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A DECADE TREND OF UTILIZATION OF DESIGN TOOLS AND METHODS IN JAPANESE PRODUCT INDUSTRIES

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Abstract

Researchers in the design engineering domain have devoted to develop various tools and methods which support new product development activities. However, there are less research works surveying their utilization in industries, and few works focusing on its trend during a certain period. This research aims at clarifying how much design tools and methods have been utilized in Japanese industries in the last decade, and what factors promote or disturb their effective utilization. First, this paper reports a questionnaire survey performed in 2014 on utilization of various tools and methods in product development process of Japanese manufacturing industries. Its results are compared with those of Japanese survey carried out in 2002. Three metrics are set to evaluate the utilization: awareness, usage and effectiveness. The analysis of the questionnaire survey can roughly reveal some trends of the utilization. In addition, this research carries out the interview to analyze the detailed situations. Analysis of the changes of the three metrics during the decade and the interviews reveal factors behind those trends.

Keywords: Design engineering, Design for X (DfX), Design methods, Computational design methods, New product development

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1 INTRODUCTION

Building methods and tools that support product design and development has been a main topic of design engineering research domain. A concept of concurrent engineering and Design for X (DFX) had been initiated as a main branch of design engineering around 1990. They focus on the integrity of products across the viewpoints such as quality, cost and delivery. The trend has recognized various design methods, such as quality function deployment (QFD), design for assembly (DFA), Taguchi method, as effective means. Simultaneously various digital engineering tools, such as CAD, CAE, PDM, etc., have become widely available and enhanced in performance under down-sizing of computers, etc. After entering 21st century, 3-dimensional CAD, CAE and software packages of optimal design have been defused in product design and development activities. They help engineers represent products comprehensively, evaluate products without expensive physical porotypes even at the early phases, explorer various design candidates and find an optimal or at least preferable design solution with shorter lead time and less cost than before. The progress of digital engineering tools has made design engineers called to design highly complex problems. To handle complex problems, methods of system modeling and model-based development are proposed. Recently, additive manufacturing technology so called 3D printer has attracted the attention.

While many works have devoted to develop various tools and methods, there are some research works concerning the utilization of methods and tools in new product design and development with questionnaire surveys and interviews for industries. For example, Bacciotti et al, (2016) reports the utilization of the methods and tools in industry, and differences between research trajectories and industry expectations. An open issue for those surveys is that they are heavily fragmented (Graner and Missler-Behr, 2012). Fujita and Matsuo (2005) compares the Japanese survey results with the UK survey (Araujo, *et al.*, 1996) and the New Zealand survey (Whybrew, et al., 2001), and discusses the features of the three country's industries. However, few works focus on the time axis viewpoint.

This research aims at clarifying how the utilization of design tools and methods have been transformed in industries in the last decade, and what factors promote or disturb their effective utilization. This research attempts to answer those research questions by seeing changes between two surveys. The findings of the survey will show possible measures that the academic society can carry out for the utilization. First, this paper reports a questionnaire survey performed in 2014 (survey 2014) on utilization of various tools and methods in the product design and development process of Japanese manufacturing industries, and compares its results with those of Japanese survey carried out by Fujita and Matsuo (2002) (survey 2002). Three metrics are set to evaluate the phase of utilization: awareness, usage and effectiveness. This paper analyses the changes of the three metrics between the two surveys, and analyses factors behind those trends based on the survey results and the interviews for the questionnaire answerers. While this research focuses on Japanese industries, the discussion based on the survey results attempts to be universal for global industries.

2 TOOLS AND METHODS EXAMINED

Various tools and methods for product design and development exist covering the design process and product life-cycle. From the viewpoint that the design process is iterative with problem setting and problem solving, this research categorizes them into the following four types: (1) methods for analyzing and understanding design problems, (2) methods for building design solutions, (3) methods for evaluating design solutions and (4) methods for managing design process. Some of them are implemented as digital engineering tools such as CAD, CAE, PDM and optimization software.

