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The Impact of Product-Industry Characteristics on Effective Patterns of Product Development

Takahiro Fujimoto
The University of Tokyo

Masanori Yasumoto
Shinshu University

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Takahiro Fujimoto, Faculty of Economics, Tokyo University
Masanori Yasumoto, Faculty of Economics, Shinshu University

Summary

A product development project can be regarded as a bundle of problem-solving cycles by which an organization tries to construct a "cause map" for a future value-creation (i.e., production-consumption) process. Effective patterns of product development, in this context, means a set of organizational routines that can articulate such a cause map accurately and efficiently, and thereby enhance the chance of the new product's success. It follows that, to the extent that typical patterns of value creation processes differ by industry and product type, effective patterns of product development routines may also differ between them. Based on this contingency perspective of successful product development routines, we collected questionnaire-based data from 203 Japanese product development projects, derived some generic and specific hypotheses from the above framework, and tested them through a simple correlation analysis between 32 effective routine variables and 20 product-industry characteristic variables. The statistical results supported most of our 16 specific hypotheses. Although we need further empirical investigation along this line, the current study is consistent, at least partially, with our contingency perspective: Effective patterns of product development routines may differ when the underlying patterns of value creation processes are different across products, markets and industries.

(Product Development, Problem Solving, Effective Routines, Value Creation Process, Contingency Perspective)

1. Introduction

What determines the success and failure of product development projects? Since the beginning of empirical research in innovation management, a number of researchers have tried to answer this basic question. Whereas some of the important works in this subject have been case-based, there have also been many empirical studies that relied on systematic data collection and statistical analyses. The present paper aims at contributing to this stream of research by introducing a contingency perspective for effective product development.

The existing statistical-analysis based research on effective innovation may be classified into two groups: **generic studies** and **industry-specific studies.** Much of the early empirical research in the 1960s and 70s tried to identify generic patterns of successful innovation that could apply to any industry. Major contributions in this first category include Myers and Marquis 1969, Project HINDSIGHT (Office of the Director of Defense Research and Engineering 1969), Langrish et al. 1972, Gibbons and Johnston 1974, Project SAPPHO (Rothwell et al. 1974), Rubenstein et al. 1976, von Hippel 1976, Allen 1977, and Stanford Innovation Project (Maidique and Zirger 1984, 1985)[1]. By

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[1]The study by **Myers and Marquis (1969)** surveyed 567 cases of innovation in railroad companies, railroad suppliers, housing suppliers, computer manufacturers, and computer suppliers through key informant interviews. This study argued that the majority of the innovations in the sample were of the demand-pull type as opposed to the technology- push type. The study focused on the input source of the information which is processed in product development, emphasizing the importance of outside sources for idea generation, as well as intra-company informal networks for problem solving information. **Langrish et al.** (1972) argued based on 84 innovations mostly from industrial goods (all recipients of the Queen's Award for technological innovation), that customer needs tend to initiate innovations more frequently, although the study denies naive or unilateral demand-pull models. "**Project HINDSIGHT**" (Office of the Director of Defense Research and Engineering 1969), conducted by the US Department of Defense on twenty development projects for weapon systems, also agrees with the demand-pull hypothesis. **Gibbons and Johnston** (1974), on the other hand, emphasize the contribution of scientific information (journals, personal contacts, etc.) based on an information flow analysis of thirty innovations. Generally speaking, most of the systematic studies show that the majority of innovations are induced by market needs.

"**Project SAPPHO**" is presumably one of the most elaborate (Rothwell et al. 1974). It explored twenty-nine pairs of attempted innovations, each of which consisted of one successful and one unsuccessful project in chemicals and scientific instruments. A major strength of this study is that it explicitly introduced an effectiveness indicator (pairing of success and failure). The results generally agree with the main conclusions of the Myers and Marquis study: the factors which discriminate success and failure most clearly include understanding of the market, and communication with outside scientists whose work is closely related to the innovation. In addition, the study identifies certain managerial factors which discriminate success and failure, including the power and responsibility of the firm's innovators and the size of the project team.

