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A STUDY ON THE MANAGEMENT OF SOFTWARE ENGINEERING CAPABILITIES IN JAPAN USING PANEL ANALYSIS

Yasuo Kadono
Tokyo University of Technology, Japan, kadono@media.teu.ac.jp

Hiroe Tsubaki
The Institute of Statistical Mathematics, Japan, tsubaki@ism.ac.jp

Seishiro Tsuruho
Information-Technology Promotion Agency, Japan, tsuruho@ipa.go.jp

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Hiroe Tsubaki, The Institute of Statistical Mathematics, tsubaki@ism.ac.jp

Seishiro Tsuruho, Information-Technology Promotion Agency, Japan, tsuruho@ipa.go.jp

Abstract

We designed a survey on software engineering excellence (SEE) and administered it in 2005, 2006 and 2007 with the Japanese Ministry of Economy, Trade and Industry to better understand the mechanism of how software engineering capabilities relate to IT vendors' business performance and business environment. We measured the SEE survey results with regard to seven factors: deliverables, project management, quality assurance, process improvement, research and development, human development, and contact with customers.

In this paper, we integrated 233 valid responses to the SEE surveys received over three years into a new database and identified 151 unique IT firms. We conducted panel analyses of the seven SEE factors using the three years of data to clarify what influence SEE factors have within a year, year-to-year, and mid-term. Based on the results of the panel analysis, our first observation is that most SEE factors for a year had significant positive influences on the same factors the next year. Second, there were three paths to improving the level of deliverables through project management, quality assurance and research and development in a year. Third, some SEE factors had significant positive influence on different SEE factors in the following year. Fourth, there were some negative paths, implying that effort put toward a particular factor did not pay off during the duration of our research. These efforts, however, might be expected to have longer-term effects on other SEE factors.

Keywords: Software engineering, Management of Technology, Social research, Panel analysis.

1. INTRODUCTION

The information service industry is a 10.5 trillion yen market in Japan, which includes 7.6 trillion yen in software development and programming. In 2009, orders for software totaled 6.4 trillion yen, accounting for 60.3% of the entire information service industry, while the software products market was 1.2 trillion yen (METI, 2010). Like the rest of the world, many companies in Japan that use enterprise software have not been fully satisfied with the quality, cost, speed and productivity of software that IT vendors deliver. At the same time, IT vendors in Japan are facing drastic changes in their business environment, such as technology innovations and new entrants from emerging countries all over the world. There are issues that are characteristic of the IT industry in Japan, such as multilayer subcontractors and business models being dependent on custom-made applications for the domestic market (Cusumano, M., 2004; Kadono, Y., 2007).

In order for the IT industry in Japan to meet these challenges, an important step is to understand how software engineering capability is significant for achieving medium- and long-term success. Therefore, we designed a research survey on software engineering excellence and administered it in 2005, 2006 and 2007 with the Japanese Ministry of Economy, Trade and Industry.

The objectives of the research were to:

- assess the achievements of the Japanese software engineering discipline, as represented by IT vendors, and
- better understand the mechanisms of how software engineering capabilities relate to IT vendors' business performance and business environment.

To achieve these objectives, we developed a measurement tool called Software Engineering Excellence (SEE), which can evaluate the overall software engineering capabilities of IT vendors based on several factors: deliverables, project management, quality assurance, process improvement, research and development, human development, and customer contact. We introduced two other indicators as well: business performance and business environment. The business environment complements the relationship between SEE and the business performance of software vendors.

In the 2005 SEE survey, we analyzed the relationships among SEE, business performance and business environment based on data collected from 55 major IT vendors in Japan. We conducted a path analysis, during which we found that SEE characteristics have a direct positive impact on business performance and that the competitive environment directly and indirectly (i.e., via SEE) affects business performance (Kadono, Tsubaki, Tsuruho, 2006).