Table 1 shows tools and methods examined in this research. An asterisk denotes a digital engineering tool. Note that the aim of this categorization is to confirm that examined tools and methods cover all categories. They are not exclusive, so they can be in multiple categories. For example, patent retrieval is categorized into building solution methods, but it is often used for problem analysis. Seven ones written in italic, i.e., 3D printer, customer value chain analysis (CVCA), design structure matrix (DSM), IDEF0/IDEF3, kansei engineering, SysML/UML and TRIZ are not examined in the survey 2002, because they are developed or popularized after 2000. In the questionnaire sheets, items of some digital engineering tools, i.e., CAE, optimal design and PDM, are divided into commercial ones and originally developed ones.

Table 1. Tools and methods examined in this research

(1) problem analysis	Benchmarking (competitive product), Benchmarking (current product), Bottleneck analysis, *Customer Value Chain Analysis (CVCA)* , Design of experiment, Function structure mapping, Ishikawa (Fishbone) diagram, Pareto analysis, Quality function deployment (QFD), Systems engineering approach, Value analysis (VA), Value graph
(2) building solution	2D CAD system*, 3D CAD system*, *3D printer* *, Brainstorming, Design catalog retrieval, Design mockup, KJ method, Literature survey, Optimal design software*, Patent retrieval, Rapid prototyping, *System Modeling Language* (*SysML/UML*), Taguchi method, *TRIZ*
(3) evaluating solution	CAE software*, Design for assembly (DFA), Design for manufacturing (DFM), Entropy assessment, Failure mode effect analysis (FMEA), Failure tree analysis (FTA), *Kansei engineering* , Life-cycle assessment (LCA), Morphological chart, Numerical analysis / Simulation*
(4) managing process	Activity-based cost (ABC) accounting, Design review meeting, *Design Structure Matrix (DSM), IDEF0/3* , PDM system*, Statistical process control, Statistical quality control, Total quality control / Total quality management (TQC / TQM)

*Digital engineering tool

3 METHOD OF SURVEY

3.1 Distribution and Collection

The survey 2002 was carried out by sending questionnaire sheets to manufacturing companies by mail and requesting to return their filled ones by an assigned date in the autumn of 2002. The companies which sheets were sent to are ones that offer employment opportunities to the students of Department of Mechanical Engineering, Osaka University, ones that are listed in a company information magazine published by a regional branch of the Japanese Society of Mechanical Engineers (JSME), and ones that are supplementary added from graduates of the design engineering laboratory at Osaka University. Since some Japanese manufacturing firms simultaneously produce different kinds of products, for instances in the cases of home appliances, heavy industries, etc., five, three or one sheets were sent to each company and it was asked to distribute each to different sectors according to the type of industry.

The survey 2014 was carried out online. Letters of request for answering the questionnaire by an assigned date in the winter of 2014 were sent to the companies of the same lists as the survey 2002. The requests were sent to both department director positions and section/subsection chief position in order to collect answers from various roles. Supplementary, a request e-mail was sent to members of the design and systems (D&S) division of JSME. Answerers were asked to access the web site of questionnaire sheets and to answer them online.

3.2 Questionnaire Items

The questionnaire items of the survey 2014 were designed in the same format of the survey 2002. The utilization of each method and tool is examined from the three metrics, i.e., (1) awareness, which means an answerer knows its existence, (2) usage, which means an answerer practically uses it in product design and development activities, and (3) effectiveness, which means an answerer considers that it is utilized effectively in product design and development activities. The three metrics correspond to the phase of the utilization.

The awareness and usage are evaluated as a percentage of the number of answerers who answer yes out of the number of all answerers. The effectiveness is evaluated as a percentage of the number of answerers who utilize tools and methods effectively out of the number of ones who use them, not the number of all answerers. In addition, there are the items to ask the type of products and business, their scale and so on.

4 SURVEY AND TREND ANALYSIS

This section explains the results of the survey 2014 and the trend analysis comparing it with the results of the survey 2002. Please see the detailed analysis of the survey 2002 in the article (Fujita and Matsuo, 2005).

