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Product Modularization and Modularization Development Systems Brought about by Vehicle Electrification and Computerization

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1. Introduction

Vehicle electronic control systems were first adopted at the end of the 1970s. Since then, vehicle electrification and computerization have swept through the market in response to demand from both society and the market for features such as security, environment and comfort. This momentum has been particularly striking since the 1990s in the Japanese auto industry, a pioneer in electrification. The main areas of innovation have been electric components, electronic devices and secondary batteries.

As shown in Fig. 1, from 29.3 per cent of Japanese domestic auto part shipments in 1988, the share

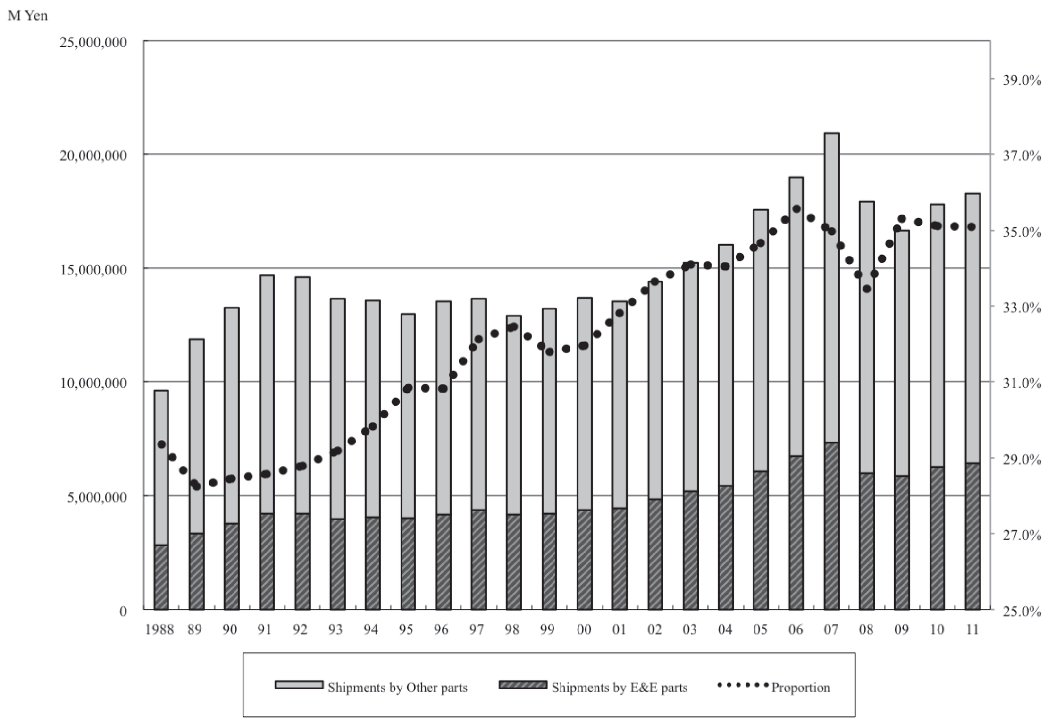

Fig. 1 Proportional transition of the E & E parts among the amount of domestic auto part shipments
Source: Statistics compiled by JAPIA (Japan Auto Parts Industries Association)

of electric and electronic parts (E & E parts) rose to over 30 per cent in 1995 and 35.6 per cent in 2006, i.e. over one third of total shipments. Clearly, these E & E parts are far from being a special niche; indeed, in their absence any discussion of auto parts would be virtually impossible. It is the presence of electronic control systems among E & E parts that contributes in particular to an increase in vehicles' added value. Since these contain various technology systems, they can be considered as products that use multiple elemental technologies. Multiple elemental technology products refer specifically to embedded systems, which function through the complex interaction of hardware and software. The term explicitly indicates products in which technology from a wide range of industrial domains: machines, electricity, software, semiconductors, communications and new materials interact in a complex way.

