Discussion Paper Series No.143

System Architecture Dynamics
The case of Japanese Car Navigation Systems

Munehiko Itoh　Kobe University

November　2003

System Architecture Dynamics
The case of Japanese Car Navigation Systems

Munehiko Itoh
Research Institute for Economics and Business Administration,
Kobe University

Abstract

This paper attempts to clarify how the integration of software and hardware is related to product systems and product development organization in the growing electronic equipment market in the IT age. As a framework for analyzing the effect of integration, we will examine the influence of software on product functions, product development organization and product innovation by introducing the concept of system architecture, which represents the nature of a system, and is defined as a combination of hardware and software.

As a particular case, Japanese car navigation market is analyzed. Regarding system architecture, we discuss how both software and hardware have open architecture dynamics, how those dynamics have several trajectories, and have a major impact not only on cooperation between product development structure and external organization, but also on innovation.

1. Introduction

Software has come to play a key role that very much determines the success or failure of a product in the growing electronic equipment market of the IT age. This paper attempts to clarify how such software, especially databases and contents that are key elements, are related to product systems and product development organization. In addition, as a framework for analyzing the effect of integration on software and hardware, by introducing the concept of system architecture, it attempts to paint a clearer picture of how software affects product function and product development organization.

As a particular case, the Japanese car navigation market is investigated in detail, and discussed how system architecture is related not only to the interplay between product development structure and external organization, but is intimately related to the nature of the software that is built in, and has a major impact on innovation.

2. Concept of System Architecture

In this paper, product development of electronic equipment is discussed. Globalization of product development and the shortening of product development lead-time are recognized as a factor responsible for the success of Japanese enterprise. However, it has been pointed out for instance that in electronic equipment for the IT age, such as gaming machines, cellular phones, personal computers, music reproduction equipment, digital cameras, car navigation systems, PDA, routers or semiconductors, it is not only Japanese companies that have succeeded, and there are also problems with the Japanese business model and its insistence on vertical integration[1]. Several common success factors are seen to be responsible for the generalization of such electronic equipment. For example, some factors are absent from the conventional business model, such as the use of external network features, high-level integration and networking of content or software such as databases (IP in the wide sense - also including intellectual property rights and databases), and virtual organizations such as electronics manufacturing services (EMS) or foundries. In such a business model, how to promote systematization by integrating hardware and software to achieve effective performance is a key issue of product development. This paper proposes the concept of system architecture and aims to consider an analysis framework for systematized products.

Product architecture can be classified as integral or modular from the viewpoint of product function and as open or closed from the viewpoint of cooperation with other product development and production in other organizations (Ulrich, 1995; Boldwin and Clark, 1997; Boldwin and Clark,2000). However, when we analyze systems where software is highly integrated into hardware as it is in the electronic equipment produced in recent years, some problems can arise. For instance, if the hardware that comprises a certain system is closed, and the software has an open structure, it may be that the structure of the system cannot be determined. Thus, to analyze systematized products, classification according to whether product architecture is modular or integral, or open or closed, is inadequate. In this paper, we propose the new analytical framework of system architecture for this type of software interaction.

In this context, system architecture is defined as the nature of the system specified by hardware and software architecture. Fig.1 illustrates this system architecture concept.

In Fig.1, the software and hardware product architectures are shown respectively on the X and Y axes, open or closed, and the system architecture is represented as a matrix. Here, open is a state where the interface between product components is standardized at the industry level beyond the enterprise, and closed is a state where the design of the interface is limited to one company (Ulrich,1995:Baldwin and Clark,2000;Fujimoto and Yamamoto,2000). In the figure, the system architecture is classified into four regions depending on the combination of software, hardware, open and closed.

These designations depend on where the software is present in the system; i.e., what is it combined with. To facilitate understanding, we will describe an example of the system known as a word processor. A standard word processor is an integration of software and hardware, and these cannot be upgraded separately. In this word processor, the software is integrated with the main body (set), and is therefore referred to as a set bind. In addition, when the number of word processor models increases, to avoid software development time and development costs, the software is

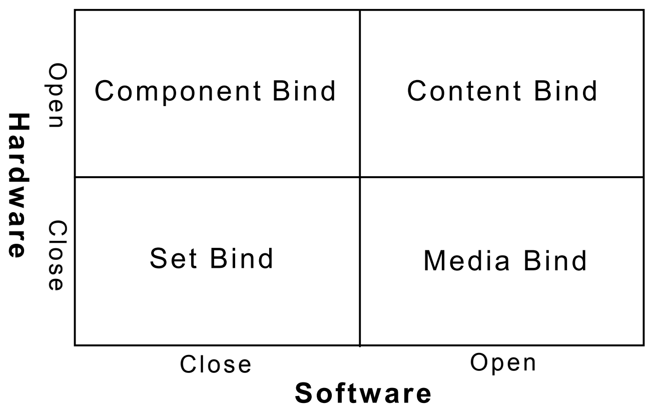

Fig.1: The classification of system architecture

likely to be shared by different hardware. As the software is bound to common components in different word processor models, it is referred to as component bind. If the word processor software can be upgraded using a medium such as a CD-ROM, it is referred to as media bind. Finally, assuming that the word processor can freely download software on a network like the Internet, the software is referred to as content bind because it is delivered as content on the network. The naming of the four system architectures is as shown in Fig. 1.

The concept of each system architecture is shown in Fig.2. In the figure, M1 and M2 represent modules, these modules being connected by interfaces referred to as I1-I8, and integrated by design rules referred to as DS1 and DS2. SM1 and SM2 are sub-modules. The sub-modules here indicate modules having open interfaces like I5-I8 in the figure. Hardware can be classified as open or closed even in the presence of sub-modules (Baldwin and Clark, 2000;Aoki and Ando, 2002). First of all, in the case of set bind, as the software is integrated into the product by interfaces I3

