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Abstract

Multi-functional technologies widely influence on organization and often require organizational technology integration capabilities to achieve the total effectiveness. Technology integration capability here implies not only utilizing technologies in the present setting of organizational environment but also reforming organizational process and structure towards total optimization. This paper aims to exam technology integration capabilities among Japanese and Chinese firms through questionnaire surveys regarding impact of 3D technologies on product development process and performance. The results indicated that Japanese companies improved their total performance with process reformation leveraged by 3D technologies; however, among Chinese companies, no significant relationships were observed among 3D technology usage, process reformation and the total performance improvement although they improve the partial performance such as manufacturability by utilizing the technologies. Chinese companies, which have a huge growing market and are on the process of rapidly improving their productivities without strong organizational inertia, could have enough advantage by utilizing technologies to improve the partial performance. On the other hand, Japanese companies, which compete in mature market and have already had highly efficient organizational process, could not find the merits of technology usage without technology integration capabilities. This would be regarded as disadvantage of process-advanced company that they cannot have enough incentive to introduce advanced technology and new entries have a chance to leap-frog the advanced companies in usage of technology in general.

INTRODUCTION

Nowadays, technologies have been expanding their functions and multi-functional technologies tend to influence on organization broadly. As a number of function of a technology increasing, a number of departments that are required to be concerned with and business processes that are related to the technology increase. Eventually, multi-functional technology could be a tool of fulfilling the corporate-level strategy and achieving the total performance.

However, it is not enough to achieve the total performance merely by using the technology but it is often necessary to change organization and technology at the same time (Leonard-Barton, 1988; Burkhardt & Brass, 1990; Barley 1990). To change organization, in particular, is a difficult work because of organizational inertia, thus the company's technology integration capabilities to carry out the mutual adaptation between technology and organization are required.

Technology integration capability here implies selecting appropriate sets of technologies, customize, implement, support and evaluate them to fit with organization and corporate strategy; at the same time, it implies reforming organizational process and structure towards total optimization.

3 dimensional information technologies used in product development process are typical multi-functional technologies. The new generation 3D computer aided design (CAD) called a solid modeler, a basis of 3D technologies, has started being used by the manufacturing companies in the 1990s. The earlier generation 3D CAD before the 1990s defines only lines or surfaces of a product; thus, in many cases, it was not used for product design but for preparing data of simulation or factory machines. In that era, companies using 3D technologies enhanced the performance of each process only partially, and they could not share the common data throughout the whole process. It was not a rare case in which a number of different types of drawings were separately

made in a project, for example, drawings for product design, styling, prototyping, dye, mold, and inspection.

Since the emergence of the new generation of 3D CAD, which defines not only lines and surfaces but also solid shapes, product engineers have been able to use 3D CAD as a design tool and the 3D data are used in various processes including computer aided industrial design (CAID) for styling, computer aided engineering (CAE) for simulation, computer aided manufacturing (CAM) for process engineering and prototyping, rapid prototyping for prototyping, and computer aided testing (CAT) for inspection of products.

3D technologies used in product development process are technologies that highly require organizational process reformation to achieve total optimization. How well a company can derive the potential of 3D technologies highly depends on the company's perception towards the technologies (Robertson & Allen,1993; Adler, 1995; Takeda 2000a; Takeda 2000b) and its capability to utilize and integrate the technologies with organizational change (Aoshima et al. 2004; Takeda et al., 2004).

This paper aims to exam technology integration capabilities among Japanese and Chinese firms through a questionnaire survey regarding impact of 3D technologies on product development process and performance.

3D TECHNOLOGY AND INTEGRATION CAPABILITY

3D Design Tool as Socially Constructed Technology

Technology has an aspect that is socially created through the interaction of its users (Orlikowski, 1992; Giddens, 1984). Barley (1986) followed the implementation of CT scan equipment in two hospitals at the same time in the same region by using a discourse analysis between x-ray technicians and engineers, showing that the implementation of the technology had differing effects on organizational structure such as the dispersion of power. Orlikowski (1992) observed the implementation processes of CASE (Computer Aided Software Engineering) tools in a particular company, showing that the organizational context has an effect on the way users apply the tool. Social Influence Theory/Social Construction Theory (Fulk et al., 1990; Schmitz & Fulk, 1991;Fulk, 1993) maintains the view that the awareness and actual usage of information technology by fellow workers in the same organization affects the use of information technology.

Information technologies for product development are extremely socially constructed technologies rather than simple function-based technologies. Robertson & Allen (1993) considered that there exist three levels as the degree of utilization of CAD systems in engineering work: design, analysis and communication. Design use is a basis of analysis and communication use; the latter two functions lead to achieve higher performance compared to simple design use; 3D CAD tends to be more frequently used for communication purpose. Adler (1995) regarded that CAD/CAM have more flexible, context-depended characteristics in that it varies constraints of interdepartmental interaction modes -standards, schedules, mutual adaptation and teams (Thompson, 1967 and Van de Ven et al. 1976) and the timing of coordination in the interface between design and manufacturing. The higher the degree of novelty of product, the closer to team, the most highly mutual interactive coordination mode should be; the lower the analyzability of design and manufacturing fit issues is, in the later phases the coordination effort should be done. However, CAD/CAM have possibility to loosen the contingent constraint.

Takeda (2000a; 2000b) found that Japanese mechanical manufacturers regarded 3D technologies in two ways - as programmed information processing tools and as communication mediating tools; effectiveness of 3D technologies defers depending how they perceive the technologies. As the result, a synergy effect of programmed information processing perception and communication mediating perception on the performance was observed, that is consistent with the Robertson & Allen (1993)'s conclusion. Under the competitive environment which Japanese manufactures confront with, they should develop novel and integrative products that should be extremely coordinated, thus the result also consistent with Adler (1995) 's contingency framework. Takeda (2000a; 2000b) called a firm's social perception towards technology, which influences on organizational behavior when they implement the technology as implementation strategy. 3D technologies used in product development process are highly affected by the company's implementation strategy.

