top market share in Japan, and are assembly products.

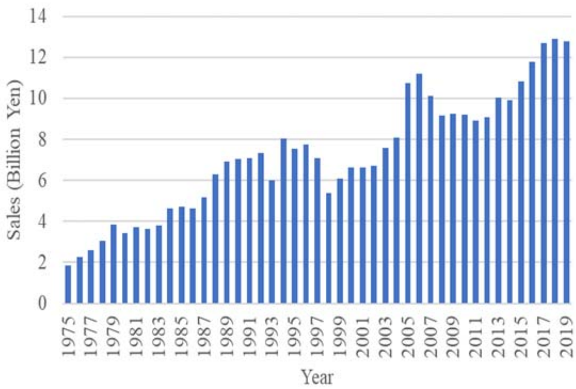


Figure 5. Sales trend of the Company Y

Figure 6 shows the sales trend of large refrigerated trucks of Company Y. From this figure, it can be seen that the point at which the company's performance declined and then quickly recovered, that is, the local change point in large refrigerated trucks business, was 1999.

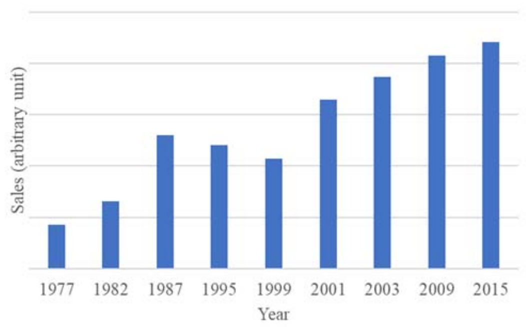


Figure 6. Sales trend of the Large Refrigerated Trucks

4.2. Dynamic Shifts in the Architectures

In subsection 3.2, it is indicated that dynamic shifts in the architectures can be analyzed by properly quantifying the integrality of the architecture before and after the change points. An assembled product is assumed to analyze the product architecture and process architecture based on the correspondence among functional, structural, and process elements. In particular, when analyzing the correspondence between structural and process elements, conducting a factory inspection and an interview survey is preferable.

The second layer in the hierarchical representation is selected as the granularity to analyze the architectures quantitatively. This layer is closest to the product and process systems of the first layer, so it can be considered to represent the architecture of the product and process system from a broad perspective. Using Figure 2 as an example, the first layer is F and S, and the second layer is F1, F2, S1, and S2. Next, the number of items in the functional, structural, and process elements should be as close as possible in determining the correspondence. If the architecture is completely modular, the one-to-one correspondence is established. These two points seem to be important for proper quantification.

Moreover, this analysis is a limited comparison because it analyzes the time change before and after the change points for the same product of the same company. Therefore, clarifying the fixed and variable elements of the time change is easy. If attention is paid to this viewpoint, it will be possible to quantify it more properly.

Based on the above, the architecture before and after 1999, which was the change point in Company Y's large refrigerated trucks business, was analyzed. The product architecture is shown in Figure 7(1) and (2), and the process architecture is shown in Figure 8(1) and (2). The integrality of the product architecture increased from 31/63=49% to 39/63=62% before and after the change point. In other words, before the change point, the product architecture was in the middle of the integral type and the modular type, but it shifted to the integral type after the change point. The integrality of the process architecture increased slightly from 56/90=62% to 52/80=65% before and after the change. This means that the process architecture was already integral type before the change point, and it was also integral after the change point. It is essential to note that even though the product architecture changed to the integral type, the process architecture also maintained it. As shown in Figure 8, the number of processes was reduced by one.

4.3. Technological Changes and Core Technologies

In subsection 3.3, it is showed that the status of technological change in the product can be investigated in the time domain before and after the change point, and the core technologies can be analyzed quantitatively.

A refrigerated truck mainly consists of a chassis cab, a refrigerator unit, and a container. Several insulated panels surround the container, and the insulated panels greatly affect the cooling capacity, which is one of the important characteristics of refrigerated trucks.

In the past, corrugated panels were commonly used as insulated panels. First, company Y started to develop a new type of insulated panels to reduce the cost. Then, in the late 1990s, Company Y succeeded in creating large sandwich panels for large refrigerated trucks, which were low in cost and had the excellent cooling capacity and loading capacity. After the change point, a technological change in insulated panels occurred, and sandwich panels became the mainstream of the company′s insulated panels.

The core technology of the large refrigerated trucks of Company Y was analyzed following the previous study [5]. Consequently, it was found that the function most appreciated by customers was ″maintaining the temperature inside the container", and that the elemental mechanism and parts that were highly relevant to this function were the thermal insulation mechanism, the thermal insulation material, the inner panel, the adhesive material that bonded the thermal insulation material to the inner panel, and the thermal insulation packing (gasket). Therefore, it was concluded that the core technology of Company Y was sandwich panel technology.

