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: Findings from 188 Japanese Product Development Projects

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Abstract

The study considers the determinants of alternative product development strategies for introducing advanced technologies into new products. Past studies have frequently related novel technology introduction to cross-functional integration. However, the strategies for novel technology introduction could be distinguished from cross-functional integration in product/process engineering stages. Novel technology introduction, which may include advanced technology development, would not necessarily require cross-functional integration in product/process engineering stages. We assume alternative product development strategies for novel technologies introduction: “technology integration” and “separated technology development.” We attempt to explore the determinants of each of the product development strategies for novel technology introduction. Based on a contingency perspective, we collected and analyzed questionnaire-based data from 188 successful Japanese product development projects. At first, we confirmed that cross-functional integration in product/process engineering stages is distinguished from the two novel technology introduction strategies. Second, the results also demonstrated that technology development separation is effective for developing less complex products in relatively volatile markets while technology integration is apt for relatively complex products in less volatile markets. Firms do not need to choose one of the alternative strategies for introducing novel technologies, but are required to exploit either of the strategies according to each product’s product characteristics. The findings are expected to help firms elaborate not only platform/multi-project strategies at corporate level but also technology introduction strategies at project level.

Key Words

: novel technology introduction, technology integration, separated technology development

Introduction

Cross-functional integration and associated collaborative practices across different development stages (e.g., overlapping, preliminary information exchange, and so on) are critical factors for project success (Clark and Fujimoto, 1991; Brown and Eisenhardt, 1995). Furthermore, the cross-functional integration and related practices are assigned the role for exploratory knowledge creation (Benner and Tushman, 2003; Inansiti and Clark, 1994; Kusunoki et al., 1998).

Product life cycles have dramatically shortened as technologies rapidly change particularly in competitive hi-tech product markets. The industrial volatility urges firms to develop novel technologies into new products faster than ever. Reflecting the industrial volatility, it is frequently emphasized that cross-functional integration and associated practices for novel technology introduction are regarded as key factors for project success in high-tech industries.

Product development performances, such as productivity, development speed, and product quality, rely on how firms choose and refine novel technologies so that the technologies work well together in new products. Cross-functional integration teams for novel technology introduction contribute to the performances effectively integrating novel technologies into new products (e.g., Eisenhardt and Tabrizi, 1995; Gobeli and Foster, 1985; Gomory, 1989; Iansiti, 1995; 1997; Tatikonda and Rosenthal, 2000; Song and Xie, 2000).

However, novel technology introduction into new products should be distinguished from cross-functional integration in product/process engineering stages. As is shown in a comparative study between automobile and supercomputer development projects (Iansiti and Clark, 1994), technology introduction strategies could be distinguished from cross-functional integration in product/process engineering stages.

Furthermore, recent studies have asserted the power of modularity and associated modularly partitioned practices in product/process engineering stages, which are mostly found in hi-tech segments such as software, personal computers, network systems, and so on (e.g., Baldwin and Clark, 1997; Cusumano and Yoffie, 1998; Gawer and Cusumano, 2002; Iansiti and MacCormack, 1997). The studies suggest that firms may refurbish a portion of a product system by adopting element technologies from the outside of the product development group, and thereby facilitates the novel technology introduction. The line of studies also discusses platform/multi-project strategies drawing on the design concept of “product architecture” (e.g., Gawer and Cusumano, 2002; Robertson and Ulrich, 1998).

The above mentioned situation reveals two issues on novel technology introduction strategies at project level. At first, we may cast a doubt if cross-functional integration for novel technology introduction could be mingled with cross-functional integration for product/process engineering. Second, we pose a question on how firms should make use of either of novel technology introduction strategies: introducing novel technologies through cross-functional integration or element technology development separation.

Researchers have paid particular attention to the impact of product design attributes on product development projects. However, antecedents also suggest that market and technological factors other than product design attributes have impacts on product development projects and platform/multi-project strategies. We have not sufficiently explored how these factors as well as product design attributes have impacts on novel technology introduction strategies.

The lack of the knowledge on the determinants of novel technology introduction strategies would hamper firms from choosing proper product development strategies at project level and shaping effective platform/multi-project strategies at corporate level. Making proper use of novel technology introduction strategies at project level, which are closely interrelated to platform/multi-project strategies, is necessary for firms particularly in hi-tech industries.

Drawing on the data from successful product development projects of Japanese firms, the study is to explore how firms make use of novel technology introduction strategies. Based on a contingency perspective, the article posits that product development strategies for novel technology introduction may differ according to product characteristics.

Whereas focusing on project level strategies for novel technology introduction, the attempt would also contribute to elucidating the impacts of critical factors for effective platform/multi-project strategies for novel technology introduction (e.g., How platform and derivative projects should play different roles according to the factors?). Since the purpose of the article rests on hypothesis generating rather than hypothesis testing, the study does not hypothesize any specific causality. We predict nothing but that product development strategies for novel technology integration may differ according to product characteristics.

The paper outline is as follow. First, we review antecedents, and thereby propose a generic prediction. Based on the prediction, we examine the questionnaire-based data from 188 successful Japanese product development projects. Following the results, we attempt to draw implications on novel technology introduction strategies.

Backgrounds

Product Development Strategies for Novel Technology Introduction

Let us review how researchers have characterized effective product development strategies for novel technology introduction. From the mid 1980s, drawing on the cases of technology-based product development projects, which successfully developed advanced technologies into novel products, researchers attempted to explore the effective product development strategies for introducing novel technology into new products (e.g., Gobeli and Foster, 1985; Gomory, 1989).

In the 1990s, researchers collected product/industry-specific data of successful projects from firms, and explored effective product development strategies for introducing novel technologies. Based on the data of about thirty super computer or work station development projects of US and Japanese firms, Iansiti (1995; 1997) examined product development projects, which are accompanied by core technology development.

The study suggested that the "system-focused" approach facilitates the "technology integration" among related functional groups, which is characterized by overlapping and associated intensive communication between element technology development and product/process engineering groups. The system-focused approach results in shorter development leadtime, and enables more radical technologies than the "element-focused" approach.

The line of studies suggested that communication and overlapping between advanced technology development and product/process engineering groups are critical for successful commercialization of novel technologies. Several generic studies made use of large sample data from various industries, and suggested that cross-functional integration is critical for developing new products with novel technologies (e.g., Eisenhardt and Tabrizi, 1995; Song and Montoya-Weiss, 2001; Song and Xie, 2000; Tatikonda and Rosenthal, 2000; Olson et al, 1995).

On the contrary, since the 1990s, product modularity has been highlighted in reference with successful US firms particularly in IT industries: computer, electronics, and software (e.g., Baldwin and Clark, 1997; Cusumano and Yoffie, 1998; Gawer and Cusumano, 2002; Iansiti and MacCormack, 1997). Researchers have suggested that modular design enables manufacturers to decompose complex problem-solving into a set of localized problem-solving (Baldwin and Clark, 1997). The decomposability enables firms to separate advanced component/element technology development from specific product development projects.

Modularity permits the introduction of novel elements/technologies into products with relatively low cost and high agility. The advantage enables firms to drastically improve product performance without tight organizational coordination (Sanchez and Mahoney, 1996; Ulrich, 1995). Product development based on modularity seems to obscure the importance of cross-functional integration and associated product development practices, which were once regarded as one of the critical factors of effective product development.

