Requirements to Realize of Technology Integration in the Automotive Parts Business

――Comparative Analysis of Enterprise Behavior at the Time of the Introduction of Electronics――

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【Abstract】The purpose of this paper is to show that technology integration, which is the act of integrating multiple technologies, is effective in enabling enterprises to continue to exist by overcoming technology conversion. This paper also intends to clarify the conditions for realizing technology integration. In accordance with this purpose, a comparative analysis is made of the technology integration processes regarding the electronically controlled gasoline injection device business ("electronically controlled gasoline injection device," hereinafter referred to as "EFI device" [electronic fuel injection device]) of the following two enterprises: DENSO Co., Ltd. (hereinafter referred to as "DENSO"), which continues to exist after having successfully adapted to the computerization of automobiles—a type of technology conversion; and Japan Electronics Co. Ltd. (hereinafter referred to as "Japan Electronics"), which failed to adapt to this aforementioned technology conversion. This paper's argument obtained from this case analysis is as follows. In previous studies, when any existing enterprise encountered a technology conversion, the resulting threat was overcome by having the advantage of possessing complementary assets. However, the means whereby any existing enterprise overcomes a technology conversion is not necessarily limited to complementary assets. Furthermore, even if the enterprise has an advantage from owning complementary assets, it must also acquire the new technology. Acquiring this technology is certain to become an issue. Previous studies argued that startup enterprises displaced existing enterprises. As distinct from these studies, this paper emphasizes the point that existing enterprises improve their technological capabilities and maintain competitiveness, not through complementary assets but through the force of technology integration. A comparison of the technology integration process of Japan Electronics, which failed to realize technology integration, and the technology integration process of DENSO, which realized technology integration, clarified that the centralized management of technical knowledge is a required condition for technology integration.

1. Introduction

The purpose of this paper is to show that technology integration, which is the act of integrating multiple technologies, is effective in enabling enterprises to continue to exist by overcoming technology conversion. This paper also intends to clarify the conditions for realizing technology integration. In accordance with this purpose, a comparative analysis is made of the technology integration processes regarding the electronically controlled gasoline injection device business ("electronically controlled gasoline injection device," hereinafter referred to as "EFI device" [electronic fuel injection device]) of the following two enterprises: DENSO Co., Ltd. (hereinafter referred to as "DENSO"), which continues to exist after having successfully adapted to the computerization of automobiles—a type of technology conversion; and Japan Electronics Co. Ltd. (hereinafter referred to as "Japan Electronics"), which failed to adapt to this aforementioned technology conversion. Based on the case analysis, this paper's argument is as follows. In previous studies, when any existing enterprise encountered a technology conversion, the resulting threat was overcome by having the advantage of possessing complementary assets. However, the means whereby any existing enterprise overcomes a technology conversion is not necessarily limited to complementary assets. Furthermore, even if the enterprise has an advantage from owning complementary assets, it must also acquire the new technology. Acquiring this technology is certain to become an issue. In this paper, the grounds for the argument for processes whereby existing enterprises continue to exist by achieving a technology transfer are based on technology integration, which entails integrating existing technologies into new technologies to create new original technologies. Thus, the conditions for realizing the previously described situation are discussed.

To deploy the aforementioned basic arguments, this paper consists of five sections, including this section. In Section 2, a survey of previous studies on innovation processes is presented, and the positioning of this paper is clarified. In Section 3, a comparison is made of DENSO's technology integration process, which realized technology integration, and Japan Electronics' corresponding process, which failed to realize this integration. In Section 4, methods to manage technical knowledge are analyzed using a background causal factor for the realizability or otherwise of technology integration. Furthermore, the effectiveness of technology integration is substantiated. In Section 5, a summary of this paper is provided.

2. Previous studies and the positioning of this paper

2-1. Investigation into previous studies on innovation processes

Abernathy (Abernathy & Utterback, 1978) traced the history of the automotive industry in the United States, thereby clarifying that industries undergo changes by going through the following three phases: the fluid phase, the transition phase, and the fixed phase. The fluid phase is a period during which it is not at all definite what products are like, no clear target customers are ascertained, and—therefore—various technologies are made to compete with one another in a bid to find the optimal customers for individual technologies. An influential technology suddenly becomes conspicuous among these technologies, leading to the appearance of a dominant design and the start of the transition phase. Subsequently, the technology required for the product is established and the product functions are clarified, resulting in the start of the fixed phase (Anderson & Tushman, 1990; Utterback, 1994). However, given the appearance of a new technology, an opportunity for post-maturity occurs. Subsequently, the old technology is converted to a new technology, and existing enterprises that employed the old technology are forced to make changes. Existing enterprises are able to deal with capability-expanding technology conversion but also find it difficult to address capability-destroying technology conversion. Consequently, a significant possibility exists that they lose their positions and fall into a decline (Tushman & Anderson, 1986). Abernathy (Abernathy & Clark, 1995) considered not only the evaluation axis of whether technologies are destructive or expansive but also the evaluation axis of whether prices in existing markets are destructive or preservative. According to Abernathy and Clark, existing enterprises are placed in a particularly disadvantageous position if the type of technology conversion is market destroying. Regarding the aspect of value in the market, the following is pointed out with respect to new technologies that could display high functions if evaluated on the basis of new evaluation axes: enterprises are swayed to such a degree by customers' evaluations that, in the early development stages, these technologies are judged to be inferior by evaluation axes based on old technologies, leading to decelerated development and the possibility that existing enterprises will decline (Christensen, 1997). Furthermore, even in cases in which no technology conversion occurs, or in which no conventional technology components undergo changes, instances are reported of existing enterprises declining because of changes in architecture types, which are ways to combine these components (Henderson & Clark, 1990). Thus, in conventional innovation process studies, only one dominant technology is considered to exist and processes in which old technologies are displaced by new technologies because of technology conversion are repeated, resulting in the fulfillment of technological progress (Dosi, 1986).