4.4. Organizational Capability Changes

In subsection 3.4, it is indicated that in the time domain described above, the factors of competitiveness, such as manufacturing

		Function						
		Load capacity	Cooling capacity	Rigidity & Durability	Operability & Safety	Cleanliness & Corrosion resistance	Optionally available	Appearance
Structure	Chassis cab	○		○			○	
	Refrigeration unit	○	○	○			○	
	Evaporator housing		○					○
	Container			○				
	Side panel			○				
	Floor	○	○	○	○	○	○	
	Door			○	○		○	○
	Interior parts		○	○	○	○	○	○
	Exterior parts			○	○		○	○

Figure 7(1). Product architecture before the change point

		Function						
		Load capacity	Cooling capacity	Rigidity & Durability	Operability & Safety	Cleanliness & Corrosion resistance	Optionally available	Appearance
Structure	Chassis cab	○		○			○	
	Refrigeration unit	○	○	○			○	
	Evaporator housing		○					○
	Container	○	○			○		
	Side panel	○	○			○	○	○
	Floor	○	○	○	○	○	○	
	Door	○	○		○	○	○	○
	Interior parts		○	○	○	○	○	○
	Exterior parts			○	○		○	○

Figure 7(2). Product architecture after the change point

		Structure									
		Chassis cab	Refrigeration unit	Evaporator housing	Container	Side panel	Floor	Door	Interior parts	Exterior parts(1)	Exterior parts(2)
Process	Container assembly			○	○	○					
	Chassis cab installation	○		○	○	○					
	Polyurethane foaming	○		○	○	○					
	Floor installation	○		○	○	○	○				
	Door installation	○		○	○	○	○	○			
	Interior parts installation	○		○	○	○	○	○	○		
	Exterior parts installation(1)	○		○	○	○	○	○	○	○	
	Refrigerator installation	○	○	○	○	○	○	○	○	○	
	Exterior parts installation(2)	○	○	○	○	○	○	○	○	○	○

Figure 8(1). Process architecture before the change point

		Structure									
		Chassis cab	Refrigeration unit	Evaporator housing	Container	Side panel	Floor	Door	Interior parts	Exterior parts(1)	Exterior parts(2)
Process	Container assembly			○	○	○					
	Floor installation			○	○	○	○				
	Door installation			○	○	○	○	○			
	Interior parts installation			○	○	○	○	○	○		
	Exterior parts installation(1)			○	○	○	○	○	○	○	
	Chassis cab installation	○		○	○	○	○	○	○	○	
	Exterior parts installation(2)	○		○	○	○	○	○	○	○	○
	Refrigerator unit installation	○	○	○	○	○	○	○	○	○	○

Figure 8(2). Process architecture after the change point organizational capabilities and deep performance are qualitatively analyzed from examples of activities of companies and organizations. These activities are sometimes disclosed as the results of surface performance in company histories and websites. Still, the specific activities inside the companies and organizations, such as manufacturing organizational capabilities and deep performance, are rarely disclosed outside the companies. Therefore, to clarify the organizational capabilities that are the source of competitiveness, the specific activities and the ideas and policies of the top management behind them were investigated.

The following are three specific activities related to manufacturing organizational capabilities that companies and organizations carried out before and after the change.

The first was a production process improvement project undertaken in the late 1990s. Based on the improvement methods learned from consultants, the company added its originality to fit its production lines better. The second project was the change in employee′s thinking led by the top management in the late 1990s. The project was designed to instil the top management's belief that approaching their work with a sense of management is important for each employee. At the same time, the company introduced a divisional system as an organizational reform to visualize business profits and raise cost consciousness. Thirdly, the company implemented the quality improvement project in the early 2000s, acquiring ISO certification and providing continuous quality education to all employees.

As an outcome of these changes in organizational capabilities, the following deep performance emerged. One was the reduction of lead time by improving the production process, which was reduced by about half before and after the change point. The other was the increase in productivity due to improved production process and quality, which reduced the occurrence of defective products and the wastage of rework. The root of these outcomes was the cost consciousness of each employee.

5. Discussion

The results of the previous section, which analyzed the changes in the internal environment of the large refrigerated trucks business of Company Y before and after the change point in 1999, show that the multiple factors of creating core technologies, improving productivity in manufacturing, and raising cost- and quality-oriented consciousness were synergistic at the change point. In other words, there was a shift toward providing customers with products differentiated by core technologies at the lowest possible price while maintaining high quality. Consequently, customer satisfaction was achieved, and high competitiveness was acquired.

The core technologies, manufacturing organizational capabilities and management awareness of each employee result from basic behaviors that are faithful to the founding spirit of Company Y, which is to realize products that customers want with high quality. Thus, it can be said that the source of competitiveness of Company Y lies in its basic behaviors based on the founding spirit.

6. Conclusion

In this study, the new analysis method to quantitatively measure the integrality of product and process architectures and to analyze the factors of dynamic shifts in architectures, such as technological changes including core technology and organizational capability changes, was proposed. Its effectiveness was demonstrated through the case study. The analysis results showed that the product architecture of the large refrigerated trucks of Company Y shifted to the integral type due to the development of the insulated panel technology, which was the company′s core technology. However, supported by the manufacturing organizational capability for production process and quality improvement, the process architecture maintained the integral type despite the change in product architecture. This means that technological and organizational capability changes caused the dynamic shifts in the architectures, that is, internal environmental changes.

In the niche assembly industry of large refrigerated trucks, the company adopted the integral product and process architectures and achieved customer satisfaction through differentiated products. As a result, it was found that the competitive advantage was created, and the company's performance turned upward at that time.

The following point needs to be discussed in more detail in this study. The results are obtained from the case study of a niche-top company in the large refrigerated trucks industry in Japan, assuming an assembly industry. Case studies should be carried out for sustainable growth companies with change points in other industries to refine this method.

Acknowledgements

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