Technology Utilization Capability

In the literature of information system research, based on the resource-based view of the firm, firm-specific information technology resources are regarded as IT capabilities including infrastructure, human resources, skills, knowhow, organizational routines, strategic thinking, relationship within/between organization(s), and relationship with customers. It is generally known IT capabilities are positively related to firm's performance (Bharadwaj, 2000; Santhanam and Hartono, 2003; Tippins & Sohi, 2003; Wade & Hulland, 2004; Melville et al., 2004).

Although intangible assets like routines, strategic thinking and relationship are related to the performance more strongly than tangible assets like infrastructure and human resources because of their rarity and inimitability (Wade & Hulland, 2004), still it cannot be said that tangible assets are easy to prepare when the system is complicated and large-scaled. 3D technologies in product development process require to investment on huge amounts of hardware and software, and engineers having skills to utilize the technologies that are discontinuously different from 2D-based traditional designing methods (Baba and Nobeoka, 1998).

In this paper, the firm's specific tangible assets to utilize technologies are called as technology utilization capabilities. Complicated large-scaled system usually requires firms to have technology utilization capabilities. Only with technology utilization capabilities, although it is not enough to improve firm's performance in many cases, localized efficiency or effectiveness directly related to the technology can be expected to improve. In the case of 3D technology implement, partial performance mainly within a department like quality and efficiency of design, ability of simulation and accuracy of data transmission would improve by the firm's technology utilization capabilities.

Technology integration capabilities

To improve the performance beyond the local effect directly related to the technology, intangible assets such as the firm's specific knowledge, skills, and routines would be required. The most difficult challenge is the alignment of technology and organization. There is always a gap between a newly introduced technology and the existing organizational process and structure, thus mutual adaptation of technology and organization should be managed (Leonard-Barton, 1988). The technology's attributes have an immediate impact on work roles and social network; on the other hand, roles and social networks have mediate the technology's structure (Barley, 1990). The use of the technology enacts in the social network structure; it also impose changes in the social network structure (Burkhardt & Brass, 1990; Orlikowski, 2000).

Intangible abilities to integrate technology and organization which are required to realize the performance beyond local effect are called as technology integration capability in this paper. Firms having technology integration capabilities select appropriate sets of technologies, customize, implement, support and evaluate them to fit with organization and corporate strategy; at the same time, they can reform organizational process and structure towards total optimization. Technology integration capabilities include deep and wide understanding of the technology and the organization, organizational routines of handling technology to fit with organization, and routine of carrying out organizational reformation. Technology integration capabilities are activated when system focused approach is adopted that is project specification is done considering systematic impact of technical options in the organization based on past experiences (Iansiti, 1995).

In implementing 3D technologies in product development process, Aoshima et al. (2004) found that firms that changes their boundary of tasks initiated by corporate-level project rather than by department-level project improve their performance in Japan. Japanese firms reformed processes and increased linkage with suppliers with using 3D technologies in 2000s compared with in 1990s and improved their product development performance (Takeda et al., 2004). These facts implied that technology integration capabilities are required to improve the product development performance leveraged by 3D technologies

RESEARCH FRAMEWORK

As the previous discussion, usage of multi-functional technology have possibilities to leverage total performance improvement only when firms have technology integration capabilities that enable deep understanding both the technology and the organization and executing reformation of them. However, the partial performance improvement would be achieved only with technology utilization capabilities that mainly consist of tangible assets like infrastructure and human resources. As it is impossible to integrate technology and organization effectively without enough infrastructure and human resources, technology utilization capabilities can be considered as a basis of technology integration capabilities (see Figure 1).

Insert Figure 1 here

Aoshima et al. (2006), conducting questionnaire surveys on 3D technology usage among Japanese and Chinese manufacturing companies, found that the diffusion of 3D CAD in China was approximately four years behind Japanese companies. 3D CAD was introduced in Japan in the 1980s, it took off in the mid-1990s. The diffusion rate seems saturated around 80% at the present time. Chinese companies started using 3D CAD in the mid-1990s and rapidly caught up with the Japanese (see Figure 2). Although the diffusion rate of Japanese companies is higher than that of Chinese companies which tend to be polarized into extremely advanced or extremely retarded in terms of 3D-CAD use, the percentage of engineers who can use 3D CAD among 3D user companies was higher in China, 42.7% than that of Japan, 34.5% in 2004.

Insert Figure 2 here

From these facts, we can guess that there was not a significant difference between Japanese and Chinese 3D user companies with regard to amount of infrastructure and human resources; but with regard to quality and depth of intangible assets like deep knowledge, skills, and routines about relationship among technology and organization, the difference between two country would be observed because Chinese companies adopted 3D technology so quickly that they did not afford to cultivate technology integration capabilities at the moment. Thus, by analyzing the same data sets of Aoshima et al. (2006), we would found the following facts:

Operational hypothesis 1: Japanese firms improve the total performance leveraged by technology and organizational reformation.

Operational hypothesis 2: Chinese firms do not improve the total performance leveraged by technology and there is no significant relationship between technology usage and organizational reformation.

Operational hypothesis 3: Chinese firms improve the partial performance leveraged by technology.