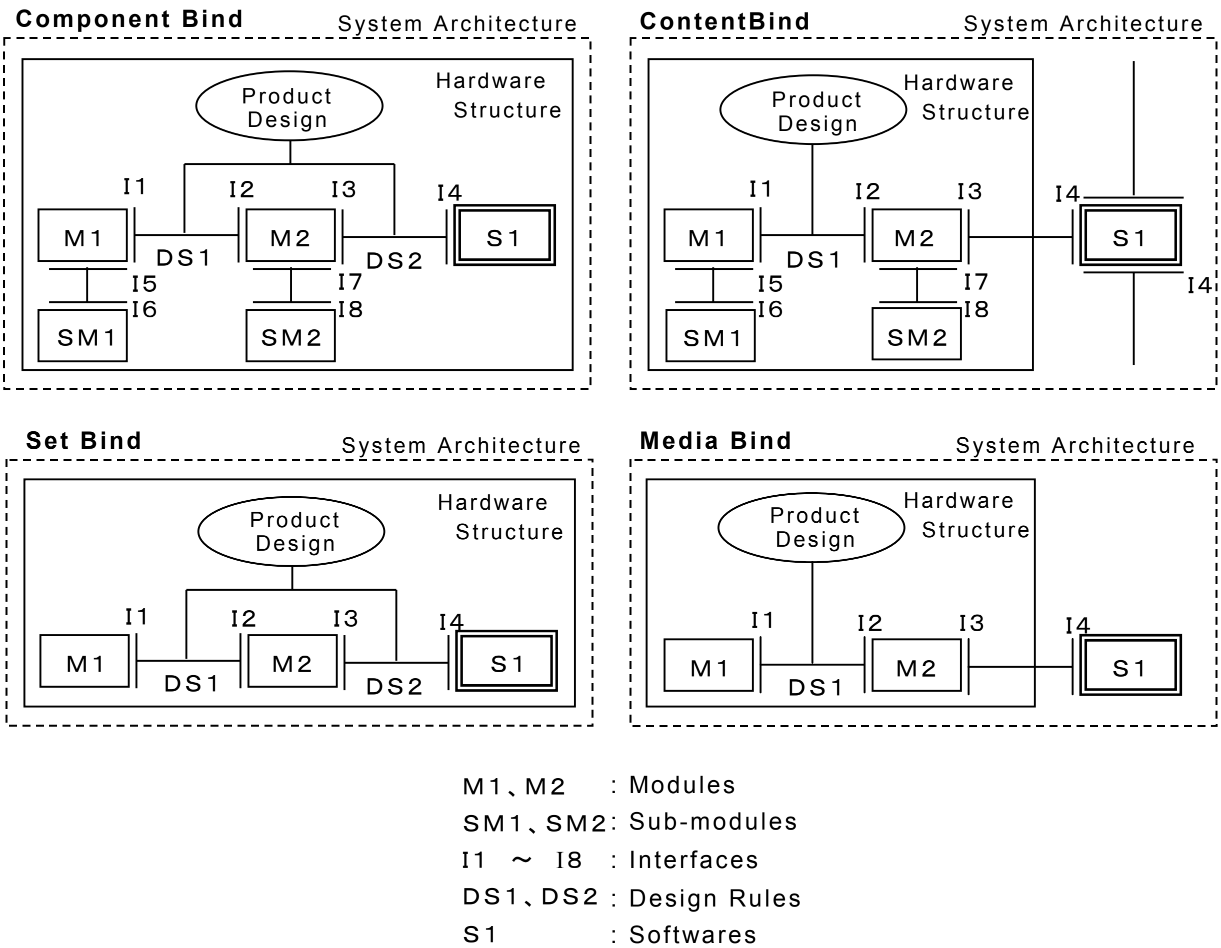

Fig.2: The concept of system architecture

and I4 and design rule DS2, both hardware and software are closed architectures. Next, with a component bind product, the difference is that, although the software is integrated into the hardware by interfaces I3 and 14 as in the case of set bind, there is a sub-module, so the hardware has an open structure. In a media bind product, the software is connected by interfaces I3 and I4 via media, such as various storage media. Here, the difference from set bind is that, as the software has an open structure, it is interchangeable with other software. The hardware, on the other hand, has a closed structure. A content bind product shares the common point with media bind that the software has an open structure. The difference is that the hardware, like the software, also has an open structure.

Above, the concept of product architecture has been extended to system architecture. In system architecture, modules which are product components are not merely distinguished by a simple reason of whether they are physical or non-physical, but are specified according to the nature of the software to be integrated. In this text, using this concept of system architecture, we analyze the relation with product strategy and product architecture, and product development structure within a company and between companies.

3. Purpose of This Paper

The purpose of this paper, by analyzing the architecture of a product wherein the software and hardware are systematized from the viewpoint of software development, is to answer the following questions:

1. How is the product development structure related to product strategy?
2. What dynamics does the system architecture have?
3. What product development strategy can be taken to anticipate innovation?

System architecture is a concept of representing product composition systematized by software and hardware. The aim of this text is to dynamically analyze the relations between system architecture, innovation and product development structure by using this concept. The car navigation system was selected as an analysis case in this study.

The reason for selecting the car navigation system is because this is a new product that is only ten years old since dynamic design started, because it was not difficult to acquire materials to perform the actual study, and because, as the development of car navigation hardware and software such as digital maps is completely separate, and handled by different companies, a precise analysis of system architecture is possible.

4. Innovatory Changes in The Car Navigation System Market

This chapter discusses innovatory changes in the car navigation system market. First of all, let us review the history of the car navigation system. The navigation technology has a long history. A prototype of the system can be found in China, B.C. At that time, in China, there were expeditions every time there was a war, so a rickshaw having a rudimentary navigation system which made use of the difference between the inner wheels of the car, known as a "teaching car[2]", was used as a guide from the battlefield to the hometown.

In August 1981, HONDA developed a product known as the "Honda Electrogirocator" that employed a gas sensor[3] for munitions purposes. This product required manual replacement of maps and was inconvenient to use, so it was not commercially successful. Subsequently, a displacement position difference detection sensor[4] known as an optical fiber gyro was invented and introduced to the market successively by Toyota, Nissan and Mitsubishi Motors Corporation that offered higher precision, but due to its high cost and difficulty of using maps, it was not accepted by the market. About 10 years later, in 1991, revolutionary US-led GPS[5] technology, bulk storage technologies such as CD-ROM and digital map technology reached a stage where it could be used, so car navigation dynamic design was born. At the time, GPS car navigation systems were still costly, but when Sony developed products at an affordable price, the market suddenly woke up. Let us now look at the innovatory changes that took place after that.

First of all, the dominant design of the car navigation system was established in 1991. The epoch-making technology known as GPS was introduced, and market growth of the car navigation system started. Since then, the basic product composition of combining the position detecting functions of GPS with a digital map has not yet changed. In 1992, second-generation products were introduced where GPS technology was combined with gyro-sensors. Due to the concurrent use of gyro-sensors, car navigation could be performed even in tunnels and basement car parks where the GPS signals could not reach. The third-generation car navigation system of 1993 was a major turning point. This generation aimed to change the initial concept of the car navigation system from "knowing the present position" to "guiding the driver to his destination". In the fourth generation of 1996, real-time traffic information known as VICS[6] was added to the technology for guiding the driver to the destination, so that the driver could be guided to the destination in the shortest possible time. With the fifth generation introduced in 1997, DVD was introduced which permitted large amounts of visual driver functions and information on roads leading to the destination. Subsequently, in the sixth generation up to the present day, digital maps based on industry-wide standards known as KIWI[7] newly drawn up in 1999 were introduced, and the kinds of maps that could be used were expanded. In addition, in 2002, a digital map with a world standard named KIWI-W appeared, so that the same hardware could be used all over the world simply by replacing the map.

Fig. 3 shows an overview of how the innovations mentioned above are related to market expansion. This diagram shows how the car navigation system market - which began by using first generation GPS that started in 1991, and was technologically transformed by the fifth generation that started in 1997 - has expanded. It also shows that product development progresses in two ways; i.e., gradual improvements in the products of each generation, and innovations.