Table 2 Distribution and Collection

	2002		2014	
	# of companies	# of sheets	# of companies	# of persons
Sent requests	289	1167	228	342
Returned answers	118	221	74 (66+8)	134 (126+8)
Return rate	41.8%	18.9%	28.9%	36.8%

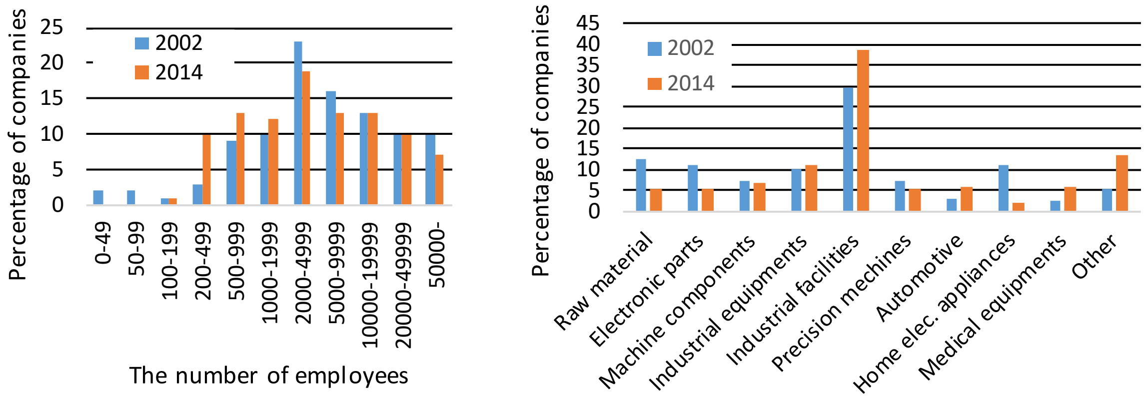

Figure 1. Breakdown of returned answers by the number of employees (left) and the type of industry (right)

4.1 Overview of Returned Answers

Table 2 shows the numbers of distribution and collection of questionnaire answers of the survey 2002 and 2014. The return rate means a percentage of the number of returned answers out of the number of sent request letters. That of the survey 2014 excludes eight returned answers that are replies for the request sent by e-mail. As shown in Table 2, the return rate was high as this kind of questionnaire surveys.

The left of Figure 1 shows the breakdown of returned answers by the number of employees. Their size tends to be larger than the actual distribution in Japan. This rough trend does not differ between the two surveys. The right of Figure 1 shows the breakdown by the type of industry. The percentage of industrial facilities tends to be larger than the actual distribution. While some changes take place during the decade, for example, the percentage of home electronic appliances has drastically decreased; its rough trend does not differ between the two surveys. Those show that the answerers of the two surveys have similar characteristics.

4.2 Results of Questionnaire Survey 2014

Figure 2 shows the percentages of awareness and usage of respective tools and methods in the survey 2014. They are sorted in the ascending order of awareness. The following findings are obtained:

- Digital engineering tools such as 2D and 3D CAD systems, a commercial CAE software have the most known and used ones. Optimal design software is not known and used so much.
- According with digital engineering tools, commercial software is used much more than originally developed one excepting PDM.
- In general, the higher the awareness, the higher the rate of usage per awareness. However, some ones have relatively lower usage with higher awareness, such as 3D printer, Taguchi method, TRIZ and kansei engineering.
- According with conceptual design methods, FMEA, FTA and QFD are well known and used. DFA and DFM are less popular.
- Systems engineering methods, such as DSM, SysML/UML and IDEF0/3 are not known at all.