Product development capabilities which yield complex/novel products are regarded as the source of competitiveness (Anderson, 1999). Cross-functional integration for novel technology introduction is effective in developing these complex/novel products. However, the attention to the novel technology introduction strategy recently seems to languish. Element technologies may be developed separated from product/process engineering, and introduced into products in the form of independent module units. The research stream would indicate that there are alternative strategies for introducing novel technologies into products: "technology integration" and "separated technology development."

Making Proper Use of Product Development Capabilities

In the line of generic studies based on large sample data from various industries, the concept of cross-functional integration is liable to include both technology integration and cross-functional integration in product/process engineering stages (e.g., Eisenhardt and Tabrizi, 1995; Song and Montoya-Weiss, 2001; Song and Xie, 2000; Tatikonda and Rosenthal, 2000; Olson et al, 1995). However, industry/product specific studies demonstrate that novel technology integration is distinguished from cross-functional integration in product/process engineering stages.

Iansiti and Clark (1994) asserted that technology integration is the effective product development strategies for technology-based complex products, which are accompanied by high technological uncertainty (e.g., super computers). The "external integration" is related to uncertain customer needs of consumer product markets, and the "internal integration" is for high product complexity (e.g., automobiles). The study makes us predict that we could distinguish technology introduction strategies from cross-functional integration in product/process engineering stages.

On the other hand, from the 1990s, researchers have implied that effective (i.e., market success) product development strategies relevant to novel technology development may differ by product characteristics and/or industrial dynamism. As mentioned above, Iansiti (1995; 1997) examined advanced computer development cases, and suggested the effectiveness of technology integration among related functional groups. The study demonstrated that the technological uncertainty in advanced core technology development influences the mode of novel technology introduction.

Pisano (1997) examined 23 projects of pharmaceutical development projects, and pointed out that effective product development process depends upon the uncertainty of manufacturing process engineering. The study demonstrated that "learn before doing" is suitable for developing conventional chemical products while "learn by doing" is effective for developing bio-pharmaceuticals.

In the case of conventional chemical product development, separated technology development in advance of product/process engineering contributes to shortening the development leadtime because the knowledge on product/process engineering for conventional chemical products is relatively sufficient (relatively low technological uncertainty). On the contrary, experimentation in product/process engineering stages contributes to shortening the development leadtime of bio-pharmaceuticals because knowledge on product/process engineering is relatively insufficient (relatively high technological uncertainty). The study would also suggest that technological uncertainty influences product development strategies for novel technology introduction.

Product complexity as well as technological uncertainty also has impacts on product development projects. Tight cross-functional integration and associated practices, such as HWPM (Heavy Weight Project Manager) organization, are effective corresponding to the product complexity of automobiles (Clark and Fujimoto, 1991). Also in advanced computer development projects, product and/or associated project complexity may have impacts on product development strategies for novel technology introduction (Iansiti, 1997). The complexity of the relationships between core technologies and related technologies encourages firms to adopt technology integration.

Several generic studies have explicitly considered the effects of product characteristics on product development strategies. The studies are supposed to contribute to generalizing the results from product-specific case-based studies. Compared to the case of incremental model change projects, projects for novel products urge firms to adopt cross-functional integration and overlapping between element technology development and product/process engineering (Song and Montoya-Weiss, 2001; Song and Xie, 2000; Olson et al, 1995). Particularly when the products concerned are complex, technological uncertainty is likely to enhance the need for the cross-functional integration (Tatikonda and Rosenthal, 2000).

On the other hand, Eisenhardt and Tabrizi (1995) examined 72 development projects of computer products, such as personal computers, super computers, work stations, and peripheral products. The study elucidated that, as a whole, the “experiential approach” based on cross-functional integration contributes to shortening development leadtime.

The experiential approach is particularly effective in the field of rapidly evolving products. However, the study also suggested that product development projects in relatively stable environments are likely to adopt the “compression approach” based on planning and overlapping. The line of studies particularly emphasized that effective product development strategies vary with market variability (Eisenhardt and Martin, 2000). Cross-functional and associated flexible processes are likely to be adaptive in volatile and thus uncertain market/industrial environments.

Contrary to the studies, recent studies have suggested that modular product designs and associated organizations enable firms to effectively cope with technological changes and/or market variability (e.g., Cusumano and Yoffie, 1998; Gawer and Cusumano, 2002; Iansiti and MacCormack, 1997). The capabilities to cope with technological changes and/or market variability rely on product complexity. If sufficiently reducing product complexity, firms could refurbish a portion of the product system with novel technologies according to market variability (Baldwin and Clark, 1997). Though we find two different suggestions on the impacts of market uncertainty on novel technology introduction strategies, market uncertainty is expected to have impacts on the choice of product development strategies.

Reflecting the above findings from past studies, we presume that successful projects make proper use of product development strategies according to product characteristics: technological uncertainty, product complexity, and market uncertainty.

The accumulated knowledge on product innovation management has implied that successful projects adopt proper product development strategies corresponding to product attributes (Song and Montoya-Weiss, 2001; Song and Xie, 2000; Souder et al., 1998; Tatikonda and Rosenthal, 2000; Yasumoto and Fujimoto, 2005). The line of studies makes us infer that the mode of novel technology introduction strategies is contingent upon product characteristics and/or industrial dynamism. Therefore, our next step is to examine how firms employ product development strategies in relation to novel technology introduction.

Empirical Research

Basic Direction

Let us describe the direction of our analysis. At first, the study examines whether or not firms distinguish technology introduction strategies from product/process engineering. Second, the study shows how firms successfully adopt novel technology introduction strategies according to product characteristics.

Because of the variety of products, modern manufacturing firms are required to employ apt product development strategies for novel technology introduction according to product characteristics and/or industrial dynamism. Examining the contingent application of product development strategies for novel technology introduction would help us understand how firms could successfully introduce novel technologies into the products.

Though the basic logic of the present contingency analysis is relatively simple, actual data collection and empirical analysis is not easy, partly because of some difficulties in measuring product characteristics, development strategies, and performances across various industries. After trying various methods, we decided to use subjective measures as the main yardsticks, and considered that each of the respondents would have a broad perspective in evaluating product development strategies in a better method.

What we measured in this study is the “perceived” characteristics of the product in question and product development practices. Product development performances were also measured in terms of respondents’ perceptions. This method may have some potential problems in measurement and validity. There is a fundamental trade-off here between accuracy and comparability of data[1].

Considering the trade-off, we presumed that objective environments, novel technology introduction strategies, and performances would be aligned in projects which project leaders themselves regard as successful. Therefore, focusing on projects deemed to be as successful, we explored the relationship between product characteristics and estimated success levels of product development strategies.

Data Collection

We combined clinical field studies and statistical data collection. At first, from 1995 to 1997, we visited 32 development projects of products in various industries, such as apparel, automobiles, construction equipment, chemical textile and resin, consumer electronics, communication devices, electronic components, food/beverage, pharmaceuticals, industrial chemicals, industrial machinery, mechanical parts, medical equipment, office equipment, precision mechanics, software, and toiletries, covering virtually all the product/industrial categories we intended to study in our questionnaire survey. Combining our knowledge from both the literature survey and field research, we selected variables and designed the questionnaire. We then moved on to the questionnaire survey.