Rubenstein et al. (1976) also conducted a wide-ranging study on the source of successful innovation. Based on 103 projects in six different firms and industries, the authors examined the correlation between project performance (technical and economic: respondents' self-evaluation) and a variety of indicators for environment, project, and organization. After collecting large sample data from multiple industries in most cases, these researchers have identified much of the main research agenda to date in this field. These generic studies however, tended to lack international and competitive perspectives. Many of them focused only on domestic industries; the linkage between innovation processes and competitive performance was not investigated explicitly. Measurement of innovative performance was rather simple: binary measures of success or failure (e.g., Rothwell et al. 1974, Allen 1977, Maidique and Zirger 1984, 1985), self-evaluation of "successfulness," and so on.

In the late 1980s, reflecting intensifying international competition, industry-specific empirical studies, with explicit focus on the impact of innovations on competitive performance, increasingly attracted attention (Clark and Fujimoto 1991, Cusumano 1991, Iansiti 1993, Pisano 1995, Utterback 1994, Cusumano and Nobeoka 1998, Eisenhardt and Tabrizi 1995). While carrying over much of the existing research agenda set by the earlier generic studies, most of this industry-specific research collected project data internationally, measured specific project performance indicators such as lead times, product development productivity and design quality, and compared organizational and process variables across projects in order to identify better practices for international competitive advantage.

Whereas this stream of research has strengthened linkages between technology management and competitive analysis in other fields of

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finding many correlations in various areas, they concluded that there is "no magic single factor or single set of factors that govern project success and failure" (18). "**The Stanford Innovation Project**" (Maidique and Zirger 1984, 1985), based on data from 158 product development projects in the electronics industry (pairs of successful and unsuccessful projects by financial criteria), concluded that the following eight factors are statistically correlated with project success: understanding of the customers, better cross-functional coordination, higher contribution margin, utilization of existing technological and marketing strength, proficiency and resource commitment in marketing, better planning and coordination in the R&D process, higher level of management support, and early market entry. The results are generally consistent with those of the earlier studies.
Allen (1977) focused very intensively on patterns of information inputs and communication networks in R&D organizations. This study also employed the paired case approach as an indicator of effectiveness. The sample cases were government-sponsored projects and the research laboratories conducting them, mostly were either in the aerospace or electronics industry. Major findings of this study include highlighting the importance of inter-project communication compared with intra-project communication, as well as the importance of "technological gatekeepers" as centers of the laboratory communication networks. Allen's study also examined the impact of formal organizational structures (e.g., functional versus project organizations) and physical architecture (e.g., nonterritorial offices) on communication. **von Hippel** (1976) intensively investigated the nature of the customer-producer linkages in certain types of products. Based on data from 111 innovations in the scientific instruments industry,

management and applied economics, there is an obvious limit to this type of study -- generalizability. These industry-specific studies themselves, as well as many other in-depth case studies, have already indicated that effective patterns of innovation and product development may differ by industry or across product categories. Thus, based on the body of knowledge accumulated thus far from both generic and industry-specific studies, one of the next steps in the agenda of this field seems to be conducting inter-industry analyses that try to explain why effective patterns of innovation differ across industries by identifying the key variables involved. There have been relatively few studies which explicitly focused on such a subject[2].

Against this background, the present study, based on data collection from about 200 product development projects in multiple industries in Japan, tries to identify certain product or industry characteristics that may affect successful patterns of product innovation management. In **section 2**, we propose a conceptual framework that links effective product development routines and product-industry characteristics. In **section 3** we derive some hypotheses from this framework. **Section 4** discusses empirical research design and the issue of measurement and validity. **Section 5** analyzes the results of our statistical analyses. **Section 6** discusses some implications of our research.

2. Basic Framework

2.1 The Product Development Project as a Set of Organizational Routines

First of all, we propose a conceptual framework for effective product development that can give a common background to our hypotheses linking product-industry characteristics and product development routines. We start from the stylized fact that modern product innovations are by and large organizational efforts by firms (**Freeman 1982**) developing, producing and selling multiple products, and that the vast majority of product development activities are more or less repetitive. Even in technology intensive industries

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von Hippel concluded that the user-dominated mode of innovation is prevalent in this industry.