Given technology conversion, the life cycles of the products of existing enterprises come to an end and new products of startup enterprises come to the front and replace the first aforementioned products. As a result, existing enterprises decline. This connection clarifies why existing enterprises encountering a technology conversion follow a path of decline; however, certain enterprises dominate markets by overcoming the threat of a major technology conversion. The presence of complementary assets is a causal factor that previous studies noted and that was proven to be a condition that enabled existing enterprises to overcome a technology conversion (Rosenbloom, 2000; Rothermel, 2001; Tripsas, 2001). Complementary assets are the various assets required to commercialize new technologies and to supply them to markets, thereby securing competitiveness. Teece provided the following explanation regarding complementary assets. To commercialize technological innovations, the know-how for problems should, without exception, be mandatorily utilized in such a way that it is combined with other capabilities or assets. Marketing, competitive manufacturing, and services including after-sales services and customer support are almost always necessary. Moreover, these services are typically obtained from specialized complementary assets (Teece, 1986). According to Teece, the following case is true. If a high possibility exists of monopolizing new technologies through patents, innovators who are precursory in terms of technology have an advantage. If the possibility of such monopolization is low, the possibility exists that technological followers who have an advantage in terms of complementary assets will drive away innovators. The possibility exists that existing enterprises fall behind in technical actions given low incentives for investment in new technologies. However, as long as existing enterprises have an advantage in terms of complementary assets, it is possible for these enterprises to maintain market superiority. Thus, in certain cases, existing enterprises overcome the threat of a major technology conversion that they encounter, with the result that they can dominate markets. In previous studies, argument grounds for these cases are found in complementary assets.

As previously described, in previous studies, the clarification was made that technology conversion enabled the displacement of old technologies by new technologies. Additionally, in conjunction with the previous statement, the unfolding of the following consequences was clarified: existing enterprises decline and startup enterprises come to the front. Furthermore, existing enterprises that overcome the threat of the technology conversion encountered are noted as having an advantage over startup enterprises, thereby continuing to exist by surmounting technology conversion.

2-2. Positioning of this paper

As clarified in previous studies, existing enterprises decline because of technology conversion and startup enterprises come to the front to replace the existing enterprises. The reason that existing enterprises encountering technology conversion follow a path of decline is clarified; however, certain enterprises dominate markets by overcoming the threat of the major technology conversion encountered. These enterprises overcome the threat of technology conversion by maintaining an advantage through complementary assets. However, the following question is asked: Are complementary assets really the only means for existing enterprises to overcome technology conversion? If the means for overcoming technology conversion are found only in complementary assets, the following question arises: What complementary assets should be owned to be able to overcome technology conversion in the event that it occurs? The answer to this question is unknown until the technology conversion occurs. That is, if existing enterprises are able to maintain an advantage, the reason is because they happen to own complementary assets that become valid after the technology conversion. Whether or not advantages can be gained is a matter of chance. In this situation, it is extremely difficult to take action to prepare for a technology conversion and to carry out management as a systematic corporate action. For this very reason, existing enterprises are displaced once technology conversion occurs under these circumstances.

However, in the real world, a very large number of cases occur in which existing enterprises are not displaced or in which the means of overcoming technology conversion cannot be explained only by complementary assets. Intercorporate business relations do not constitute all of the complementary assets. However, business relations are taken up as a causal factor of complementary assets. A relevant case is presented in specific terms. With regard to technology conversion that consists of the computerization of mechanical gasoline engines, DENSO overcame this conversion but Japan Electronics was unable to surmount it. When viewed only from the viewpoint of complementary assets, DENSO owned a complementary asset consisting of a business relationship with Toyota Motor Corporation, and Japan Electronics owned a complementary asset consisting of a business relationship with Nissan Motor Co., Ltd. On the basis of these facts, the means whereby existing enterprises overcome technology conversion are not necessarily limited to complementary assets. Furthermore, how new technologies themselves are either acquired in addition to complementary assets or are created is certain to constitute an issue. Therefore, the following actions should occur. A solution other than complementary assets will be derived for the question of why existing enterprises are able to overcome technology conversion. The conditions for the solution will be clarified and, as a result, practical implications will be suggested.

Previous studies argued that startup enterprises displaced existing enterprises. As distinct from these studies, this paper emphasizes the point that existing enterprises improve their technological capabilities and maintain their competitiveness not by means of complementary assets but by dint of technology integration.

The case taken up in this paper is the EFI device business of both DENSO and Japan Electronics. DENSO and Japan Electronics introduced quite the same technology from Robert Bosch GmbH (hereinafter referred to as "Bosch") in the same year. However, subsequent developments were surprisingly different. DENSO became the second largest automotive parts manufacturer in the world, on the level of Bosch, from whom the technology was introduced. In contrast, Japan Electronics was merged and disappeared. The decisive factor leading to these consequences was whether or not realizing technology integration to overcome technology conversion consisting of computerization was possible. In the next section, a comparison is made of the history of DENSO, which overcame technology conversion consisting of computerization, and the history of Japan Electronics, which failed to do similarly. Consideration is given to the aspects of the two companies that led to the different results of success and failure.

