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Exploring the Causal Model of 3D-CAD Technology: Interfirm Communication and Product Development Performance in Japanese Automobile Parts Industry

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Abstract: 3D-CAD technology impacts the performance of product development in two ways. One is a positive effect that the use of the 3D-CAD decreases the number of problem solving cycles directly, so that development performance improves. The other is the negative effect that 3D-CAD increases interfirm communication, which increases the quantity of coordination. In conclusion, the overall phenomenon of a correlation between the use of 3D-CAD technology and improved performance cannot be seen, because the two effects of the 3D-CAD offset each other.

Keyword: 3D-CAD, product development, interfirm communication

1. Introduction

Over the past few years, many existing studies on 3D-CAD information technology have examined what kinds of influence 3D-CAD has had on product development and its process (e.g., Aoshima, 1998; Aoshima & Nobeoka, 2001; Aoshima, Nobeoka & Takeda, 2001; Takeda 2000a, 2000b; Nobeoka, 1997; Robertson & Allen, 1993;). Many empirical studies including Aoshima and Nobeoka (2001) have reported that the introduction and use of 3D-CAD

has the effect of 'improvement of product quality.' However, they have reported that the use of 3D-CAD is irrelevant to 'the development efficiency (cost and development lead time).' In other words, there were inconsistencies between the theoretical expectation effect and the empirical study results of 3D-CAD technology.

In the present study, we were not able to find the relations (correlation) between 3D-CAD technical use and development efficiency when we

chose the Japanese auto parts industry as our object of analysis. In Japanese auto parts industry, why was the relations (correlation) between the increasing introduction and use of 3D-CAD technology and the development efficiency in product development not found?

To address this question, this paper built a model considering interfirm communication and analyzed the effects between the increase of introduction and use of 3D-CAD technology and development efficiency. Considering interfirm communication, 3D-CAD technology indirectly brings 'promotion of effective communication' and 'front load of a communication timing.' However, few studies to date have dealt with the effects of 3D-CAD considering both 3D-CAD as communication tool and the quantity of interfirm coordination.

If a conclusion is taken in advance, it was found that 3D-CAD technology has effects on the development efficiency through two paths. That is, one path is that 3D-CAD technology reduced the number of problem solving cycles and it contributed to shortening of development lead time. The other path is that interfirm communication increased and inversely gave the influence that seemed to let the number of problem solving cycles increase. In other words, because a negative effect offsets a positive effect, correlation between 3D-CAD use and the development efficiency was not found.

This result indicated that company should not merely require the efficiency of 3D-CAD as a communication tool. That is to say, it may imply that engineers of a division and/or suppliers can participate in design communication process more actively and frequently by a computer screen, and this can largely improve product quality.

Actually, 3D-CAD can provide high visibility and enable engineers to check easily many parts interference problems on a screen and do simulations such as a check or a function test of part interference with lower cost and enable digital virtual assembling (e.g., Aoshima, 1998; Baba & Nobeoka, 1998; Nobeoka, 1997; Robertson & Allen, 1993; Takeda, 2000b; Takeda, Aoshima, & Nobeoka, 2000). In this point, the result of this paper indicates that 3D-CAD improves quality of development performance rather than improving development speed directly.

2. 3D-CAD, Development Efficiency, Communication

The typical good example that revolutionized a product development process with 3D-CAD technology is the development of Boeing 777. The development lead time of Boeing 777 was greatly shortened by the use of 3D-CAD technology. It became easy to ascertain the problem of many parts interference on a computer screen by introducing 3D-CAD technology into the design process of the aircraft which is an extremely complicated product. As a result, a check and a function test of component interactions were enabled at an early stage and at low cost, which brought rapid improvement of development performance (e.g., Aoshima, 1998;

Baba & Nobeoka, 1998). In other words, with 3D-CAD, digital virtual assembling can be done on a screen in the middle of a design process where detailed product information is converted into digital data.