DATA COLLECTED

Data Collection

We conducted questionnaire surveys regarding 3D technology usage and its impact on product development projects in Japan and China. For the Japanese survey, questionnaires were distributed by mail in 2004. They were sent to 700 companies, which included all the machine-related manufacturing companies listed in the First Section of the Tokyo Stock Exchange, other machine-related manufacturing companies randomly selected from a list of IPOs, and unlisted companies. Questionnaires were addressed to either heads or planning section heads of product development departments. Of the 700 questionnaires distributed, 153 were returned.

For the Chinese survey, we selected 114 manufacturing companies, taking into consideration their size and industry sectors. To raise the response rate, research associates in the Southern Yangtze University personally visited each of the 114 companies in 2004, and the respondents were requested to fill out the questionnaires in the presence of the research associates. The questionnaires were successfully filled out in all the companies visited.

The following Table 1 indicates the number of responses according to industry type and the distribution of the number of employees for each sample. The Japanese sample consists of a greater number of electrical and electronics companies. Thus, we include a dummy variable of electrical and electronics industry in the operational model that we mention later.

Insert Table 1 here

The questionnaire had two parts. The first part contained questions about the present situation of the companies and divisions in terms of 3D technologies introduction and use. The second part focused on the project level. We mainly used the project level data obtained from the questionnaire for analysis.

In the project-level part, the respondents selected 1 product development project that was the most advanced and recent with regard to the use of CAD. We designated this as the “present project.” We then asked the respondents to select another project from the past that developed the same type of product as the present project and designated it as the “previous project.” We asked respondents to specify the most advanced project in respect of CAD use and to evaluate it compared with the past project of the same kind of product by 5-point Likert scale from “Not applicable at all” to “Very applicable” regarding a variety of process changes and performance indexes.

Status of Process Reformation among 3D Technology Users

To overview a status of concurrent processes of 3D technology use and organizational reformation, Table 2 shows various process change including design, prototyping, simulation, data linkage with downstream and collaboration among 3D heavy users whose 3D data share in the design process is 50%+ and light or non-users whose 3D data share is under 50%.

First, the absolute scores of both heavy users and light/non-users in China were significantly better than Japanese with all indexes. However, we should be slightly careful in interpreting absolute amount of scores because the Chinese respondents consistently tended to provide more optimistic responses throughout the questionnaire as compared to the Japanese. Thus, it would be better that we focus on the differences of indexes between heavy users and light/non users of each country.

In Japan, there are significant differences between heavy users and light/non users in all indexes shown in Table 2. On the other hand, the statistically significant differences were observed only in the “rapid prototyping technology was more utilized” in China. There seems to be wider and larger differences between 3D advanced companies and not so advanced companies in Japan than in China.

Insert Table 2 here

Next, among organizational process changes, let we focus on two typical process reformation closely related to 3D technologies, incorporation of downstream task and task frontloading.

Incorporation of downstream task

In the product development process, it is not enough for product engineers to decide what they product but also to consider how they product it because of the interdependence between product definition and production process. 3D technologies have potentials to cope with this interdependency. 3D CAD defines a product more accurately than 2D CAD, thus product engineers can design the product incorporating downstream process such as dye/mold requirements with 3D CAD. CAM automatically outputs numerical control of factory machines from 3D CAD data, and downstream engineers become unnecessary to re-input the control data. The progress of CAE technologies makes easy of simulation for engineers, then they have been becoming to do simulation with 3D CAD data by themselves and the need to ask simulation specialists decreases. Although experience of downstream engineers and ex post adjustments are still important, 3D technologies have function to reduce interdependency of product design process and downstream tasks to some extent.

Table 3 shows the status of each department's incorporation of downstream/upstream task and the change of division of labor among 3D heavy users and light/non-users. In Japan, apparently, product engineers became incorporating downstream tasks such as process engineering and dye/mold-making and became doing computer simulation by themselves. Oppositely, downstream department became not to do upstream's tasks in Japan. In China, the change of incorporation of other department's task and change of division of labor did not occur significantly.

Insert Table 3 here

Frontloading

Frontloading problem-solving is "a strategy that seeks to improve development performance by shifting the identification and solving of [design] problems to earlier phases of a product development process" (Thomke and Fujimoto, 2000), one of the most critical process changes in the manufacturing industry in recent years. Inefficiency of product development is often caused by design reworks, which take place in the latter stage of the development process. The later the design reworks occur, the greater the cost and time incurred on account of them. A development project must therefore predict and solve potential problems as early as possible.

Frontloading is difficult to be realized merely by rationalizing each work or implication of efficient tools. Upstream department usually do not have enough information and know-how about downstream process, thus it is necessary to communicate or collaborate with downstream departments to acquire down stream's knowledge. Thus, just considering about downstream requirement is often not enough, cross-functional process reformation is required. Thus, incorporation of downstream task can be observed with frontloading at the same time, but it does not always give rise to frontloading.

3D technologies have potential to facilitate frontloading. 3D technologies provide advanced media functions by which design information can be visualized in an intuitively understandable form. Once design information is visualized as a 3D image, staff involved in various functions can exchange their viewpoints. This characteristic of 3D technologies enables individuals performing different roles, such as process engineers, dye designers, jig designers, dye makers, suppliers, manufacturing engineers, marketing personnel, and even customers, to input their perspectives into the design data during the early stages (Takeda, 2000). 3D technologies have possibilities to improve accuracy and quality of information through cross-sectional experiment iteration (Thomke, 2003).

Figure 3 shows a detailed comparison of the extent of frontloading. The upper figure is a comparison among heavy, light, and non-users in Japan; the lower figure shows the comparison in China. The number for the vertical axis indicates a change in the taskload between the previous and the present project, ranging from 1: significantly decreased to 5: significantly increased. The number 3 implies no change.