3. Case analysis

3–1. Technology integration process at DENSO

The history of electronically controlled gasoline injection devices dates back to 1951 when Bendix Corporation obtained a patent for a complete electronically controlled gasoline injection device, including the controls. Bosch put this technology to practical use. The resulting device was called the D-Jetronic electronic gasoline injection device, which was mounted on the 1968 Volkswagen 1600 as standard equipment. In those days, the evaluation of electronically controlled gasoline injection devices led to the general view was that application was limited to certain high-class automobiles and sports cars for the following reasons, among others. These devices were expensive compared with mainstream mechanical carburetors and were complicated and liable to breakdown; moreover, their after-sales service in the market was difficult to obtain (Kobayashi, 2003). However, the global situation began to change incrementally. First, the issue of atmospheric pollution from automobiles came under close scrutiny. In 1960, the Automobile Pollution Regulation Law was formulated in the State of California in the United States and was put into force in 1965. Meanwhile, regarding electronic technology, using semiconductors as automotive parts became possible in terms of cost and reliability. Against such a background, the L-Jetronic electronically controlled gasoline injection devices were put to practical use by Bosh to improve the control accuracy of the air–fuel ratio, which is the ratio of air to gasoline at the time that fuel is burned(1).

Starting in 1957, the production of diesel engine fuel injection pumps occurred at DENSO on the basis of the technology introduced from Bosch. Tests and adjustments were repeated to realize mechanical gasoline injection devices based on the technology that was introduced and the technology that was cultivated for diesel engine injection devices (mechanical devices). During these repetitive processes, high accuracy air–gasoline mixture ratios were expected to be realized for mechanical gasoline injection devices. However, limits on accuracy existed because of the mechanical devices, and the conclusion was reached that the required conditions for gasoline injection amounts could not be met (Document compiled by DENSO Co., Ltd., 2000). In 1968, D-Jetronic electronically controlled gasoline injection devices manufactured by Bosch were installed in 1600 cc engines for Volkswagens, 10 years after Bendix obtained a patent for the entire electronically controlled gasoline injection device, including controls. At this time, DENSO had just started research on the manufacture of semiconductors in anticipation of the arrival of the age of electronics. DENSO judged that EFI devices truly belonged to its field of expertise; therefore, the company formally agreed in 1970 to conclude technical assistance agreements with Bendix Corporation and Bosch. Additionally, the Japanese government's approval was obtained (Kobayashi, 2003). D-EFI devices (the D-Jetronic electronically controlled gasoline injection devices), whose development was completed in 1972, were installed in the Mark II, a mass production model. However, for D-EFI devices, a pressure sensor was used to measure the pressure in the engine, and the measured values were used to estimate the amount of air that filled the engine. Therefore, there was a limit on the improvement in the accuracy of controlling the air-gasoline mixture ratio. To further improve control accuracy, a technical assistance agreement was concluded with Bosch in 1973, with the result that L-Jetronic technology (which is EFI technology) improves control accuracy by directly measuring the amount of air. In this connection, repeated failures of general purpose semiconductors were an issue with D-EFI devices. To address this issue at the same time, dedicated semiconductors were developed jointly with Tokyo Shibaura Electric Co., Ltd. (now Toshiba Corporation), and efforts were made to improve reliability. Success was achieved in in-house development in 1975 with injectors (switches), which are parts that have a decisive influence on performance. These injectors were adopted in GM Cadillacs. Also in 1975, the development of EFI devices was successful. These devices were installed in six-cylinder M-E engines of Toyota Motor Corporation and contributed to compliance with the "FY 1975 Exhaust Gas Regulations." For EFI devices, the basic principles were introduced from Bendix Corporation and Bosch. Therefore, the range of original technologies, including those of dedicated semiconductors and electronic control units (ECUs)—dedicated computers—was steadily extended (Document compiled by DENSO Co., Ltd., 2000).

Complying with exhaust gas regulations and realizing gasoline saving requirements was an instance of antimony. Therefore, jointly with Toyota Motor Corporation and Toyota Central R&D Labs, Inc., DENSO developed a system that combined three-way catalysts with a unit consisting of an EFT device and an O_2 sensor. The area in which the performance of three-way catalysts is exhibited is limited only to a narrow range in which the air–fuel ratio, which indicates the air–gasoline mixture ratio, is in the vicinity of the theoretical air–fuel ratio(2). Therefore, the following actions are done: oxygen concentration is directly detected using an O_2 sensor; the amount of gasoline injected from the injector (switch) is adjusted depending on the oxygen concentration; thereby, the air–gasoline mixture ratio is controlled to bring the mixture into a region in which the three-way catalyst performance is demonstrated. Toyota Motor Corporation was able to meet the "1978 exhaust gas regulations" through this system that combined three-way catalysts with a unit consisting of an EFT device and an O_2 sensor.

3–2. Technology integration process of Japan Electronics

In 1969, Diesel Co., Ltd. (hereinafter referred to as "Diesel") concluded technical assistance agreements with Bosch and Bendix Corporation, thereby introducing the D-Jetronic technology. Diesel pushed forward the domestic production of D-Jetronic devices. In 1973, Diesel started a mass production setup with a production capacity of 2,000 devices per month. The resulting products were delivered to Nissan Motor Co., Ltd. for use in Bluebird (Document compiled by Diesel Co., Ltd., 1981). Furthermore, Diesel obtained information on L-Jetronic devices, which pertained to the then next generation technology, and started a study. Under these circumstances, Nissan Motor Co., Ltd. imported all D-Jetronic device components from Germany and adopted these devices in certain grades of Datsun and Bluebird automobiles. Although the price of each Bluebird automobile was approximately 100,000 yen higher than that of an ordinary automobile, users gave the Bluebird a high evaluation because of the excellent throttle response and acceleration performance. The initially estimated number of automobiles to be sold was 1,000. However, because of the previously mentioned benefits, this number was significantly exceeded. Therefore, Nissan Motor Co., Ltd. strongly felt the need for domestic production of D-Jetronic devices instead of importing them, which was costly (Document compiled by Bosch GmbH, 1997).

