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Product architecture, organizational capabilities and IT integration for competitive advantage

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ABSTRACT

Increasingly, firms recognize the strategic implications of front-end product design for improving total cost effectiveness. Computer-aided design (CAD) is becoming firms' competitive weapon beyond its traditional function as a product design tool. Yet, it is unclear how the full potential of IT system, particularly the usage patterns of 3D CAD system, may be realized through organizational capabilities. This paper presents a model of IT system configurations and CAD usage patterns. Next, a typology of IT system configurations is presented based on (1) the degree of CAD integration between assembly makers and suppliers and (2) the structure of product design information (i.e., product architecture). The product architecture of four electronic firms illustrates that information integration through organizational capabilities is more important than IT investment itself. The findings suggest that a Korean firm accomplishes a greater level of IT integration compared to the other two Japanese firms and thus attain better market performance. This study offers valuable insight on effective IT integration strategy for competitive advantage in the global market.

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1. Introduction

Many IT researchers have focused their attention on the IT's enabling roles of business processes, IT's impact on organizational outcomes, and IT's contribution in creation of business opportunities (Davenport, 2000). Even after years of massive investment on building IT system infrastructure, many Japanese firms have not reaped the benefits in terms of desirable economic and financial outcomes (Park, 2004). Eighty percent of total costs of products is determined between concept design and production stage (Bae, 2003). Increasingly, the strategic attention of many firms is moving toward exploring IT effectiveness in the context of product architecture and organizational capabilities (Fujimoto, 2006a). 3D Computer-aided design (CAD) in particular is no longer a mere product design tool. Instead, it is becoming a strategic core competence (Fujimoto, 2006a; Ku, 2003; Takeda, 2000; Tan & Vonderembse, 2006).

An examination of the usage patterns of CAD system in Japanese auto industry and electronic industry shows noticeable differences. Major Japanese automakers have implemented integrated product development that reflects the high level of dependence among component parts suppliers (Clark & Fujimoto, 1991). Many autosuppliers commonly use the same CAD systems of their original manufacturers. On the other hand, consumer electronic product manufacturers adopt modular product development because the level of dependence among their component parts suppliers is relatively low. The majority (e.g., 70% or more) of electronic suppliers use diverse CAD systems as they see fit. Since new product development processes reflect the interactions between assembly makers and suppliers, the above differences suggest quite distinct patterns of IT system usage in the two industries. Therefore, an effective IT implementation requires strategic fit with the firm's product architecture and corresponding innovative organizational processes. Otherwise, the potential value of IT remains buried deep within the organizational system.

2. Product architecture and 3D CAD system

2.1. Structure of product architecture

In general, product-process architecture is "the overall mapping to envision and identify product functions and distributes them through common elements, essential processes and critical interfaces through which vital information and value creation opportunities are shared and realized" (Fujimoto, 2003). In other words, product architecture is the sum of the basic concepts that

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link together all core components of a product. The choice of architecture determines the essential rules on (1) how to realize desirable functions of the product, (2) how to divide them into different components, and (3) how to design the interfaces among the component parts (Fujimoto, 2003).

Fig. 1 shows how global electronic firms construct their product architectural strategy. Business processes include product development-commercialization-support that involves diverse functions and require the integrative link between vital functional architectures (i.e., product architecture, production architecture and marketing-logistics-service architecture). Such business architectures build on organizational architecture that reflects organizational, learning and innovational capabilities. IT tool, 3D CAD in particular, represents technological capability. Technology matters but strategy governs the use of technology. An effective business strategy requires a keen insight of top management. Such vital insight requires new business models that define the essential nature of problems and provides a clear sense of direction. This study, through the theoretical model and case illustrations, might be useful for electronic firms that are in serious search for better business models for their global competitive advantages.

Major classifications of product architecture are - modular or integral, open or closed (Baldwin & Clark, 2000; Fine, 1998; Fujimoto, 2003; Ulrich, 1995). Fujimoto (2003) used two parameters for classification purpose. The first one is modular-integral axis. Modular architecture refers to 1:1 relationship between function and module. Each component is self-sufficient and highly independent with little need for interactions. The issues of interfaces are simple and therefore easy to resolve. Integral architecture refers to products that are highly related between functional groups and component parts. Automobile is a typical example. Functions such as noise and vibration are important for the comfortable feeling for a ride. For such desirable functions, many component parts work together as a total system and display the effect. The relationships between functions and components are not one on one but many to many. Designers of each module must closely interact to work out all the details.

It is worthy to mention two types of product architecture here. Closed-integral type fits to products such as automobile, luxury motorcycles, TV game software and high-end copiers. Closed-modular type is about mainframe computers (e.g., IBM System 360), standardized machine tools and Lego (block toy). Open-modular type displays the product characteristics of bicycle and desktop PC. In case of Mobile PC, however, its architectural characteristics may be different depending upon the layers and positions in the product-component hierarchy. For an example, Intel microprocessor in a PC is open to other component parts but its content is not divisible as open-module. A battery in typical American cars (as an automobile functional part) shows openmodular characteristics with its interfaces standardized across the auto firms. Auto-suspension, on the other hand, is interdependent and its interfaces are complex.