By fully utilizing its simulation function, the front loading of problem solving became conventionally easy, and it directly improved design quality. Simultaneously, by reducing the number of prototypes, 3D-CAD had effects on shortening development lead time and reducing development cost (Aoshima, 1998; Nobeoka, 1997; Thomke & Fujimoto, 2000). Aoshima and Nobeoka (2001) and Nobeoka, Takeda and Aoshima (2002) who studied machinery-related manufacturing companies report that increase of use rate of 3D-CAD brings improvement of product quality much as many studies have reported until now. In addition, their studies point out that the deficiency of organizational actives for a task-redefining occurrs by introducing 3D-CAD technology, which has a negative effect on development efficiency in the short term.

On the other hand, 3D-CAD, being able to provide three dimensional image of product information, can translate tacit knowledge of product information to explicit knowledge. Therefore, designers can have nearly the same image of a product and the formation of information. In this sense, 3D-CAD technology has a large effect on communication, which is regarded as an important determinant factor in the efficiency of concurrent engineering.

Robertson and Allen (1993), Baba and Nobeoka (1998), and Takeda (2000a) pointed that the communication between engineer or designer of different divisions and/or fields are promoted by using 3D-CAD system so that they can recognize and share more correct product information and knowledge. Furthermore, because designers gain deeper understanding of product design information, it can be expected that effective communication is obtained by sharing product information on the same screen at the same time. This will allow effective communication with other divisions in an early period, which realizes shorter development lead time and improvement of product quality.

The automobile, which is the object of this study is an integral architecture product, that is, interdependences between parts are high and complex. The pattern of product development tends to be an overlapping type linking design stage and engineering stage, because functional and structural adjustments between parts are frequently required design changes by the auto maker, for the sake of cooperation and coordination, communication between auto maker and suppliers is extremely important in the design stage (Clark & Fujimoto, 1991; Dyer, 1996; Fujimoto, 1997, 1998).

The introduction of 3D-CAD technology to the auto industry greatly contributed to shorten development lead time of Japanese auto makers.

Japanese auto makers use 3D-CAD and CAE (Computer-Aided Engineering) technology, which allowed them cost reduction and shortening of

development lead time by making a prototype of high completeness at an early stage (Nobeoka, 1997; Fujimoto, Nobeoka, Aoshima, Takeda, & Oh, 2002).

To shorten vehicle development lead time, it is necessary for a supplier to shorten component development lead time, prototype building, production, and delivery.

This implies that suppliers must build the system which is regularly connected with auto maker's system. Also, as a supplier, security of system compatibility of 3D-CAD becomes more important. Therefore, it becomes difficult for suppliers to make effective the new technical introduction if the supplier introducing 3D-CAD technology does not have regular connection and compatibility with auto maker's systems to exchange drawing data. In other words, it is important that suppliers secure the compatibility of systems with auto maker's system when suppliers introduce and use 3D-CAD in product development process. We call these 'the systemic use of 3D-CAD (SYS-CAD)' in this paper.

3. Empirical Analysis
3.1. Research Method and Sample

The data were collected in a questionnaire survey called 'Questionnaire survey 1999 for auto part business in the auto industry' (Fujimoto, Matsuo & Takeishi, 1999) and interviews.

This questionnaire survey was carried out in 418 companies that are primary auto part suppliers and members of the Japanese Jidosha Buhin Kogyo

Society in March 1999. We obtained responses from 173 companies (response rate is 41.3%) and was possible to use 153 (36.6%) responses after material companies were removed. Consequently, we analyzed 125 companies in a model. This is because we removed 28 companies from data set: 25 suppliers had not introduced 3D-CAD at the time of survey and 3 suppliers had deficit values.

In the questionnaire survey, we asked respondents to assess the degree of change within their product (component) design activities and business patterns. Using 5-point Likert scales, they rated the degree of change within their design and business actives compared with four years before. However, the variable of development efficiency production cost (P1) and development lead time (P2) is assessed based on 8-point Likert scales. These are shown in Appendix 1, which present all questionnaire items.