The goal of this study is to clarify how far modularization of products and organizations has progressed, and to extract management issues, in order to reduce the explosive increase in development man-hours in the development of products using multiple elemental technologies. The study will also show the path taken by cars, a mature product, in order to arrive at their present stage of modularization. In this way, differences with respect to the management of conventional product development projects will become apparent. The study's significance is that it will be able to contribute to the theoretical development of domains related to the mutual interaction between technology and organization. The study will also analyze case studies of ECU (Electronic Control Unit) development in large Japanese suppliers. The reason for analyzing suppliers rather than auto makers is because in the Japanese auto industry division of labor is highly sophisticated, while suppliers are in charge of actual development and production. This type of bulk outsourcing system including development and production, and quality assurance, is known as the transaction of design-approved parts. (Asanuma [1985a, 1985b]).

2. E & E Parts Development and Modularization in the Japanese Auto Industry

(1) Elemental technologies required in E & E parts

Traditionally, cars were composed mainly of machine parts. However, while E & E parts such as the starter and the alternator have long been used round the engine, these parts did not require advanced control and accounted for only a small share of a car's total component parts. Although several specialized firms were founded before WWII, and Hitachi and Mitsubishi Electric also entered the vehicle electric part market, the Japanese auto market at that time was invaded by Japanese subsidiaries of General Motors and Ford, and most electric parts for new cars were also supplied by US firms.

The real boom in Japanese E & E parts began after the war, in 1949, when Nippon Denso (present Denso) split off from Toyota and entered the E & E parts market. Throughout the high growth period, Denso succeeded in massively expanding supplies of E & E parts. At the same time, the firm made positive efforts to introduce technology from the German prominent company, Robert Bosch, and worked to improve quality. During this period, other companies in the same keiretsu, and Hitachi and Mitsubishi Electric mentioned above, also achieved growth. GM's adoption of engine control technology using an MCU (micro controller unit) in 1976, provided the greatest impetus for the present boom in E & E parts. MCUs were introduced in order to respond to demand in US society at that time for gas mileage and environmental regulations. To get past these regulations and sell vehicles in the US, which was the biggest market, auto manufacturers all over the world got together with prominent suppliers and unanimously adopted the electronic fuel injection system. Thereafter, to meet demand for security, environment and comfort, the range of application of E & E parts was broadened to include control of car frames and bodies. Recent years have seen progress in computerization embracing the communications field. There has also been a rapid increase in the electrification of the power supply; in 1997 Toyota produced a hybrid vehicle and in 2010 Nissan and Mitsubishi both commenced full-scale mass production of electric vehicles. Since electrification goes hand in hand with computerization, the range of application for E & E parts is still expanding.

Because auto industry innovations such as electrification and computerization increase the complexity of product development, firms must provide more sophisticated forms of management. This is why the modularization method was introduced. As the life cycle aspects of a firm's own products move on, it seems that interest in innovation shifts from product differentiation into how to produce the product more cheaply without any waste (Abernathy and Utterback, [1978]). In other words, when market penetration by a particular product has passed a certain threshold value, a firm begins to rationalize production and turns to recovering capital invested up till then in product differentiation. However, previous research has not looked closely at the methodology involved. Furthermore, while the principal innovations have shifted to production rationalization, a certain degree of product differentiation continues to be implemented for the sake of competition. Yet previous research has not paid sufficient attention either to whether this continued product differentiation has been implemented efficiently. The product modularization method can explain these points.

(2) Modularization trends and economic rationality

Modularization means to change the design concept of a product, so that it fulfils its performance and functions as a product, by simplifying the relationship between elements in a highly integrated product and joining together several fixed unit modules. The modular argument must be understood from the concept of product architecture. Product architecture is a fundamental design concept which looks at the correspondence between structure and function in a product's component elements, and the extent of interface generalization. Various methods of typification exist: integral type or modular type depending on whether the correspondence between the structural elements and the functional elements is nearly many-to-many or nearly one-to-one; or closed type or open type depending on the degree of openness of the interface generalization. (Morris and Ferguson, [1993], Ulrich, [1995], Ulrich and Eppinger, [1995], Fine, [1998]).