A product as a whole may be combined with different architecture types. According to Fujimoto (2003), a certain product may not be classified as either modular-integral or open-closed. In general, product function and product process structure might be explained in hierarchical manner. Modular-integral classification in this model merely shows two extremes of product functions and structures for our analysis purpose. Nobeoka, Ito, and Morita (2006) also classifies modular characteristics of electro-digital products within the wide range between closed-integral to open-modular. In this paper, we use the modular/integral and open/closed classifications by Fujimoto (2003) and Nobeoka et al. (2006).

2.2. Relationships between CAD and product architecture

2.2.1. CAD usage and impact on organization in new product development

To further explore the relationships between product architecture and CAD, we now consider 3D (three-dimensional) CAD usage and its impact on characteristics of product development organizations. 2D (two-dimensional) CAD mostly focuses on efficiency of internal design activities. Digitalization of product information has partly been realized in 2D CAD. On the other hand, 3D CAD with the function of solid modeling has the capacity to visualize images of physical products in a realistic way. As a result, introduction of 3D CAD system caused fundamental changes in product development processes, development task definitions and designer skill requirements (Adler, 1989; Baba & Nobeoka, 1998; Aoshima, Nobeoka, & Takeda, 2001). Many Japanese firms have used 2D CAD simply for replacing design drawings with electronic design data without changing their product development processes. As numbers of engineers who can read complex design drawing decrease, they started to rapidly introduce 3D CAD systems. However, 3D CAD usage has not yet impacted changes in internal design activities, choices of process technology and analytical methods (Aoshima et al., 2001). Tan and Vonderembse (2006), on the other hand, analyzed the integrative effects on marketing, design and manufacturing by the use of 3D CAD system. 3D CAD also simplifies the information transfer process in new product development (Aoshima et al., 2001).

3D image definition allows each development group to change database on the common database (Aoshima et al., 2001). With 3D CAD use, it is possible for sharing information crossfunctionally among engineering, marketing, and manufacturing (Koufteros, Vonderembse, & Doll, 2001). As design information



Fig. 1. Architecture strategy.

becomes more digitized, such functional units might become more interdependent. The existing task boundaries become blurred and task overlap may occur as well. With increasing task integration, traditional functional boundaries might gradually disappear (Aoshima et al., 2001).

Existing researches indicate that concurrent design shortens the lead-time (Clark & Fujimoto, 1991) and the work of cross-functional team accelerates new product development (Crawford, 1992). 3D CAD further facilitates concurrent activities (Aoshima et al., 2001; Koufteros et al., 2001). By electronically linking product and process design information, concurrent usage of 3D CAD enhances design processes. Product information flexibility through 3D CAD usage also enables integration of mechanical design, electronic design (circuit design) and concurrent analysis of design stages. In 2D draft context, development processes involve product planning, concept design, mechanical design, and electronic design, molding and production. In 3D CAD design context, mechanical design and electronic design may be combined as one stage and therefore concurrently accomplished. This may have substantial impact in divisional structure and design skills requirements. 3D CAD also impacts the manners of organizational communication (Ku, 2003). The use of 3D CAD necessitates more precise information sharing and enhances communication among different functional specialists (Robertson & Allen, 1993; Baba & Nobeoka, 1998; Takeda, 2000). Based on the empirical studies of auto-industry practices, 3D CAD usage is reported to expand the scope and depth of communication among organizational units (Ku, 2003). In other words, the above findings also suggest that 3D CAD usage requires an increasing level of organizational communication and process innovation.

2.2.2. Organizational capabilities for effective use of CAD system

An increasing use of 3D CAD opens greater business opportunities. Many empirical studies report the positive effects of CAD usage (Baba & Nobeoka, 1998; Ku, 2003; Tan & Vonderembse, 2006). The presence of 3D video images in the early stage of product development provides more insight on what might be anticipated in downstream processes. With better anticipation of possible design changes needed in the later stage, it may substantially reduce the iteration and resolution cycles and give rise to product innovation. But traditional organizational structure, division of functional boundaries, scope of professional skills may need redefinition and changes (Aoshima et al., 2001).

However, adoption of 3D CAD system without corresponding organizational innovation may not result in desirable outcomes. The gap between the ideal goals and actual outcomes of 3D CAD system use is real and wide in various organizations and sectors (Beatty, 1992; Symon & Clegg, 1991). In one of the surveys by Nikkei, whether a firm introduces 2D or 3D CAD did not bring about any real difference in business outcomes (Nikkei, 2006, 8). The underutilization or ineffective use of 3D CAD might be the reasons for such disappointing performance (Buxey, 1990; Liker, Fleischer, & Arnsdorf, 1995). The inability of CAD to facilitate accurate communications of designers' intent might be another reason (ECPC, 2006). If there is no particular CAD function that reflects the intent of the designer, the designer's intent cannot be effectively communicated to the manufacturing function. Too often 3D CAD data must be re-translated back to 2D draft drawings. Such recurring incidents have little to do with technology itself but more to do with the organizational arrangements. 3D CAD-CAE promises reduction in development time through smaller design changes by front loading, but its performance is different by organizational capabilities using 3D CAD (Fujimoto, 2006a; Thomke & Fujimoto, 2000).