Subsequently, Nissan Motor Co., Ltd. decided to introduce Bosch's technology and started negotiations with Bosch in 1971. In this regard, given the size of the market in Japan, Bosch's policy was not to grant a technology license to any entity other than Diesel and DENSO, which had been granted licenses. However, the eagerness and sincerity of Nissan Motor Co., Ltd. bore fruit in such a way that Japan Electronics Co., Ltd. was founded as a new joint venture company by the following three companies: Nissan Motor Co., Ltd., Diesel, and Bosch (Document compiled by Japan Electronics Co., Ltd., 1993). Bosch and Japan Electronics concluded a technical assistance agreement for L-Jetronic devices.

The approach of Japan Electronics Co., Ltd. was as follows. In the beginning, the sale of D-Jetronic devices was to be conducted on the basis of the sale right obtained from taking over the agreement between Diesel and Bosch. Next, a goal was set for the development and domestic production of L-Jetronic devices, with 30,000 devices being planned for monthly production. At the founding of Japan Electronics, Diesel not only sent the president and managing directors to the company but also temporarily transferred a large number of D-Jetronic device engineers, thus providing strong assistance for establishing a technical foundation (Document compiled by Diesel Co., Ltd., 1981). Of all component parts of each L-Jetronic device, three items were produced by Japan Electronics, including the ECU, which is a computer. In principle, Japanese-made machines were used as production equipment. However, for important processes, machines were imported from Bosch. Additionally, after coordinating with Bosch on the detailed specifications, machines were purchased from companies such as Universal Inc. in the United States (Document compiled by Japan Electronics Co., Ltd., 1993). ECUs as computers were products of a completely different nature for people engaged to that point in automobile production. Many new technologies were involved in both design and production engineering, including assembly, adjustment, and inspection. The first product was for Nissan Motor Co., Ltd.'s Fair Lady Z for export to North America. The Development Department cooperated with Nissan Motor Co., Ltd. and decided on the specifications by mutually repeating trial production and experiments.

The most difficult item pertaining to electronic parts was the domestic production of semiconductors. Japan Electronics carried out joint development with Hitachi, Ltd., thereby realizing domestic production (Document compiled by Japan Electronics Co., Ltd., 1993). Trial production and experiments were repeated for a long period. However, domestic production was not completed in time for ECU serial number 1. Therefore, parts imported from Bosch were used.

Japan Electronics succeeded in the in-house production of three products, including the ECU. Subsequently, the company decided to engage in in-house production of injectors (switches), which were at the time purchased from Bosch and Diesel. In those days, Japan Electronics had no equipment capable of trial production of injectors and lacked the technology to take measurements to check whether the trial products were manufactured in compliance with the drawings. For the trial production, cooperation was obtained from not only Nissan Motor Co., Ltd. but also equipment manufacturers. Meanwhile, investigators were sent to Bosch, and studies were conducted on problems with, and remedial measures for, injectors manufactured by Bosch. Strict regulations for exhaust gas were to be imposed starting in 1978. To meet these regulations, combining three-way catalysts with a unit consisting of an EFT device and an O_2 sensor were effective. For the production of this O_2 sensor, production preparations were pushed forward in the Central Engineering Laboratories of Nissan Motor Co., Ltd. as well. In the Nissan group, whether Nissan Motor Co., Ltd. or Japan Electronics was to produce O_2 sensors was a pending question (Document compiled by Japan Electronics Co., Ltd., 1993). Finally, Japan Electronics was selected to take charge of the production of O_2 sensors. In July 1978, Japan Electronics concluded a technical assistance agreement with Bosch regarding O_2 sensors. In November of the same year, Japan Electronics sent engineers to Bosch to carry out process and equipment investigations, thus making efforts to learn the technology. Furthermore, Japan Electronics received temporary transferees from the Central Engineering Laboratories of Nissan Motor Co., Ltd. and started trial production and experiments. Because the material for O_2 sensors was ceramic, there were many pieces of know-how in the manufacturing processes and carrying out manufacturing under the same conditions as in Bosch was necessary. Therefore, the following actions were taken for important equipment: machines of the same model as Bosch were introduced; engineers for relevant processes were invited from Bosch; and technical guidance was received in preparation for the start of production (Document compiled by Japan Electronics Co., Ltd., 1993). For O_2 sensors, products were significantly affected even by slight changes in manufacturing conditions, resulting in defects being generated one after another. Production started in 1979 (Document compiled by Japan Electronics Co., Ltd., 1993).

3-3. Consolidation of discovered facts

The discovered facts regarding DENSO's technology integration process can be presented as follows on the basis of the company's history referred to in this paper.

(1) The technologies for the key parts of D-EFI devices were introduced on the basis of a technical assistance agreement, resulting in the acquisition of the core technologies.
(2) To develop the original ECUs of DENSO, dedicated semiconductors were created. Bosch injectors, as they were, used to be adopted. However, these products were switched to DENSO in-house products. Thus, peripheral parts were subjected to in-house production.
(3) To comply with the 1978 Exhaust Gas Regulations, DENSO jointly developed a system consisting of an EFT device and an O_2 sensor with Toyota Motor Corporation and Toyota Central R&D Labs, Inc.

Regarding item (1), the core technologies indispensable to producing products were acquired. As for the acquisition method, in-house development was not particularly insisted on. For example, cases exist in which core technologies were obtained through technical tie-ups with other companies, such as the case in which the manufacturing technology for CMOS[(3)] was obtained from RCA. Cases also exist in which core technologies were developed in-house, as was the case with a common rail system[(4)] used in diesel engines. The purpose was absolutely to acquire technologies regardless of the particulars of the acquisition. For the in-house production of peripheral parts mentioned in item (2), products were developed using technologies acquired through technical tie-ups and were manufactured in in-house plants. In specific terms, efforts focused on the in-house production of dedicated semiconductors for EFI devices. In particular, regarding the development of semiconductors, a significant cost was involved in matters such as the acquisition of equipment. However, it was possible to make this investment decision without hesitation. Against the background of this fact, there was a conviction that the age of electronics for automobiles would arrive. Item (3) pertains to an arrangement that not only enables relevant parts to be supplied as individual parts but also that enables an optimal system to be established by combining relevant parts and supplying the resultant product to the customer as a system product. Thus, in this paper, a system product means a set of parts consisting of peripheral parts and a key part (ECU) that serves a specific function. In this regard, a system means an arrangement with control specifications to realize specific functions.