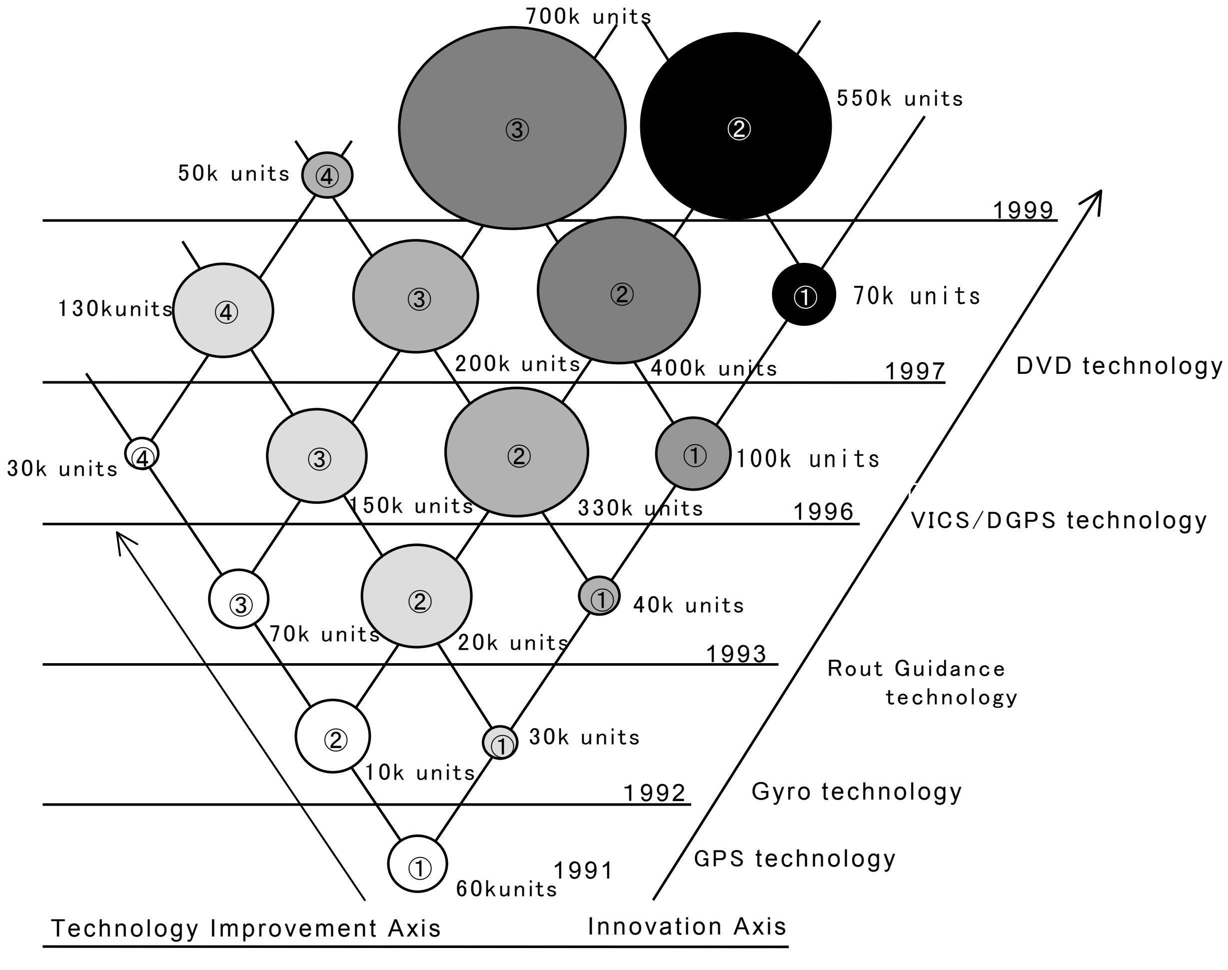

Fig. 3: Market expansion model in car navigation system products

5.System Architecture And Product Development Strategy

In this chapter, we will compare the product development strategies of two companies that supply digital maps. This analysis was done based on the results of interviews with Zenrin Co., Ltd. (hereafter, Zenrin) and Increment P Ltd. (hereafter, Increment P) that are digital map companies[8]. The reason for selecting these two firms as an analysis target is that these are the only two enterprises selling digital maps for car navigation systems in the Japanese domestic market, and they monopolize the market. These two companies have been supplying digital maps ever since car navigation systems entered the market full scale in 1991. Zenrin has offered its own brand name products based on the specifications of the car navigation society[9], a consortium of car navigation system enterprises. On the other hand, Increment P does not use its own brand, but developed a map database and applications in cooperation with car navigation system companies.

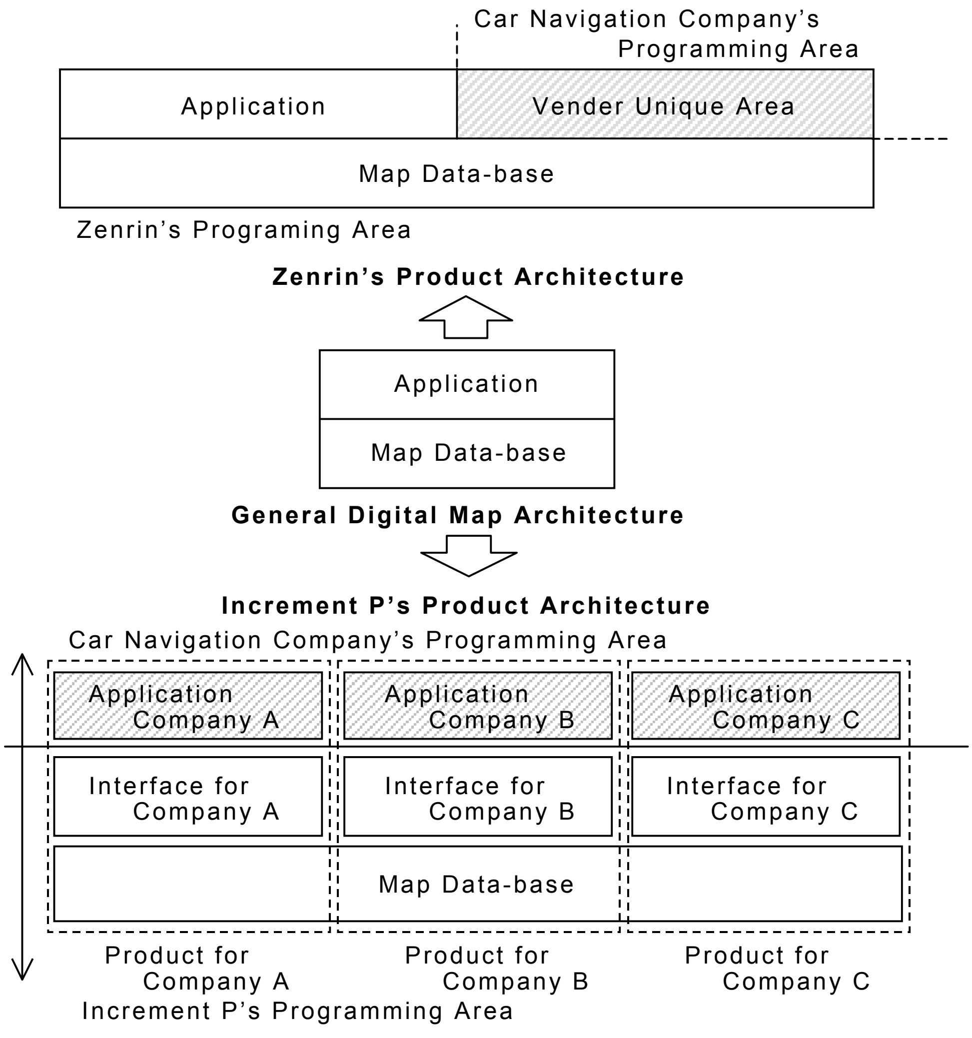

Fig. 4: Comparison of product strategies of two digital map companies

First, we will analyze the product strategy of the two companies from such a viewpoint. The two companies both cooperate with several car navigation system companies. Digital maps generally consist of application areas where active work is done to link a database of information such as roads, houses, landmarks, telephone numbers, addresses, lamps and lanes, with requests from the driver using the car navigation system that comprises a route deduction engine, a search engine and a speech engine. If a car navigation company's digital maps are to secure a market share as standard products, this product composition is sufficient, but there is usually a demand for many improvements, changes and development of new functions. Fig.4 shows the product strategy adopted by Zenrin and Increment P in the face of such demands.