For example, existing researches suggest that the average US and European automobile manufacturers have been suffering from longer product development lead times than their Japanese counterparts despite the fact that the former adopted 3D CAD systems earlier and more thoroughly than the latter (Fujimoto & Nobeoka, 2006). Without the management's proper understanding of CAD potential its potential might not be better realized (Adler, 1989; Twigg, Voss, & Winch, 1992). That is, while implementing the same types of information technologies, the Japanese automanufacturers report that their average product development lead time was shorter than 20 months, whereas it took the US firms around 30 months to develop similar products (Fujimoto, 2006b). The US and European firms (Chrysler as an example) adopted 3D CAD roughly three years earlier than Japanese firms and the actual results show that Japanese firms are still ahead in virtual digital mockup (Fujimoto & Nobeoka, 2006). In the late 1990s, most of USA Firms adopted 3D CAD for drafting their 100% component parts while Japanese counterparts did only 49% of component parts. Thus, although the Japanese firms were lagging behind USA Firms in terms of adopting the latest IT, they outperformed their Western rivals, as they could build a set of organizational routines for utilizing IT more effectively. In other words, Japanese auto manufacturers have organizational capabilities for collaborative problem solving at the early stage through organizational routines.

According to the 240 USA Firms study by Tan and Vonderembse (2006), CAD usage did not directly impact product development outcomes. That is, although CAD usage affected the extent of cross-functional information sharing in product development organizations, it did not show any significant contribution to real improvement in product development outcomes. Thus, this research also suggests that integrating CAD-related database is important for product development process (Angeles, 2009; Harison & Boonstra, 2009; Hartono, Li, Na, & Simpson, 2010; Malhotra & Temponi, 2010; Seah, Hsieh, & Weng, 2010).

In general, patterns of CAD usage of the Japanese automobile firms can be divided into two stages. The first one involves 3D model formation in such upstream activities as product planning and engineering design. The second one includes adoption of 3D CAD models by such downstream departments as manufacturing, purchasing, service and advertisement, as well as parts suppliers. In Japanese auto industry, a shift from 2D draft to 3D solid model has already taken place, but it is reported that neither "upstream" nor "downstream" areas has fully used 3D CAD models yet (ECPC, 2006). Possible reasons are as follows: (1) software functions of 3D CAD are inadequate, so 3D Model might not be able to communicate all the required design information effectively; (2) although 3D CAD expression is possible, creating 3D design information in detail requires lots of efforts and time; (3) communication rules of 3D model has not been well-established and standardized among different departments of the company; (4) the downstream units including production departments may not have installed necessary IT tools; (5) the downstream units still use 2D models widely, and they are not fully ready to use with 3D model with efficiency (ECPC, 2006).

Organizations must innovate if they are to survive in today's fiercely competitive environment (Lindič, Baloh, Ribière, & Desouza, 2011). An intermediary organization is important that acts as an agent or broker in any aspect of the innovation process between two or more parties (Howels, 2006). An intermediary can help companies to maximize their chances and success of innovation in developing new products and services and R&D activities (Hartono et al., 2010; Lee, Park, Yoon, & Park, 2010). Portals are also an intermediary through IT technology which can significantly impact organizations, completely changing how they work and operate (Al-Mudimigh, Ullah, & Alsubaie, 2011). In this paper, we explore how leading organizations are using emerging technologies to attain competitive advantage.

3D CAD system is a communication tool through which crossfunctional teams, from the early stage of development, share information on complex problems related to planning, design, prototyping, experiment, process technology, purchasing and manufacturing (Fujimoto, 2006a). Using CAD data as a communication medium, product development teams can better integrate upstream and downstream activities. Many firms have also implemented PDM (Product Data Management) and PLM (Product Lifecycle Management) including ERP (Enterprise Resource Planning). PDM refers to the overall product data managing effort that involves product planning, design, process technology, sales and maintenance and that improves the product development productivity and information utilization. PLM, as a more comprehensive concept than PDM, refers to comprehensive management of information that encompasses all relevant internal activities and information (e.g., marketing, planning, manufacturing to sales, maintenance, recycling, relevant costs) and external activities and information (e.g., suppliers of component parts and costs). Assembly firms, which integrate product component information, engineering drawings, manual for inspections, and all the relevant process information through computer system, may need to adopt PDM. Any legitimate users may have access to the information in any time of need (e.g., 3D model sharing and utilization through product development cycle).

2.2.3. 3D CAD and product architecture

In this section we examine the relationship between product architecture and 3D CAD. Our case analysis focuses on product architectures of Japanese automobile and electronic products. Japanese automakers depend on their suppliers for the product development and manufacturing capacities. Active participation of their suppliers enables their assembly makers to achieve the high level of performance results (Clark & Fujimoto, 1991). In auto product development, 70% of major issues are about design changes related to part interferences and component parts design (Ku & Fujimoto, 2000). Japanese automakers installed 3D CAD in the development site for front loading and concurrent engineering. With such practices, Japanese automakers have reduced product development time from 30 months to 20 months (Ueno, 2005).