[2] Fujimoto (1989) and Clark and Fujimoto (1991) indicated that effective patterns of product development may differ between high volume products and high-end products. Eisenhardt and Tabrizi (1995) investigated a similar research topic in the computer industry. See also, Fujimoto (1993) for further discussion of this research direction.

where products are rapidly evolving, innovating firms tend to evoke a set of procedures that were used at least partially for past projects. Thus, modern product development usually relies on a set of organizational routines (**Nelson and Winter 1982**). To the extent that product innovation is the production of information assets (**Allen 1977, Freeman 1982, Clark and Fujimoto 1991**), the organizational routines for product development are essentially stable patterns of information processing and information creation[3].

We also know that a firm tends to develop many new products each year, and that only a fraction of them are recognized as successful. Effective product development organizations may thus resemble high-performing batters in baseball -- their "batting averages" are higher than those of the average players, but they also do fail many times. In this sense, successful (or effective) product development routines mean those practices which bring about a higher success ratio over a long period of time and many attempts.

2.2 Product Development as the Construction of a Cause Map

Having defined a product development project as a set of organizational routines, let's examine the relationships between such routines and product-industry characteristics.

As traditional contingency theories have suggested, effective organizational routines may reflect patterns of task environments (**Aldrich and Herker 1977**). Task environments for product development organizations may include relations with scientific communities, government bodies, suppliers, and customers, but the most direct task environment for a product development project is the *value-creation process* that the new product brings about in the future, or the process by which the product is produced, distributed, used, interpreted and ultimately generates satisfaction or value for the customer.

We can conceive of a cause-effect chain for each value creation process around a given product, which eventually results in actual customer attraction and satisfaction (**Figure 1**). Under the assumption of today's mass production system, the chain starts from a certain *production process*, which leads to the replication of an identical physical *product structure.* The physical product is

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[3] More recently, the term "knowledge creation" has been used (Nonaka and Takeuchi, 1995), but we define information more broadly so as to include knowledge as systematic information

then brought to the consumption space, in which it generates *product function* through the usage process, or through its interactions with its context. The product functions are then translated into *customer perception and satisfaction* through the interpretation process of the customers. (Note that there are other causal paths as **Figure 1** indicates.)

Figure 1 around here

However, this cause-effect chain is not directly observable to the product developers, partly because it has not yet happened when product development is going on, and partly because it is usually complex, equivocal, and specific to each individual customer. At best, what the producers can do is create a *cause map* (**Weick, 1979**) and impose it on the target production and consumption process for the product in question (the sales process has been omitted for simplicity). In other words, the product developers try to enact the future value creation process.

In this context, the product development process can be regarded as *the gradual articulation of a cause map for a future product's value creation process* **(Figure 1).** It starts with the developer's vision of future customer satisfaction, or at a product's *concept creation*. It then goes backwards through a means-ends chain to the product's *functional design*, its *structural design*, and its production *process design*. The causal relations around these elements are also investigated at each step. These four steps are the major components for product development processes in general (Clark and Fujimoto, 1991).

In this map-making process, the firm developing a product tries to predict the most effective and efficient causal path that results in satisfaction for the targeted customer by tracking the cause-effect chain backward. If the map turns out to be reasonably accurate judging from the sales performance and revealed customer satisfaction, the practices used for this map construction may be retained and reused as organizational routines for similar projects in future.

In this sense, effective product development routines are related to accurate, fast and efficient construction of a cause map for the future processes of production-sales-consumption for a given product. To the extent that the patterns of this value-creation process differ product by product, effective