Figure 3 shows the percentage of effectiveness of respective tools and methods in the survey 2014. The following findings are obtained:

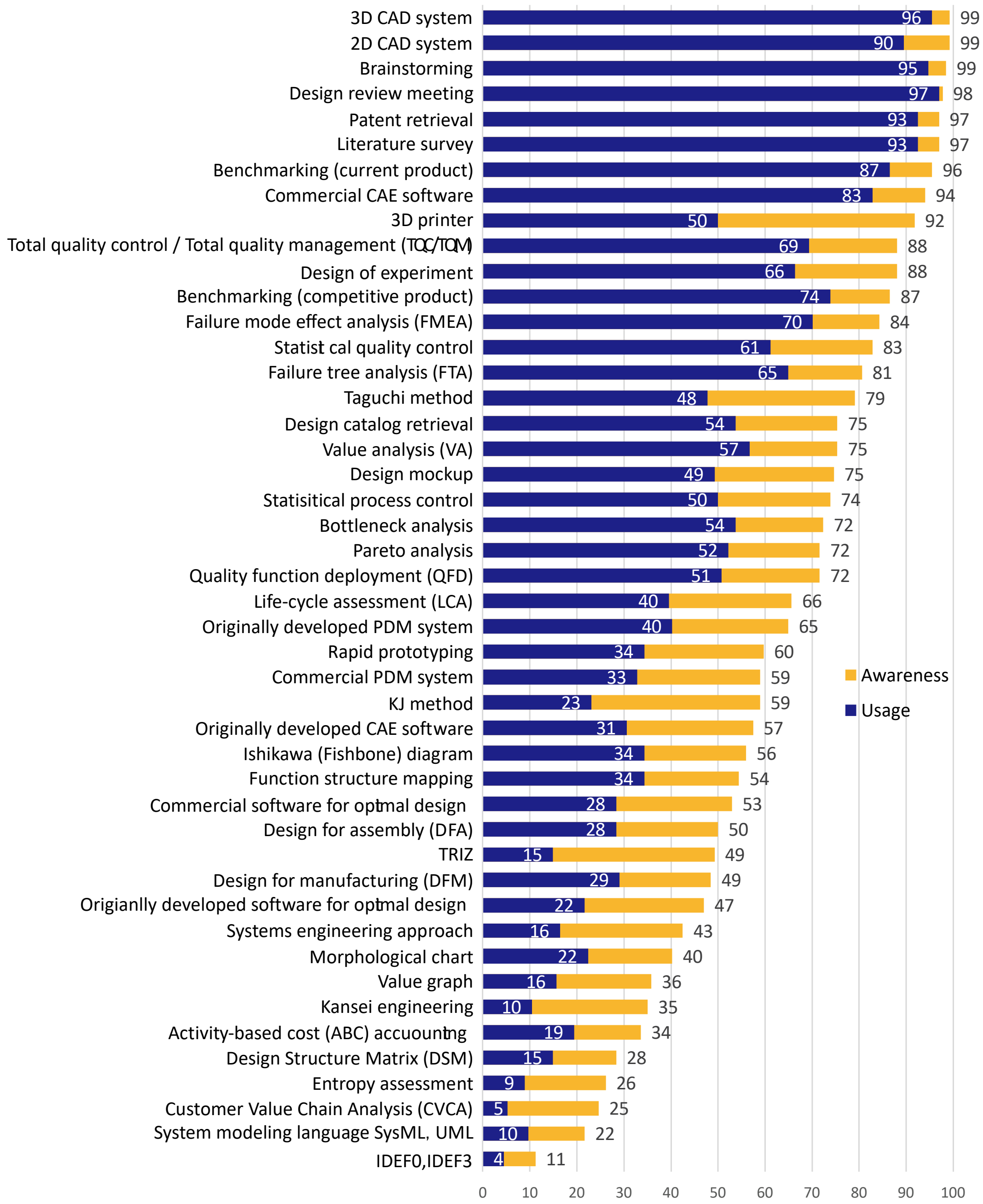

Figure 2. Awareness and usage of tools and methods in survey 2014

- The most used ones such as CAD systems and commercial CAE software are highly rated in the effectiveness as well.
- Almost all tools and methods have more than 50% effectiveness. Some methods which are at the medium or lower in the awareness and usage rate, such as rapid prototyping, FTA, FMEA and PDM, are in the top 30% in the effectiveness rate. This means that tools and methods tend to be effectively utilized if they are once introduced into product design and development activities.
- According with digital engineering tools, there are not significant differences of effectiveness between commercial software and originally developed one.