A typical car has more than 20,000 components and product integrity requires high level of coordination between assembly makers and suppliers (Clark & Fujimoto, 1991). With increasing digitalization, more electrical and electronic component parts are added to a car. The needs for 3D CAD usage between assembly makers and suppliers are ever more imperative. Among three leading Japanese automakers, Toyota no longer uses TOGO-CAD that was developed within Toyota and instead has adopted CATIA-V5 and PROENGINEER for engine parts. Nissan used I-DEAS by SDRC in 1995 but from 2005, it chose to use NX by UGS as the next generation CAD. Honda has used CATIA from the beginning without its own internal version.

However, these assembly makers demand design integration to its suppliers. Since most of recent design and draft change information is exchanged through 3D CAD data, suppliers are compelled to own 3D CAD system that their assembly makers use; otherwise, suppliers may not participate in development competition (Ku, 2003). Suppliers adopt 3D CAD as passive conformance move and naturally the full potential of 3D CAD is seldom realized (Ku, 2003).

In electronic industry, the product life cycle is relatively short. In May 2006, product life cycle of mobile phone with Casio calculator and digital camera is four and six months respectively (Toriya, 2006). The pressure to reduce lead-time is very strong. In electronic industry, technological innovation in component parts is very fast. Each project is small in scale. In the past, 3D CAD usage in electronic products was not so widely applied. However, as product innovation centers require more timely information from the product development processes, 3D CAD system adoption is increasingly emphasized (Ueno, 2005).



Fig. 2. Product architecture and CAD integration between assembler and supplier.

Most of electronic products are made of common parts. In product design process, electronic assembly makers and their component parts suppliers often do not tend to use the identical CAD system. In electronic industry, no pyramid structure (i.e., hierarchical) exists between assembly makers and suppliers. For an example, in the course of switching from traditional 2G closed integral type to 3G open modular type, Japanese mobile phone makers have adopted the same CAD system that Chinese component part makers use. Why is it so? In electronic industry, everyone can obtain semiconductors and electronic parts as long as it is not the custom parts. Therefore electronic product development does not depend on particular suppliers. Neither does it involve massive production facilities, nor does it require enormous technological competencies. Outsourcing of PCB (Printed Circuit Board) design and manufacturing is easy and numerous. Therefore, in electronic industry the barriers of entry are low and the numbers of firms are too many. Without a pyramid type of business relationships as in auto-industry, electronic firms are much more willing to share information, coordinate processes, develop and market products together with their suppliers (Ueno, 2005). With such different industry characteristics, product architectures of electronic products and their CAD usage patterns are quite different from those of auto-products.

Fig. 2 contrasts auto-products and electronic products with this framework. On one extreme, the auto-industry is presented as closed integral product architecture (Nobeoka et al., 2006) and consumer electronic products use open-modular product architecture (Fujimoto, 2006a). At present, Japanese automakers assume relatively strong competitive position while Japanese electronic firms struggle in their increasingly challenging competitive reality. For this reason, in the remainder of this paper the focus is on electronic industry (Table 1).

3. Research methods

This paper, based on above observations, examines (1) how to build up CAD data and PDM common database and (2) CAD data integration between assembly makers and suppliers of consumer electronic industry products. The A-Firm in this paper has built the high level of integrative database and effective data exchanges with its suppliers. Through in-depth interviews, it is found that the critical success factors are in A-Firm's organizational capabilities. We analyze how A-Firm made the transition to the Path A and the Path B (see Fig. 3) and positioned its competitive advantage through the organization-wide usage of 3D CAD. We also conducted additional interviews of Firm B and Firm C to compare the practices.

Fig. 3 shows two critical factors why Japanese Automakers (e.g. Toyota and Honda) sustain their competitive advantages in the

Table 1

Comparison of auto-industry and consumer electronic industry.

Classification	Auto-industry	Electronic industry
Comparative domestic competitive strength	High	Low
Value-added formation	High	Low
Number of component parts	More than 20,000	About 1000
Ratio between full and common component parts	Full (specialized components parts) focus	Common component parts focus
Development time	Long-term (2 years)	Short-term (less than one year)
Production time	Two years	Within one year
Number of production volume (one product line)	Relatively large	Relatively small
PLC (product life cycle)	Long	Short
Supplier relationships	High level of integration	Low level of integration
Integration with suppliers' CAD	Relatively high	Relatively low

global market: (1) high interdependence between assembly makers and component parts suppliers and (2) easy integration of design information. Other global automakers have not attained such level of integration and organizational capabilities. Fig. 3 also shows what particular paths Japanese electronic industry should take to improve their current, weak competitive position. Path A is the vertical integration path of design information between manufacturers and suppliers. Path B is the horizontal integration path between manufacturer and component parts suppliers through geographical proximity. In the subsequent section, case illustrations highlight the details of Path A and Path B.

4. Case analysis

4.1. Global consumer electronic maker A-Firm case

4.1.1. Overview of A-Firm: Background of CAD system adoption in product development

A-Firm is established in 1969. It is the global leader in semiconductor, LCD, information and communication business, digital media and electronic businesses. Since 2000, its sales rapidly increased and by 2005 the overall sales are 56.7 billion dollars. Each segment of product lines has been achieving healthy growth and global competitive advantages. Revenue contribution by business sectors is: semi-conductor (32%), LCD (17%), Telecommunication (33%), digital media (11%), appliances and others (7%).