In Japan, it can be confirmed that the taskload upstream significantly increased and that of downstream decreased among heavy users in Japan. Among light users, the same tendency was observed but decrease in downstream was smaller than for heavy users. Among non-users, there is no tendency of frontloading.

In contrast, in China, although heavy users tend to decrease taskload, all processes evenly decreased and frontloading was not observed.

Insert Figure 3 here

It seems that there is a significant relationship between 3D technology use and organizational reformation in Japan; the relationship is rarely observed in China. However, to examine the operational hypotheses in the previous chapter, the relationship among use of 3D technologies, process changes and performance should be analyzed both in the total optimization and the local optimization level.

Operational Model and Measurement

Based on the previous chapter's discussion, we examine the following two operational model in Figure 4 by structural equation modeling. The models indicate that 3D technologies affects on performance directly as "direct utilization" and indirectly through process change as "integration of technology and organization."

Model 1 is in the total optimization level. In Model 1, the target is the total performance improvement that includes lead time, engineering hours and product quality. Usage of 3D technologies affects on the total performance directly or accompanied with reforming total process, a combination of incorporation of downstream task and frontloading,

Model 2 is the partial optimization level. In Model 2, the partial performance, design quality connected to manufacturing is oriented, and 3D technologies affect on the partial performance directly or accompanied with partial process changes related to the design quality.

Insert Figure 4 here

Table 4 indicates the measurements for each construct.

The dependent variable is the product development performance measured by the average of the total reduced lead time, the total reduced engineering hours, and improvement of product quality in Model 1, improvement of manufacturability and reduction of confirmation of size and shape from downstream in Model 2.

As for an independent variable, 3D technology use was measured by a difference of 3D data share in the product design between the previous and present projects in both models. Since all our indicators of performance and process change are measured in relative terms between the present and previous projects, a relative measure may be more appropriate. An increase in 3D use is assumed to have both direct effect (direct utilization) and indirect effect (integration between technology and organization) on performance, as shown in Figure 4.

As process changes with which 3D use affects on performance, Model 1 assumes a combination of frontloading and incorporation of downstream task; Model 2 assumes only incorporation of downstream task. Incorporation of downstream task is measured by "Product design engineers became considering dye/mold-making requirement" and "Product design engineers became considering process requirement."

The frontloaded task was calculated in the following manner. We first averaged the scores of the increased taskload, ranging from 1 (dramatically decreased) to 5 (dramatically increased), for industrial designers, product design engineers, and CAE engineers. This averaged score indicated the increase in taskload for people upstream. Likewise, we calculated the increase in taskload for people downstream by including scores for prototyping engineers, dye designers, jig designers, and production engineers. We then used the ratio between these two to create the frontloaded task indicator.

We also included other control variables. 3D Design Experience specifies the number of years since they introduced 3D-CAD. Firm size is the logarithm of the number of employees. Industry dummy variable is 1 if it is electrical and electronics to reduce a bias of Japanese having larger share of electrical and electronics industry.

Insert Table 4 here

RESULTS

Based on the operational model, as shown in Figure 4, we constructed a series of structural equation models to examine the differences in the direct and indirect impacts of 3D technology use on performance at the total and local optimization level. Table 5 shows the results for Model 1, at the total optimization level.

Insert Table 5 here

In the Japanese data set, the increase in 3D technology usage directly impacted performance, and at the same time, there was an indirect effect through process change. The direct effect of 3D usage on the performance is 0.190, which was slightly larger than the indirect effect through process change ($0.249 \times 0.569 = 0.142$). Among the Japanese companies, 3D usage did not only improve product development performance directly but also did so by promoting the total process change, frontloading and incorporation of downstream task.

An impressive difference was apparent through analysis using the Chinese data set. The use of 3D use did not affect performance either directly and indirectly in these countries. In addition, frontloading and incorporation of downstream task did not work together.

Thus, the operational hypothesis 1, that is "Japanese firms improve the total performance leveraged by technology and organizational reformation." and the operational hypothesis 2, that is "Chinese firms do not improve the total performance leveraged by technology and there is no significant relation between technology usage and organizational reformation." are supported. In China, the total process reformation itself is rarely observed.

With regard to control variables, the period using 3D technologies improved performance in Japan. This is naturally considered as an experience effect of technology. On the other hand, among Chinese companies, the experience of 3D design did not influence performance, and large firms tend to improve performance. Histories of 3D implemented in China are relatively shorter than in Japan, and absolute difference of organizational resource between large companies and small company is larger in China than in Japan. Thus, it can be considered that the firm size is more important than experience effect in China .

Currently, at the developmental stage of the machinery industry in China, the total process reformation may not be a critical issue. It is possible that the Chinese companies are satisfied with the improvement of partial performance, such as efficiency in design quality linked to manufacturing. Table 6 shows the results for Model 2, at the partial optimization level.

Insert Table 6 here

In model 2, 3D use and process change significantly affected on the partial performance independently both in Japan and China. When the target is partial optimization, in this case, design quality connected to manufacturing, direct effectiveness of using technology was available as well as process improvement, design considering downstream requirement. Thus, Operational hypothesis 3, "Chinese firms improve the partial performance leveraged by technology" is supported, and the same tendency was observed in Japan.

Again, 3D experience was important for Japanese companies and firm scale was important for Chinese companies. In Japan, firm size was also at significant level in Model 2.

DISCUSSION

This paper aimed to exam technology integration capabilities among Japanese and Chinese firms through questionnaire surveys regarding impact of 3D technologies on product development process and performance. The results indicated that Japanese companies improved their total performance with process reformation leveraged by 3D technologies; however, among Chinese companies, no significant relationship was observed among 3D technology usage, process reformation and the total performance although they improve the partial performance such as manufacturability by utilizing the technologies. These facts are consistent with existence of technology integration capabilities in the upper layer on the lower layer, in which technology utilization capabilities exist.