Next, the discovered facts of the technology integration process of Japan Electronics can be presented as follows on the basis of the company's history as described in this paper.

(1) The key technologies for L-Jetronic devices were introduced on the basis of a technical assistance agreement, resulting in the acquisition of the core technologies.
(2) Equipment was introduced directly and engineers were invited from Bosch, resulting in technologies being learned. Consequently, success was achieved in the in-house production of component parts. Regarding ECUs, products imported from Bosch were used. However, semiconductors were jointly developed with Hitachi Ltd., and in-house production of peripheral parts was pushed forward.
(3) The technology for O_2 sensors was introduced on the basis of the technical assistance agreement concluded with Bosch. The same production equipment as Bosch's was purchased. Furthermore, engineers were invited from Bosch, resulting in the realization of in-house production.

For item (1), the core technologies indispensable to producing products were acquired. In some cases, steps were taken to directly introduce technologies from Bosch. Additionally, some technologies were acquired through secondary technology transfer, in which technologies introduced to Diesel by Bosch were introduced from Diesel. For the in-house production of peripheral parts mentioned in item (2), products were manufactured in in-house plants using technologies acquired through technical tie-ups. Thus, Japan Electronics' in-house production refers strictly to a practice through which products based on Bosch technologies and drawings are produced in in-house plants; that is, in-house production is not a practice whereby original products were developed and produced in in-house plants. Item (3) means that O_2 sensors developed by Bosch were produced in a Japan Electronics plant. Item (3) also means that efforts at the in-house production of peripheral parts in item (2) were further promoted. The result is that additional products were subjected to in-house production, thus leading to production lines being extended. It is true that Japan Electronics followed the processes of acquiring core technologies through technical tie-ups and in-house production of peripheral parts; however, the company failed to achieve a state in which the mechanics and electronics were technologically integrated, thus leading to the establishment of mechatronics and resulting in system products being supplied. Now, consideration is given to the reason for Japan Electronics failing to carry out technology integration.

A comparison is made between the technology integration process of DENSO and that of Japan Electronics. By determining the differences, the conditions required for technology integration are clarified. The viewpoint of technology trends (external environment) and the viewpoint of methods of managing technical knowledge at the time of the introduction of technologies (internal environment) are adopted as points of view of the analysis. Both the external and the internal environments involve various causal factors. In this paper, consideration is given in such a way to limit the subject of consideration to technology trends and methods for managing technical knowledge. First, in the latter half of the 1960s, when DENSO and Japan Electronics attempted to introduce technology, the following two types of control coexisted: mechanical control, which came under existing technology; and electronic control, which came under new technology. Even Bosch, which was to become a leading enterprise in the field of electronically controlled fusion injection devices in later years, was groping in the dark to determine which of mechanical control or electronic control could become a dominant design. Bosch applied managerial resources to both L-Jetronic devices (which came under electronic control) and K-Jetronic devices (which came under mechanical control). In 1972, Bosch simultaneously developed both L-Jetronic devices and K-Jetronic devices. Both DENSO and Japan Electronics attempted to introduce the technology for L-Jetronic devices. In 1977, systems consisting of an EFT device and an O_2 sensor were each developed on the basis of L-Jetronic devices, and the next generation model of K-Jetronic devices was not developed. Therefore, the dominant design of gasoline injection devices was consider to be L-Jetronic, which came under electronic control. From this fact, it follows that both companies took decisive action to introduce the technology for L-Jetronic before a dominant design was determined. Therefore, both DENSO and Japan Electronics were under the same environmental conditions. Therefore, that differences existed in the external environment between the individual enterprises was not judged.

Next, regarding the internal environment, consideration is given to the methods for managing technical knowledge at DENSO and Japan Electronics. The most significant difference in the management methods between the two companies is in the management setups. At DENSO, both mechanics technology and electronics technology were managed centrally in a single department. However, in Japan Electronics, no such centralized management was carried out, creating a significant difference between the two companies. As a result of the analysis conducted from the viewpoints of external and internal environments, the external environments were under the same conditions. Therefore, the internal environments (the methods of managing technical knowledge) are considered to affect the feasibility or infeasibility of technology integration.

4. Analytical remarks

4-1. Comparison of technology introduction processes

In the previous section, the method of managing technical knowledge was shown to affect the feasibility or infeasibility of technology integration. In this section, consideration is given to why technology integration cannot be realized if the methods for managing technical knowledge are different.

The realizability or non-realizability of technology integration depends on whether the outside technologies introduced and the in-house technologies in possession can be subjected to centralized management in a single department. At DENSO, the following was the case. Electronics, which represented a new technology, was introduced from Bosch; the responsible departments taking charge of mechanics, which was an existing technology, and electronics, which was a new technology, were determined; mechanics and electronics were subjected to centralized management, resulting in the accumulation of a wide range new technologies. Given this situation, the fusion of both technologies was accelerated, leading to the realization of technology integration.