A-Firm, by 1980, strategically caught up the leaders in the target market segments by using reverse engineering of the competitors' new products. After analyzing the functions, structure, component assembly and costs of the products, A-Firm aggressively engaged in product planning, design and structure design in the shortest possible time. Based on output draft, although not yet sufficient in details, sample products were designed and produced and went through testing. For correcting any troubles, revision processes often show inconsistencies between draft and real thing. For an



Fig. 3. Two paths (A and B) for case analysis.

example, after circuit design, they made Printed Circuit Board (PCB) and tested the real machine. Too often, the circuit flow and PCB draft did not match. To respond to this type of troubles, they adopted CAD-CAM. For this research, we interviewed the IT vice president who had 10 years of experiences with CAD adoption and usage in A-Firm. We then examined how A-Firm achieved the successful CAD adoption and built up the CAD system for their new product development (Table 2).

Our initial proposition was that in electronic products, CAD usage success depends on integrative database within internal organizational units and data integration with suppliers. To test this proposition, we examined how A-Firm has utilized CAD in all stages of product development (i.e., product planning, design, production) and has integrated database with their suppliers.

4.1.2. Building integrative database

In June 1993, A-Firm, as a specific follow-up plan of its CEO's 1993 declaration of the new management manifesto, established E-CIM (Engineering Computer Integrated Manufacturing) Master Plan with 60 members of task force team. Such an initiative was based on detailed analysis of development process, benchmarking of its competitors and the prediction of changes in information technology. From 1994, A-Firm established E-CIM Center to facilitate innovative product development with the goal of expanding product development capabilities three times. A-Firm and four other firms made standardized data system for component parts data and established new development process based on the principles of Concurrent Engineering (CE). Through an effective building up CAD infrastructure, A-Firm moved toward systematic management of development information. As a supporting tool of sharing information of related functions, E-CIM managers adopted PDM (integrative design information management system) as the next strategic priority. Through series of innovative effort by E-CIM, A-Firm reduced product development lead-time from 4 years to 4 months. In product development, A-Firm also achieved a drastic improvement through using Design-Fix.

4.1.3. E-CIM Center

The old business model is characterized as "physical product based development, lack of information infrastructure, heavy work load of designers and unavailable design data". On the other hand, the new business model was to achieve "new development process, standardization of all component parts, 3D building of CAD/CAM/CAD and building product design information management structure (PDM)". Fig. 4 shows how E-CIM Center is formed to support the strategic goals of A-Firm by using the new business model.

Specifically, as its physical product focuses development effort, E-CIM moved away from serial process and instead adopted RPI (Rapid Prototype Interface) process so as to achieve cooperative design that is based on principles of concurrent engineering. In order to overcome their lack of information infrastructure they also

CAD Adoption history of	A-Firm's product development.		
Category	Before 1987	1988-1995	1996-1999
Design change	Design by draft Manual draft transfer	Design by CAD usage	Concurrent d
CAD system change	Walluar draft traffster	offling CAD data transfer	design inform

Design change CAD system change	Design by draft Manual draft transfer	Design by CAD usage Computer-use draft work; offline CAD date transfer	Concurrent design Smooth flow of network-based design information; integration of Product Data Management (PDM) and CAD data	Simulation-based design Design reuse and scientific base development
IT Environment Advocate Name	Draft/PC environment \leftarrow CAD Center \rightarrow (1994) (1994) \leftarrow E-CIM Center \rightarrow Now	Host/EWS environment	Server/Client environment	Web based environment

adopted 3D CAD system as a way of effective use of product model in all the processes – from design to metal molding. For an example, E-CIM chose I-DEAS for mechanical design, Mentor and Zuken system for Electronic Design respectively. For building product library database, E-CIM also vigorously implemented standardization of all common parts and applied product data management. For the reduction of designers' heavy workload and effective storage of design data, the use of CAD/CAM/CAE and PDM was all followed through as strategic initiatives.

4.1.4. Product Database Management

The management of A-Firm, after adopting diverse IT system in the late 1980s, found that design engineers had to inquire about relevant information from those in other units or divisions. Securing timely relevant information remained unresolved. By forming its own internal PDM system A-Firm could manage all productrelated information across functional and divisional boundaries and then provided BOM information globally as needed. Fig. 5 describes the details of Product Database Management by E-CIM Center. The purpose of PDM (Product Data Management) is to integrate all databases by standardizing technology and component parts. Recent PDM for many firms is mostly purchased from their vendors but A-Firm has built up its own PDM with using the tools provided by IT vendors. Through constructing PDM throughput A-Firm's functional boundaries, integrative standard processes that link all divisions were established. The issue of organizational overlap was resolved as well. As mentioned before, electronic products, different from auto-products, are diverse in terms of features and functions. Most of Japanese electronic Firms have such characteristics. Therefore, each business unit has its own BOM (bill of materials) and purchasing materials are all different by business units.

The information infrastructure of A-Firm is governed by super standard-set processes. PDM in particular became the portal system for each participant (i.e., suppliers, cooperation firms and assembly makers) to store and retrieve vital information.