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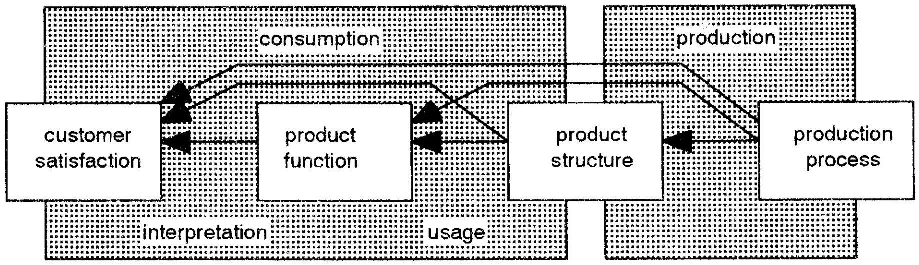
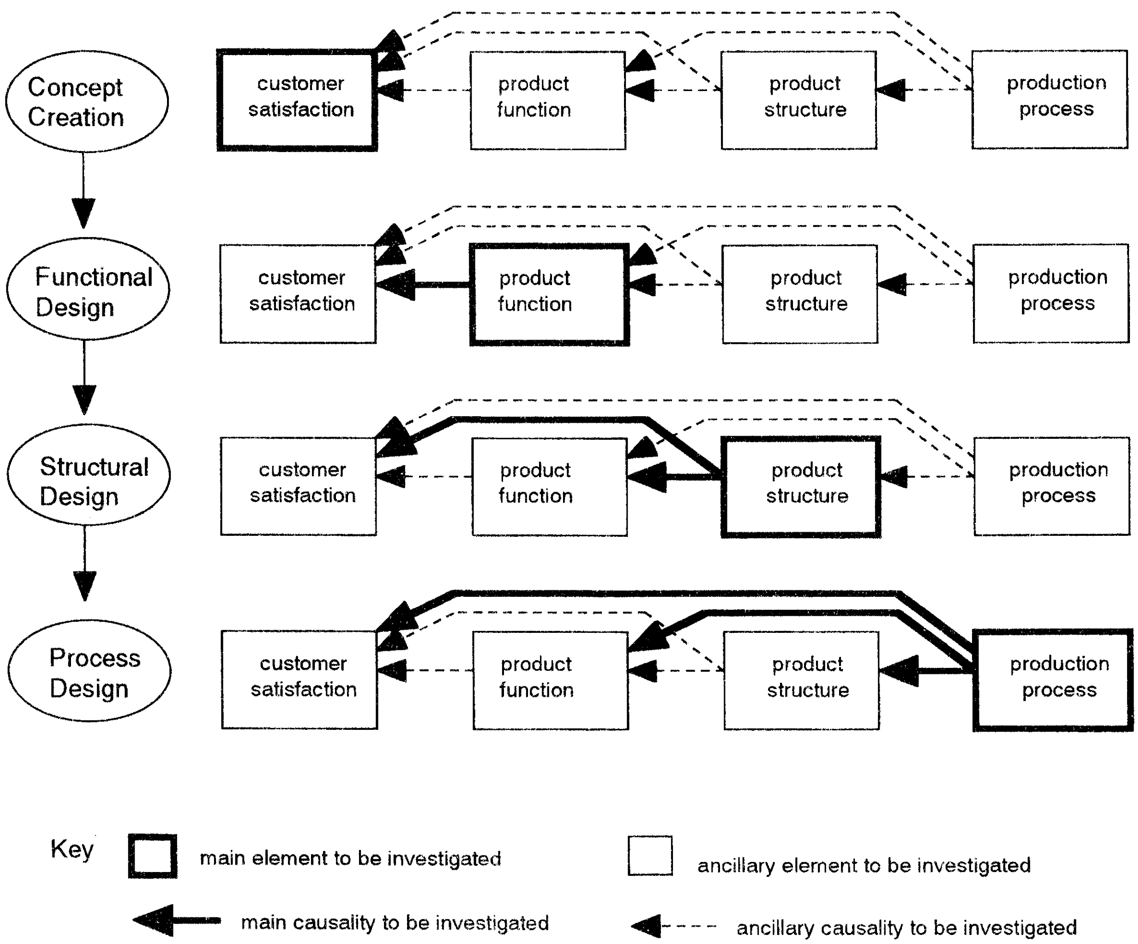
assets embodied in people's minds (Fujimoto, 1989; Clark and Fujimoto, 1991).

Figure 1 The Value Creation Process and Product Development Process

(1) The Value Creation Process



(2) Product Development Process as Construction of a Cause Map



Note: Environments for production and consumption are omitted for graphical simplicity.

patterns of product development may also differ depending on product-industry characteristics. This, we think, is the basic logic behind a contingency framework for effective product development.

2.3 Product Development as Problem Solving Cycles

An effective cause map for a future value-creation process is difficult to construct, however. If the causal relationship linking a product and a state of customer satisfaction was straightforward and perfectly predictable by applying existing knowledge, product development would be a simple matter of taking an inverse function of the predicted causal relation ($Y = f(X)$) and creating designs ($X = f'(Y)$) for each step. There would be no simulation models, no prototypes, no testing, and no design reviews needed in such a simple mapping process.