We collected data through a questionnaire survey mailed to 700 business units and research laboratories of Japanese public firms in July 1997. The survey asked about product development projects of commercialized mass-production products.

The unit of analysis was an individual project of product development. Some of the surveys were sent to different business units or institutes within the same multi-divisional company. We asked potential respondents to select a relatively successful project that he or she had direct experience with in recent years, and to answer the questions consistently about this particular project[2].

We received 203 answers (response rate: 29 %) from 145 firms by the end of October, 1997. The means of the sales and number of employee of respondent firms were respectively 7.92 billion yen and 12,360 employees[3]. We checked the non-response bias on firm size (sales)[4]. No significant difference in firm size

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[1] A popular method for understanding effective or adaptive strategies is a pair approach: asking the responding firms to give us a pair of projects, a successful and an unsuccessful one from their point of view, and to evaluate the level of adoption or effectiveness of each routine. If the level is significantly different between the pairs for a given routine, we could say that it is an effective or adaptive routine. In reality, however, it is rather difficult to get responses about failed projects from firms.

[2] 68.85 % of the sample projects consisted of less than 25 members (including part-time members) from planning to release. The mean product sale for the first year after release was 27.41 billion yen. Projects for novel product categories for the respondent firms accounted 23.98 % of the samples. The mean quantity of related Japanese patents was 27.99. Core project members had on average experienced in respondent firms for 14.21 years. The mean period after the first model of the product genre was released was 10.13 years, and the mean generation of the product in the product line was 3.14.

[3] Firms with less than 5 billion yen constituted more than 50% of the samples, and firms with more than 6,000 employees accounted more than 50% of the samples.

[4] The mean of the sales of potential respondent firms was 6.84 billion yen.

between respondent firms and other potential respondent firms (t = 1.34, p = .18; F = 1.13, p = .27).

The 203 responses were spreading across a variety of products/industries: textile and apparel (n = 18); food/beverage (n = 15); chemical, pharmaceutical and rubber (n = 43); consumer chemical and toiletry (n = 9); metal (n = 13); electronics, systems, and software (n = 64); precision mechanics (n = 15); transportation machines (n = 10). The diffusion of respondents by industries was not significantly different from that of potential respondent firms.

Product Development Strategies

We asked respondents 19 variables of product development strategies, and conducted a factor analysis. The respondents of the questionnaire were asked if each of the following descriptions fits a characteristic of the product development project in question, compared with other products in general, using a 5-point Likert-scale (1 = "not successful at all" to 5 = "quite successful").

After eliminating 15 cases with defect values, we applied factor-analysis (principal components analysis) to 188 samples, selected the factors of more than one (1.00) in Eigen-value, and named the selected factors as types of development strategies following past studies (Appendix 1). The measures loaded mostly on separate factors with all factor loadings above .40, which is a common threshold for acceptance. The factor analysis model reasonably fitted the data (χ square = 888.495, df = 210, p < .001).

From the original factor analysis, we chose the results of 11 variables concerning element technology development, function design, product design, prototyping and test, and manufacturing process design[5]. We identified three factors related to novel technology introduction and product/process engineering.

We found that the Factor 1 (Eigen-value = 3.96, contribution ratio = .21, α = .82) consisted of variables such as communication in product/process engineering stages and overlapping between product and process engineering stages. Therefore, the Factor 1 could be named "engineering integration." The factor included cross-functional integration across engineering sections and overlapping between product engineering stages and pre-manufacturing stages.

Effective overlapping contributes to shortening lead time, and thus raising the accuracy of simulation (Clark and Fujimoto, 1991; Iansiti, 1997). While overlapping between related stages is not necessarily accompanied by communication between the stages, information exchange is critical for effective problem-solving in overlapping (Adler, 1995; Clark and Fujimoto, 1991; Terwiesch and Meyer, 2002). This is nothing other than cross-functional integration in product/process engineering stages.

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[5] Since customer involvement, supplier involvement, and development investment amount were supposed to be factors extraneous to the other 16 variables, we did not include the variables in the factor analysis. We eliminated three factors and variables related to concept integration, front-loading, and leadership from the original result of the factor analysis on 19 variables.

The factor 2, the first factor of the novel technology introduction strategy, was named “technology integration” (Eigen-value = 1.41, contribution ratio = .07, α = .71) as it was heavily loaded with five variables related to the search and simulation of element technologies in early stages. Project members need to collaborate among technology and product/process development groups to effectively integrate novel technologies into products (Song and Montoya-Weiss, 2001; Song and Xie, 2000; Tatikonda and Rosenthal, 2000). This is nothing other than the “technology integration” of Iansiti (1997). In super computer product development, product development projects conduct intensive search and simulation of materials, components, and product design from early stages.

The factor 3, the second factor of novel technology introduction into products, was heavily loaded with the variables of the separation of element technology development from product/process engineering. Therefore, we may call the factor “separated technology development” (Eigen-value = 1.18, contribution ratio =. 06, α = .60). Firms can reduce technological uncertainty by separating element technology development from product/process engineering. Separating problem-solving on element technology development from product/process engineering reduces search and simulation for technology integration in product/process engineering, and thus facilitates product/process engineering per se (e.g., Gawer and Cusumano, 2002).

Independent Variables

We employed three measures of product characteristics, and eliminated 15 samples from the original 203 samples because of the defect values in the samples. At first, as for technological uncertainty, we measured the necessity of element technology development with a 5-point Likert-scale (1= “not necessary at all” to 5= ”extremely necessary”)6. Technological uncertainty is supposed to arise from novel element technology development.

As described in the case of advanced computers (Eisenhardt and Tabrizi, 1995; Iansiti, 1997) or pharmaceutical development (Pisano, 1997), technological uncertainty on advanced/high element technologies could require the integration of element technology development with product/process engineering (Song and Montoya-Weiss, 2001; Song and Xie, 2000; Tatikonda and Rosenthal, 2000). It is also asserted that, in fast changing technological environments, firms are required to develop advanced element technologies into products in short cycles and adopt relatively modularized product development teams (e.g., Cusumano and Yoffie, 1998; Iansiti and MacCormack, 1997).

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6 In our analysis, we did not use the quantity of patents associated with the products concerned (mean=27.89). The quantity of patents was significantly correlated with the quantity of evaluated product functions (r = .27, p <. 01), quantity of product elements/design drawings (r = .22, p <. 01), and number of project members (r = .25, p <. 01) as well as the importance of advanced element technologies (r = 0.19, p <. 01). The number of patents would be related to product complexity rather than technological uncertainty.

On other hand, we measured the level of product complexity with the quantity of evaluated product functions, which were checked in the test process of the projects concerned. We asked respondents to check the approximate number on a 5-point logarithm scale (1= "1", 2 = "10", 3 = "100", 4 = "1,000", 5 = "10,000").

Kusunoki (1999) considered product complexity in terms of the amount of evaluated product functions, and thereby explicated the cross-functional integration and related routines in Japanese semiconductor firms. We followed this perspective because of the measurement problem of product complexity.