Development Process CAD/CAM/CAE Innovation **Environment Innovation** Mech CAD Circuit CAD Mech CAE Product Line-up Design Circuit Thermal analysis Product Planning Design Eng PDB Design CE Impact Mold вом Production Vibration Unification Embed Data Prepation Lib/DB ESPECT 3D Data Drawing Mgt Parts Mgt Design Change Mgt Project Mgt Tech/Parts Managemei Parts Standard Design standard Tech material standard **Global Network**

Fig. 4. E-CIM Structure.

Another built-up infrastructure called CPC (Collaborative Product Commerce) Exchange acted as a critical linkage for developing standard communication processes among partner e-processes and company e-processes through continuous digital convergence processes. As shown in Fig. 5, PDM enabled all internal functions to better cooperate and collaborate with its suppliers and other business entities as freely as needed.

After 2000

Through technology standardization effort by PDM, in the mid-1990s A-Firm and other three firms reduced nine BOM code systems into one standard system and accordingly streamlined 52% of non-use codes (390,000 were eliminated out of 750,000 codes). Furthermore, they achieved the same level of consistency for all the codes used in 30 overseas factories, too.

With such strategic and systematic integration effort, identical codes are used for the same materials throughout the world. In regard to component information, with one time approval all business units could use. Besides, information about component parts characteristics from various suppliers were all shared. Drastic productivity increases have been shown in all business processes. By combining SAP (adopted in 1995) and its own PDM, A-Firm reduced lead-time of color TV from 12.1 months to 6.2 months by 1997. Unexpected by-products of such information integration showed in the areas of cost reductions. For example, A-Firm has widely adopted massive group purchasing practices through the support of its suppliers who provide more vital detail information about the component parts (from A-Firm's 30 years history).

4.1.5. VIP (Value Innovation Programming) Center

Although E-CIM Center tried engineering-related comprehensive innovation through PDM integration, it was not easy for them to accomplish integration of all cross-functions involving in product development. Soon VIP Center was established for horizontal integration of cross-functions. A-Firm first changed accounting methods. During critical development time periods, all the



Fig. 5. Product Data Management in A-Firm.



Fig. 6. VIP Center.

participants of new product development teams were brought together in the same location. It was somewhat similar to Toyota's large room methods (in Japanese oobeya). Such development methods enabled A-Firm to accomplish cost innovation in mobile phones that have short PLC (Product Life Cycle).

As shown in Fig. 6, the mission of VIP (Value Innovation Programming) Center was to promote product value innovation, cost innovation, engineering solution and quality enhancement. Functions that involved were design engineering, design marketing, purchasing, quality and manufacturing. VIP Center invited suppliers and other collaborative firms to apply principles of concurrent engineering in its purest form. After 1997, A-Firm eliminated molding division and outsourced its operation instead. However, A-Firm limited the number of these molding firms – only to a few. All these firms were also invited for value innovation program. Through joint effort, these firms also contributed to reducing product development time. In this sense, A-Firm achieved integral product development as shown in Path B in Fig. 3. Such innovative practices have achieved the innovation goals in terms of development time and overall cost reductions.

4.1.6. Data Exchange Center

Under E-CIM Center, in 1994, Data Exchange Center (DEC) was established for 3D data integration (Fig. 7). Initially, about 20 people worked there. From 1994 to 1998 no real progress occurred in DEC. A-Firm used diverse CAD prior to 1994 and after 1994 they combined to I-DEAS but some parts were still using CAD systems called PRO-Engineering. By 1998 CAD Data integration between A-Firm's internal functions and suppliers was a serious issue. However, A-Firm, by establishing Exchange Center, provided an environment where CAD data could be freely exchanged. After 1998 DEC displayed its critical roles in facilitating data communication and information exchange with suppliers. Through Data Exchange



Fig. 7. Data Exchange Center.

Center A-Firm accomplished Path A through 3D data integration as shown in Fig. 3.

4.1.7. A-Firm's mobile phone and mobile PC development

In 1986, A-Firm started producing car phone. From 1996 A-Firm started mobile phone production and marketing according to CDMA standard. At present A-Firm is recognized for its superb design capabilities as a global mobile phone maker. Success factors for such drastic growth are (1) its high-risk move for global communication standard adoption and (2) innovation in its design capabilities.