First of all, we analyzed 128 companies which introduced 3D-CAD for the correlation between 'systemic use of 3D-CAD' and 'development efficiency' that seemed to be insisted by many existing studies. The results are shown in Table 1. Excepting the correlation between P1 and P2, all other correlation coefficients are not statistically

Table 1. Correlation Matrix

	X1	X2	X3	P1
P1	0.032	0.162	0.085	1.000
P2	0.062	0.152	0.094	0.358**.

$**p<0.01$

Table 2. Average and Variances

	X1	X2	X3	C1	C2	R1	R2	P1	P2
Ave.	3.992	3.764	3.742	3.703	3.601	2.781	2.711	4.698	4.272
Var.	(0.606)	(0.547)	(0.571)	(0.511)	(0.415)	(0.834)	(0.664)	(2.196)	(2.538)

significant at the 5% level.

Therefore we will build a causal model to explain such a phenomenon.

3.2. Building Causal Model

The points that have become clear by existing studies are summarized as follows.

(a) 3D-CAD Problem Solving Development Performance (Development Efficiency): 3D-CAD technology digitizes product information and, on the basis of sharing product knowledge and information, enable visual design and simulation. Also, 3D-CAD lets firms reduce the number of prototypes by using them effectively. In this respect, we can predict that 3D-CAD causes positive effects on development efficiency.

However, a direct positive effect on the development efficiency is not observed by many existing empirical studies yet. In other words, the theoretical effects of 3D-CAD are not supported by many empirical studies. It is assumed that delay of organizational compatibility for new technology is the cause. The phenomenon is caused by the transit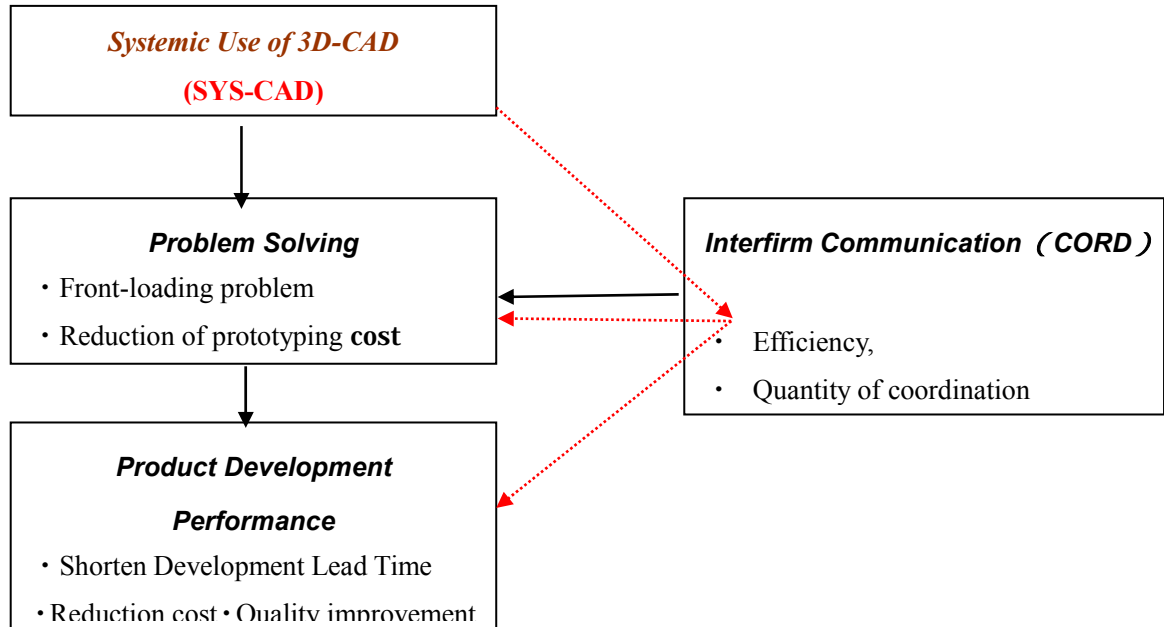ion period in 3D-CAD technology introduction process pointed out by many studies (Aoshima & Nobeoka, 2001; Fujimoto, Nobeoka, Aoshima, Takeda, & Oh, 2002; Nobeoka, Aoshima & Takeda, 2002).