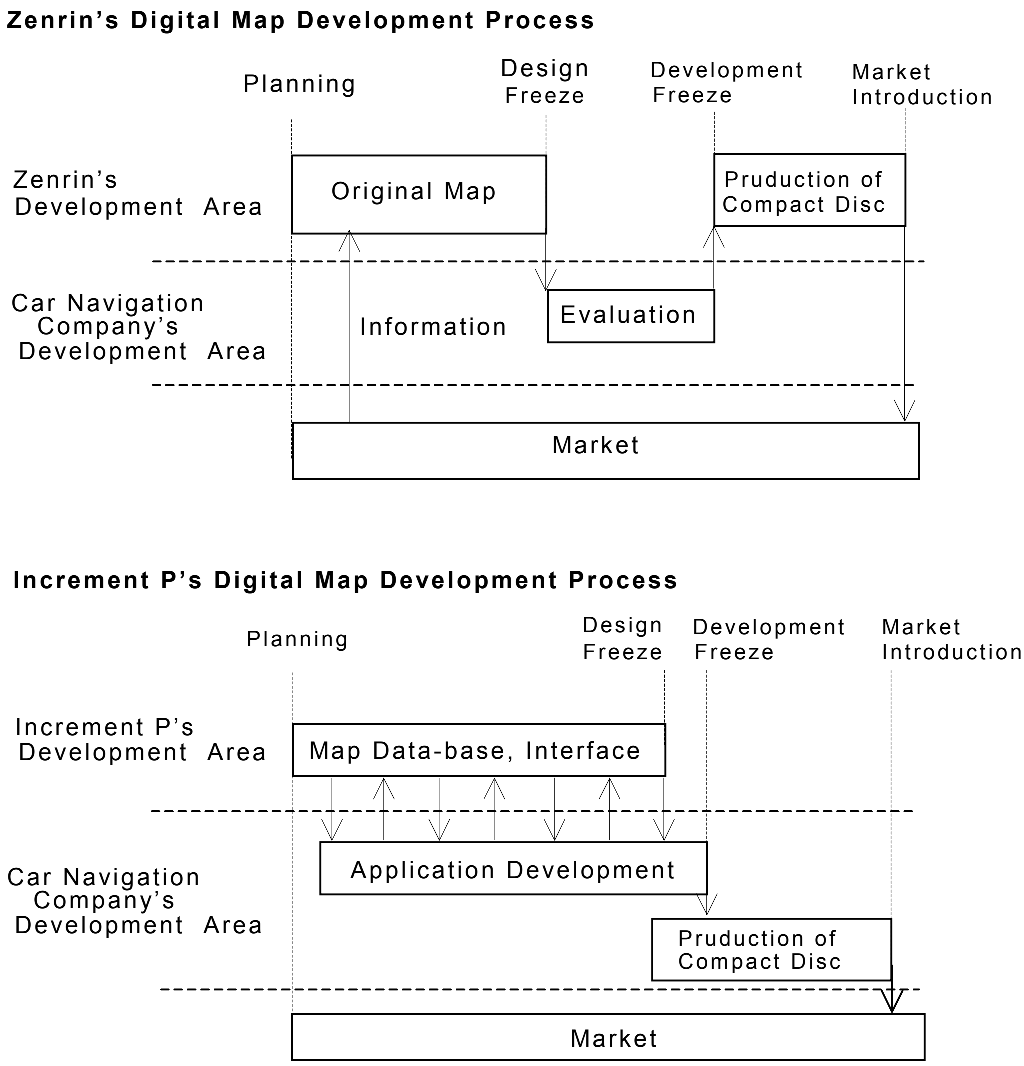

Fig5: Comparison of digital map company product development processes

First, Zenrin created a vendor unique area[10] where the car navigation system company programmed and designed its own functions in the application area, and published the specification. By so doing, a standard product is offered to car navigation system companies, and the car navigation system company has its own customization area while maintaining compatibility with other companies. By not entertaining any customization requests from car navigation system companies and selling only one product, the best use is made of economy of scale. On the other hand, Increment P adopts a product structure that embeds applications matched to requests from each company in its own map databases, and tries to integrate them into the systems developed by each car navigation system company.

Fig. 5 shows the difference between these product strategies, and compares the product development processes of the two firms. First, Zenrin makes company proposals based on a specification decided by the consortium, and from the market, it directly acquires opinions and information required for product development such as setting up user clubs, management information and product buyer surveys. After the design of a new digital map planned by Zenrin is finished, it is released as an alpha version to receive functional and quality evaluations and feedback from the car navigation system companies. If required, a beta version is also released. After the quality standards for the software have been met, Zenrin manufactures a CD and ships it under the Zenrin brand to the car navigation system companies where it is bundled together with the car navigation system, and sold.

On the other hand, in the case of Increment P, information is exchanged with car navigation system companies from the planning stage based on its own digital map database specifications, and the

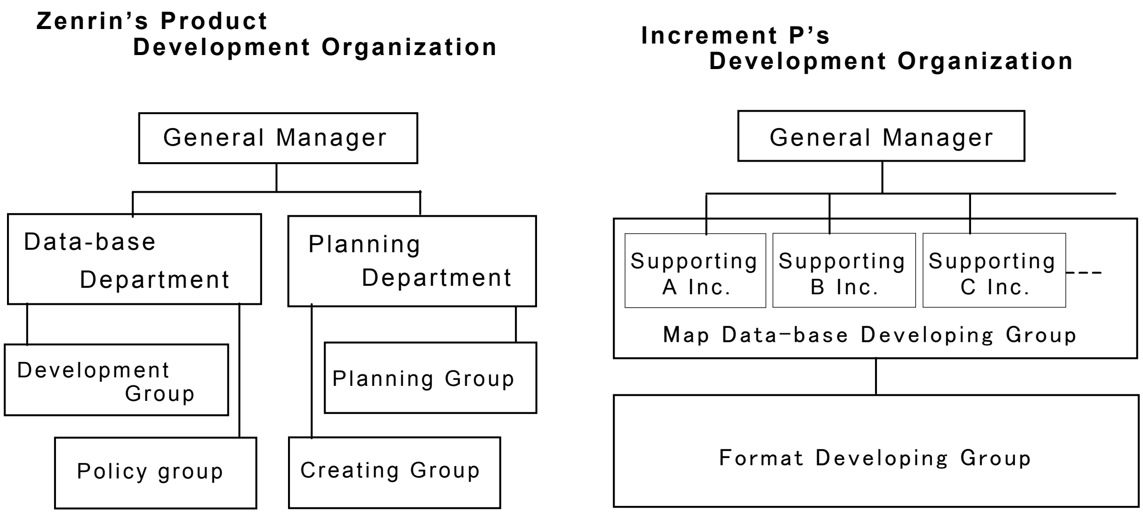

Fig. 6: Comparison of Product development Organization

development is undertaken jointly with Increment P. This joint development is continued until just before product manufacture, so the interface created by Increment P is incorporated into the map database, and the product is then shipped to car navigation system companies. The car navigation system company manufactures the CD after its own application part has been added, and sells it as its own brand. Fig. 6 shows the organization of this product development process.

Firstly, in the case of Zenrin, it develops its own brand products under an independent plan based on the specification of the consortium. In the general digital map part, a database part that deals with map databases and a car navigation map planning/production part are arranged side by side. On the other hand, in the case of Increment P, where product development is carried out co-operatively in synchronism with planning by a car navigation company, and which supplies products that are not its own brand, a project organization suited to the car navigation company is adopted. In this organization, a map database section that is used by both, follows a formatting part which creates a special interface for the car navigation system company involved in joint development.