As the data that we analyzed was obtained in 2004, there is a possibility that the situation has changed at the present time. Chinese companies may have started to cultivate their technology integration capabilities. However, at least at the timing of the survey, Chinese companies were not at a stage where they pursued total performance improvement through process reformation; rather, their focus is to increase the efficiency of each process. Chinese companies, which have a huge growing market and are on the process of rapidly improving their productivities without strong organizational inertia, could have enough advantage by utilizing technologies to improve the partial performance. In contrast, Japanese companies, which compete in mature market and have already had highly efficient organizational process, could not find the merits of technology usage without technology integration capabilities. This would be regarded as disadvantage of process-advanced company that they cannot have enough incentive to introduce advanced technology because it takes time and cost to would have technology integration capabilities than to have technology utilization capabilities in general. In fact, as shown figure 2, the speed of introduction of 3D CAD was slower in Japan than in China.

Other Asian industrial developing countries have been also rapidly adopted 3D technologies in recent years like China, and the diffusion of 3D technology in such countries is fast catching up with the level in Japan. Although it takes time for them to be at the stage of integrating the whole process, it would be enough for them as far as they adopt a strategy to produce modular costless products. In addition, as extensive usage of advanced technology accelerate to accumulate deep knowledge and skills, there would be a possibility that firms in the catching-up countries will leap-frog firms in advanced countries in the near future.

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Figure 1
Optimization requirement and firm's capability regarding technology

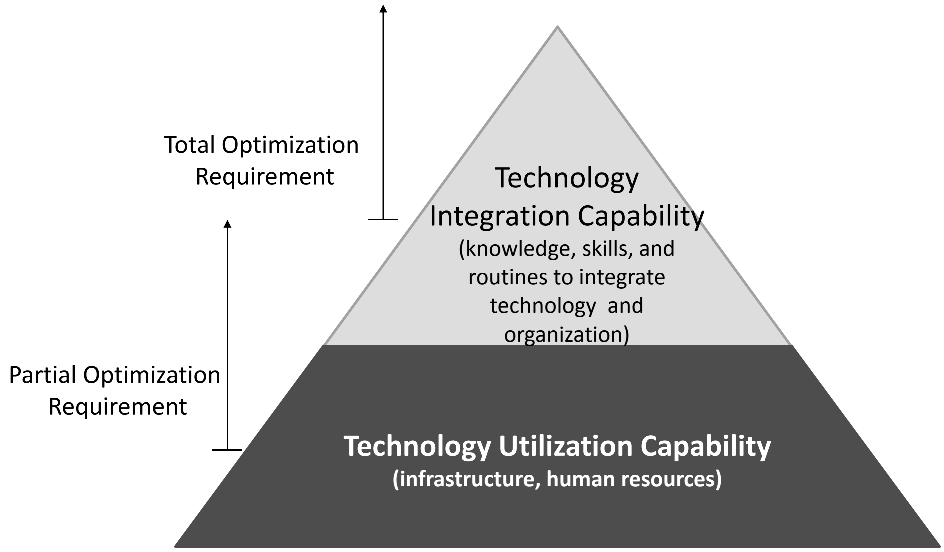
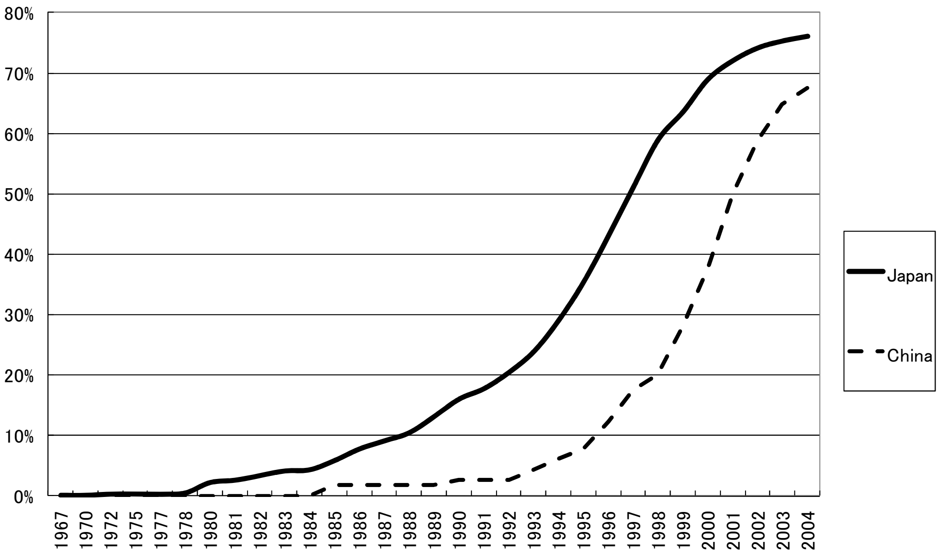


Figure 2
Diffusion curves of 3D CAD



(Japan N = 136; China N = 114)

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TABLE 1

Sample Composition

	Japan N=153	*China N=114*
Industry		
General Machinery	30.1%	33.3%
Electrical and Electronics	26.8	9.6
Transportation	19.6	11.4
Precision Machinery	5.2	6.1
Other Manufacturing	10.5	32.5
Missing	7.8	7.0
No. of employee		
Mean	3875.6	6207.0
Std	15434.4	25288.3