(b) 3D-CAD Interfirm Communication: To visualize and simulate design, 3D-CAD technology decreases the gap and error of recognition among engineers, and brings exchange and sharing of more precise product information. Accordingly, it can possibly promote effective communication between divisions or firms. Then, the quantity of the coordination between firms or divisions should decrease.

In addition, with introduction of 3D-CAD, the problem of component interactions occurring frequently in a post-process can be solved in the early stages. By promoting communication between divisions in the early stages, 3D-CAD can be effective in shortening product lead time.

(c) Interfirm Coordination and Communication Development Performance (Development Efficiency): In the case of the automobile industry, suppliers tend to take part in the early development

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Figure 1. Building Causal Model

stage. Simultaneously, components are developed in cooperation between an auto maker and its suppliers. To develop components effectively and shorten development lead time, frequent and close communication is needed by both.

Figure 1 shows the result of existing studies. According to Figure 1, the introduction and utilization of 3D-CAD technology is connected with shorter lead time, development cost reduction, quality improvement and development performance. The solid line in Figure 1 shows these relations. However, as mentioned above, the theoretical conclusion that 3D-CAD technology has a positive effect on development performance is not empirically supported yet. Existing studies pointed

out that 3D-CAD technology brings positive effect on product quality in a development performance, however, it is not directly connected with development efficiency. On this point, there is inconsistency between the theoretical conclusion and empirical studies on the effect of 3D-CAD technology.

The purpose of this paper is to explore why this inconsistency occurs. When we analyze this question, we consider an important factor, which is interfirm communication, because 3D-CAD technology indirectly brings 'promotion of effective communication' and 'the front loading of a communication timing.'

To examine the effects of introducing 3D-CAD

Table 3. Correlation Matrix

	X1	X2	X3	C1	C2	R1	R2	P1
X1	1.000							
X2	0.535**	1.000						
X3	0.547**	0.649**	1.000					
C1	0.226*	0.233**	0.196*	1.000				
C2	0.261*	0.099	0.245**	0.505**	1.000			
R1	0.143	0.165	0.172	0.193*	0.151	1.000		
R2	0.084*	0.292**	0.270**	0.038	0.109	0.622**	1.000	
P1	0.032	0.162	0.085	0.029	0.044	0.081	0.224**	1.000
P2	0.062	0.152	0.094	0.026	0.027	0.205*	0.173	0.358**

*p 0.05, **p 0.01

technology considering the frequency of communication between an auto maker and suppliers (dotted line), we claim the possibility that two effects of 3D-CAD in the development efficiency offset each other.

(i) First Effect: 3D-CAD technology provides superior visibility which promotes effective communication and brings about a positive effect in the development efficiency. As product information is generally shared among divisions and companies, in depth communication between divisions and engineers can be done at a time. After all, the quantity of interfirm and interdivision coordination decreases and brings about a positive effect. In summary: sharing product information and knowledge using 3D-CAD closer and deeper

communications promoted reduced number of problem solving cycles and front loading problem solving shorter development lead time and cost reduction.