In addition, let us compare the product strategies of the two companies from the system architecture aspect. First of all, Zenrin's digital maps are single products to give priority to interchangeability between the companies that use them, and the

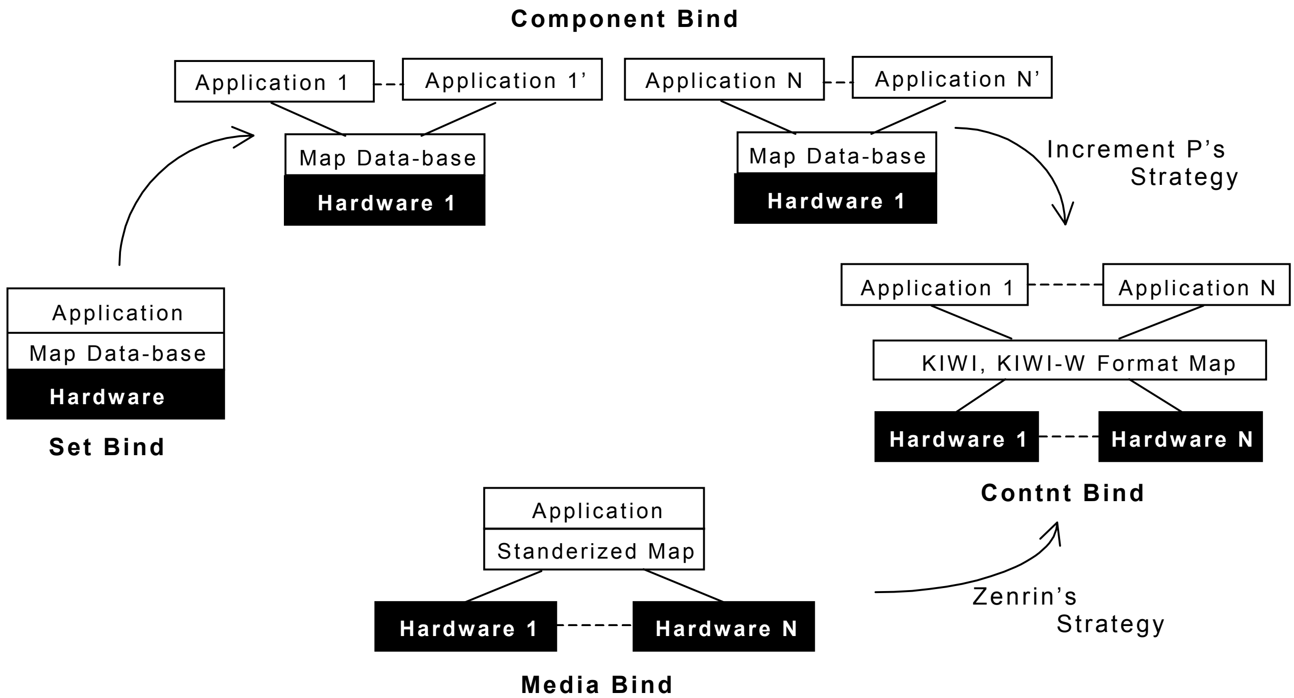

Fig. 7: Comparison of Zenrin and Increment P Strategies

products were developed based on the Navigation Study Groups, KIWI, KIWI-W and the standards of the consortium from beginning to end. KIWI and KIWI-W are map databases standardized to correspond to a variety of car navigation system models, and have a structure that is open to all sorts of application software. Also with hardware, to match the standards KIWI and KIWI-W, as for position detection, a standard product composition is defined such as combinations of GPS with gyros and supply of digital map information by DVD, while sub-modulization is increasing, and an open structure is now being adopted. Thus, the Zenrin system architecture selected a strategy that starts from media bind which emphasized interchangeability between car navigation system companies that adopted the standard format of the Navigation Study Group, and is aiming for content bind to be able to correspond to all car navigation systems.

On the other hand, Increment P originally started with the development of special digital maps for one car navigation system company named, Pioneer. In other words, it started from set bind as shown in Fig. 7.

It then became independent, the number of customers increased, and digital maps customized for the number of dealer companies came to exist. Increment P became involved with innovation in the car navigation system market very early on. However, as will be seen also in Chapter 4, after 1991 when the dominant design of the car navigation system had been decided, innovation shifted gradually from major innovations accompanied by changes in the concept of guiding to the destination, to the incremental ones of making use of traffic information and higher volumes of map data. In addition, on the hardware side, functions like GPS, DVD and displays became modular as the market expanded, and the focus of product development by car navigation system companies shifted from hardware to the perfection of software. Consequently, car navigation system companies must now face the cost of updating maps in the original format every year, various emerging demands according to user age groups, region and applications, and the fact that car navigation systems are now expanding all over the world. Also, instead of developing their own maps, they will have to share map databases by conforming to the industry-wide standard specifications of KIWI and KIWI-W. Digital maps have changed from a closed to an open architecture. Thus, from the concept of system architecture, a strategy that started from set bind, went through component bind and is now aiming for content bind, has now been adopted.

Above, we showed how Zenrin and Increment P dealt with car navigation companies by different product strategies, but with the growth of the market, both firms now conform to the industry-wide standards KIWI and KIWI-W. The two firms actually have a different organizational structure. However, the result is that the standard specifications of KIWI and KIWI-W are now unbundled from car navigation products and are now platforms, so that product development elements like application and hardware have become separated and their development has proceeded separately. Against a backdrop of these industrial structure changes, Zenrin is focusing on developing map databases for the platforms KIWI and KIWI-W, whereas Increment P that has a project type organizational structure is stressing the development of client applications based on KIWI and KIWI-W.

6. Dynamics of system architecture

What role does a digital map play in the evolution of product systems, and how has each car navigation system enterprise evolved products and systems? Here, we shall analyze the dynamics of the system architecture of car navigation system companies. First, we will define the system architecture of a car navigation system product. We decided whether hardware was open or closed from the results of a survey of all car navigation system enterprises[11]. As hardware, if a GPS receiver and DVD-ROM was used as the subsystem shown in Fig. 2, the architecture was determined to be open, and if it was integrated by an original specification, it was determined to be closed. On the other hand, for software, if it used industry-wide standards such as those of the Navigation Society, KIWI and KIWI-W, it was determined to be open, and if it

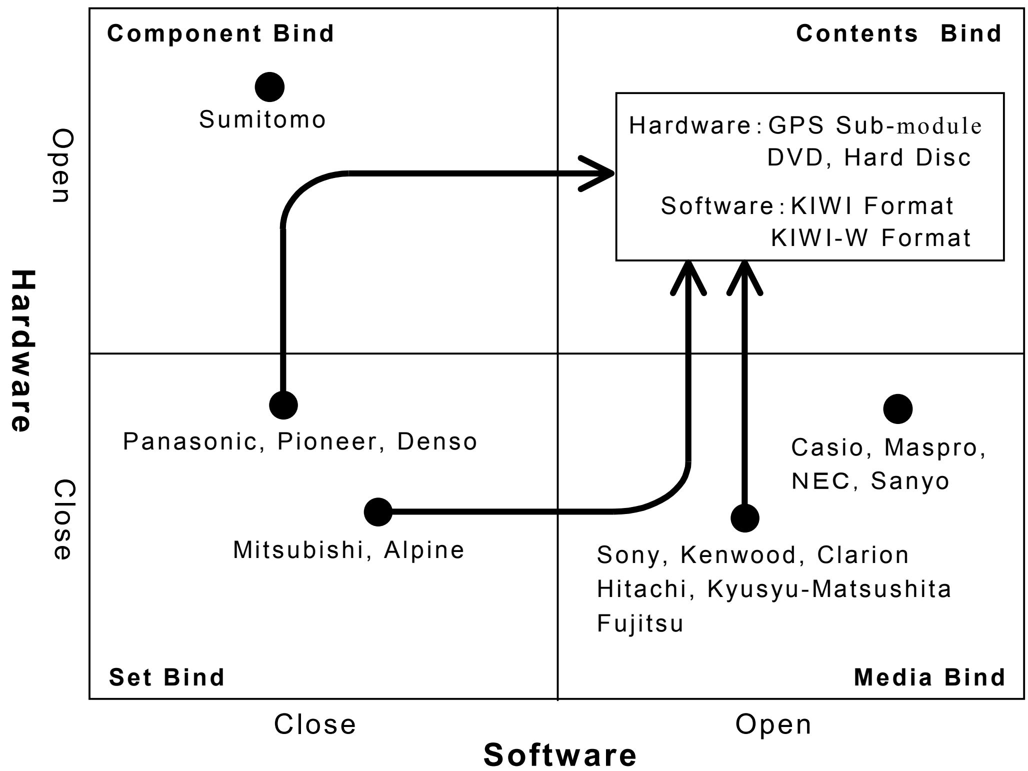

Fig. 8: Dynamics of system architecture in car navigation system market

used an original digital map database as in the case of Increment P, it was determined to be closed. Fig. 8 shows what system architectures car navigation system companies have actually adopted. In the diagram, the black circles show market entry, and that set bind, component bind or media bind is adopted when the market was entered.