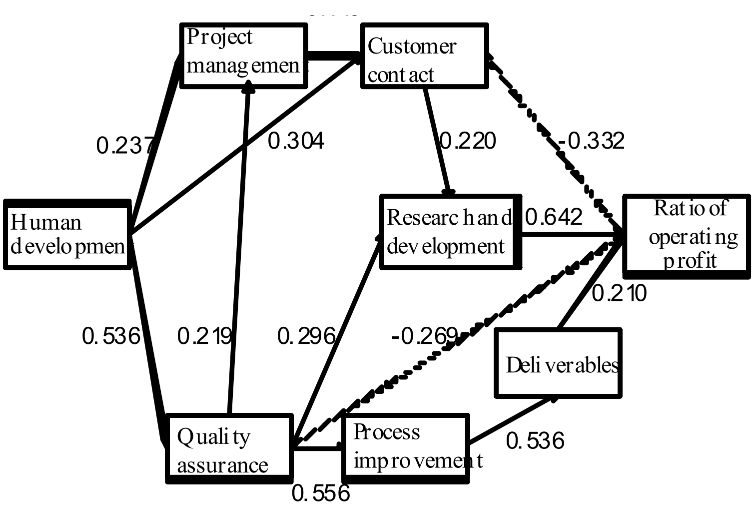

Figure 1. Path Analysis Results of the SEE survey for 2006.

In the 2006 SEE survey, we increased the number of surveyed Japanese IT vendors from 55 to 78 in order to more deeply investigate the impact of software engineering on business performance and the business environment. In particular, in this study we focused on the relationships among the SEE factors, the business environment, and business performance as measured by sales profit ratios (Kadono, Tsubaki, Tsuruho, 2007). By analyzing the data collected from 78 major IT vendors in Japan (Bollen, 1989), we found that superior deliverables and business performance have significant correlations (5% level) with effort expended, particularly on human resource development, quality assurance, research and development and process improvement as shown in *Figure. 1*.

In 2007, we analyzed the data collected from 100 major IT vendors in Japan. At that time, we reproducibly observed that the level of effort expended on human resource development, quality assurance and project management improved the performance of IT vendors in Japan in customer contact, research and development and process improvement, the same tendency we found in 2006. However, the causal relationships differ significantly depending on the vendors' origin, i.e. whether a business is a maker-turned vendor, a user-turned vendor or an independent vendor (Kadono, Tsubaki, Tsuruho, 2009).

For this paper, we integrated the data for the three years into a single new database and identified 151 unique companies, consisting of 42 maker-turned vendors, 33 user-turned vendors and 76 independent vendors. We focused on investigating the relationships among the SEE factors during the three years.

Year	2005	2006	2007	2005/06/07
Questionnaires sent	230	537	1000	NA
Valid responses	55	78	100	151
(Maker-turned, User-turned, Independent)	(17,15,23)	(27,15,36)	(27,20,53)	(42,33,76)
Response rate (%)	24	15	10	NA

Table 1. Software Engineering Excellence (SEE) Surveys.

2. RESEARCH MODEL

In this section, we describe the construction of the hypotheses of the structural and measurement models based on interviews, a literature search (Barney, 2007; Fujimoto, T., 2003; Matsumoto, Y., 2005; Ministry of Economy, Trade and Industry) and the empirical results of the SEE results from 2005, 2006 and 2007.

2.1 Structural model

The hypothesized structural model is shown in *Figure 2*. The original structural model for the SEE survey was developed by interviews with successful IT vendors in Japan. Based on these interviews, we identified three key factors for successful vendors: sales force management, operational improvement and R&D. First, vendors who manage their sales force effectively succeed in efficiently assigning their software engineers to upcoming customer projects. As a result, one such vendor operates at an average of 90% capacity. Second, some profitable vendors have accumulated data on quality, cost, delivery and productivity for more than 30 years in order to improve their operations (Kaizen). Third, most large-scale system integrators in Japan are working very hard on R&D activities in addition to effectively managing their sales force management and efficiently improving their operations. The hypothetical structure is consistent with the empirical results from the SEE 2006 and 2007 surveys (*Figure 1*).

Therefore, in *Figure 2*, within each year (horizontally), we assume three paths to improvement of deliverables (quality, cost, delivery etc. See the next subsection):

- from human development to project management and customer contact in the upper level each year,

- from human development to R&D in the middle level each year, and
- from human development to quality assurance and process improvement in the lower level each year.

Also, vertically, year-to-year, we assume that each factor is consistent. For example, if a vendor has a high human development factor score in 2005, it also has a high human development factor score in 2006. This tendency continues in 2007. The opposite is also true.