(ii) Secondary Effect: By sharing knowledge and activating communication, the number of problem solving cycles does not actually decrease as much, but inversely increases. In a current design review and a production review, it is necessary to accumulate a considerable level of know-how and experiences which allows understanding of material characteristic, component shape, the production situation and so forth. Therefore, because the number of designers or engineers who can have specific and constructive argument on the degree of product design has conventionally been limited, and

even if there were some, few engineers can discuss the issue to an extent of examination range. However, as 3D-CAD provides high visibility on PC, much more designers and engineers can easily come to share and understand product information. For example, in design review stage, if many engineers should come to give their opinion and positively propose improvement plan (Kaizen), communications become activated between companies and divisions.

By the way, as engineers examine design reviews or production reviews beyond the scope of consideration of examination, it results in the increase of design reviews. Because such indiscriminate examinations beyond the necessary examination range result in waste of time and increased cost, it leads to large increase in man-hours of the product development process. The effect of 3D-CAD introduction and usage cannot reduce the number of problem solving cycles as have been expected. Consequently, it brings negative effects on development efficiency.

Furthermore, from this point, Aoshima and Nobeoka (2001) and Nobeoka, Takeda and Aoshima (2002) pointed out that the designers' lack of skill and experience could bring increase in unnecessary man-hours of post-process and it suffers from the development efficiency of ex-process.

As described above, the influence on development performance by 3D-CAD can be divided into 'a direct path' and 'an indirect path going through the communication which is an

important means for coordination and cooperation between companies.' In particular, as our analysis considers the effect of communication, both effects

a positive effect by effective communication and a negative effect by activation of communication coexist and both effects can possibly offset each other, after all. Therefore, we examine how 3D-CAD impacts development performance, in particular development efficiency, while we take communication frequency (the dotted line in Figure 1) as the quantity of coordination between companies.

4. Covariance Structure Analysis (Structural Equation Modeling)

This paper conducts covariance structure analysis. Table 2 and Table 3 show observed variables to constitute each latent variable and an average and variance of these observed variables.

The following result was obtained (Figure 2). At first, the Chi-square value of the model is 29.724 and p value is 0.157. Here, Chi-square statistic indicates whether the model has covariance structure.

Let us see the goodness of fit of this model. As p value is 0.157 and so exceed 0.05, null hypothesis that the model has covariance structure is not rejected. Thus, the causal model has a good fit (GFI = 0.952, AGFI = 0.906). Therefore, we can accept this causal model. Interpretation follows below.

As all of the causal coefficients between latent

variables and observed variables used in the model are significant at the 5% level, we can confirm that all constructs were adequately measured by these observed variables. Moreover, the paths among all latent variables were also statistically significant at the 5% level.

Firstly, the relation between 'SYS-CAD' and 'PSC' is negative. In other words, an increase of systemic use of 3D-CAD decreases the number of problem solving cycles. Also, the relation between 'PSC' and 'Efficiency' is positive, and it was confirmed that the development efficiency improved when the number of problem solving cycles decreased.

On the other hand, let us pay attention to 'the quantity of coordination between companies (CORD).' The relation between 'SYS-CAD' and 'CORD' is positive. That is to say, the increase of systemic use rate of 3D-CAD cause communication frequency to increase, as a result of coordination and adjustment between companies.

However, the relation between 'CORD' and 'PSC' is positive. This implies that an increase of the systemic use rate of 3D-CAD brings increase in the quantity of coordination between companies. As a result, the number of problem solving cycles increases. That is to say, the number of problem solving cycles decrease when the frequency of communication   the quantity of coordination between companies   decreases.