Many companies entered from media bind, and there were also five companies entered from set bind. Only one company entered from component bind. Although different system architecture was adopted when entering the market, what product strategy did each company select afterwards? As a result, of 16 companies that entered the car navigation system market, 11 companies aimed for content bind.

Let us consider the reason for this from the software view of points. Progress in software is later than in hardware, because it is thought that, as the software becomes larger scale, its development increases more than linearly, while productivity falls less than linearly (Brooks,1995; Iansiti,1998). There are also two reasons why software follows progress in hardware. Software cannot easily be given a modular format like hardware, and as new hardware functions are transmitted to the user by software, it is thought that software exceeds hardware development speed when the advancement of hardware stops. Therefore, many companies concentrate on the development of hardware when entering the market; i.e., they enter the market from set bind or media bind.

We will analyze this point in further detail. The structure of software consists of content and application. In the case of a car navigation system, it consists of a map database of roads, telephone numbers and landmarks, and an application that retrieves and displays this information. Other electronic equipment has an identical construction. For instance, with a cellular phone, the receiving melody is content, and an application stores and plays it. Considering the three elements of hardware, content and application, we may make the following classification:

1. Set bind is when the development and integration of all elements is performed in-house,
2. Media bind is when the focus is on development of hardware,
3. Component bind is when the focus is on development of applications.

Then, how is contents bind actually expressed? Of the three elements, the application is related to the hardware development and content being independent. In the market growth period, content influences the success or failure of the product. For instance, with the receiving melody of a cellular phone, how much content there is; i.e., the number of tunes and the tones that can be offered, become a factor in success.

However, once content is present to some degree, differences in performance disappear, and it is then range of choice, ease of download and speed that become competing factors. Content is always being updated due to maintenance and addition of new information. Each user only uses a fraction of a huge amount of content, but it takes a great amount of effort and time to construct the content, hence, the number of users must continually be increased to realize a profit. Therefore, if content aims for product maturity, and network externalization by platforming, market opportunities will increase (Fine,1998), and it has a tendency to stratify/differentiate and become more open, as shown in Fig. 7.

For instance, whereas cellular phone receiving melodies were previously specific to each company and each model, it is now possible to download them from various sites via a network. With digital cameras, whereas at the beginning they could only handle photographs in an original format, they now use the common JPEG format, so photographs made by any company or model can be moved, stored and printed freely. Likewise, in car navigation systems, digital maps can be selected according to usage. Therefore, content bind means stratifying contents, which can be understood to be a concept wherein different elements such as application, hardware, development speed and development method, are differentiated. Such a concept can generally be applied to electronic equipment. Content can be shared by any model of cellular phone, digital camera and music reproduction device in the format known as MPEG3. In addition, personal computers may be described by a similar concept.

However, with gaming machines and DVD recording/reproduction devices, the content is not stratified or differentiated, and it is thought that set companies are still adopting a set bind or component bind architecture as they have not made their software interface public.

We have shown the dynamics involved on the path to content bind, but why, then, are there two routes by way of component bind and media bind? In the car navigation system market, 8 out of 16 companies aimed for content bind via media bind. These companies are enterprises that aimed at differentiation by hardware as a strategy when entering the market. On the other hand, there were 3 companies that aimed for content bind from component bind, and these may be considered to be enterprises that concentrate on application development rather than hardware. Thus, it appears that the strategy used by an enterprise to reach content bind is decided according to where the competitive edge of the enterprise lies.

In this chapter, we have been discussing the dynamics of system architecture. Consequentially, many car navigation system companies are now aiming for a content bind architecture. Such dynamics mean that, as the focus of competition shifts from hardware to software and content matures, differences of competitive edge between companies entering the market will disappear, and as they aim for platforms and network externalization, they will stratify and differentiate. In car navigation systems, two companies, Matsushita Electric Industrial Co., Ltd. and Pioneer, which entered the market from set bind, have led the market from beginning to end. This suggests that beating the competition requires a wealth of experience of hardware and software integration techniques. Similarly, in the gaming machine and cellular phone markets too, the competitive edge of companies that entered from set bind has been built up over a long period.

7. System architecture and innovation

Let us now analyze the relation between architecture and innovation. Again, we will consider the relation between product development strategy and innovation in the two firms Increment P and Zenrin. By this analysis, we also want to discuss what strategy a firm should take to lead innovation.

Here, we will examine the product development history and the accompanying innovatory changes in the two digital map firms. Fig. 9 shows details of the product development of Zenrin and Increment P according to year by using a system architecture frame.