Table 2

Differences between 3D heavy users and light/non-users regarding process changes

	Japan			China		
	Heavy users (71)	Light/non users (72)	Difference	Heavy users (28)	Light/non users (55)	Difference
Design						
Re-use of past design data or design modulization was promoted	3.40	2.75	0.65***	3.89	3.89	0.00
Product was designed thinner or was more downsized	3.51	3.08	0.42***	3.74	3.76	-0.02
Prototyping						
Frequency of prototyping decreased	3.50	2.72	0.78***	3.59	3.39	0.20
Rapid prototyping was more utilized	2.97	2.42	0.55**	3.68	2.96	0.72**
Simulation						
Cases that designers simulate independently increased	3.47	2.81	0.67***	3.59	3.46	0.13
The number of different types of simulation increased	3.61	3.06	0.56***	3.50	3.43	0.07
Data linkage with downstream						
Data were sent to downstream more accurately	3.71	2.79	0.92***	4.04	3.89	0.14
Data were sent to downstream earlier	3.51	2.72	0.79***	3.96	3.93	0.04
Collaboration						
More suggestions from production departments were adopted	3.29	2.68	0.61***	3.75	3.42	0.33
More suggestions from suppliers were adopted	3.16	2.62	0.54***	3.75	3.25	0.50

t value's significant level is *p<.1, **p < .05, ***p<.01.

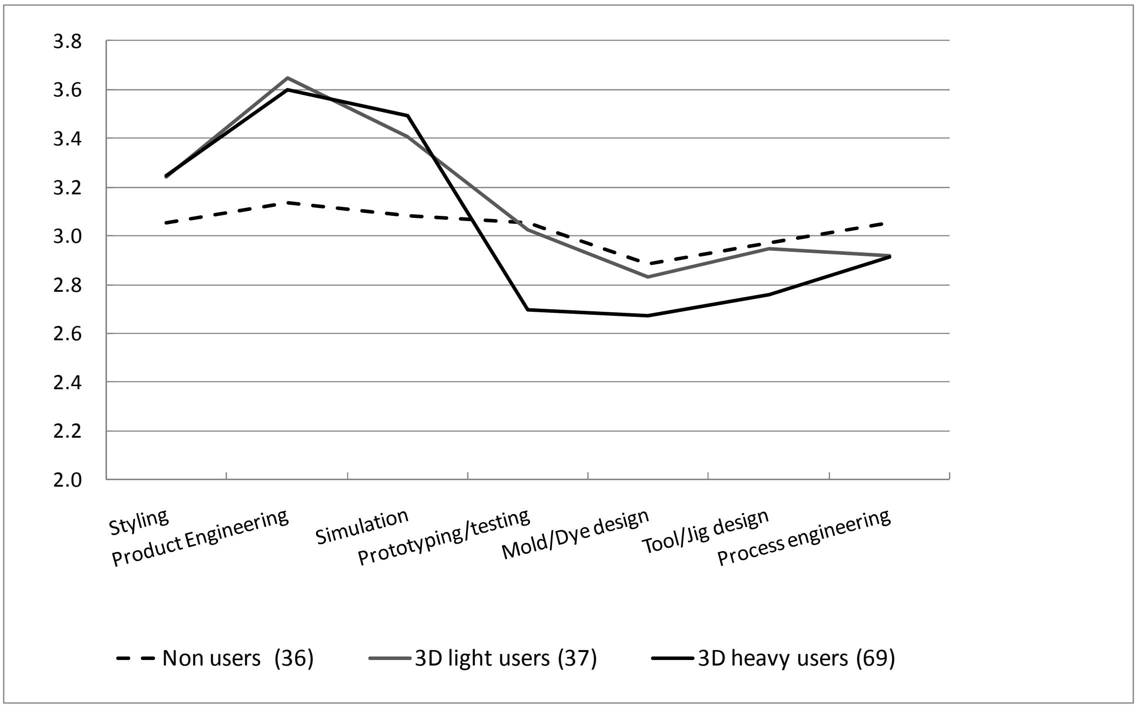
Table 3
Differences between 3D heavy users and light/non-users regarding incorporation of downstream task

	Japan			China		
	Heavy users (71)	Light/non users (73)	Difference	Heavy users (30)	Light/no nusers (55)	Difference
Upstream dept.'s incorporation of downstream task						
Industrial designer became considering product engineering requirements	2.78	2.60	0.18	3.67	3.57	0.09
Industrial designer became considering dye/mold-making or process requirements	2.70	3.15	0.15	3.69	3.70	0.26
Product engineer became considering process requirements	3.75	2.17	0.60***	3.76	3.13	0.05
Product engineer became considering dye/mold-making requirements	3.41	2.41	0.70***	3.53	3.29	-0.18
Downstream dept.'s incorporation of upstream task						
Process engineer became making comments on product design	2.73	2.34	0.14	3.70	3.57	-0.06
Dye/mold engineer became making comments on product design	2.58	2.34	0.21	3.59	3.39	0.10
Change of division of labor from downstream to upstream						
Industrial designer became to do product design	2.17	2.93	-0.17	3.63	3.30	0.06
Product engineer became to do dye/mold design	2.04	2.37	-0.23	3.24	3.48	-0.06
Product engineer became to do computer simulation	3.45	2.60	0.52***	3.66	3.76	0.36
Change of division of labor from upstream to downstream						
Simulation engineer became to do product design	1.99	2.49	-0.43**	3.30	3.51	0.01
Dye/mold engineer became to do product design	1.79	2.55	-0.38**	2.87	3.43	-0.27
Integration of departments						
Product design department and process engineering department were integrated	2.38	2.71	-0.11	3.47	3.72	-0.04
Product design department and simulation department were integrated	2.44	2.28	0.09	3.50	3.30	0.11

t value’s significant level is *p<.1, **p < .05, ***p<.01.