Product complexity has been conceptualized in terms of the interdependency between product elements. The level of interdependency between product elements may define the required knowledge and cost for realizing a new product (e.g., Baldwin and Clark, 1997; Garud and Kamaraswamy, 1995; Langlois and Robertson, 1992). Product architecture, which is defined in terms of the product design complexity, determines the proper mode of organizational coordination for a product development project (Sanchez and Mahoney, 1996; Ulrich, 1995). Because of the interdependency between product elements, effective problem-solving in projects for complex product, such as automobile, supercomputer, and so on, requires overlapping between stages, design-test-build cycles iterations, and related tight coordination between engineers (Adler, 1995; Clark and Fujimoto, 1991; Iansiti, 1997; Terwiesch and Meyer, 2002)

Thus, a successful manufacturer of a complex hi-tech product, such as supercomputer, may need a coherent cross-functional team headed by a strong project leader (Iansiti, 1995; 1997). On the contrary, a relatively successful developer of a more modular product, such as a personal computer, software, and so on, may form a federation of many small module-specific teams that are relatively independent of each other (e.g., Cusumano and Yoffie, 1998; Iansiti and MacCormack, 1997).

However, measuring the interdependency is difficult in practice. For the difficulty, product complexity is thought to be measured in terms of the amount of product elements (Anderson, 1999). An automobile has product complexity largely because an automobile consists of 20,000 to 30,000 parts. Logically speaking, adding another component dramatically increases product complexity, since the maximum quantity of relationships between components is $n(n-1)/2$ (n=quantity of component). Larger amount of product elements would in general cause more interdependent relationships between elements.

Nevertheless, we predicted two difficulties in measuring product complexity with the quantity of product elements. First, measuring the amount of product elements could not be applicable to process products. Second, the level of interdependency would not be subject to the quantity of product elements as is the case of many of mechanical parts and process products.

Reflecting these problems, we decided to measure product complexity with the quantity of evaluated product functions. The quantity of evaluated product functions in test stages could be measured for both assembly and process products. As an objective measure, the variable was presumed to approximate product complexity.

Other things being equal, a larger amount of evaluated product functions will be related to several interdependent elements, and are attained as the results of the synthesis of the interdependent elements. Therefore, we attempted to estimate product complexity in terms of the quantity of evaluated product functions.

As for market uncertainty, we measured the real number of the standard model change cycle (months) within the market of the product concerned. In a changing and/or competitive market, faster product releases could help firms obtain a competitive advantage against competitors (Dater, 1997).

If the state or shift of market needs is difficult to predict, firms do not have sufficient knowledge on the state or shift of market needs. Some of the past studies suggested that volatile (thus uncertain) markets encourage firms to develop the products faster than competitors and to adopt more cross-functional routines than stable markets (e.g., Eisenhardt and Martin, 2000; Eisenhardt and Tabrizi, 1995).

On the contrary, recent studies have suggested that volatile markets urge firms to adopt less cross-functional product development strategies (e.g., Cusumano and Yoffie, 1998; Iansiti and MacCormack, 1997). A firm may separate element technology development from product/process engineering particularly in the case that relationships between element technologies are sufficiently standardized across the firm's related products. In a volatile market, firms would not be liable to adopt technology integration.

Contexts

In order to examine contextual differences between product types, we measured several context variables such as target market, product novelty, and project size in the field related to the products. These context variables would provide fundamental conditions of the sample projects. We considered the effects of two context variables, target market and product novelty, in our analysis. Project size[7], which we measured with the number of core project members, was assumed to be substituted by the product complexity variable: the quantity of evaluated product functions.

We presumed that the predictability of customer needs would be fundamentally provided by the distinction between consumer and industrial products[8]. We asked respondents to choose the most approximate product

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[7] Product development management studies have suggested that the scale of an organization influences the organizational structure. See Clark and Fujimoto (1991). The number of project members was positively correlated to the quantity of evaluated product functions ($r = .31$, $p < .01$) and amount of product elements ($r = .5$, $p < .01$). The number of project members would depend upon product complexity.

[8] Although market growth rate was on average similar across the assembly and process product groups, the mean of standard model change cycle of the consumer product group, 24.97 months, was significantly shorter than that of the industrial product one, 37.59 months (R square = .05, $p < .01$). The mean of the number of competing products of the consumer product group, 10.18, was significantly larger than that of the industrial product one, 6.12 (R square = .04, $p < .01$). These differences would indicate that competition is in general more intensified in consumer product markets than in industrial product ones not only

category in terms of the target market from two categories: consumer products (= 1) or industrial products (= 0). After the elimination of the samples including defect values from 203 samples, the quantity of consumer products was 67 (35.64 %) while that of industrial products was 121 (64.36 %).

This simple categorization had the risk of obscuring more specific market characteristics, which might be perceived by project members to have directly impacts on product development strategies. However, we predicted that the target market could define the fundamental market condition, which could not be attributed to any of the single market uncertainty variables.

Market needs would largely depend on the target customer of the product in question. In development projects for many of consumer goods, such as apparel, automobiles, consumer electronic appliances, and so on, customer needs are uncertain and/or equivocal. For example, whereas exterior styling, color, aesthetic design, and feeling are critical factors in automobile development, these ergonomic features are hardly defined in articulated manners, and changes in tastes are also difficult to predict (Clark and Fujimoto, 1991; Iansiti and Clark, 1994). As these features may not be attributed to single technologies, novel technology development in consumer product development would not be separated from product/process engineering.

On the contrary, some studies on industrial products show different market situations. The target customers of industrial products in this study included firms, business men, professionals, SOHO, hospitals, and so on. Even if not clarified at the beginning of product development, requirements on industrial products would be directly indicated or suggested by customers (von Hippel, 1988).

Also, goal specifications of business/industrial products could be derived from specific functional criteria, such as processing speed, capacity size, and so on, at least as long as the value network is stable (e.g., Chrsistensen, 1997). For example, Iansiti (1997) described advancement in a single technological function, processing speed, as the major goal of super computer development. Thus, in contrast to the cases of consumer product development projects, developing industrial product would be directed to relatively instrumental and specified features. As each of these features may be required to be prominent, firms would employ separated technology development in industrial product development.

We considered product novelty as another context variable. We asked respondents whether or not the product concerned was completely new to the preceding product genre within the respondent firm (1 = “novel” or 0 = “conventional”). The quantity of novel products was 46 (24.5%) while that of products in the line of conventional product genre was 142 (75.5%).

The question was intended to understand the product novelty of the product in question in terms of the distinction between conventional products following past products and novel products without any preceding

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because of market uncertainty but also because of fundamental unpredictability, equivocality, of customer needs.

product models/lineups. If firms do not have preceding product models/lineups of the product concerned, firms could hardly reuse the technologies, design, parts, and/or manufacturing process of preceding products.

Product novelty in this sense could have significant impacts on product development strategies (e.g., Song and Xie, 2000; Tatikonda and Rosenthal, 2000). While a novel product is not necessarily accompanied by new advanced technologies, advanced technologies are applicable to conventional product lines as is the case of modular products. Thus, we collected the data of product novelty apart from technological novelty, which we measured in terms of the importance of advanced element technologies.

Assembly and Process Product Groups

We conducted the analysis dividing the samples into two groups: "assembly product" and "process product" groups. Innovation management studies have suggested that product development capabilities are different between assembly products and process products (e.g., Kusunoki et al., 1998; Utterback, 1994). Kusunoki et al. (1998) asserted that effective product development capabilities are significantly different between these groups according to the difference in assembly/system and process/material development project groups.