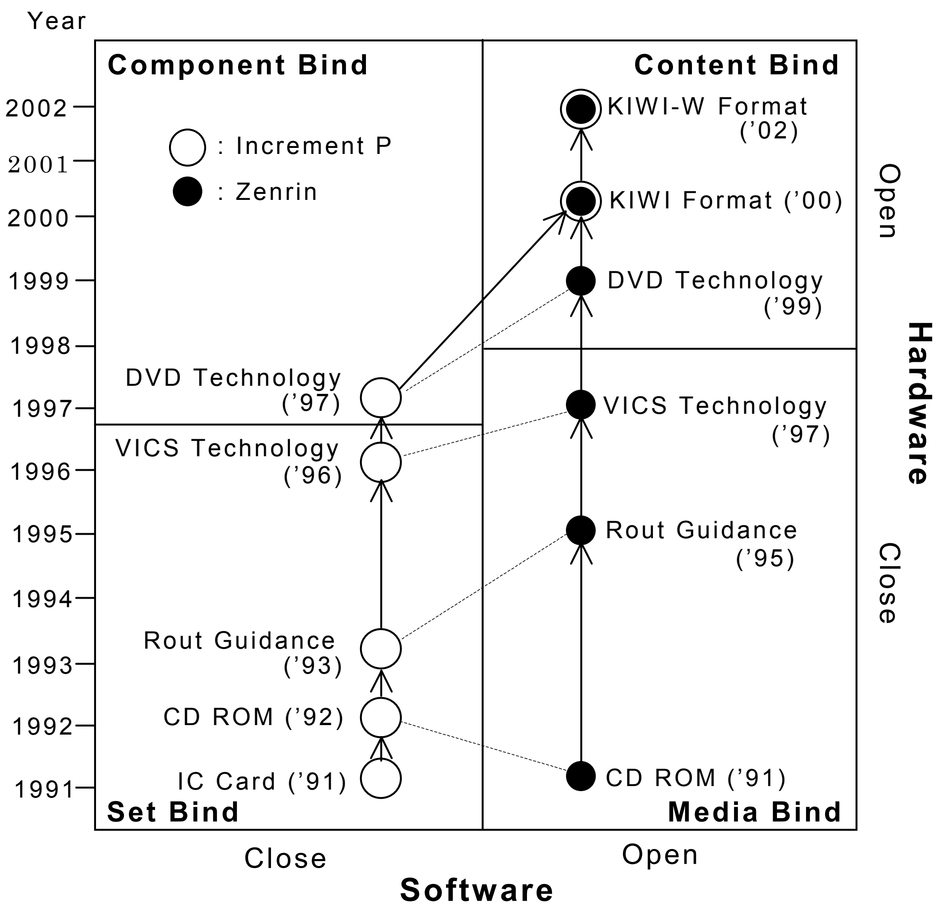

Fig. 9: Response of digital map companies to innovation

As is clear from this diagram, innovation in the car navigation system market has always been preceded by a product development that is 1-2 years ahead of its time via the digital maps of Increment P. There are several reasons why Increment P has led the field. First, Zenrin's digital maps are based on the standard specification of the consortium known as the Navigation Society, and if the wishes of all participating companies are brought together, the specification will always follow innovation. In other words, the specification easily becomes that corresponding to the company that was slowest to adapt. Conversely, as Increment P was able to determine the specification relatively freely for every company, the possibility that innovative products would be developed was high.

Subsequently, all companies participated in KIWI, which is a digital map consortium, and after 2000, put out products at the same time. In this product development, the environment surrounding these two companies that deal with digital maps; i.e., innovation in car navigation systems and consortium activity, etc. in car navigation, is the same and they are facing similar technical problems. Software development is characterized by the successive introduction of product functions, so there is not much difference of product functions between the competing companies, and they have rather come to resemble each other (Iansiti, 1998).

We have seen how digital map companies have dealt with changes of innovation in the car navigation system market. The products of Increment P were always fast at keeping up with innovations. On the other hand, Zenrin has responded by marketing open architecture digital maps. As a result, the differences of the two companies have disappeared in the development of digital maps specified by the consortium. In other words, this shows that in systems, software that aims at a closed product architecture leads innovation, but the new functions are finally incorporated, and the differences gradually disappear. This means that in the system architecture, hardware has a closed architecture, set bind and component bind precede innovation, media bind takes a "follow-on" product strategy, and these finally converge to content bind. As we have said in the previous chapter, companies that had their own maps like Matsushita Electric Industry and Pioneer, which designed the car navigation system in collaboration with map firms like Increment P, have always led the market. In electronic equipment innovation, hardware is first, followed by software. Here, many innovations are made at the set bind stage. However, as the market grows, there is increasing modularization; i.e., hardware becomes more open, and the platforming of software proceeds at the same time. This increased modularization and openness often follows techniques of those companies that have led innovation, and the experience of software and hardware integration in set bind before market growth is an extremely important factor for the success of the market.

8. Conclusion

This paper has chiefly discussed the product development activity of the electronic equipment industry based on the case of the car navigation system, and has clarified the relations between various elements. With the development of IT, perfection of systematization that ties hardware and software together is a center concern of product development in electronic equipment products, however simple they may be. Software like content and databases are complex and will diversify more and more in the future. On the other hand, as the burden of this product development increases, companies are demanding more shortening of lead-time. To respond to these conflicting needs, there are many consortiums and alliances between companies, but now a new problem of product discrimination has arisen. To define this complex problem, the concept of system architecture was introduced. Fig. 10 summarizes the relationships between system architecture and various elements of product development that have been described in this text.

Here, we see that system architecture has dynamics that tend towards content bind. In the diagram, the dimensions of different innovations are respectively shown on the vertical axis and horizontal axis. The corresponding organizational structure is also shown. In the bind system on the left of the diagram, the hardware and software to be incorporated are

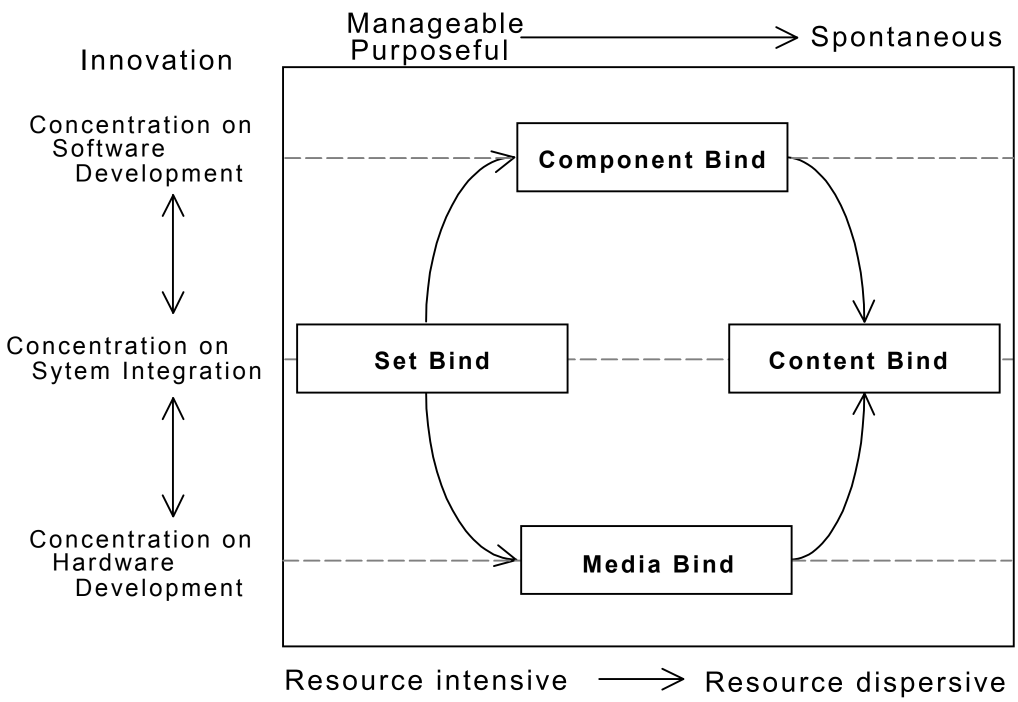

Fig. 10: Relation between system architecture and product development elements

both specially developed. Here, to market a new system, some level of technical breakthroughs is required, innovation is a necessary condition, and it is manageable and purposeful. Also, as the market for the required technology has not matured and there is a great necessity to develop products in-house, this is resource-intensive. In other words, efforts are focused on system integration. This set bind has dynamics together with market growth.

After the market has developed to some extent, once existing customer needs are reflected in product functions, product differentiation is required. When the key product techniques can be procured in the marketplace, the number of participating companies increases, companies concentrate on their own core competence, and other requisites are procured. In other words, as software and hardware have different natures, they are difficult to manage under the same organization. Therefore, some companies appear that procure software in the marketplace and concentrate on their own hardware technology, while others procure hardware in the marketplace and attempt to discover special features of software. At least, the emphasis will be placed on either hardware or software that respectively has a media bind or component bind system architecture. As the key techniques are procured in the marketplace, the meaning of manageable/purposeful and resource intensive is weaker than in the case of set bind.

As the modularization/standardization of hardware continues, and software becomes standardized, the system moves towards content bind. This type of dynamics is an essential requirement for market growth, but it is not a sufficient condition. For example, in the case of gaming machines, work machines or DVD recorders/players, standardization/regulation have not advanced very far even if the market has grown, so there is no move towards content bind. In content bind, software and hardware are layered, and their respective markets are supported by different companies on a common platform. For example, in the case of car navigation, a map company deals with hardware and application software by KIWI, a common digital map interface, and in a personal computer, there are the layered elements hardware and software on the platform known as Windows. In this type of content bind, innovation appears spontaneously, and due to a plural number of organizations, non-resource intensively for each respective element. Hence, set companies concentrate their resources on hardware and software integration.