In today's product development, however, the above story is far from reality in virtually all cases. Producers' knowledge about the cause-effect chains that lead to a state of customer satisfaction is incomplete, as there is a significant level of uncertainty, equivocality and complexity involved in this process and its environment.

To the extent that the causal relation is unpredictable for the producers, there is a need to do *search* for alternative means and *simulation* to predict the consequences of each alternative, as well as analysis and evaluation of such consequences. In other words, a product developer without complete knowledge aiming at constructing the cause map needs to evoke a set of organizational routines including search and simulation. This is nothing other than what H. Simon described as *problem solving* **(Simon 1969, Clark and Fujimoto 1991)**. It refers to a set of information processing routines in which goals or problems (i.e., input information) are converted to solutions to the problems (i.e., output information) under the conditions of uncertainty and bounded rationality. A generic model of a problem solving cycle with five steps (goal setting, alternative idea generation, model development, experiment, and selection) is illustrated in **Figure 2**.[4]

Figure 2 around here

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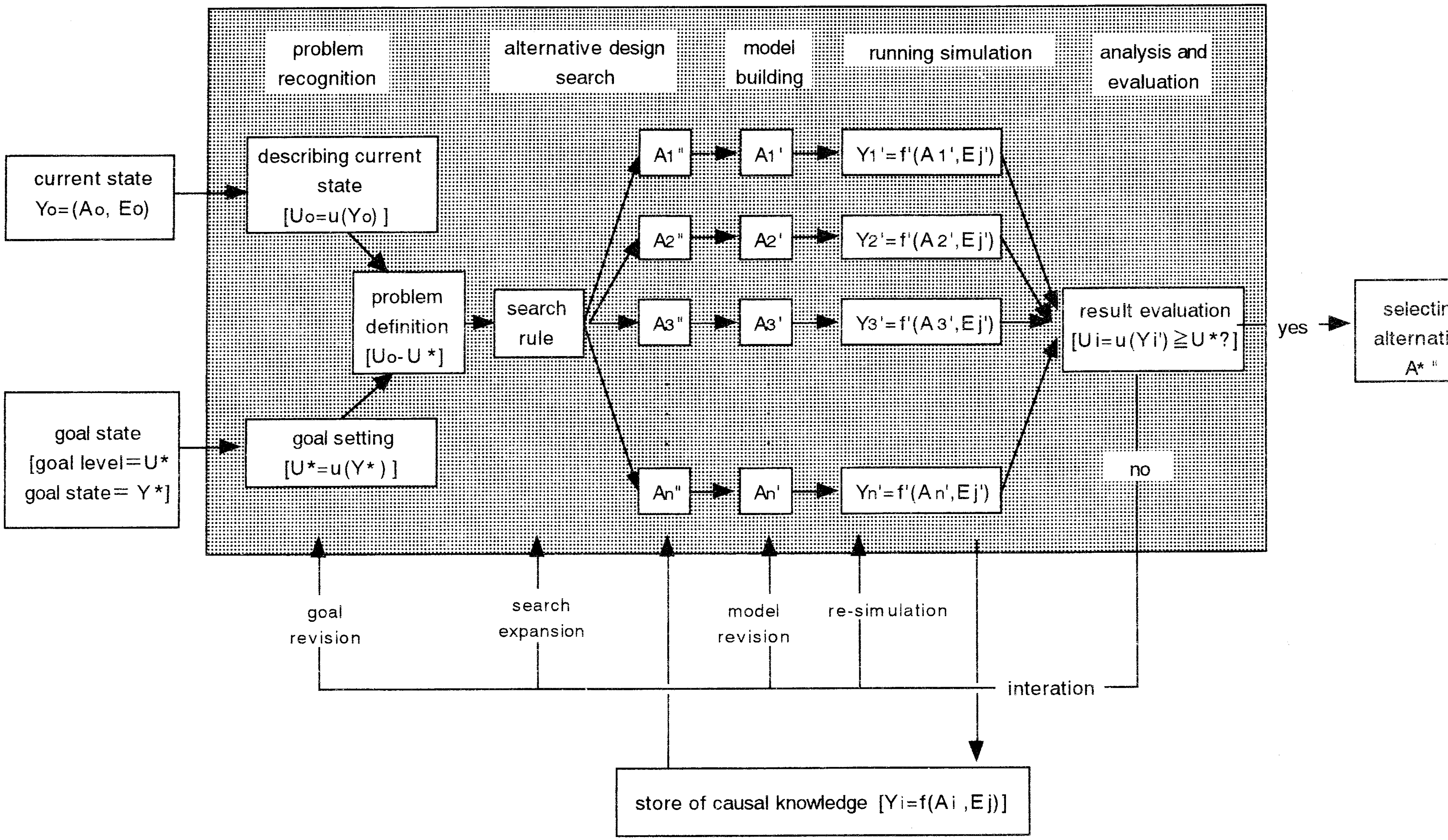
[4]The present problem solving model is a modification of Herbert Simon's original framework (1969). For further detail of the model, see Clark and Fujimoto (1987).