However, the distinction between assembly and process products is not as easy as is usually expected. For instance, products with a small amount of components/ingredients are not always process products, and visa versa. We asked the respondents to give the ratio of the engineering-hours in the total product engineering-hours for product and component design in the product/process engineering stages.

We presumed that the ratio of the engineering-hours for product/component design would reflect the fundamental product complexity of the product in question. The fundamental complexity would define the knowledge level on the product structure. Firms of assembly products at least have knowledge that an assembly product is designed as a set of distinctive components. Accordingly, assembly product development projects are expected to allocate many of resources to product/component design and related prototyping and testing.

On the contrary, in many cases, firms of process products would scarcely have sufficient knowledge to articulate the structure of a process product into a set of physical designs. Thus, process product development projects would use most of resources for process design and related prototyping/testing. The difference in the knowledge level from the fundamental product complexity could bring about the differences in the product development strategies between the assembly and process product groups.

Reflecting this difference, we tentatively divided the samples at the ratio of 36 % since the mean of the ratios is 35.13 %[9]. The mean of the assembly product group was 43.06 % while that of the process product group was 23.26 %. The ratio of the assembly product group seemed to be relatively low. The reason will be that many of resources should be allocated to prototyping and testing even in assembly product development projects.

Most of the samples from electronics/system/software, precision mechanics, and transportation machine industries fell into the assembly product group. Relatively more of the samples from food and chemical/pharmaceutical/rubber industries than from the above mentioned assembly industries were classified into the process product group.

In order to confirm the differences in statistical structure between these groups, we applied Brown-Forsythe's F-test to the ratio of the engineering-hours for product/component design. The standard deviation of the assembly and process product groups were respectively 1.98 and 2.59. The result evidenced the significant difference in the variance between the assembly and process product groups ($F = 12.96$, $p < .0001$). The distinction between the assembly and process product groups could also have significant meanings also in terms of statistical structure.

Product Development Performance

Much of the literature on product development management has considered project performances in order to identify effective attributes of product development projects. As the unit of analysis in our study was a single product development project, we collected the data of six performance variables of the product in question: customer satisfaction/total quality, engineering-hours, development leadtime, specific functional performance, sales/market share, and profit[10].

Considering the problem of the comparability of performance between industries, we asked respondents to check each of the performance levels on a 5-point Likert-scale (1= "not successful at all" to 5= "highly successful"). Objective performance measures were not supposed to be appropriate for inter-industrial studies. Even though we could successfully collect objective performance data, comparing the data across various industries would be almost impossible.

All the performance scores of the sample projects appeared on average quite high across product types. Every respondent estimated the selected project as more or less successful in all the measures. Mean scores of customer satisfaction, functional performance, and sales/market share were particularly high across industries: 4.46, 4.40, and 4.24 respectively (Appendix 2). This might indicate that customer satisfaction, functional

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[9] The ratio of the engineering-hours for product/component design in the total engineering-hours had significant positive correlation with the amount of product elements/design drawings (R square = .30, $p < .01$).

[10] All of the performance variables significantly contributed to sales and profits ($p < .01$).

performance, and sales/market share are particularly critical performance measures in successful projects in all the industries.

In order to check whether or not respondents applied similar criteria of success, we collected the data on success criteria asking respondents to choose success criteria from five alternatives (multiple-answer). Respondents chose “compared with products of rivalry firms (n = 148, 37.19%)”, “compared with past products (n = 109, 27.39 %)”, “compared with past products of the firm concerned (n = 67, 16.83 %)”, “compared with success criteria within the firm concerned (n = 71, 17.84 %)”, and “others (n = 3, .75 %).” The ratios on the success criteria were not significantly different between the assembly and process product groups[11], which means that respondents applied similar success criteria in both the assembly and process product groups.

We also checked differences in the mean score and the variance of each performance measures between the assembly and process product groups (Appendix 2). As suggested in the previous section, assembly and process products were different in fundamental product complexity. The difference would encourage firms to pursue different product development performances and adopt different strategies for attaining the different performances.

However, we could not identify any of significant differences. This result seemed to suggest that subjective project performance estimation of project managers, which indicates how project managers put priorities among performance variables, was similar across both of the product groups. The result made us infer that examining relationships between performance variables and product development strategies would not derive significant results from the samples.

We also examined the correlation between product development performances and strategies (Appendix 3). The data demonstrated that engineering integration was significantly correlated with all of the performance measures while other product development strategies but technology integration did not have significant correlation with all of the performance measures.

The result would mean that, at least for sample Japanese product development projects, most of product development performances are attributed to engineering integration while technology integration could contribute to several specific performances: customer satisfaction/total quality, specific functional performance, and profit. These findings indicated that technology integration is more critical for product success than technology development separation. We needed to further examine the impacts of product characteristics and/or industrial dynamism on the choice of novel technology introduction strategies.

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[11] The results were as the followings: “compared with products of rivalry firms (χ square = .001, p = .98)”, “compared with past products (χ square = .01, p = .92)”, “compared with past products of the firm concerned (χ square = .02, p = .89)”, and “compared with success criteria within the firm concerned (χ square = .61, p = .44).”

Results

We attempted to check the differences in the mean scores of product development strategies, product characteristics, and context factors between the assembly and process product groups (Table 1). We conducted double sided t-tests on all the variables but the quantity of evaluated product functions.

We applied O'Brien's F-test to all the variables in order to examine the variance differences in these variables. We did not identified significant variance differences in all the variables but the quantity of evaluated product functions (F = 9.70, p < .01). Nothing but the variance of the quantity of evaluated product functions was significantly different between the assembly and process product groups. Thus, instead of simple double sided t-test, Welch's test was applied to the examination of the quantity of evaluated product functions.

Table 1 Mean Differences between Assembly and Process Product Groups

	Num of Sample	Engineering Integration	Technology Integration	Separated Technology Development	Necessity of Element Technology Development	Quantity of Evaluated Product Functions(a)	Model Change Cycle(mo.)	Target Market (1=consumer/ 0=industry) (b)	Product Novelty (1=novel /0=conventional) (b)
assembly	118	0.01	−0.23	0.16	3.55	2.87	32.34	0.40	0.23
s.d.		0.88	0.94	0.89	1.02	1.02	1.06	0.49	0.42
process	70	−0.02	0.39	−0.26	3.73	2.17	31.82	0.43	0.24
s.d.		1.07	0.76	0.94	0.96	0.65	0.89	0.50	0.43
t		0.02	4.07**	−2.80**	0.95	7.40**	−0.12	0.50	0.29
F		1.43	1.76	0.14	0.47	9.70**	0.89	0.30	0.10
total	188	0.00	0.00	0.01	3.62	2.52	32.07	0.41	0.23
s.d.		1.00	1.00	1.00	1.29	0.78	27.59	0.49	0.42

Double-sided *t*-test and O'Brien's *F*-Test.

a: Welch's test was applied to the examination of the mean difference.

b: The dummy variables were originally nominal data.

† *p* <.10, **p* <.05, ***p* <.01

The results indicated that the means of technology integration (t = 4.07, p <.01) and separated technology development (t= -2.80, p < .01) are significantly different between the assembly and process product groups. The mean scores of assembly product development projects were significantly higher than those of process product cases in separated element technology development, while the mean score of technology integration of assembly product development projects was less than that of process product development projects.