Above, we have described system architecture. Systemized products can only be produced by integrating the different elements of hardware and software. This system architecture is intimately related to product development strategy and product development organization, and the relationship is changing.

-Note-

[1] See discussion by Aoki (2001).

[2] The origin of the basic technique of navigation technology is a teaching car in the chronicles of China's Shin Dynasty. The oldest mention is in these chronicles, where it is said that when the Emperor; i.e., the Yellow Emperor, fought his enemy ShiYu on the fields of Takuroku, he built a teaching car and trapped the enemy even in thick fog which ShiYu created. Also, in the "Kokinchu," Yofuku, there is a reference that a teaching car was built in the Chou Dynasty (770 B.C.-221 B.C.). However, these are only fables or anecdotes, and it appears that a teaching car was only really built from the Wei Dynasty (220-265).

[3] A sensor used at that time as a fighting machine. A thin nozzle is installed in a tube, and when the direction of airflow issuing from the nozzle changes, the position of a sensor that detects the airflow in the opposite direction changes and the difference is used.

[4] Device that measures the rotation speed of a moving body. The rotation angular velocity is integrated and the direction of the moving body is outputted. An optical-fiber gyroscope detects the rotation angular velocity from a shift in interference fringes due to an arrival time difference of light traveling in mutually opposite directions in an optical fiber wound like a ring by angular velocity, and is high precision.

[5] GPS: Abbreviation for Global Positioning System. This is a global positioning system under management of the U.S. Department of Defense. In this infra-system, 27 satellites are positioned above the earth, and by measuring the signal arrival time from the satellites, a position anywhere on the earth can be calculated with high precision (usually 5-10m).

[6] VICS: Vehicle Tracking and Communication System. A system managed by the Vehicle Information and Communication System Center in Japan, which broadcasts traffic information in real time by FM multiplex broadcasts, light and radio wave beacons. There were 3 million or more members as of 2001.

[7] The Technical Committee TC 204 for ITS (Intelligent Transportation System) was set up by ISO executive board meeting in 1992, and following this, 17 car navigation companies from all over Japan set up the KIWI Test Committee in 1996. The first digital map using KIWI was commercialized in March, 1999. The KIWI-W consortium that aims at global standardization was established in 2002. The name KIWI is from the name of the bird found in Australia, which recognizes TC204.

[8] For interviews and questionnaires, we obtained the cooperation of Zenrin K.K., which has its Head Offices at Tohata-ku, Kityakyushu, and Increment P K.K., which has its Head Offices at Meguro-ku in Tokyo.

[9] Now, there are about 20 companies that manufacture car navigation systems. Considerable capital and time is required for development of digital maps associated with this hardware, so the consortium aimed at joint development by the participating companies set up a Navigation Study Group in 1991. The main 14 companies opted for a unified map format. The version is still updated every year. The number of affiliated companies is about 40.

[10] Vendor unique is a term often used by the software industry. In the commercial software market, the source code is not disclosed in many cases. Therefore, when the customer himself wants to customize the software, only the specification of the user interface part is disclosed so that it can be freely modified. This is referred to as vendor unique. In Zenrin, Inc., digital maps that had this function were marketed in 1996.

[11] We surveyed a total of 16 companies: Clarion, Alpine, Pioneer, Casio Computer, Denso, Fujitsu Ten, Seiko Epson, Kenwood, Mitsubishi Electric, Matsushita Communication Industrial(Panasonic), Kyushu Matsushita Electric, Maspro Denkoh, Sanyo Car Electronics, Sony, Sumitomo Electric

Industries, and Xanavi Informatics Corp(Hitachi). For the survey, we asked the person in charge of product development directly by a registered form, but only 13 of the 16 companies actually replied. The condition for replying to the questionnaire was that the respondent was involved in the car navigation development at the time of the survey. The survey was conducted in June, 2001.

Aoki, M (2001),"Toward a Comparative Institutional Analysis," MIT Press

Baldwin,C.Y and K. B. Clark (2000),"Design Rules: The Power of Modularity," Cambridge, MA: MIT Press

Baldwin,C.Y and K. B. Clark (1997),"Managing in an Age of Modularity," Harvard Business Review, Sept./Oct., pp.84-93.

Brooks,F.P, (1995),"The Mythical man-month: essays on software engineering" Addison-Wesley Publishing Company

Clark, K.B. and T.Fujimoto (1991)," Product Development Performance: Strategy, Organization, and Management in the World Auto Indutry," Boston, MA: Harvard Business School Press

Fujimoto, T. and M. Yamamoto (2000)," The Road to a 'New Standard' Camera, the Cannon EOS 1000: a Case of Dynamic Capability Building in a Japanese Camera Firm," Enterprise et Histoire, Vol.23, pp11-35.

Chesbrough, H.W and David, T.(1996),"When is Virtual Virtuous?: Organizing for Innovation," Harvard Business Review, Jan./Feb., pp.65-74

Child, J and David Faulkner (1998),"Strategies of Co-operation: Managing Alliances, Networks, and Joint Ventures," Oxford University Press

Christensen, C. M. (1997),"The Innovator's Dilemma," Harvard Business School Press

Dosi, G.(1982),"Technological paradigms and technological trajectories," Research Policy, Vol.11.

Dussauge, P and Bernard Garrette (1999),"Cooperative Strategy: Competing Successfully through Strategic Alliance," Wiley

Fine, C.(1998),"Clockspeed: Winning Industry Control in the Age of Temporary Advantage," Reading, MA: Peruseus Books

Garud,R. and A.Kumaraswamy (1995),"Technology And Organizational Designs for

Economies of Substitution," Strategic Management Journal, Summer Special Issue, 16, pp.93-109

Henderson, R and K. B. Clark (1990), "Architectural Innovation: The Reconfiguration of Existing Product Technologies and the failure of Established Firms," Administrative Science Quarterly, Vol.35, pp.9-30.

Iansiti, M(1998),"Technology Integration: Making Critical Choice in a Dynamic World," Boston, MA: Harvard Business School Press

Morris, C. and C. Ferguson (1993),"How Architecture Wins Technology Wars," Harvard Business Review, Mar./Apr., pp.86-96.

Pine, B.J., and J.H.Gilmore(1999),"The Experience Economy," Harvard Business School Press

Shapiro,C. and Hal R. Varian (1999)," Information Rules: A Strategic Guide to The Network Economy," Harvard Business School Press

Simon, H. A (1969),"The Architecture of Complexity: Hierarchic Systems," The Science of the Artificial, 3rd ed. (1996), Cambridge, MA: MIT Press

Tshman, M. and C. O'Reily (1997),"Winning Through Innovation," Boston, MA: Harvard Business School Press

Teece,D.J. (1980),"Economies of Scope and The Scope of The Enterprise," Journal of Economic Behavior and Organization," 1,pp.223-247

Ulrich, K.T.(1995),"The Role of Product Architecture in the Manufacturing Firm," Research Policy, 24, pp.419-440

Utterback, J. M. and W. Abernathy (1975)," A Dynamic Model of product and Process Innovation," Omega, Vol3 No.6, pp.639-656.

Utterback, J.M (1994),"Mastering The Dynamics of Innovation," Harvard Business School Press

Wheelwright,S.C., and K.B.Clark (1992)," Revolutionizing Product Development," The Free Press, New York, NY.

Williamson, O.E. (1985)," The Economic Institutions of Capitalism." New York : Free Press