In integral architecture, the correspondence between structure and function is nearly many-to-many and a rigorous mutual dependence arises between the component elements. For this reason, if an arbitrary element is changed, other related elements must also be changed. Modern passenger cars are the archetypical example. On the other hand, in modular architecture, the correspondence between structure and function is nearly one-to-one, and mutual dependence between component elements is relatively low. The greater the degree of modularization, the more insignificant the effect on other elements of a change in one arbitrary element. Recently, many products have tended towards modularization in order to reduce the complexity of artifacts.[1)] Digital household electric appliances such as cellphones and LCD televisions fall into this category.

Let us turn now to interface generalization. Where artifacts are modularized, the interface connecting the component elements must follow some kind of rule. The application of this design rule (Baldwin and Clark, [2000]), if it remains within specific firms and between very closely-related firms, constitutes closed architecture. Open architecture, in contrast, is not confined to specific firms but is found throughout the whole industry, and also the application of open architecture straddles the whole industry. Put in simpler terms, over what range are component elements compatible? This compatibility enables existing knowledge to be maintained and recycled and encourages economies of substitution (Garud and Kumaraswamy, [1993]).

In studies on innovation prior to the positing of the concept of architecture, discussions focussed exclusively on the totality of the value added to the product as a whole from the point of view of technological development and did not sufficiently reflect the nearly decomposable features (Simon, [1969]), of artifacts which had grown notably more complex in the 20th century. Generally, artifacts are layered in order to dissolve their complexity (Suh, 1990), and design tasks are separated into ever smaller units (von Hippel, [1990]). A different type of innovation is needed for each individual separated component element. Depending on changes in the way in which component elements are joined together, it is also possible to differentiate the product as a whole (Henderson and Clark, [1990]).

The special feature of product architecture is that it also affects the developing organization. This is because the organizational structure is determined to a considerable extent by the various coordination tasks attendant upon product design. Organizations where close coordination is possible are more suited to the design of highly integrated products, while organizations which can get away with relatively infrequent coordination are more suited to the design of highly modularized products.

1) Since 2000, Japan's electric appliance industry, unable to keep up with the rapid progress in product modularization, has been thoroughly trounced by the cheap products made in emerging nations like China.

The compatibility relationship between such product and organizational architecture has been indicated in many previous studies (Morris and Ferguson, [1993], Chesbrough and Teece, [1996], Sanchez and Mahoney, [1996]).

(3) Limitations of prior research

From the foregoing discussion of prior research it is clear that product and organizational architecture have a firm relationship of mutual dependence with the business system as a whole, and that for this reason the choice of architecture must be perceived as an advanced strategic scheme. This does not mean that the product architecture framework is a tool capable of accurately analyzing every product. Since the 1990s, performance improvements and lower prices in semiconductors have led to the generalized adoption of electronic control systems as the control method for a wide range of product lines. This trend affects not only digital household appliances, but also extends to vehicles.

The problem is how to position these software-controlled electronic control systems theoretically in the framework of product architecture. Up till now, discussions about product architecture, to put it in extreme terms, have specialized in the analysis of hardware. Therefore, in order to analyze the architecture of a product and the organization that designs it, where the product is an electronic control system spanning the three domains of machinery and semiconductor circuit board as hardware, and the software contained in the semiconductor, all three coexisting in the electronic control system, we will have to modify traditional frameworks. In this way, it should be possible to clarify the progress being made in reducing the explosive increase in software design man-hours at electronic control system development sites, i.e. the progress in modularization. In order to analyze this point, let us examine an actual case of product development carried out by a firm.

3. Electronic Control System Development Case Study

(1) ECU development for engine control at Keihin

Let us first consider ECU development at Keihin.[2] Keihin, the biggest company in the Honda keiretsu, came into being when three companies belong to Honda keiretsu amalgamated in 1997. Since engine control ECUs were the main product of one of the constituent companies, Denshi Giken (founded in 1981), in the present Keihin too, the development organization of the former Denshi Giken is in charge of developing this product. Very few companies have specialized in the manufacture of ECUs from the earliest days of automotive electronic control systems. Keihin is an ideal subject for our research since it has a clear picture of the ECU development situation over a long period.