The peripheral and key parts of EFI devices consist of mechanical and electronic parts. Mechanical and electronic parts require knowledge of mechanics and electronics, respectively. Departments consisting of members familiar with both types of parts were organized. For this reason, pertinent members became proficient in both types of technologies. These technologies were managed by single departments in a centralized manner. Consequently, relevant knowledge and know-how were integrated in the pertinent organizations, with the result that mechatronics was created—a combination of electronics and mechanics. System establishment capabilities were acquired through the mechatronics obtained from the aforementioned technology integration. In the case of EFI devices, the following sequence takes place: all states of an engine are detected by sensors (detectors), which are electronic parts; detected data are subjected to logic processing as electrical signals; the detection results are provided through electrical signals to the injector (mechanical part), which is the only gasoline injection switch; as a result, gasoline in the amount established by logic is injected. Mechatronics is a technology whereby, as previously mentioned, the operating state of a mechanical part is picked up by electronic parts, optimum conditions are computed by electronic parts, and mechanical parts are controlled on the basis of these conditions. Mechatronics was created in such a way that the knowledge and know-how in sensors, which are electronic parts, and engines, which are mechanical parts, are managed centrally, resulting in the integration of this aforementioned knowledge and know-how.

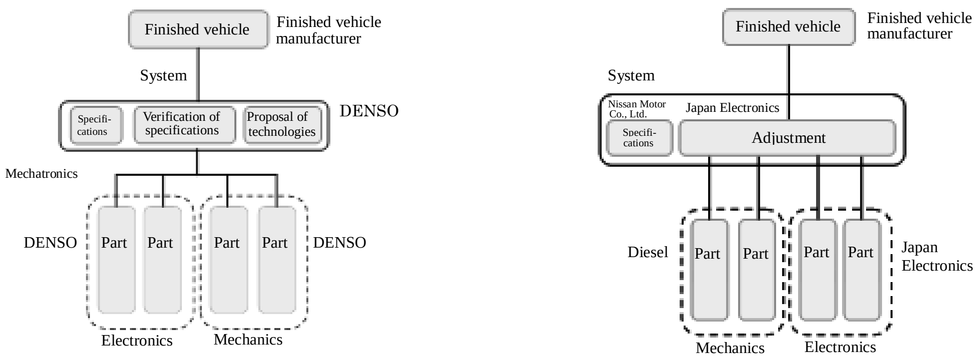
Actually, in DENSO, with respect to the component parts of 12 types of D-Jetronic devices for which technologies were introduced from Bosch, the following action was taken and enabled the Fuel Injection Pump Division to play a key role in overall coordination: departments in the Fuel Injection Pump Division that were considered to be excellent at handling such component parts were asked to carry out product manufacturing processes from design to prototype. As for component parts for which no appropriate departments existed in terms of organization, individuals regarded as appropriate were selected from among members of the Research and Development Department and others, and these individuals were asked to carry out the design (Kobayashi, 2003). As previously described, in DENSO, a specific in-house division carried out centralized management of technical information. Regarding product manufacturing design and prototyping, consideration was given to the technologies held by departments in charge of these technologies. Moreover, friendly departments with technologies were asked to carry out product manufacturing design and prototype.

In contrast, at Japan Electronics, management performed only electronics-related activities. In 1969, Diesel received information on L-Jetronic devices from Bosch after it mass produced D-Jetronic devices and started developing D-Jetronic devices. However, as previously mentioned, in connection with the intention of Nissan Motor Co., Ltd., Japan Electronics Co., Ltd. was founded with investments made by the following three companies: Nissan Motor Co., Ltd.; Bosch, and Diesel. The technology for L-Jetronic devices was introduced at Japan Electronics from Bosch. As a result, parts that were newly adopted in L-Jetronic devices, such as ECUs, were produced by Japan Electronics. Diesel and Bosh took charge of the production of injectors, to which it was possible to convert the D-Jetronic device technology. In that regard, when Japan Electronics was to take charge of ECUs and others, Diesel temporarily transferred a large number of D-Jetronic-related engineers to Japan Electronics, thereby providing strong assistance in establishing a technical foundation. Additionally, Bosch sent people such as the Director of the Development Department to Japan Electronics, thus taking action to establish technical capabilities. As for the control technology, business was conducted in the form of "receiving orders based on specifications," where Nissan Motor Co., Ltd. carried out development and Japan Electronics prepared programs using the development results (Document compiled by Japan Electronics, 1993). Thus, Japan Electronics only managed the electronics and was not involved in the centralized management of the knowledge of mechanics and electronics.

Next, the setup for the management of DENSO's technical knowledge and the corresponding setup of Japan Electronics is considered from the viewpoint of organization. Starting around 1950, at Toyota Motor Corporation, a large shareholder and the largest customer of DENSO—a person at the department director level—was appointed as project general manager in charge of vehicles and was engaged in the development of new model automobiles. This project general manager's activities were limited to those in engineering departments. In 1965, the Project General Manager's Office, which had belonged to the Technology Management Department, became independent and was called the Product Planning Office. As a result, a setup was established in which the stages from product planning to sales were consistently managed (Document compiled by Toyota Motor Corporation, 1987). Meanwhile, at Nissan Motor Co., Ltd., which is a large shareholder of Japan Electronics, the Design Department was reorganized in 1979. In conjunction, the Product Development Office was founded by gathering vehicle development leaders. That is, a group was formed that consisted of several members, including a supervisory officer in charge who corresponds with the project general manager at Toyota Motor Corporation (Document compiled by Nissan Motor Co., Ltd., 1985). As previously described, in 1978, when Japan Electronics introduced the L-Jetronic device's technology, a consistent management setup led by a project general manager was established at Toyota Motor Corporation. However, Nissan Motor Co., Ltd. was in the process of transition to such a management setup. This management setup at Toyota Motor Corporation and the corresponding setup at Nissan Motor Co., Ltd. were considered to influence DENSO, which is an affiliate of the former, and Japan Electronics, which was an affiliate of the latter. The result was that DENSO carried out centralized management but that Japan Electronics failed to do similarly.