In the case of assembly product development, engineers could assign a portion of element technology development to advanced technology/platform development groups. The task for element technology development is more likely to be separated from product/process engineering in assembly product development than in process product development. These results made us infer that the difference in product development strategies between the assembly and process product groups would mainly lie in novel technology introduction.

As for product characteristics, only the mean of the quantity of evaluated product functions of assembly products was significantly larger than that of process products ($t = 7.40$, $p < .01$)[12]. As demonstrated above, the variance was also different between the assembly and process product groups. These results would imply that the differences in product development strategies between the assembly and process product groups come from the fundamental difference in the level of product complexity.

Following the above analysis, for each of the assembly and process product groups, we used four multi-regression analysis models from the product characteristics and context variables to the two novel technology introduction strategies. Table 2 and 3 shows the results.

Table 2 Results of Multiple-Regression Analysis: Assembly Product Group

	Technology Integration				Separated Technology Development			
Independent Variables	Model 1	Model 2	Model 3	Model 4	Model 1	Model 2	Model 3	Model 4
Necessity of Element Technology Development	0.32**	0.30**	0.33**	0.28**	0.17*	0.19*	0.16 †	0.18*
Quantity of Evaluated Product Functions	0.00	0.01	0.00	0.04	0.16*	0.15 †	0.18*	0.17*
Model Change Cycle	0.04	0.06	0.03	0.04	0.01	−0.04	−0.06	−0.12
Necessity of Element Technology Development *Quantity of Evaluated Product Functions			−0.10	−0.07			0.03	0.03
Necessity of Element Technology Development *Model Change Cycle			0.00	0.02			0.18*	0.19*
Model Change Cycle *Quantity of Evaluated Product Functions			−0.03	−0.06			−0.05	0.01
Target Market (Dummy, 0=industry)		−0.06		−0.13		0.21*		0.24**
Product Novelty (Dummy, 0=conventional)		−0.12		−0.13		0.13		0.11
R square	0.11	0.13	0.12	0.15	0.07	0.15	0.11	0.19
F	4.56**	3.32**	2.48*	2.29*	2.63*	3.68**	2.19*	3.17**

n = 118. Standardzed values were used for all the models.
† *p*<.10, **p*<.05, ***p*<.01

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[12] The quantity of evaluated product functions had positive correlations with the amount of product elements ($r = .49$, $p < .01$) and number of project members ($r = .35$, $p < .01$). Accordingly the means of the amount of product elements ($F = 182.85$, R square= .10, $p < .01$) and number of project members ($F = 21.73$, R square = .48, $p < .01$) were significantly larger in the assembly product group than in the process product group.

Table 3 Results of Multiple-Regression Analysis: Process Product Group

	Technology Integration				Separated Technology Development			
Independent Variables	Model 1	Model 2	Model 3	Model 4	Model 1	Model 2	Model 3	Model 4
Necessity of Element Technology Development	0.20 †	0.19 †	0.22 †	0.23*	0.22 †	0.21 †	0.23 †	0.18
Quantity of Evaluated Product Functions	−0.28*	−0.26 †	−0.3*	−0.29*	0.32*	0.30*	0.32*	0.35*
Model Change Cycle	0.22 †	0.33*	0.31*	0.49**	−0.31*	−0.30*	−0.26 †	−0.41*
Necessity of Element Technology Development *Quantity of Evaluated Product Functions			−0.44*	−0.42*			−0.01	0.00
Necessity of Element Technology Development *Model Change Cycle			0.06	0.18			0.04	0.01
Model Change Cycle *Quantity of Evaluated Product Functions			−0.16	−0.43*			−0.23	−0.01
Target Market (Dummy, 0=industry)		−0.19 †		−0.27		0.30*		0.30*
Product Novelty (Dummy, 0=conventional)		0.06		0.13*		−0.11		−0.12
R square	0.16	0.18	0.24	0.32	0.18	0.25	0.20	0.29
F	3.89**	2.56*	3.06**	3.2**	4.31**	3.84**	2.30*	2.76**

n = 70. Standardzed values were used for all the models.
† *p*<.10, **p*<.05, ***p*<.01

Model 1 is the baseline model that only includes product characteristics as the main factors. In model 2, two context variables were added to model 1. The interaction terms for the three product characteristics variables were added to model 1 in model 3. In model 4, both of the context variables were added to model 3.

In other potential models which focused on examining the effects of each of the interaction terms or context variables, the R squares and/or F-values in any models decreased compared to the presented four models. Each of the interaction terms or context variables rarely had stronger effects in any of the potential models. Thus, we decided to consider the presented four models in order to simplify our examination.

We found significant correlations between the quantity of evaluated product functions, model change cycle and target market, and between the necessity of element technology development and product novelty (Appendix 4 and 5). However, the variation inflation factors (VIF) and condition indexes associated each of the regression coefficients ranged from 1.03 to 1.08, and the condition indexes associated each of the regression coefficients were below 2.56. The results suggested no serious problems with collinearity in our analysis.

For each of variables, we paid attention to significant effects common across these models. The interaction terms partly had significant impacts on product development strategies. Nevertheless, it is important to note that the main effects of product characteristics remained robust in most of the models even when the interaction terms were included. These interaction terms increased R squares while F-values were decreased. These interaction terms rarely had strong effects on the product development strategies.

Technology integration was simply explained by the necessity of element technology development, technological uncertainty, in the assembly product group (p<.01). Also in the process product group, the necessity of element technology development had significant positive effect on technology integration (in most of the models, p<.01 or p<.05).

The results would support the past finding on technology-driven product development (e.g., Eisenhardt and Tabrizi, 1995; Iansiti, 1995; 1997; Song and Montoya-Weiss, 2001; Song and Xie, 2000; Tatikonda and Rosenthal, 2000). The result of the necessity of element technology development would be also consistent with the finding on process product development (e.g., Pisano, 1997).

In the process product group, the quantity of product functions showed significant negative impact on technology integration (p<.05). The effect of the necessity of element technology development was moderated by the quantity of evaluated product functions (p<.05). Technological uncertainty could have negative impact on technology integration as product complexity increases.

Model change cycle also had significant positive effects on technology integration in the process product group (in most of the models, p<.01 or p<.05). In the process product group, technology integration was explicated by longer model change cycle. Longer model change cycle, which means lower market uncertainty, would allow firms to employ technology integration.

Target market scarcely had impacts on technology integration in both of the product group. Product novelty had positive effect on technology integration only in the process product group (p<.05). While not applicable to the assembly product group, the result would be consistent with past studies (e.g., Iansiti, 1997; Pisano, 1997; Song and Xie, 2000; Tatikonda and Rosenthal, 2000; Olson et al, 1995).

On the other hand, the quantity of evaluated product functions, product complexity, had significant positive effects on separated technology development in both of the assembly and process product groups (p<.05 or p<.10). The necessity of element technology development, technological uncertainty, also showed significant positive effect on separated element technology development in the assembly product group (p<.05 or p<.10). Interacting with model change cycle, the necessity of element technology development had positive impact on separated element technology development in the assembly product group (p<.05). The necessity of element technology development slightly explicated separated element technology development in the process product group (p<.10).

In general, the above mentioned facts would evidence the findings that the knowledge insufficiency from technological uncertainty could be distinguished from the knowledge insufficiency from product complexity (e.g., Tatikonda and Rosenthal, 2000). Thus, in both the assembly and process product groups, the task load for element technology development in product/process engineering stages could be alleviated by separating element technology development from product/process engineering.