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2) This case study is based on interviews carried out at Keihin on August 31, 2007, April 11, 2008 and March 2, 2011.

There are thee principal design departments involved in ECU development at Keihin: these are the mechanism design, electricity design and software design departments. Electricity design is subdivided into a circuit design department which compiles circuit schematics and a board design department which does the wiring and electronic components layout on the actual board; while software design is subdivided into specification compilation department as a previous process and coding (and debugging) department as a subsequent process. Although the number of personnel involved in each design process fluctuates according to the difficulty of the design, several persons are allocated to each design department i.e. mechanism design, circuit design, board design (Shanghai subsidiary is also used) and software design (subsidiaries in Sendai and Shanghai are also used). Designers are often involved with other models at the same time and it is rare to find a designer exclusively devoted to one particular model.

A project leader (PL) is elected mainly from among young people in these departments to consolidate the processes. PLs for each separate functional department are elected not only from design, but also from process engineering, service, quality assurance, purchasing, etc. A Large Project Leader (LPL) supervises these PLs and has overall responsibility for development. Since the LPL is responsible for profits and oversees all PLs including those in the design departments, he has considerable authority. Many LPLs come originally from the design departments, especially circuit design.

Let us now look at coordination among design activities. Since the only mechanical part in an ECU is the outside of the aluminum cover, and this poses few problems, we will concentrate on the electricity and software design departments. In electricity design, both the circuit design and board design departments must be rigorously coordinated with each other for print circuit board (PCB) development. In coordination with other departments, a high level of mutual dependence with the mechanical department is observed. This is because both departments must coordinate closely with each other so that the PCB function works while the ECU installed in the engine room stands up to water, dust, heat and vibrations. On the other hand, there appears to be a low level of mutual dependence with the software design department. This is because once the interface between software and hardware has been decided in the initial stage of the design, the individual design departments work in isolation from each other.

Next, the software design department. Keihin outsources some of the subsequent processes to subsidiaries in Shanghai in China and in Sendai and the outsourcing ratio for all software code is as high as sixty per cent. By outsourcing subsequent processes and reducing development units, thus making verification of functional units relatively simple, the firm achieves an advantage in terms of quality. Though the remaining forty per cent of code is developed in-house, this domain is dogged by the constant possibility of specification changes. Since this is the domain in which know-how is concentrated, Keihin wants to carry out development itself. Moreover, a high degree of mutual dependence means that task-division would not be easy even if Keihin did attempt to outsource. In the outsourcing of subsequent processes, tasks are indicated in detail by an enormous quantity of specification requirements. The subsidiary does not know what software it is developing for which part of which function and has little grasp of the overall picture. This is because the enormous specification sheets for connecting prior processes with subsequent processes i.e. the interfaces are clearly determined so that software can be developed even with unilateral instructions from the previous process. The situation is also linked to the stifling of know-how leaks in China in particular.[3] As above, in the software design department, most coordination between previous and subsequent processes is intradepartmental, and coordination with other departments is virtually non-existent.

Again, at Keihin, if a design modification should arise, conflicts over coordination about which design department should deal with the change and to what extent, can be resolved thanks to the following two circumstances. Firstly, coordination is carried out by the PLs, mentioned above, and the LPL who oversees the project as a whole. Secondly, the mechanical design department does not have much to say about engine ECUs, unlike other products, and the LPL himself usually comes originally from circuit design. This is because when the former Denshi Giken, which is in charge of Keihin's engine ECU development, was established as an ECU specialist, the electricity and software design departments were not detached from the mechanical design department. Instead, the electricity design department (circuit design in particular) formed the nucleus of ECU development from the start. Although coordination between other design departments is generally good, it is in software design aspects where unforeseen obstacles are most likely to arise during development. While mechanical design and electricity design usually proceed as planned, enormous man-hours are involved in software design and even after the hardware design has been completed, it is normal for work on software to continue. At Keihin this has always been perceived as an important issue.