Figure 2 A Standard Problem Solving Cycle Applied to Product Development



Keys: U=utility、Y=effect state、A=artifact、E=environment、f=causality

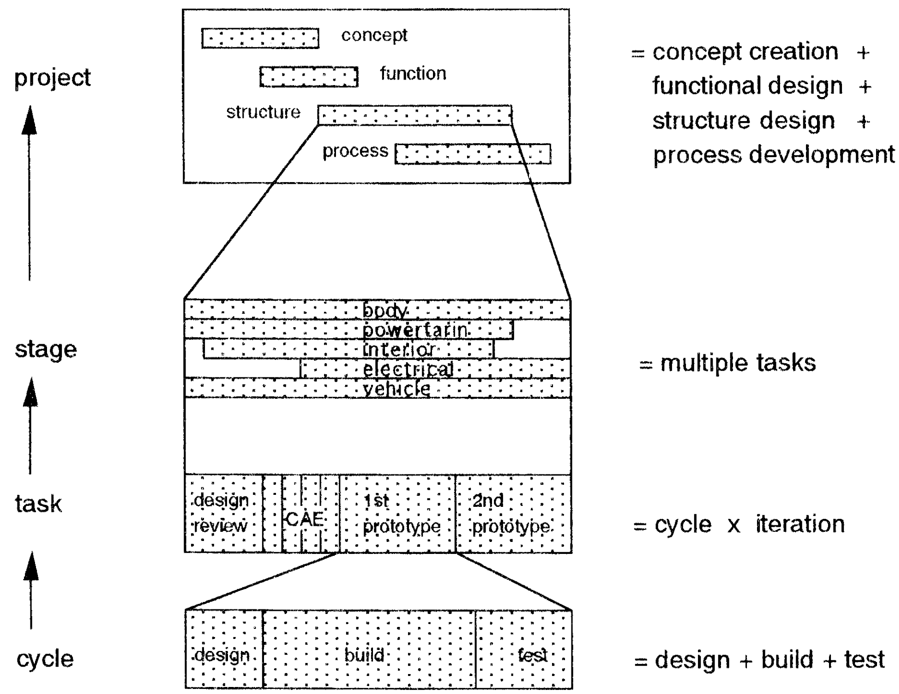
As the diagram indicates, a cycle of problem solving is typically initiated by the recognition of certain problems (i.e., gaps between goals and current situations). Alternative ideas are then created or retrieved from the repertoire. As knowledge on the causal relationship between the alternatives and their consequences is normally imperfect, the cycle typically develops models and conducts experiments for various possible combinations. After the results are evaluated, an acceptable alternative may be selected, or a new cycle of problem solving may begin in search of a better solution. Also, the problem solving cycles may be linked to one another so that solutions in the upstream cycles become goals for the downstream cycles.

In the detail product engineering stage at an automobile manufacturer, for example, informational outputs of the product planning stage, including product specifications, styling, and layout, become the goals of the stage (goal setting); possible product designs are then searched for (alternative idea generation); prototypes are constructed according to the designs for subsequent simulations (model building); the prototypes are simulated or tested in proving grounds and laboratories (experiment); and the cycles are iterated until a satisfactory result is achieved, i.e., when the final engineering drawings are chosen as a solution (selection). This solution, in turn, becomes an input or an assumption in the subsequent process engineering stage. The so called "design-build-test cycle" (**Wheelwright and Clark 1992, Thomke 1998**) corresponds to this problem solving framework. According to one of the Japanese automobile companies, a typical automobile product development project involves several thousand problems which need to be solved. These cycles are hierarchically organized and mutually interconnected in and across projects (**Figure 3**). In this context, effective product development means integrated, efficient and early execution of problem solving cycles.