Furthermore, the path reaching 'Efficiency' via 'CORD' from 'SYS-CAD' is not found. In other words, the influence on 'Efficiency' of 'SYS-CAD' is divided into two paths, as in Figure 2. To be concrete, 'SYS-CAD' does not directly provide 'Efficiency', and 'SYS-CAD' has effects on 'Efficiency' through two indirect paths: (a) CORD Path (the path of the quantity of coordination between companies: SYS-CAD   CORD   PSC   Efficiency), (b) PSC Path (the path of the number of problem solution cycles: SYS-CAD   PSC   Efficiency).
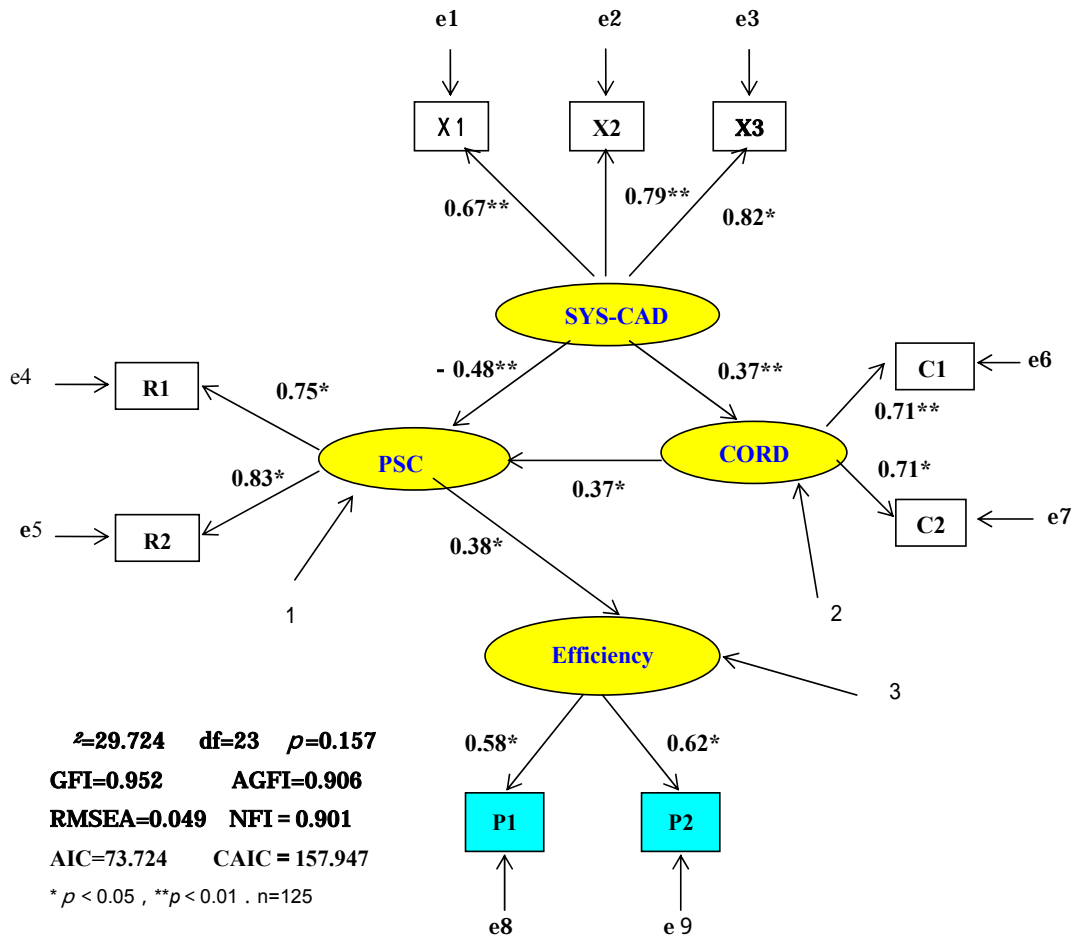
5. Conclusion and Discussions

This paper focused on why the correlation between the introduction and use of 3D-CAD technology and the development efficiency has not been observed. Considering the quantity of communication (frequency of communication between companies), this paper examined the relation both by covariance structure analysis.

As a result, it was found that 3D-CAD influenced development efficiency through two paths. That is, one path is that 3D-CAD technology reduced the number of problem solving cycles and thus contributed to the shortening of development lead time. The other path is that interfirm communication inversely had the influence which seemed to let the number of problem solving cycles increase. In conclusion, correlation between development efficiency and 3D-CAD could not be observed because positive effect and negative effect offset each other.