(2) Electronic control system development at Aisin

Our second case study concerns electronic control system development at Aisin, a company in Toyota's keiretsu.[4] Aisin, originally a manufacturer of machine parts, became involved in electronic control systems in the 1970s. It is now a distinctive supplier of mechatronics parts. At Aisin, three departments: chassis design, electricity design and software design, are in charge of designing ECUs, the part that controls electronic control systems. In ECU design, these departments design the domain for which they are responsible and coordination is carried out with other departments. The fact that Aisin largely practices spin-off management means that it is also essential to consider the

3) However, in recent years the outsourcing ratio to Shanghai has plummeted while Keihin's in-house production ratio has risen.

4) This study is based on interviews conducted at Aisin on July 2, 2008.

relationship with development and production companies in the group and with other outsourcing subsidiaries, and virtually impossible to consider the tasks of each department in complete isolation. Conflicts between design departments are basically resolved through inter-departmental negotiations, although sometimes team leaders allocated to each product deliver a final judgment based on technical, scheduling, cost or other considerations. Since team leaders must have substantial knowledge and experience, Aisin considers it crucial to foster human resources with truly optimal decision-making powers. Consequently, the focus is on how to manage coordination between design departments, and task partitioning between departments is important in order to reduce man-hours needed for coordination. If these efforts at coordination produced ideal results, it follows that it would be possible to prevent the outbreak of conflicts. At Aisin, human resources capable of making decisions about task partitioning are known as architects or systems engineers.

Since it is taken as given that task partitioning at Aisin up till now was incomplete, conflicts were resolved as they occurred by organic connections which dynamically coordinated and optimized division of labor relationships between design departments and between firms. However, in Aisin's product development, connections were vital not only with electronic control systems, but also with machine parts. In architecture, where this tendency was particularly pronounced, it was hard to distinguish clearly where the electronic domain ended and the machine domain began and vice versa. In sites involved in the development of electronic control systems at present, on the other hand, there is a serious man-hour deficiency and the practice of resolving conflicts by relying on the coordinating ability of the persons concerned, as in the past, is reaching its limits.

Nowadays, Aisin must attempt to prevent the outbreak of conflicts that can be forseen beforehand by optimizing task partitioning between design departments. Fig. 2 sets out the discussion so far and illustrates the role of architects who act as coordinators between design departments and between

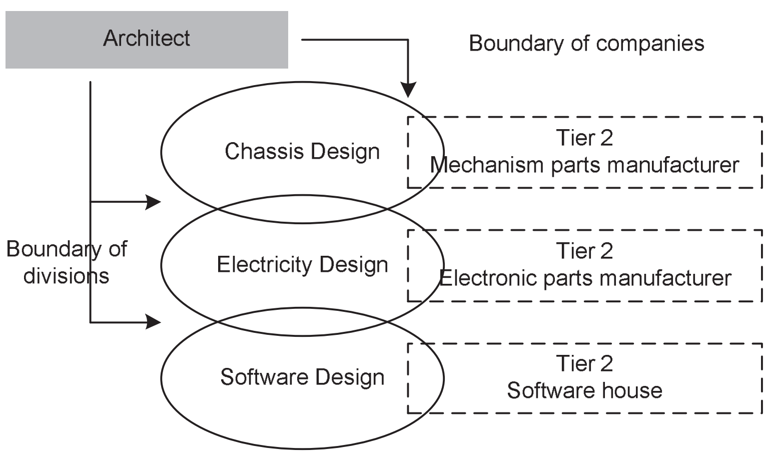

Fig. 2 Role of "Architect" in the phase of ECU development

firms. It is difficult both to draw a clear demarcation line between individual design departments, and to set boundaries between subsidiaries to which work has been outsourced. The architect is in charge of designing and managing boundaries between these organizations.