In 1993 after its CEO issued new management manifesto, importance of design innovation was more keenly recognized. For example, the CEO showed all the recent models of new products and asked the senior managers to choose the best from them. They all selected based on design features. With this experience, A-Firm implemented design-focused management. Initially, power to evaluate design quality was director of design center, not the head of business unit and the evaluation of designers was based on the numbers of models they made. With 3D, a designer could come up with one design model per period and therefore received poor evaluation. However, with 2D draft more than 20 models were possible and accordingly good evaluation. Therefore, since it was faster for them to do 2D draft than 3D design, designers were mostly used in draft 2D design. To resolve this issue, in 1996 the top management transferred designer evaluation authority to business director. As a result, designs reflected each business director's business priorities. The mobile phone unit did not show any real profit for a few years. Even so, business director's assessment was that design features were more important than functional elements. For the better visibility, understandability and clarity, 3D data design was rather adopted. The mobile phone business director decided to use 3D CAD in product planning and design stage in order to speed up product introduction faster than that of the competitors. 3D CAD tool in design was Rough Sketch and ALIAS. After Soft Mockup, the last exhibition and final approval, designer transferred 2D draft and 3D data to engineering department. Then, engineering department simultaneously accomplished mechanical design and electronic design (circuit design) within a short period. Through such process, A-Firm reduced product development time for global competitive advantages. Recently, for 3rd and 3.5-generation new product development, A-Firm's product architecture is similar to integral type in our model. A-Firm's business division utilized integrative development system through VIP Center, used Toyota's large room methods (oobeya), and accomplished high level of integration with its molding suppliers. In brief, this indicated that A-Firm successfully achieved the Path B (i.e., drastic improvement in product development time and cost reduction through integrative effort) as shown in Fig. 3.

4.1.8. Mobile PC development

In 1978 A-Firm developed printer using CRT Terminal. In 1983, it succeeded in developing PC and with additional R&D investment, within one year it accomplished 3 times of growth (A-Firm's 30-year history). In 1990, it focused on Mobile PC. Its product architecture is similar to Open-Modular. For Mobile PC, just like Mobile Phone, A-Firm utilized 3D data from design. In design engineering, 3D data are exchanged with external component parts suppliers. If component parts suppliers use different 3D CAD, Mobile PC division receives data from DEC (Data Exchange Center) and therefore achieves 3D CAD data integration with them as well. Through DEC (its own data integrative organization), A-Firm utilized 3D integrative digital mockup in realizing the reduction target of product development time.

Such effort represents Path A as shown in Fig. 8. On the other hand, for molding design, just like mobile phone, VIP Center invited



Fig. 8. Mechanism of integration of CAD data in A-Firm.

a few molding suppliers into product development process and reduced molding design time.

4.2. Mobile phone development by B-Firm

B-Firm is Japanese consumer electronic and mobile phone manufacturer. Mobile phone division of B-Firm was established in 1980. In its inception, B-Firm produced car phone and personal mobile phone. At present, in terms of market share and production volume it is Japan's leading manufacturer. We also conducted interviews with executives from B-Firm. For B-Firm's mobile phone development, CAD System usage was from 1987 and at that time, 2D CAD was used. By 2002, 3D CAD was more widely used.

Initial 2D CAD adoption was through its IT department initiatives. Design engineers, after receiving about 3 years of training, were made responsible for mobile phone development. The characteristics of B-Firm's mobile phone development were as follows: (1) design department located in its headquarters and (2) design engineering and production department were stationed at the same manufacturing sites. Designer put design in the draft, and then operator made 3D data by using Pro-E. Afterward, 3D data was passed to engineering team, and design engineers engage in 3D design. 3D design was restricted to structure design. 2D CAD/CAE was used for electrical engineering and subsequent analysis.

Engineering department engages in design engineering by product groups. All the processes are one cycle from product design to production. For this reason, although two engineers use one CAD system, either 2D or 3D system, no problems occur. Design engineering takes care of E-BOM (Engineering BOM) and M-BOM (Manufacturing BOM). Prototype engineering is outsourced.

Adoption of 3D CAD has not reduced engineering man-hour. Engineers still used both 2D and 3D and therefore their workload remained unchanged until the early part of 2000. With 3D CAD adoption within structure, design division of labor was possible. As the result, design engineers in 2D period required two to three years for structure design; with 3D CAD system adoption, after one year simple structure design became possible.

4.2.1. Construction of PDM

Although B-Firm has its own integrative database, the engineers did not see any practical usage. The effect of integrative database was electronic storage of design draft. Different from A-Firm, standardization of component parts was not yet realized.

4.2.2. Data exchange with external molding suppliers

B-Firm's mobile firm product architecture is close to openintegral rather than open-modular. Since electronic products have short PLC (product life cycle), the level of integration between assembly makers and suppliers is low. Specifically, after equipment design, transferring 3D data to molding suppliers, they still use both 2D draft and 3D data. Since not all molding suppliers use the same CAD system like B-Firm. Different from A-Firm, B-Firm does not have DEC (Data Exchange Center) and therefore they use tools such as IGES for data transformation. Even with IGES transformation rule, product external design is not always transferred in clear and complex design details. Many suppliers merely do very simple component parts design. Therefore, the level of integration with its suppliers is quite limited.

4.3. Mobile PC development by C-Firm

C-Firm is Japanese leading digital consumer electronic firm. Its business division offers notebook PC and PDA computer network equipment that contain cutting core technologies. From concept design, C-Firm thoroughly analyzes customer voice and develops products with high level of practicality and originality. It fulfills network construction by PC target providing products with dream and comfortable computing environment. C-Firm started note PC business from 1980s and from 1989 notebook type of PC development and commercialization series occurred.

C-Firm adopted 2D CAD from 1970 and design draft disappeared after 1995. From 1997 C-Firm has applied 3D CAD. Development of Mobile PC is done through 3D design by design division in the headquarters.