Because the management of technical knowledge was carried out as previously described, vertical integration occurred at DENSO, and the great majority of parts constituting L-Jetronic devices were the result of in-house production or in-house development. In contrast, horizontal specialization took place through which Japan Electronics took charge of only the ECU. Other parts were consigned to companies such as Diesel. In the case of vertical integration, both parts requiring the knowledge of mechanics and those requiring the knowledge of electronics were handled by a single enterprise; therefore, technologies and knowledge regarding both types of parts can be accumulated. However, regarding horizontal specialization, the following was the case. For example, technologies and knowledge regarding electronics were accumulated at Japan Electronics, which handled ECUs. As previously described, because Japan Electronics was subjected to horizontal specialization, the technology and knowledge regarding the electronics of which Japan Electronics took charge were accumulated at this company. However, because Japan Electronics did not take charge of mechanics, neither technology related to nor knowledge of mechanics was accumulated at this company. To realize technology integration, both mechanical technology and electronic technology are required. Therefore, Japan Electronics failed to accumulate technology related to and knowledge of mechanics. Therefore, it was difficult for the company to integrate mechanical and electronic technology, thereby establishing mechatronics technology, which resulted in the creation of system products (See Figure 1).

Figure 1 Roles played by DENSO and Japan Electronics



Roles played by DENSO　　　　Roles played by Japan Electronics

To substantiate the contents of these descriptions, verification will be performed of the degrees of vertical integration of DENSO and Japan Electronics. To clarify the degrees of vertical integration at DENSO and Japan Electronics, the ratios of products subjected to in-house production are investigated. If L-Jetronic devices (EFI devices) are used as examples, they consist primarily of 11 types of parts (Document compiled by DENSO Co., Ltd.; Fujisawa, 2000). Regarding these installed parts, the fiscal years during which mass production was initiated were investigated from the corporate histories of the relevant companies. The results are presented in Table 1. At DENSO, nine out of a total of 11 types of L-Jetronic device component parts were subjected to in-house production. However, at Japan Electronics, only four types were subjected to in-house production. As Table 1 shows, at Japan Electronics, the ratio of the number of parts manufactured by other companies was 7/11 = 64%. The corresponding ratio at DENSO was 2/11 = 18%. A comparison of these two values indicates that the ratio of parts subjected to in-house production at Japan Electronics is overwhelmingly low. In other words, a low ratio of the number of parts subjected to in-house production at Japan Electronics indicates that this ratio for other companies is high. Therefore, more progress in the area of division of labor was made at Japan Electronics than at DENSO.

(Insert Figure 1, which is 11-line high in the printing area.)

Table 1 Results of investigation of years in which L-Jetronic device component parts were subjected to mass production

Component part	Fiscal year (calendar year) when mass production was started	
	DENSO	Japan Electronics
Fuel pump	1772	Product of another company
Fuel filter	1970	Product of another company
Injector	1972	1977
Pressure regulator	Product of another company	Product of another company
Airflow meter	1975	1975
Throttle body	Product of another company	Product of another company
Air valve	1973	Product of another company
ECU	1972	1974
Throttle position sensor	1981	Product of another company
Water temperature sensor	1970	Product of another company
O_2 Sensor	1977	1978

Source: Data prepared by the author by referring to the corporate histories of the relevant corporations

As of 1993, product formation at Japan Electronics consisted of electronic control products (primarily ECUs), air system products (primarily airflow meters), fuel system products (primarily fuel injectors), and sensors and the like. System products that would have become realizable through technology integration were not supplied (Document compiled by Japan Electronics, 1993). As a matter of course, developing the specifications for system products and proposing these specifications to finished vehicle manufacturers was not done. In contrast, in the case of DENSO, "since 1980s, at the request of a finished vehicle manufacturer, which is a customer, this company has been participating in study meetings not only for the specifications for current engines but also for the specifications for the development of engines of the next generation but one(5)." This fact implies that DENSO can offer system-related proposals for the development of engines. That is, this fact made it possible for DENSO to participate jointly with the finished vehicle manufacturer in engine development starting in the vehicle development stage. Thus, DENSO proposes control specification to the customer and urges the customer to adopt these specifications with the result that the sales of key parts and peripheral parts are expanded. This fact means that design-in, which has become a normal practice these days, has been realized.

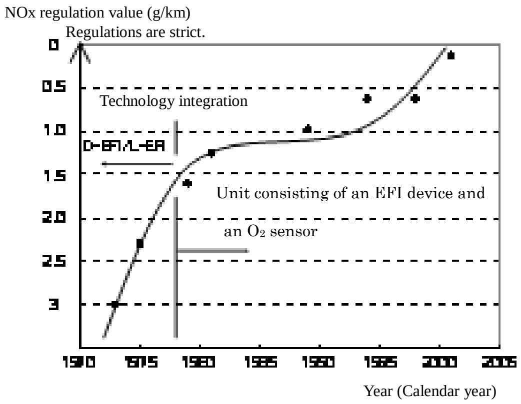
As previously stated, for the purpose of technology integration, subjecting technical knowledge to centralized management was found to be important. Now, the issue is the effects of technology integration, the effectiveness of which is verified in the next section.

4–2. Verification of the effectiveness of technology integration

In this section, the effectiveness of technology integration is verified. The conclusion is that control accuracy and sales turnover undergo improvements. First, why control accuracy improves is shown. Next, an explanation is provided for the improvement in sales turnover.

In the case of EFI devices, improvement in control accuracy implies that strict NOx control values are imposed (that is, only a small amount of NOx is discharged). DENSO improved control accuracy through the following evolution process: [Mechanical gasoline injection control] → [D-EFI or EFI] → [System consisting of EFI device and O_2 sensor]. Changes in NOx regulation values from 1970 to 2005 are shown (see Figure 2) to substantiate the contents of the previous statement. DENSO can be observed to have improved control accuracy through technology integration, thereby overcoming the difficulty of meeting regulation values.