Architects as viewed by Aisin are different from IT systems engineers. In the case of vehicles, it is not enough to examine only the main constituents of the control system i.e. ECUs and sensors. The actuators and the mechanical section i.e. the parts being controlled must also be considered. This is common to embedded systems in general. Nevertheless, even if an architect exists, optimal task partitioning is hard to achieve. To take the example of the chassis, or the external part of the ECU, here it is essential not simply to design a pure structure, but to achieve an integrated performance related to electric and software design including thermal, aseismic, moisture proof and EMC design. The problem therefore arises of whether to put together a special team of chassis designers or whether to include them in the ECU design team.

Clearly therefore, where minute coordination between departments is required, task partitioning is more easily said than done. It may be inefficient to continue to carry out development as in the past by coordinating between the individuals concerned on an ad hoc basis. However, it is realistic to expect the coexistence of task partitioning by architects as far as possible and coordination for sections which cannot be resolved by task partitioning alone

(3) Product modularization in the auto industry: hybrid architecture perspective

From the facts that have emerged from our study of Keihen and Aisin, we can conclude that the most important feature in electronic control systems is "hybrid architecture" combining the features of both integral architecture and modular architecture. To define this concept, hybrid architecture, in relation to the elements which make up a product and the organizations which develop these, means that the correspondence of structure and function between component elements in the same layer has the features of both integral and modular architecture. Originally, product architecture for artifacts was concerned with the question of where to position it on a spectrum which had theoretically complete integral architecture at one extreme and theoretically complete modular architecture at the other (Ulrich, [1995]). However, in the case of our two firms, electronic control system architecture cannot be allocated to a single spectrum, but straddles several spectra for each elemental technology. For an artifact under these conditions, the design logic is such that there is a mix of several different elemental technologies inside both the product and the organization. In this study, this feature is known as hybrid architecture and is distinguished from integral architecture and modular architecture.

The important point about this concept is that a vehicle's electronic control system may be thought of as a multisystem. Specifically, products and organizations are analyzed from a matrix of two assessment axes. From the structural range, are they physical structures or logical structures? From the functional range, on the other hand, is the object reproduced by the function reproduced by physical

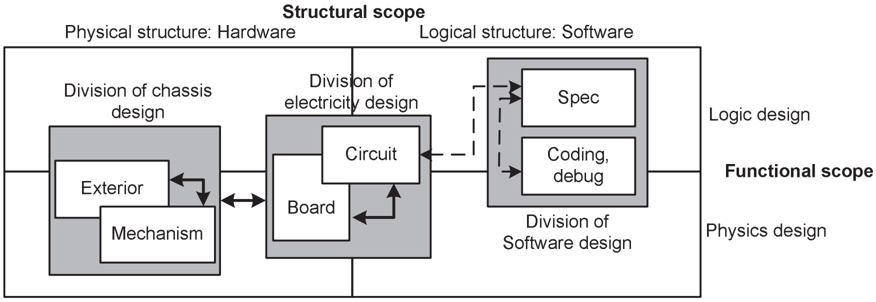

Fig. 3 Development organization characterized by hybrid architecture

design or logical design? The uniqueness of this method lies in the fact that it analyzes the structural range and the functional range of artifacts by unifying both aspects. In conventional research, most analyses focussed on hardware such as cars and electric appliances and visualized component elements were regarded as supply units. This is because discussions up till now were concerned mainly with the structural range. In contrast, the concept of multisystems proposes the concept of functional range as an alternative point of view determining the range of an artifact. It is not a question of killing two birds with one stone, but rather of unifying both assessment axes. Since our study takes the compatibility of product and organizational architecture as shown in previous research as given, the discussion from now on will proceed mainly from the perspective of development organization and will focus on the fact that each component element corresponds to an individual design department.

Fig. 3 subdivides the processes involved in the development of electronic control systems in each design department and shows the mutual dependence relationship between departments and between processes. Solid lines indicate a relatively high degree of mutual dependence between departments and processes, while broken lines indicate the opposite. The vertical axis is split into logical design dealing with intangible items and physical design dealing with tangible items. The horizontal axis is split into hardware design i.e. design of physical structures and software design i.e. design of logical structures. The stronger the orientation towards physical design, the more the architecture tends to be integral. On the other hand, the stronger the orientation towards logical design, the more the architecture tends to be modular.