Particularly when product complexity is sufficiently high, which means that the task load for product/process engineering is accordingly high, element technology development is to be separated from product/process engineering. A project for a complex product could cope with the product complexity by separating element technology development from product/process engineering.

As for market environments, shorter model change cycle, which scarcely had effects in the assembly product group, also contributed to separated element technology development in the process product group ($p<.05$ or $p<.10$). Market uncertainty would not allow firms to take time for technology integration, but it would enhance separating element technology development from product/process engineering. While identified only in the process product group, the results may support the findings and suggestions in previous studies (e.g., Cusumano and Yoffie, 1998; Gawer and Cusumano, 2002; Iansiti and MacCormack, 1997).

Lastly, we should note that, in both of the assembly and process product groups, separated technology development was enhanced for industrial product development. Separated element technology would be adopted when product functions are restricted within specific business/industrial uses. Product novelty did not explicate separated technology development in both of the product group.

Discussion

The data helped us reassure that technology integration is distinguished from cross-functional integration in product/process engineering stages (i.e., engineering integration). In many of the studies, cross-functional integration has been generalized as the bundle of communication and collaboration for knowledge processing and creation across functional organizational units (e.g., Brown and Eisenhardt, 1995; Eisenhardt and Tabrizi, 1995; Kusunoki et al., 1998; Olson et al., 1995; Song and Xie, 2000). The concept of cross-functional integration includes a broad range of organizational routines for information exchange and collaboration between functional units.

However, the data here revealed that the concept of cross-functional integration is divided into engineering integration and technology integration. Novel technology introduction strategy is distinguished from product/process engineering. At the same time, we identified two strategies for novel technology introduction: technology integration and separated technology development.

Furthermore, we predicted that, according to product characteristics and/or contexts, firms choose proper product development strategies for novel technology introduction. Most of the results provided the evidence that product development strategies for novel technology introduction may vary according to product characteristics and/or contextual factors.

At first, we identified that the remarkable differences between the assembly and process product groups lay in technology integration and separated technology development. Technology integration was employed more in the process product group than in the assembly product group. In reverse, separated element technology development was not prominent in the process product group. The differences between the groups would be attributed to fundamental product complexity: whether or not the product concerned is decomposed into distinctive elements.

As a whole, in each of the assembly and process product groups, these strategies were reasonably explicated by technological uncertainty (i.e., necessity of element technology development), product complexity (i.e., quantity of evaluated product functions), market uncertainty (i.e., model change cycle), and/or other contextual factors. The results were mostly consistent with the findings in previous studies. However, product novelty slightly had the impact on technology integration only in the process product group.

The analysis provided several findings reflecting the difference between assembly and process products. However, we identified several common determinants of novel technology introduction strategies in both the assembly and process product groups. Technological uncertainty was the fundamental factor for both of the novel technology introduction strategies in both of the product groups.

The results may suggest that product complexity as well as technological uncertainty is the critical determinant of novel technology introduction strategies. The more products get complex, the more the development activities could be divided into product/process engineering and element technology development. Though market uncertainty and other factors may influence novel technology introduction strategies, whether or not firms could respond to these factors would rely on the level of product complexity. In the sense, managing product complexity is not negligible in making a choice of novel technology introduction strategies as antecedents have suggested (e.g., Baldwin and Clark, 1997). We need to further excavate the relationship between technological, uncertainty, product complexity, and novel technology introduction strategies.

These results demonstrated that firms need to make use of either of technology integration and separated technology development project by project according to product characteristics and/or contextual factors. Technology integration, which is accompanied by both of core and related element technology development, may seem ineffective in the era of market and/or technological volatility. Nevertheless, employing separated technology development corresponding to the volatility could result in the excessive application of standardized element technologies, and thus would jeopardize firms' competitiveness.

Standardized element technologies, such as patented technologies and modularized components, would not contribute to fundamental product innovativeness, which results from organization-specific capabilities (Henderson and Cockburn, 1994). Standardized element technologies could be transferable between firms and/or imitated by other firms (Anderson, 1999; Baldwin and Clark, 1997; Henderson and Cockburn, 1994; Kusunoki et al., 1998), and thus would not necessarily secure firms' competitiveness (Anderson, 1999).

On the other hand, competitors could hardly imitate or acquire the knowledge of complex/novel products (e.g., compact car, precision mechanics, mechanical or electronic parts, fine materials, and so on), which result from firm-specific capabilities for coping with product novelty/complexity. Even if the large portion of a product is composed of modularized/standardized components, a firm which could control the interdependencies between the components and integrate them would be prominent in the product market (Brusoni and Prencipe, 2001).

Cross-functional integration for novel technology introduction, technology integration, would enable exploratory knowledge creation, and thus helps firms adapt to complex/novel environments (Benner and Tushman, 2003; Iansiti and Clark, 1994; Kusunoki et al., 1998). The novel technology introduction strategy is particularly critical in order to realize architectural changes of product designs (Chesbrough and Kusunoki, 2001). Technology integration in relation to core technologies/platforms, which contributes to realizing firm-specific product novelty/complexity, is the indispensable strategy for firms (Gawer and Cusumano, 2002; Iansiti, 1997).

The data showed that technology integration contributes to product development performances more than separated technology development. Product development performances were more attributed to technology integration than separated technology development.

However, whereas the result demonstrated the importance of technology integration, firms are required to make use of separated technology development in complex product development in volatile environments. Technology integration, which encourages firms to develop novel components in accordance with product design, is expected to require more time and cost than separated technology development (Baldwin and Clark, 1997; Garud and Kamaraswamy, 1995; Langlois and Robertson, 1992). Technological changes and volatile markets do not necessarily allow firms to spend time and cost for technology integration.

Even when attempting to employ separated technology development, firms need to consider both of the novel technology introduction strategies in order to effectively refurbish core technologies on one hand and apply element technologies to various products on the other hand. The contrived application of these strategies might be particularly required as various element technologies change at uneven paces (Brusoni and Prencipe, 2001). The above mentioned implications means that the attempt to make use of separated technology development should be based on contrived multi-project/platform strategies beyond single product development projects (e.g., Cusumano and Nobeoka, 1998; Funk, 2002; Gawer and Cusumano, 2002).

For instance, Robertson and Ulrich (1998) propose the perspective for platform formation drawing on the concept of product architecture. The results here demonstrated that firms need to consider technological novelty, market volatility, and other factors in addition to product complexity. While discussed mostly in terms of product design characteristics (e.g., product architecture) multi-project/platform strategies are required to reflect and synthesize the impacts of technological novelty, market volatility, and other factors.

As indicated above, these alternative strategies for novel technology introduction largely relies on these product characteristics and contextual factors. In order to make effective use of the two strategies, firms need to devise multi-project/platform strategies which consider product characteristics and contextual factors of each of the products.

Conclusions

Most of the results supported past findings of product development management studies. We found that firms adopt product development strategies for novel technology introduction according to critical product characteristics and/or contextual factors. The result means that the contingency framework would be viable for this line of studies.

In order to make proper use of product development strategies for novel technology introduction, firms need to contrive coherent product strategies, such as multi-project/platform strategies, beyond single product development projects (e.g., Cusumano and Nobeoka, 1998; Gawer and Cusumano, 2002). Without the product strategies beyond single projects, firms may face problems of over-specification and high product cost despite high project performances: productivity, speed, and product/technological novelty.