4.3 Trend Analysis from 2002 to 2014

A bubble chart of Figures 4 shows the changes of utilization from the survey 2002 to the survey 2014 of respective tools and methods. The horizontal axis, the vertical axis and the bubble size corresponds to the percentage increment of awareness, usage and effectiveness, respectively. A blue bubble represents a positive value. A white bubble represents a negative value. The following findings are obtained:

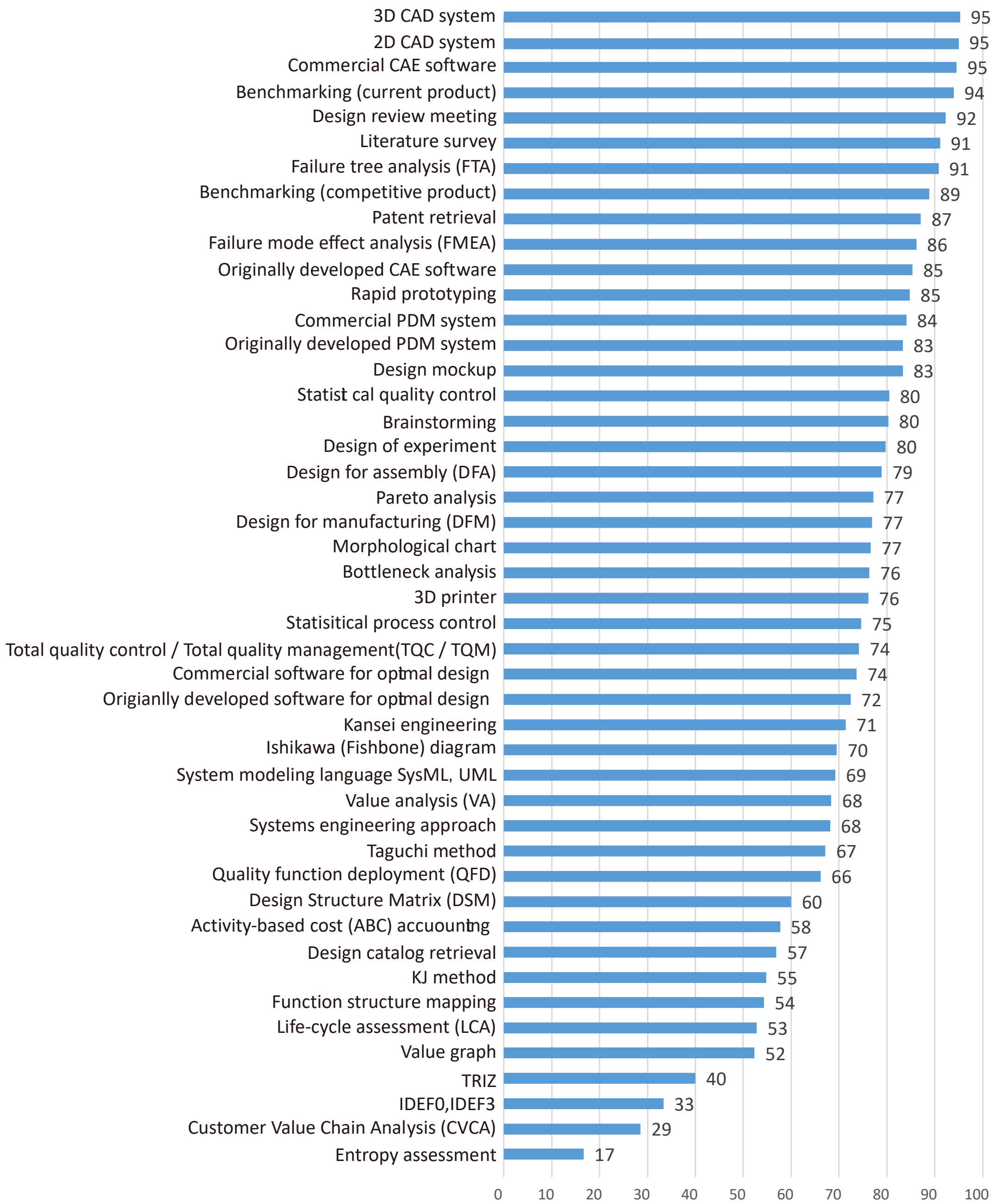

Figure 3. Effectiveness of tools and methods in 2014

- Most of tools and methods are plotted at the first quadrant. This means that they have uptrend of awareness and usage in Japanese industries in the last decade, although the details vary.
- Commercial CAE is one of the best uptrend tools. It has been substituting originally developed CAE software.
- Some ones have downward trend of effectiveness. Optimal design is its representative.
- Excepting excellent uptrend tools and methods such as 3D CAD, the increment of usage is smaller than that of awareness. This means that many industries are hesitating the introduction of tools and methods into product design and development process, while they have known about them more than a decade ago.

Figure 4. Percentage increment from 2002 to 2014 of awareness, usage and effectiveness of tools and methods

Based on the obtained findings, this research classifies the following four types of the utilization trend: (1) excellent uptrend, (2) better uptrend of usage but worse trend of effectiveness, (3) uptrend of awareness but not yet used, and (4) low awareness. Type 1 includes 3D CAD, commercial CAE, FMEA and FTA. They have been already utilized in product design and development with good effectiveness. Therefore, they will keep its uptrend of the utilization. Type 2 includes optimal design and Taguchi method. They have become used so much in the last decade. However, the effectiveness shows downward trend. Type 3 includes many methods plotted at lower left of the first quadrant such as QFD, DFA, DFM, VA and morphological chart. Those are mainly used for early phases of design. Effectiveness of those is mid-level. But the increment of usage is smaller than that of awareness. Type 4 includes system engineering methods such as DSM and SysML.

5 INTERVIEWS AND TREND FACTOR ANALYSIS