In hybrid architecture, coordination between the mechanism design department strongly characterized by integral architecture and the software design department strongly characterized by modular architecture takes place through the medium of the electricity design department. The electricity design department is where the hybrid element, referring, literally, to a mix of two different features, is seen most clearly. This department has the role of transforming back and forth design logics possessing a different architecture. In fact, even in the case of Keihin, many of the LPLs who lead product development projects came originally from circuit design department. At Aisin too, since the ideal architect is someone with a sound knowledge of the system as a whole, people from circuit design department are likely to be greatly sought after.

From the discussion so far, three points are clear. The first is the need for a third point of view in the analysis framework for product architecture. Electronic control systems are not suited to the simple categories of integral architecture or modular architecture. They are a type of product based on multiple elemental technologies, and it is important to consider the fact that architectural features are different for each elemental technology. Current suppliers of electronic control systems will have to acquire the ability to develop simultaneously, in parallel and consistently, technology and products belonging to both integral and modular architecture within the same organization.

The second point concerns the imperative need to allocate managers well-versed in both logics in order to unify compatibly the architecture of these different products and organizations. From our case studies, it is clear that people who come originally from circuit design department are competent since they can transform different design logics back and forth.

Thirdly, despite the fact that 100 years have gone by since the birth of the car, when we consider the large framework of the auto industry, we realize that modularization has still not gone very far. Although electronic control systems have been adopted in every vehicle domain, their special features are confined to "hybrids" of integral and modular architecture. Moreover, because specialized managers are appointed to unify the various heterogeneous design logics typical of hybrid architecture, the product as a whole retains an even stronger whiff of integral architecture. We cannot observe any sudden rush towards modularization of the kind we saw in the case of many digital household electric appliances. While innovations such as electrification and computerization, which have made spectacular progress in the Japanese auto industry, may use many E & E parts that fall into the category of hybrid architecture, the situation before us is one which overturns prevailing notions about product life cycles.

4. Discussion: Hybridization of Industrial Structure

So far, we have looked at technological and organizational architecture within one firm. It is time now to adapt the framework of product architecture by broadening it to the industry as a whole and to consider tentatively how the spread of electronic control systems, which fall into the category of hybrid architecture, affects the industrial structure. For the Japanese auto industry in particular, the situation in each transaction layer can be shown in Fig. 4. The white circles stand for firms that manufacture machine parts. The deeper and lower the transaction layer, the smaller the scale of the firm (size of circle). Tier 2 and below focusses mainly on transactions of design-supplied parts. Here, in the Japanese auto industry, a transaction chain centered on the traditional keiretsu i.e. a pyramid type structure is maintained. Black circles stand for E & E parts firms in charge of functional components (e.g. Keihin). Similarly, the gray circles in Tier 1 refer to manufacturers of machine parts (e.g. Aisin)

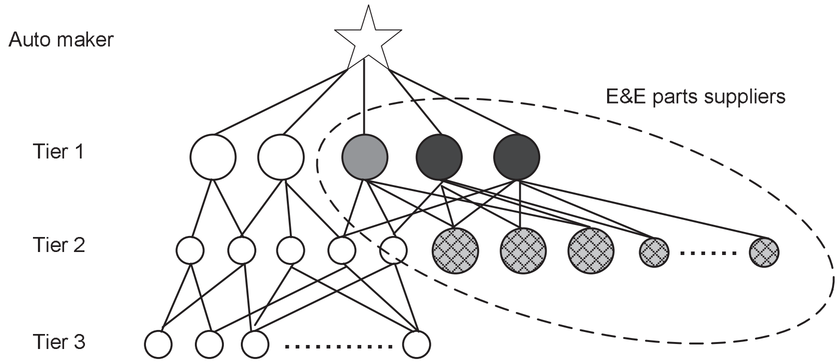

Fig. 4 Hybridization of industrial structure in Japan

which have become involved in E & E parts through diversification or M & A. The half-tone gray dots in Tier 2 are suppliers of semiconductors and electronic components.