This result may indicate that firms should not

Figure 2. Causal Model

merely pursue the effect of 3D-CAD as an efficient communication tool. That is to say, our result implies that engineers and/or divisions should more actively and frequently participate in design communication process, and these actions greatly improve product quality.

As we have said at the beginning, 3D-CAD has functions as simulation tool (a part interference check, virtual assembling, functional test, etc.). Even if how to use mainly such a function needs not to be tied to development speed shortening and cost reduction directly, it will be thought that it contributes to the improvement of quality and function of a product.

As we mentioned before, with 3D-CAD it is possible to transfer the shape, structure and attributes

of a product via digital data. The skills and experience among engineers are comparatively simplified and identified by using 3D-CAD. In this respect, companies or divisions participating in co-development can more easily exchange and share product information on a PC. More conventionally, designers or engineers than ever before can participate in development activity positively, and discussion on design can be increased.

In other words, we can say that the Japanese automobile suppliers' strong inclination to use 3D-CAD as 'a communication tool' (Takeda, 2000a, 2000b) is found in our causal model. In this point, our study leads support to many existing studies.

However, 3D-CAD technology introduced for improvement of development efficiency makes interfirm communication increase adversely and it increases the number of problem solving cycles once again. Eventually, 3D-CAD technology brings negative influence on development efficiency.

We can think of three reasons for this result.

Firstly, the suppliers' passive introduction of 3D-CAD technology is supposed to be one factor. When an auto maker chooses a supplier in a transaction, the important selective factors are quality, cost, and delivery. An auto maker needs a supplier who are capabile to contribute to shorten development lead time.

Particularly, in recent years, the exchange of drawing information and design changes are done by 3D data. As a supplier, the introduction of 3D-CAD is a basic condition in transaction. According to

interviews, because there are many cases that even participation is not allowed in development competition unless a supplier is equipped with 3D-CAD systems with compatibility. In other words, suppliers must introduce a system which is compatibile to the auto maker's system to maintain business relations. In this point, it seems that the introduction of 3D-CAD in suppliers is often a passive act from business needs rather than from strategic needs. It is assumed that such a passive introduction of 3D-CAD causes imbalance in the skill and degree of understanding between auto maker and supplier, and thereby increases unnecessary communication.

Secondly, as have been pointed out, it can be supposed that the finding is caused by over-coordination and over-examination. As a result, wasting much time and costs causes negative influence on development efficiency. Because design changes at low cost are possible, engineers can repeat examination and make alterations on a computer screen more than is needed. A general manager of development at an electronic part manufacturer says, "The efficiency characteristics of 3D-CAD did not appear as we have thought. It takes very much. In particular, if we are not in control of the imagination of engineers in some extent, 3D-CAD does not operate as an effective design tool".

The problem in the auto parts industry is quite similar to 'the paradox of 3D-CAD introduction' pointed out by Aoshima and Nobeoka (2001), and

Nobeoka, Takeda, and Aoshima (2002). In other words, it is thought that the finding is caused by the fact that short use period of 3D-CAD technology, the increase of unnecessary man-hours caused by the imbalance between organizations for a newly technical knowledge system, and an organization's internal resistance.

In this sense, it may be said that the survey period examined by this paper is a transition period, in which the 3D-CAD technology is undergoing introduction processes.

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Appendix 1. Variables List

Latent variables	Observed variables	Questionnaire item
SYS-CAD	X1	Use ratio of 3D-CAD in development processes
	X2	Connection of system
	X3	Compatibility of 3D-CAD systems
CORD	C1	Frequency of Communication between an auto maker and a supplier
	C2	Quantity of communication among suppliers
PSC	R1	The number of design reviews
	R2	The number of manufacturing reviews
Efficiency	P1	Manufacturing cost
	P2	Development lead time