Figure 2 Improvement in control accuracy attributable to technology integration



Source: Data obtained by the author from the website of the Ministry of Land, Infrastructure, Transport and Tourism.

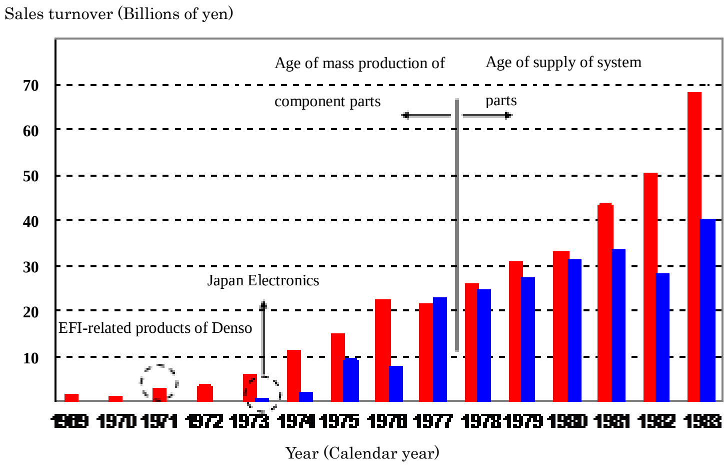
Note: Data for Mode 10-15 were adopted as NOx regulation values.

Control accuracy improvement, which was realized through the evolution from mechanical gasoline injection control to D-EFI or EFI, was carried out in such a way that information on the operating states of mechanical parts was thoroughly picked up by sensors, which are electronic parts. The result was that correct information on the operating states was obtained. By utilizing electronic parts as measuring instruments, mechanical gasoline injection control was thoroughly computerized, resulting in the operating states of mechanical parts being correctly grasped. On the basis of the resulting information, a mechanical gasoline injection device was operated. In the case of the mechanical gasoline injection device, all operating states were based on estimated values. Therefore, the conditions in which the mechanical gasoline injection device operated were unknown. Moreover, in the case of mechanical parts, individual differences existed in machining accuracy. Therefore, carrying out high precision control was difficult. By utilizing electronic parts to grasp the correct operating states, significantly improving control accuracy was possible.

Improved control accuracy realized by the evolution from D-EFI or EFI to systems consisting of EFI devices and O_2 sensors was obtained in such a way that optimal operating conditions were calculated using electronic parts on the basis of information that these parts picked up. The result was that mechanical parts were controlled. Information was picked up and was used to calculate optimal conditions using ECUs, which are computers. Then, mechanical parts were controlled in such a way as to achieve the calculated conditions. These processes brought about improvements in control accuracy. All states in an engine were detected by sensors, which are electronic parts. Detection results were processed as electrical signals by an ECU, which is a computer. The processed results were fed to an injector (switch), which is a mechanical part. Then gasoline in the amount established in the control specifications was injected. In the event of changes in the engine state, these changes were detected by sensors. The amount of gasoline injected by the injector was adjusted. As a result, the NOx discharge amount was controlled to achieve the target value. As previously stated, all states in the engine were detected by sensors. It was arranged to make perform control possible in such a way to achieve optimum values with respect to changes. As a result, maintaining the optimal conditions for the engine at all times was possible, with the result that significant improvement in control accuracy occurred.

Next, regarding the effectiveness of technical integration, sales turnover increased. An investigation is done into sales turnover regarding EFI-related products of Japan Electronics and DENSO from 1969 to 1983. In those days, Japan Electronics dealt only in EFI-related products and, therefore, the entire company's sales turnover was adopted. In 1977, system products were developed through technology integration. Times were divided into the age of component parts' mass production and the age of system parts supply, with 1977 as the boundary. Japan Electronics primarily supplied parts on the basis of the division of labor. Therefore, during and after 1977, when demand for system products began to increase, the difference in sales turnover between Japan Electronics and DENSO widened. During and after 1977, the difference in sales turnover gradually widened. In 1983, the sales turnover of DENSO was 68 billion yen, and the sales turnover of Japan Electronics was 40 billion yen, with a clear difference indicated (see Figure 3)(6).

Figure 3　Changes in sales turnover in relevant companies



Source: Data prepared by the author by referring to the corporate histories of the relevant corporations

5. Conclusion

In this paper, a search was conducted for the conditions required to realize technology integration, which integrates multiple technologies to create a new technology. To date, technology integration was known to be realizable. However, the processes through which technology integration becomes feasible or the conditions needed for technology integration were not clarified. Therefore, in this paper, a comparison was made between Japan Electronics, which failed to realize technology integration, and DENSO, which realized technology integration. The comparison clarified the concept that centralized management of technical information is an important required condition for technical integration.

(1) At the same time, Bosch presented K-Jetronic, which is a mechanical gasoline injection device.
(2) The theoretical air-fuel ratio refers to the ratio (by weight) of air to fuel at which fuel is completely burned.
(3) This article refers to a gate structure through which metallic oxidized film semiconductor field-effect transistors are arranged in a complementary manner.
(4) This method enables fuel to be pressurized to a high level through a supply pump stored in a rail (accumulator), and the fuel is injected in an appropriate amount into all cylinders from the injector under the control of the ECU.

(5) This remark is based on an interview conducted with related people at DENSO Co., Ltd. (implementation date: June 1, 2010).

(6) From 1969 to 1973, Diesel sold EFI devices, and the relevant know-how was transferred to Japan Electronics in the form of a technology transfer. Therefore, the effects of difference in sales initiation times are not taken into account.

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