A number of functional component suppliers which supply components in units are positioned in Tier 1. Broadly speaking, most of the leaders of the rapid expansion in the E & E parts market are firms that grew either through external factors, where products manufactured in-house changed gradually over the years from machine parts to electronic control systems, or through internal factors, where they saw future potential and launched spontaneously into E & E parts. Sometimes firms were encouraged by both external and internal factors. These firms partially retain conventional machine parts (external covers and structural parts). However, since they rely on electronic control systems for most of their product added value, they procure huge volumes of PCBs and electronic devices. Furthermore, even within electronic control systems, ECU suppliers often outsource software. ECU suppliers such as Keihin and Aisin described above, will need advanced technological and capital power as well as the ability to manage outsourcing subsidiaries.

Tier 2 supplies parts solely to Tier 1, and here semiconductor and electronic part manufacturers are strongly present. Among these electronic device suppliers, there are many specialist firms specializing in particular parts or categories. It used to be thought that suppliers in the lower transaction layers such as Tier 2 and Tier 3 were mainly small design-supplied-parts suppliers with relatively inferior technology. However, manufacturers of these electronic devices are huge, and even suppliers to Tier 1 often display strong negotiating skills against a background of black box technology. Besides, while these are B to B transactions, many marketed goods are involved, and cars i.e. assemblages of custom parts are an exception. In addition, many of these electronic device suppliers do not belong to the keiretsu and, typically, customers are also dispersed. These firms, in short, cannot not be freely controlled by auto manufacturers and Tier 1 firms.

Again, we must not forget that many of the small and medium-sized firms which supply design-supplied parts are also included in Tier 2. In procurement at firms manufacturing electronic control systems too, as seen in metal processing such as dies and presses, manufacturing processes such as resin molding and surface processing, and assembly processes for component parts, outsourcing, accompanying a typical layered structure, remains in transactions of machine parts. Nevertheless, the ratio of machine parts to E & E parts is relatively low both in terms of number of parts and amount of money.

It is clear that the transaction structure in the present Japanese auto industry combines a traditional pyramid structure (left of figure) with complete administrative control as in keiretsu transactions, and a horizontal structure (right of figure) where there is rivalry between firms seeking a balance of power. Where differences in transaction structure are observed in individual technology systems, the spread of electronic control systems confers a character of "hybridization" to the industrial structure.

5. Conclusion

The goal of this study was twofold: to clarify the state of modularization in the products and organizations of firms involved in the electrification and computerization innovations sweeping through the Japan auto industry, and to shed light upon the path taken by the car, a mature product, to reach its present stage of modularization. In connection with the former, an examination of the development of electronic control systems at two firms, Keihin and Aisin, revealed the fact that in this domain the features of both integral and modular architecture are found side by side. In our study, this is called hybrid architecture. In connection with the latter, it was possible to indicate hybridization of the industrial structure, i.e. the fact that the transaction structure is different for individual technology systems. The situation that emerges is one which seems to overturn prevailing notions about product life cycles. In other words, it will not be easy to modularize vehicles, which have a history stretching back over 100 years.

Nevertheless, the author was not able to talk about this factor in this study. Unlike the period up till the middle of the 1990s when computerization took the lead, now that electrification, with the sale of electric vehicles, has started in earnest, vehicle modularization will no doubt accelerate. Still, a look at the worldwide market shows that sales of EVs can hardly be said to be buoyant. The time is probably not yet right to give birth to a full-blown trend. The influence of Japanese transaction customs probably lies behind the factors which make it hard to modularize vehicles, or which mean that modularization has not really taken off. In determining the marketability of finished products, Japanese auto makers have more say and greater influence than ever vis-à-vis suppliers. Therefore, auto makers intervene forcefully in the product development process even when products are outsourced, and can coordinate arbitrarily so that specifications are not suited to modularization which would be disadvantageous to the auto makers themselves. An attempt to clarify the coordination situation and the processes and mechanisms for delaying modularization should be the author's next theme.

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