The case of Japanese mobile phone manufacturers might provide the emblematic example. Whereas commercializing the most advanced technologies in the world, Japanese mobile phone handset manufacturers' performances are mostly not prominent in the world mobile phone industries. The reason has been attributed to the different communication technology specific to Japanese market and the related domestic inter-firm relationships between manufacturers and service-carriers.

These factors have allowed Japanese manufacturers to commercialize novel technologies in Japanese market without sufficient consideration of product lineup strategies and platform management for the world market (Funk, 2002). As a result, despite the technological novelty, Japanese manufacturers are liable to employ cross-functional integration for novel technology introduction in the regular handset model development projects (Yasumoto, 2005). Most of the handsets and components are designed in accordance with critical novel technologies. In spite of the functional novelty and related product integrity, the problem of product development strategies would harm the competitiveness of the Japanese firms in terms of cost, speed, and product variety in the world market.

Refurbishing product/component design in accordance with the emergence of each of novel element technologies is not effective under the turbulent environments in many of hi-tech industries. Firms need to pay sufficient attention to both of uneven changes of various element technologies and interdependencies between the components (Brusoni and Prencipe, 2001). As suggested in the study, market and/or contextual factors should be also considered. Furthermore, drawing on the cases of specific industries, we should explore how the above mentioned implications on novel technology introduction strategies at project level could contribute to shaping platform/multi-project strategies at corporate level.

In closing, this study may be regarded as an attempt to bridge the chasm between generic and industry-specific studies in the field of product development management. Based on a contingency perspective, the present study attempted to examine the past findings from industry-specific studies within a generic study context. This type of study is still at an exploratory or preliminary stage.

Hereafter, based on international researches and case studies, we need to contrive product characteristics and performance indices, derive testable hypotheses, and strengthen the ties between conceptual frameworks and empirical data. In particular, we need to conduct international researches for the results in the study may be influenced by Japanese country attributes. Whereas we are still taking the initial steps in this research area, this line of study seems to deserve further exploration in both content and methodology.

Appendices

Appendix 1 Factor Analysis of Product Development Strategies

			Factor 1	Factor 2	Factor 3
	mean	s.d.	Engineering Integration	Technology Integration	Separated Technology Development
Alternative core technologies were compared and analyzed using prototypes in order to realize the product's concept and specifications.	3.56	1.05	0.09	0.73	-0.12
Alternative designs were prototyped and screened within a spcified search range in order to achieve the target product specification and performance.	3.39	0.92	0.11	0.64	0.23
Effective coordination and communication were made between advanced element technology development department and product development department.	3.63	0.97	0.10	0.51	-0.10
Period of core technology development was overlapped with period of product concept/specification development.	3.74	0.92	0.17	0.54	0.05
Core technologies were separately developed in advance of product engineering.	3.66	1.19	0.00	0.46	0.60
The components were developed separetely by component development groups.	3.33	0.96	0.14	-0.11	0.75
Intensive communication was made between members in element technology development stages.	3.49	0.84	0.11	0.30	0.47
Period of product engineering was overlapped with that of process engineering.	3.58	0.95	0.54	0.21	0.15
Effective coordination and communication were made within product engineering group.	4.01	0.76	0.84	0.03	0.00
Effective coordination and communication were made between product engineering department and process engineering/ production technology department.	3.84	0.83	0.76	0.20	-0.04
Intensive communication was made among members in test/experiment stages.	3.82	0.76	0.65	0.08	0.13

n =188. Factor loadings were varimax rotated.

The shaded cells indicate those larger than *0.4* or smaller than *-0.4* .

Appendix 2 Performance Differences between Assembly and Process Product Groups

	Num of Sample	Customer Satisfaction /Total Quality	Product Development Cost	Product Development Leadtime	Specific Functional Performance	Sales/Market Share	Profit
assembly mean	118	4.42	3.73	3.79	4.36	4.28	3.93
s.d.		0.61	0.76	0.84	0.60	0.77	0.75
process mean	70	4.53	3.80	3.84	4.47	4.18	3.92
s.d.		0.50	0.70	0.81	0.53	0.73	0.79
t		1.36	0.68	0.39	1.28	−0.98	−0.04
F		1.06	0.45	0.15	1.51	0.19	0.19
total mean	188	4.46	3.75	3.81	4.40	4.24	3.93
s.d.		0.57	0.74	0.83	0.58	0.76	0.76

Double-sided t-test and O'Brien's F-test.
† $p<.10$, *$p<.05$, **$p<.01$

Appendix 3 Correlation Analysis between Performance Measures and Product Development Strategies

	mean	s.d.	Engineering Integration	Technology Integration	Separated Technology Development
Customer Satisfaction/Total Quality	4.46	0.57	0.16*	0.17*	−0.08
Product Development Cost	3.75	0.74	0.18**	0.07	0.02
Product Development Leadtime	3.81	0.83	0.14*	0.01	0.03
Specific Functional Performance	4.40	0.58	0.12 †	0.14 †	0.01
Sales/Market Share	4.24	0.76	0.25**	−0.04	−0.03
Profit	3.93	0.76	0.11 †	0.13 †	0.03

n=188
† p<.10, *p<.05, **p<.01

Appendix 4 Correlation Matrix: Assembly Product Group

	mean	s.d.	1	2	3	4	5	6	7
1 Technology Integration	−0.23	1.04	1.00						
2 Separated Technology Development	0.16	0.96	−0.01	1.00					
3 Necessity of Element Technology Development	3.55	1.28	0.31**	0.20*	1.00				
4 Quantity of Evaluated Product Functions	2.87	0.82	0.09	0.11	0.01	1.00			
5 Model Change Cycle(mo.)	32.34	30.28	0.06	0.01	0.05	−0.07	1.00		
6 Target Market (dummy, 1=consumer/0=industry)	0.41	0.49	0.10	−0.2*	−0.03	0.18*	−0.25**	1.00	
7 Product Novelty (Dummy, 1=novel/ 0=conventional)	0.22	0.42	0.12	−0.10	0.14	0.06	−0.01	0.12	1.00

n=118
As for product development factors, we used factor score data instead of original product development variables' data.
† p<.10, *p<.05, **p<.01

Appendix 5 Correlation Matrix: Process Product Group

	mean	s.d.	1	2	3	4	5	6	7
1 Technology Integration	0.39	0.83	1.00						
2 Separated Technology Development	−0.26	1.00	0.01	1.00					
3 Necessity of Element Technology Development	3.73	1.31	0.19	0.24*	1.00				
4 Quantity of Evaluated Product Functions	2.17	0.48	0.11	0.14	0.09	1.00			
5 Model Change Cycle(mo.)	31.82	22.30	0.28*	−0.24*	0.02	0.05	1.00		
6 Target Market (dummy, 1=consumer/0=industry)	0.49	0.50	0.12	−0.20 †	−0.02	0.27*	−0.21	1.00	
7 Product Novelty (Dummy, 1=novel/ 0=conventional)	0.25	0.44	0.16	0.17	0.25*	0.06	0.17 †	−0.21	1.00

n=70
As for product development factors, we used factor scores instead of original product development variables' data.
† p<.10, *p<.05, **p<.01

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