In addition, diagonally, we assume mid-term effects. For example, if a vendor invests in human development in 2005, it might get good R&D results in 2006.

Based on these structural hypotheses, our research question in this paper is how SEE factors influence future SEE factors horizontally, vertically and diagonally as illustrated in *Figure 2*.

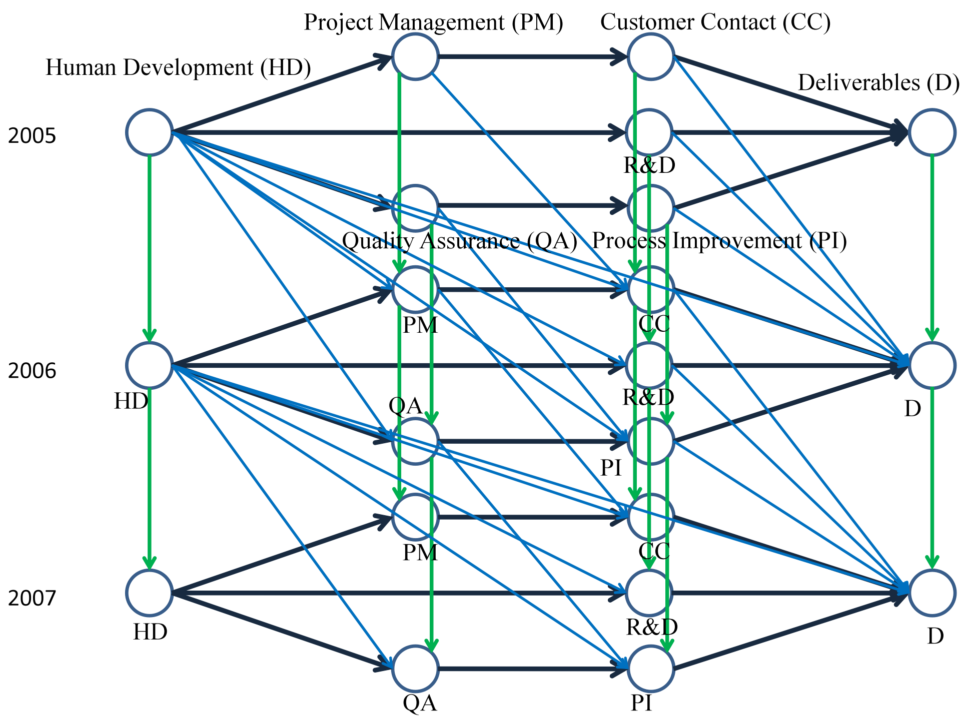

Figure 2. Structural Model Hypothesis.

2.2 Measurement model

The model we used to measure SEE (Kadono, Tsubaki, Tsuruho, 2006) was originally developed through interviews with over 30 industry experts in Japan and the U.S. and literature searches done during the 2005 SEE study period (Barney, 2007; Brynjolfsson, E., 2004; Dierickx et al., 1989; Fujimoto, T., 2003; Matsumoto, Y., 2005; Ministry of Economy, Trade and Industry). Since this research intends to encourage innovation, we surveyed state-of-the-art cases from the viewpoints of marketing, process, and product in order to develop our measurement model. Therefore, the scope of the survey includes the resource-based view of vendors (Barney, 2007). The measurement models for 2006 and 2007 were updated slightly based on the response rate of each question item, the statistical significance of each observed response to the 2005 and 2006 SEE surveys, and changes in technology and market trends.

The SEE measurement model has a hierarchical structure with three layers: observed responses to question items, seven detailed concepts, and SEE as a primary indicator. SEE as we have defined it consists of the following seven concepts:

- Deliverables: achievement ratios of quality, cost, speed, and productivity, understanding of project information,
- Project management: project monitoring, assistance to project managers, project planning capability, PMP (Project Management Professional) ratio,
- Quality assurance: organization, methods, review, testing, guidelines, management of outsourcers,
- Process improvement: data collection, improvement of estimation, assessment methods, CMM/CMMI (Carnegie Mellon University's Capability Maturity Model Integration),
- Research and development: strategy, organization, sharing of technological skills, learning organization, development methodology, intellectual assets, commoditized software, readiness for state-of-the-art technology,
- Human development: training hours, skill development systems, incentive schemes, measurement of human development, moral support,
- Customer contact: ratio of prime contracts, scope of services offered, direct communication with customers' top management, deficit prevention, and clarification of user specifications.