The analysis of the questionnaire survey can roughly reveal some trends of the utilization as stated in the last subsection of the previous section. In addition, this research carries out the interview for some answerers to analyze factors behind the trends. This research chooses six business institutions as interviewees among the all answerers of the survey 2014 considering that they are chosen from different types of industry. Types of industries of respective institutions are as follows: (A) industrial electric equipment, (B) industrial robot, (C) medical equipment, (D) aviation equipment, (E) electric and electronic consumer appliances and (F) industrial fluid equipment. Hereinafter, each institution is denoted by a letter of A to F.

They are asked about the utilization situation in product design and development process in terms of specific tools and methods, which are chosen one or a few from each trend type defined in Subsection 4.3. The following six tools and methods are chosen.

- Type 1: 3D CAD, CAE, FTA/FMEA
- Type 2: Optimal design
- Type 3: QFD
- Type 4: DSM/SysML

The following paragraphs explain the analyses for each.

5.1 3D CAD

As Figure 4 shows, 3D CAD is a rare case that the increment of usage is larger than that of awareness. This means that companies that hesitated to introduce the tool have shifted to utilize it.

According with the interview, all of six institutes utilize it in product design and development. Interviewees said "mistakes in design phases are reduced by visualizing a product in 3D" (A), "Using 3D CAD is a trend in the business community. It is necessary to make a 3D model in order to accept orders" (D), "There is no need to use 2D CAD, because 3D CAD can output drafts" (E). Those show that 3D CAD has been established as a necessity tool for product design and development. On the other hand, there is a comment that 2D CAD is also available for designing electric circuits (A, B).

The findings obtained from the interviews can be summarized as follows:

- Enhancement of computational performance gave positive impacts on the diffusion.
- Using 3D CAD becomes an industry-wide standard in many fields. This makes companies to shift to utilize 3D CAD further.
- Specific field such as electricity devises still requires 2D drawing rather than 3D modelling.