Most of designers that use 3D CAD do not involve any operators. 3D CAD application is started with analytic simulation. 2D CAD system is used for electrical design. The effect of 3D CAD application, engineering man-hours and cost reduction occurred in the early stage.

Like B-Firm, 3D datazation added design engineers workload increase. Without changing organizational processes, 3D CAD adoption has not brought any noticeable organizational performance improvement. However, like in the case of A-Firm, the top management initiated organizational process innovation and business director evaluated designer. As a result, some level of process innovation has occurred – but not much.

4.3.1. Construction of PDM

PDM in Mobile PC business division is E-Metri and the effect of application is almost none. Different from A-Firm, innovation like integrative PDM construction has not yet tried. For identical component parts, each business division still purchase at different prices.

4.3.2. Data exchange with external molding suppliers

As C-Firm still use 2D draft as its main design methods, it does not recognize the need to constructing Data Exchange Center as A-Firms does for the purpose of data integration with the external suppliers.

4.3.3. Comparison of business divisions

We briefly examined two business divisions of A-Firm and mobile phone of B-Firm and mobile PC business division of C-Firm. As consumer electronic product manufacturers they are in the category of open-modular. After three generations, mobile phones of A-Firm, mobile phones of B-Firm and new mobile PC of C-Firm are similar to open-integral. 90% of Mobile PC of A-Firm supplied to OEM, is more like open-modular somewhat different from that of the divisions of the other three firms. 3D CAD, with the short PLC, is used in design sector or mechanical design engineering.

In view of electronic product characteristics, in other firms the extent of integration with its suppliers is low. Two business divisions of A-Firm, however, have maintained a high level of close

omparison of four organizations.				
Category	Mobile phone (A-Firm)	Mobile PC (A-Firm)	Mobile phone (B-Firm)	Mobile PC (C-Firm)
Product architecture	Partial open-modular, partial open-integral	Close to open-modular	Close to open-integral	Open-modular, open-integral
Usage of 3D CAD	Design	Design, equipment	Design, equipment, partial interpretation	Design, equipment, interpretation
Numbers of component parts (compared to automobile)	Small	Small	Small (850)	Small (1000)
Ratio between complete and common parts	Complete components focus	Common component parts focus	Complete parts focus	Complete parts focus
Development time (compared to automobile)	Short	Short	Short (14 months)	Short (less than 12 months)
Production volumes (one product line)	(global market) mass production	(OEM) mass production	Mini production (500,000)	Mini production (by models)
Product life cycle	<1 year	<1 year	18 months	<1 year
Relationship with other firms	High integration	High integration	Low integration	Low integration
Integration methods	Prototype physical integration	Prototype physical integration	1	1
CAD integration with external firms	1	Relatively high	Relatively high (70%)	Relatively high
Integration methods	1	Data exchange center	2D drawings	2D drawings
Degree of PDM integration	High	High	Low	Low

able 3

communication with their suppliers, integrated product development processes and reduced product development time and costs. A-Firm has also built the integrative product development database. In contrast, B- and C-Firms have not adopted integrated product development. Their 3D usages have not shown any noticeable organizational effectiveness.

The main problem of B- and C-Firms is their failure in utilizing the potential benefits of CAD system. Successes of new product development require the adequate level of sharing of information and knowledge among the participants from product front-end planning all the way to final customers. The architecture of Band C-Firm's products that we targeted for this study is close to the open-integral and therefore mere functional and open modular approaches would strategically unfit. In fact, these products with open-integral architecture do not adopt sequential processes in their functional and structural design; instead, their product functions are determined during the structural design processes. Therefore, outstanding product development must include parameter analysis through the integrative working processes.

Table 3 summarizes the comparisons of all four business divisions. In our case studies, A-Firm, in contrast to its competitors, better utilized CAD system for process innovation and reaped its maximum potential benefits for their product development and its overall business successes. Such usage patterns of CAD system indicate how other IT tools may further impact critical outcomes of the product development processes.

5. Conclusion

This study highlights the differences of two product architectures (i.e., open-modular and open-integral) through the case studies of electronic firms. In open-integral product architecture, product functions and process modules are highly interactive while in open-modular architecture, product functions and process modules are somewhat separated. This study confirms that high level of information sharing and process innovation is much more critical in open-integral architecture. This study further demonstrates how CAD system may facilitate process innovation and information sharing in the open-integral product development architecture.

This paper conducts case studies of one Korean and two Japanese electronic manufacturers. These case studies are based on in-depth executive interviews and follow-up studies that examine how IT integration is achieved in different organizational contexts. This paper analyzed CAD usage patterns of three electronic firms. CAD is not merely tools for product development; rather, it is related to organizational process as a whole. CAD is useful for product planning, design, engineering and production - in broad level of organizational processes. Different from auto products, electronic products have shorter product life cycle and therefore, reduction of product development time is critical for their competitive advantages. However, two leading Japanese electronic firms have not yet achieved necessary level of process innovation. By failing to accomplish process integration they do not utilize IT's real potential (3D CAD in particular) and their competitive position is seriously weak. The findings suggest that a Korean firm accomplishes a greater level of IT integration compared to the other two Japanese firms and thus attain better market performance. This study offers valuable insight on effective IT integration strategy for competitive advantage in the global market.

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