3. SURVEY ON SOFTWARE ENGINEERING EXCELLENCE

Based on the measurement model, we conducted surveys on Software Engineering Excellence in 2005, 2006 and 2007 with Japan's Ministry of Economy, Trade and Industry. We designed a questionnaire on the practice of software engineering and the nature of the respondent's company. This questionnaire was sent to the CEOs of major Japanese IT vendors with over 300 employees as well as the member firms of the Japan Information Technology Services Industry Association (JISA), and was then distributed to the departments in charge of software engineering.

Responses were received from 117 companies with a total of 100 valid responses to the 2007 survey, a response rate of 10%. There were 55 valid responses, a response rate of 24%, for the 2005 survey and 78 (response rate of 15%) for 2006. For this paper, we integrated the 233 valid responses received over the three years into a new database including 151 unique companies consisting of 42 maker-turned vendors, 33 user-turned vendors and 76 independent vendors.

After collecting data from vendors in 2005, 2006 and 2007, we calculated the factor loadings of seven factors; deliverables, project management, quality assurance, process improvement, research and development, human development and customer contact, based on the responses received to the questions relevant to the measurement model described in the previous subsection (Kadono, Tsubaki, Tsuruho, 2009).

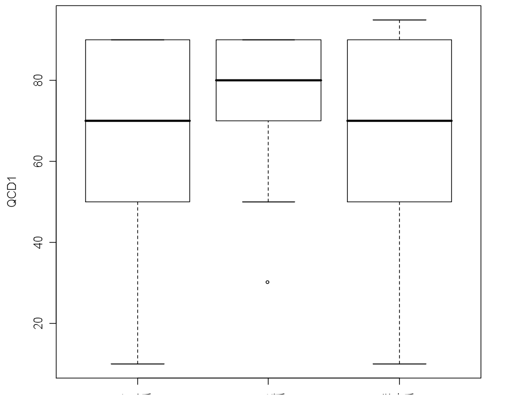

Figure 3. Quality, Cost and Delivery Achievement Ratios for SEE survey respondents in 2007 (%).

For example, the SEE deliverables score is estimated using responses to the relevant question items, such as achievement ratios of quality, cost, and delivery (QCD), productivity, and understanding of project information. The median QCD achievement ratios are over 70% for all three types of vendors (*Figure 3*). QCD achievement levels for user-turned vendors tend to be higher than those of maker-turned vendors and independent vendors.

One of the SEE questions used to measure human development asks about training hours for new recruits. The median number of hours for new recruits is over 400 hours per year, while the median hours for other experienced software engineers, another human development measurement item queried in the survey, is almost 40 hours per year (*Figure 4*). This tendency, observed in the 2007 survey results was also observed in the 2005 and 2006 results. Maker-turned vendor firms tend to invest relatively more time training engineers than do other types of vendors.

Figure 4. Software Engineer Training Hours per Year.

4. RESULTS

Based on the structural model hypotheses, we conducted a panel analysis of the data from the 233 valid responses we had received to the 2005, 2006, and 2007 surveys from 151 unique firms. The result of the panel analysis is shown in *Figure 5*. We found the following to be characteristics of the relationships among the seven SEE factors over the three years:

- Vertically, year by year, most SEE factors have significant influence on the same factors in the following year. For example, human development (HD) in 2005 influenced HD in 2006, which, in turn, influenced HD in 2007. The same holds true for quality assurance (QA) and deliverables (D). There are two exceptions. Project management (PM) in 2005 did not seem to affect PM in 2006 nor did process improvement (PI) in 2005 seem to influence PI in 2006.
- Horizontally (within each year), most causal relationships are similar and they are generally consistent with the results of the 2006 SEE survey (*Figure. 1*).
- Diagonally, some SEE factors have significant influence on different factors in the following year. Examples are Human development (HD) in 2005 and 2006, which influenced R&D in 2006 and 2007, respectively, and process improvement (PI) in 2005 that impacted deliverables (D) in 2006.