5.2 CAE

Commercial CAE software is one of the most excellent uptrend tools of type 1 as shown in Figure 4. All of six institutes utilize it in product design and development. There are some positive comments from interviewees such as "It has been a necessary activity to perform computational structural analysis and computational fluid dynamics in the business field" (D), "It has been carried out company-wide since 20 years ago. The company has a support system that CAE experts help designers" (E). Some interviewees gave negative comments such as "Although structural analysis is effective, the other computational analysis does not work so well" (A, B).

The findings obtained can be summarized as follows:

- Enhancement of computational performances gave positive impacts on the diffusion of commercial CAE software.
- Using CAE becomes an industry-wide standard like 3D CAD.
- A support system by CAE experts helps designers to utilize CAE.
- Effectiveness of CAE depends on the domain of analysis. While structural analysis is effective in many cases, there are issues to utilize the other computational analysis such as fluid dynamics.

5.3 FTA/FMEA

FTA and FMEA are the other representatives of type 1 methods. They are conventional structured, systematic techniques for failure analysis. Many cases are found by the interview that a company workflow obligates engineers to use them in product design and development process (A, B, C, D). There is an answer that engineers are taught them in in-house training in company (E). Many interviewees gave positive comments for their effectiveness such as "It is worth using although it needs labor hours" (A), "It is necessary to use them when engineers systematically analyze the failure information collected from users" (C). On the other hand, there are negative comments for their utilization such as "A novice engineer tends to make using methods more important than its purpose" (B) and "Engineers can carry out failure analysis by them, but cannot use them for reliability design which we originally want to do" (F).

The findings obtained can be summarized as follows:

- FTA/FMEA are conventional failure analysis methods, so their effectiveness is well known. In many companies, their use is obliged in company workflows.
- Some companies teach them to engineers in in-house training.
- Although they are effective for failure analysis, problems remain for utilizing them in reliability design.

5.4 Optimal Design

Optimal design is a type 2 method, that is, it has uptrend of usage but downward trend of effectiveness. Some interviewees gave positive comments for its usage such as "Engineers usually use optimization software. The company has a support system that optimization experts help designers" (E), and "A company is going to obtain its good effects on product design and development" (D). However, there are also some negative comments such as "Engineers understand its effectiveness, but it is difficult to introduce it into actual product design and development process. The skill is required." (B), "A company has introduced commercial software of optimal design, but cannot obtain its effects more than expected. It is difficult to formalize design problems when optimization is carried out" (F).

As the interviewees suggested, commercial software packages supporting design optimization become popular during the last decade. While the situation is similar to 3D CAD and CAE, there may be the other reasons specific for optimal design. The calculation of optimization can be supported by the software. However, the success of such attempts depends strongly on how well the design problem has been formulated for an optimization study, and on how familiar the designer is with the workings and pitfalls of iterative optimization techniques (Papalambros and Wilde, 2000). This is burden of knowledge which raw computing power is unlikely to ease. The knowledge-based support is crucially necessary for it (Nomaguchi et al., 2015). This is a different point from CAD and CAE.

The findings obtained can be summarized as follows:

- Enhancement of computational performances gave positive impacts on the diffusion.
- Burden of knowledge for problem formalization matters more than computing power. Therefore, the introduction of software is not enough for obtaining effectiveness of optimal design. This is why the utilization trend of optimal design is worse than the other digital engineering tools.
- A support system for the burden of knowledge is necessary for utilizing optimal design.

5.5 QFD

QFD is a type 3 method. It shows an uptrend of awareness and usage, but there are many engineers who hesitate its use. Users of QFD said "A company teaches QFD to engineers in in-house training. Designers use QFD in product planning phase. It is effective for balancing weights of requirements" (E) and "It works as a checklist of product design and development. It is effective to convey to other designers what the important needs are" (C). There is a case that an engineer personally uses QFD, but it is not used in company-wide (F). The other interviewee said that a company does not feel to use a systematic method for product planning, because they can do it without any methods (B).