Figure 3
Extent of frontloading

Japan



China

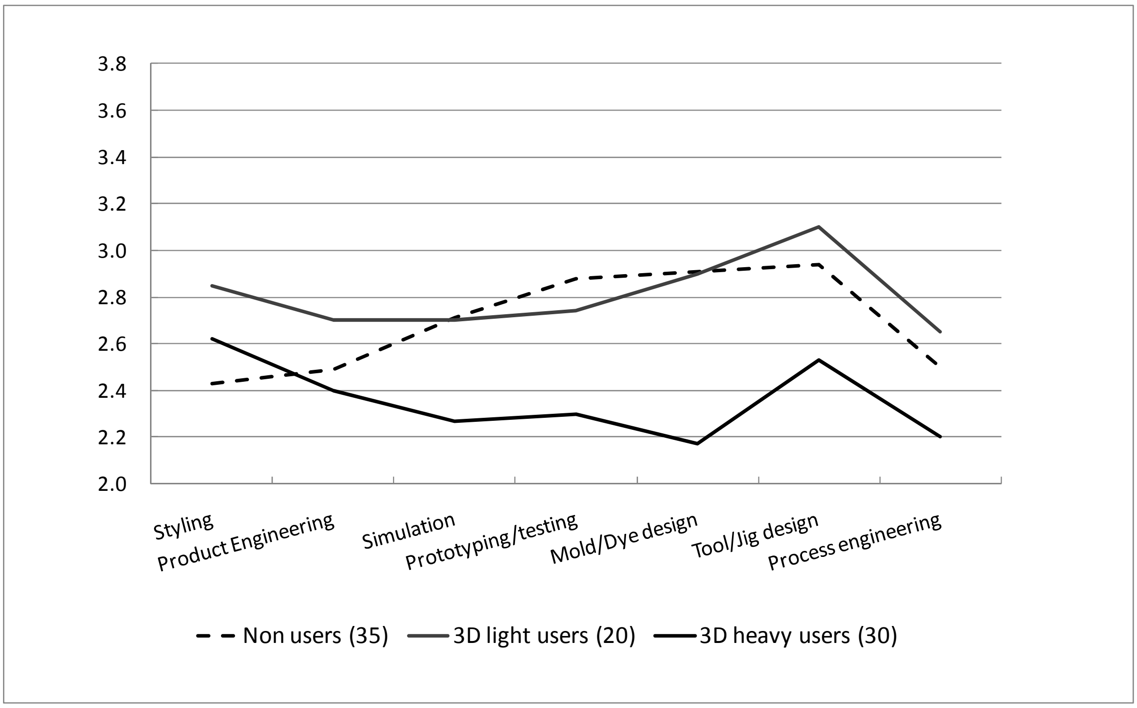
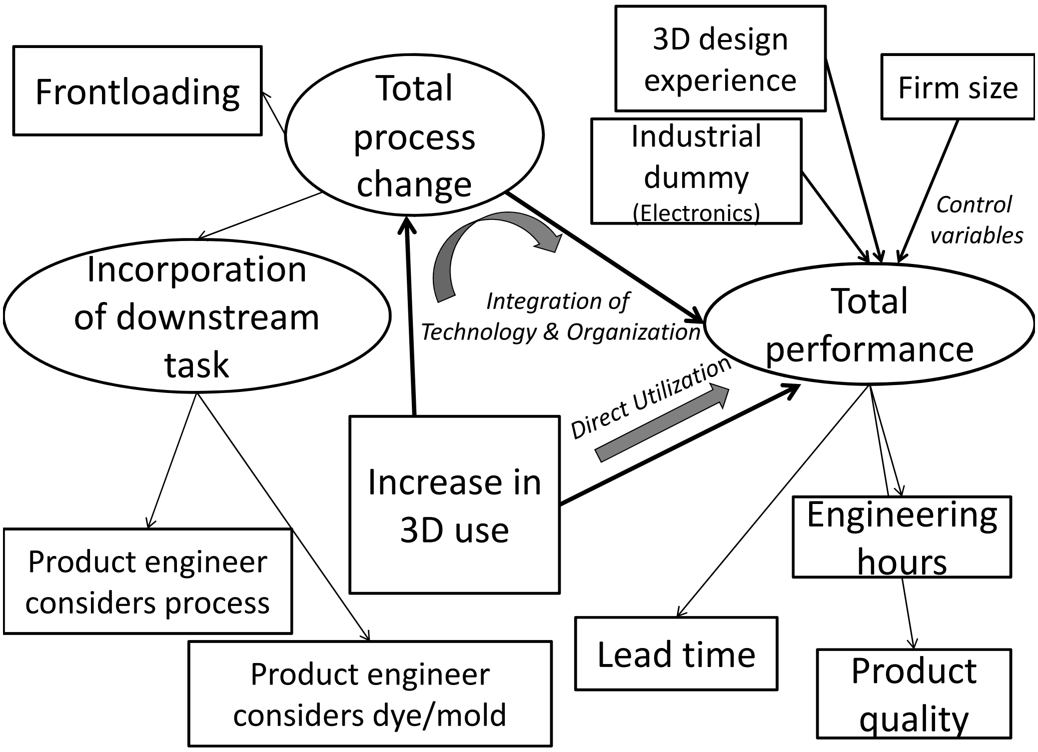