- There are some negative paths, such as R&D in 2005 and 2006 which negatively influenced deliverables (D) in 2006, process improvement (PI) in 2006 which had a negative impact on deliverables (D) in 2007 and project management (PM) in 2006 which negatively influenced customer contact (CC) in 2007.

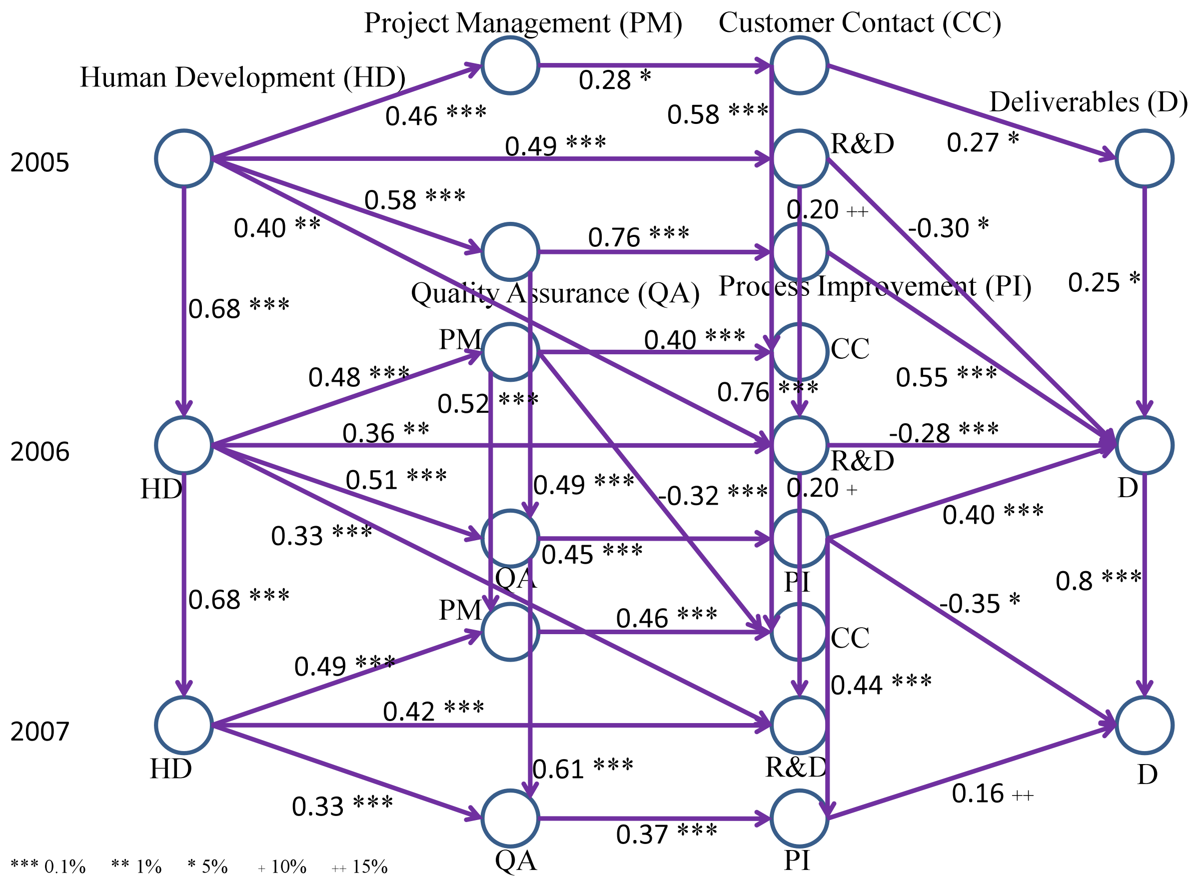

Figure 5. Panel Analysis Results.