The findings obtained can be summarized as follows:

- There are good examples that QFD is effectively utilized for product planning. Some companies teach it to engineers in in-house training.
- A company-wide effort for systematic product planning is necessary for introducing this method.

5.6 DSM/SysML

System design methods such as DSM and SysML are categorized to type 4, that is, they have been not yet known by Japanese industries. Only one interviewee (D) uses SysML effectively and said that the field of the aviation industry has trend to standardize the system modelling method in product design and development process. It would be rational to utilize SysML to explicitly represent a complicated product such as airplane. While DSM is not used by any institutes, all has motivation to rationally design a product architecture and to rationally plan a project organization structure. DSM can support both activities. This means that there is a room that DSM becomes a popular method in the near future.

The findings obtained can be summarized as follows:

- Although the system design methods have not yet been popular for Japanese industries, there are potential needs.

6 MEASURES FOR UTILIZATION

Finally, this section discusses how the academic community can serves for the utilization based on the findings of the survey. This research proposes the following possible measures.

- The success cases show that effective measures for the promotion of tools and methods include standardization of their use in a business field or a company's workflow, a support system that experts help designers, and in-house training. If the academic community can offer them for the other methods and tools, it would be effective.
- The burden of knowledge prevents the utilization of type 2 tools and methods. Therefore, consultation services for supporting the knowledge activities would be effective for this type.
- Many companies are hesitating the utilization of type 3, such as QFD. A system for sharing good example of utilizing those tools and methods, for example, a case repository, would be effective for this type.
- Many companies are not yet familiar with type 4. The promotion of those methods by society, for example, can be effective for their diffusion.

7 CONCLUSIONS

This paper reported a questionnaire survey performed in 2014 on the utilization of various tools and methods in product design and development process of Japanese manufacturing industries, and compared its results with those of Japanese survey carried out in 2002. The trend of the utilization was analyzed from the viewpoint of awareness, usage and effectiveness during the decade. Based on the survey results and the interviews, this paper discussed how the industries can effectively utilize the tools and methods for product design and development. This paper also discussed possible measures that the academic community can carry out in order to promote the utilization. Our future works include the expansion of the survey to the other regions.

REFERENCES

Araujo, C. S., Benedetto-Neto, H., Campello, A. C., Segre, F. M. and Wright, I. C. (1996), “The Utilization of Product Development Methods: a Survey of UK Industry”, *Journal of Engineering Design*, Vol. 7, No. 3, pp. 265-277.

Bacciotti, D., Borgianni, Y., Cascini, G., Rotini, F. (2016), “Product Planning techniques: investigating the differences between research trajectories and industry expectations”, *Research in Engineering Design*, Vol. 27 No. 4, pp. 367-389.

Fujita, K. and Matsuo, T. (2005), “Utilization of Product Development Tools and Methods: Japanese Survey and International Comparison”, *Proceedings of 15th International Conference on Engineering Design (ICED 05)*, Melbourne, Australia, 15-18 August 2005, Paper Number 98.81.

Graner, M. and Missler-Behr, M. (2012), “The Use of Methods in New Product Development - A Review of Empirical Literature”, *International Journal of Product Development*, Vol. 16 No.2, pp. 158-184.

Nomaguchi, Y., Mochizuki, R. and Fujita, K. (2016), “Management of Modeling and Formulation in Reflective Design Process of Multidisciplinary System”, *Proceedings of ASME 2016 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference (IDETC 2016)*, Charlotte, North Carolina, USA, 21-24 August 2016, IDETC2016-59469.

Papalambros, P. and Wilde, D. J. (2000), *Principles of Optimal Design - Modeling and Computation - 2nd Edition*, Cambridge University Press, New York.

Whybrew, K., Shaw, A., Aitchison, D. and Raine, J. (2001) “Use of Design Tools and Methodologies for Rapid Product Development in the New Zealand Manufacturing Industry,” *Proceedings of 13th International Conference on Engineering Design (ICED 01)*, Glasgow, UK, 21-23 August 2001, pp. 27-34.

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