Figure 4

Model 1



Model 2

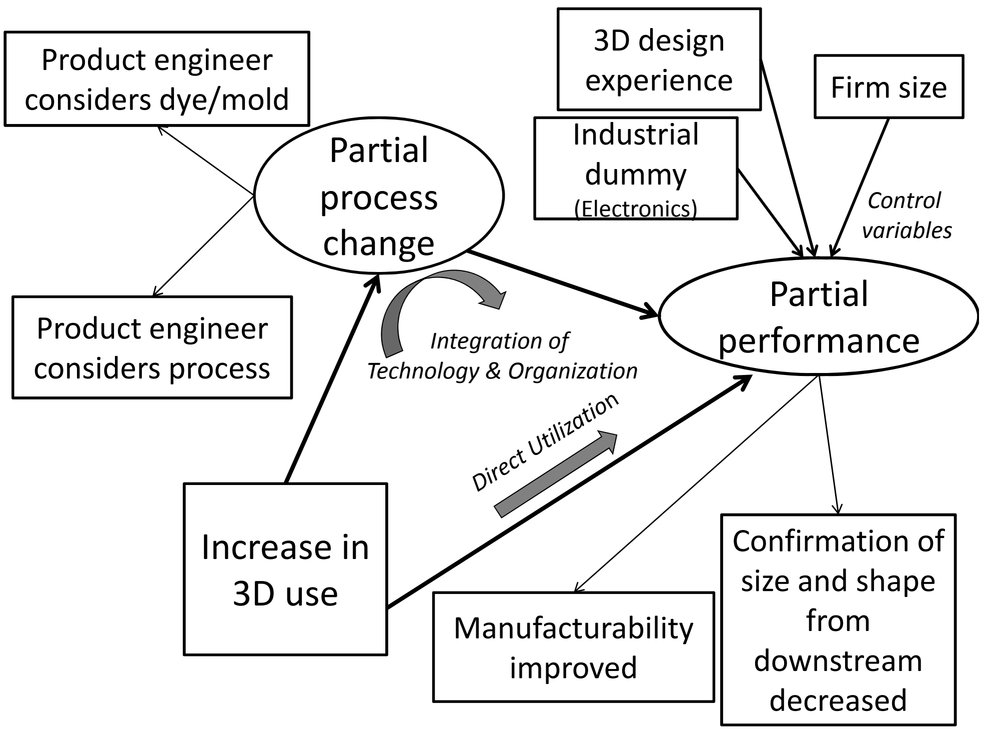


Table 4

Variables

Construct	Indexes	Japan (N = 153)		China (N = 114)	
		Mean	Std	Mean	Std
Total Performance	Total reduced lead time	3.30	1.01	4.06	1.06
	Total number of engineering hours reduced	3.12	0.88	4.00	1.07
	Improved product quality	3.55	0.74	3.71	0.95
Partial Performance	Manufacturability improved	3.38	0.80	3.47	1.04
	Confirmation of size and shape from downstream decreased	3.14	1.00	3.69	0.97
Increase in 3D Use	Difference of 3D-CAD ratio between the present and previous projects (%)	25.45	35.75	14.95	26.63
Frontloading	(Increase of taskload for industrial designers, design engineers, CAE engineers)/(increase of taskload for prototyping engineers, dye designers, jig designers, and process engineers)	1.18	0.26	1.02	0.43
Incorporation of downstream task	Product design engineers became considering dye/mold -making requirements	3.07	1.16	3.64	0.92
	Product design engineers became considering process requirements	3.45	0.94	3.68	1.00
Control variables					
Firm size	Log 10 (the number of employees)	8.01	6.16	4.81	3.70
3D Design Experience	Number of years since 3D-CAD was introduced	3.08	0.55	2.86	0.80
Industry dummy	Electrical and Electronics=1	26.8%		12.3%	

All original indexes except 3D use and control variables are measured by 5-point Likert scale.

Table 5

Results of structural equation modeling: Model 1

	Japan		China	
Standardized coefficients				
3D use -> Process change	0.249	*	0.124	
Process change -> Total Performance	0.569	***	0.821	
3D use -> Total Performance	0.190	*	0.098	
3D Experience -> Total Performance	0.238	***	-0.079	
Firm size -> Total Performance	0.070		0.242	**
Industry dummy (electronics) -> Total Performance	0.005		-0.102	
Process change -> Incorporation of downstream task	0.800	***	0.577	
Process change -> Frontloading	0.452	***	0.207	
Incorporation of downstream task -> Process requirement	0.920	***	0.811	***
Incorporation of downstream task -> Dye-making requirement	0.700	***	0.689	***
Total Performance -> Lead time	0.796	***	0.883	***
Total Performance -> Engineering hours	0.752	***	0.881	***
Total Performance -> Product quality	0.696	***	0.453	***
$\chi 2$	75.657		47.370	
NFI	0.783		0.780	
CFI	0.851		0.904	
N	153		114	

Significant level ***p < 0.01, **p < 0.05, *p < 0.1

Table 6

Results of structural equation modeling: Model 2

	Japan	China
Standardized coefficients		
3D use -> Incorporation of downstream task	0.108	0.120
Incorporation of downstream task -> Partial Performance	0.673 ***	0.582 ***
3D use -> Partial Performance	0.401 ***	0.291 **
3D Experience -> Partial Performance	0.173 *	0.056
Firm size -> Partial Performance	0.183 *	0.312 ***
Industry dummy (electronics) -> Partial Performance	0.016	-0.057
Incorporation of downstream task-> Process requirement	0.760 ***	0.822 ***
Incorporation of downstream task-> Dye-making requirement	0.846 ***	0.676 ***
Partial Performance -> Manufacturability improved	0.504 ***	0.726 ***
Partial Performance -> Confirmation of size and shape from downstream decreased	0.757 ***	0.675 ***
$\chi 2$	48.669	26.559
NFI	0.781	0.772
CFI	0.836	0.894
N	153	114

Significant level ***p < 0.01, **p < 0.05, *p < 0.1