These results indicate the following:

- Vertically, (year-to-year) IT vendors build on SEE factor levels that they have achieved thus far.
- Horizontally, the structural consistency over the different years leads us to understand that there are three paths toward improving the level of deliverables (D) through human development via:
    - Project management (PM) and customer contact (CC) that suggest marketing innovation ,
    - R&D that suggests product innovation, and
    - Quality assurance (QA) and process improvement (PI) that suggest process innovation.
- Diagonally, the factors that directly influence factors in the following year point to positive mid-term effects such as human development (HD) in 2005 leading to R&D improvements in 2006 and process improvement (PI) in 2005 influencing deliverables (D) in 2006.
- Several negative paths imply that effort invested in some factors did not pay off, at least during the duration of this research. They might, however, be expected to have long-term effects, e.g., from R&D in 2005 and 2006 to deliverables (D) in 2006 and later.

5. CONCLUSION AND DISCUSSION

In this paper, we integrated 233 valid responses to three surveys on software engineering excellence into a new database and identified 151 unique IT vendors in Japan, of which 42 were maker-turned vendors, 33 were user-turned vendors and 76 were independent vendors. We investigated the relationships among the SEE factors for three years to clarify how they influence future SEE factors horizontally, vertically and diagonally.

Within a year (horizontally), we assumed three paths toward improved deliverables (quality, cost, and delivery) through marketing innovation, which includes project management and customer contact; product innovation including R&D; and process innovations including quality assurance and process improvement. Also, year-to-year (vertically), we assumed that each factor would be consistent. For example, if a vendor had a high human development score in 2005, it also had a high human development score in 2006. This tendency continued in 2007. In addition, diagonally, we assumed mid-term effects, such as vendors who invest in human development in 2005 may be expected to see the results of that investment in their R&D in 2006.

On the basis of the structural model's hypotheses, we conducted panel analysis using the integrated data from the 2005, 2006 and 2007 SEE surveys. As a result of path analysis, we found characteristic relationships among the seven SEE factors for the three surveyed years. Vertically, most SEE factors have significant influence on the same SEE factors in the following year. Thus human development in 2005 influences human development in 2006, which in turn affects human development in 2007. Horizontally, most causal relationships each year are similar and are generally consistent with the results of the SEE 2006 survey results *(Figure. 1*). Diagonally, some SEE factors have significant influence on different SEE factors in the following year, such as the case of human development in 2005 and 2006 which affected R&D in 2006 and 2007, respectively. However, there are some negative paths, such as from R&D in 2005 and 2006 to deliverables in 2006; from process improvement in 2006 to deliverables in 2007; and from project management in 2006 to customer contact in 2007.

These results indicate that IT vendors build on the SEE factor levels that they have achieved thus far. The structural consistency between different years also implies that there are three paths to improving the level of deliverables: through marketing innovation (project management and contact customer), product innovation (R&D), and process innovation (quality assurance and process improvement). SEE factors that have direct influence in the following year indicate mid-term positive effects. Several negative paths imply that effort expended on some factors does not pay off, at least during the duration of this research. These efforts might be expected to have long-term effects.

To expand the results of this research, we need to further connect the relevant literature. In addition, although we focused on software engineering excellence (SEE) in 2005, 2006 and 2007 in this paper, analysis of the relationships between SEE, the business environment and business performance remains for future research.

Regarding the business environment, we analyzed the relationships of threats, strengths/weaknesses and the number of software engineers by vendor type, i.e., maker-turned, user-turned and independent vendors (Kadono, Tsubaki, Tsuruho, 2009). The analysis suggests that maker-turned vendors tend to expand their businesses by new acquisition of patents, well-supported R&D, offshore systems development, and offshore client development, while user-turned vendors seem to depend heavily on the demand from their parent companies. Therefore, some of them are thought to gain inimitable capabilities such as know-how on specific functions and uncopyable products or services. On the other hand, many independent vendors supply people, with the principal contractors acting as temporary staff, without specific strengths. However, independent vendors who have inimitable assets and no threat of industry stagnation seem to be the software vendor role model in Japan. We also observed significant correlation between overall SEE and the number of software engineers, which suggests a characteristic of the Japanese software industry. Therefore, we think it will be important to conduct stratified analyses by vendor type and size, i.e., maker-turned vendors, user-turned vendors and independent vendors, and the number of software engineers each employs.

To understand the relationship between SEE and business performance, panel analysis including financial data of the 151 identified firms is required. Also, to further study issues associated with the future of the IT industry in Japan, we suggest global comparisons of IT industry architecture with the United States, European Union nations, and Mediterranean and other Asian countries.

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