Figure 3 around here

As various researchers pointed out (**Abernathy and Rosenbloom 1968 von Hippel 1976, Allen 1977, Clark and Fujimoto 1989, 1991, Thomke 1998**), effective patterns of product development activities can be regarded as a bundle of problem solving cycles interconnected vertically and horizontally,

Figure 3 Product Development Project as a Bundle of Problem Solving Cycles



Note: Overlapping of design/build/test and overlapping of cycles are omitted for graphical simplicity which are usually carried out by a group of people. As such, the degree of searches, simulations and problem solving as a whole needed for the development of a product would depend on the prior knowledge levels of the causal relations in the future value creation process, as well as the nature of the causal linkages themselves.

2.4 A Contingency Perspective of Effective Product Development

Let's summarize our framework. We think that, in most modern manufacturing firms, a product development project consists of a set of organizational routines, the main mission of which is to construct a cause map for a future value-creation process. To the extent that this map-making process involves incomplete causal knowledge, the product developing organization needs to evoke a set of problem-solving routines including search and simulation. This perspective leads to the following basic contingency hypotheses of effective product development routines.

BH1: Effective problem solving routines reflect patterns of the value creation process for the product type in question.

BH2: Patterns of the cause map of the value creation process differ depending upon the type of product.

BH3: Therefore effective patterns of product development routines are different by product type and industry reflecting differences in the patterns of the value creation processes.

Note again that the project members are assumed to match their problem solving patterns with the causal map, or the perceived value creation process, as opposed to the objective causal relation, because the latter is not directly observable to the members in advance. The project members learn that the map represents reality only indirectly through the success of the project. We thus predict that a development project will tend to be successful when its problem solving routines match the cause map of the value creation process in question and when the map itself turns out to represent the objective causality reasonably well. Based on this assumption that perceived environments, objective environments and organizational routines are aligned in successful projects, we will focus on the correlation between the perceived patterns of product-industry characteristics and the problem solving routines that a successful project tends to adopt.

3. Hypotheses

3.1 Generic Hypothesis

Based on the above contingency framework, we now propose a set of generic and specific hypotheses on the linkages between product-industry characteristics and effective patterns of product development routines. Because the empirical analysis which follows potentially involves a number of testable propositions, we will proceed in this study by proposing a hierarchy of generic and specific hypotheses.

Our first step in this hypothesis building is to identify appropriate constructs for describing the product-industry characteristics (i.e., patterns of the value creation process). After investigating the existing literature and clinical data, our conclusion was that we can analyze the characteristics effectively by adopting the very basic concepts of classic organization and management literature, such as uncertainty (**Lawrence and Lorsch 1967, Galbraith 1973**), interdependency (**Thompson 1967**), analyzability (**Perrow, 1967**), equivocality (i.e., possibility of multiple interpretations; **Weick 1979, Daft and Lengel 1986**), variety (**Ashby 1956**), and so on, and applying them to the processes of value creation and product development. Thus, we chose to "put new wine in old bottles" at this step of hypothesis building.

It should be noted that the above basic concepts themselves tend to be interrelated. Uncertainty, for example, may be affected by the complexity, interdependency, and equivocality of the related elements in the process. Also, certain characteristics of the value creation process in a particular locus are likely to affect problem solving patterns of effective routines in corresponding product development steps.

Figure 4 summarizes how these hypotheses are applied in the context of product development. As in **Figure 1**, the causal linkage of the target value creation process is shown in the upper level of the diagram, whereas the corresponding product development through problem solving process is illustrated in the lower level. Complexity in terms of the number of elements (i.e., element variety and changes) and interdependency are defined for each step of the process; Equivocality is defined based upon the semantic relation between a state and its meanings; Cause and effect uncertainty is defined based upon the causality between the two states, which in turn are affected by complexity and equivocality.

Figure 4 around here

With this basic logic taken into account, we derived the following four generic hypotheses linking certain product-industry characteristics and product development routines.

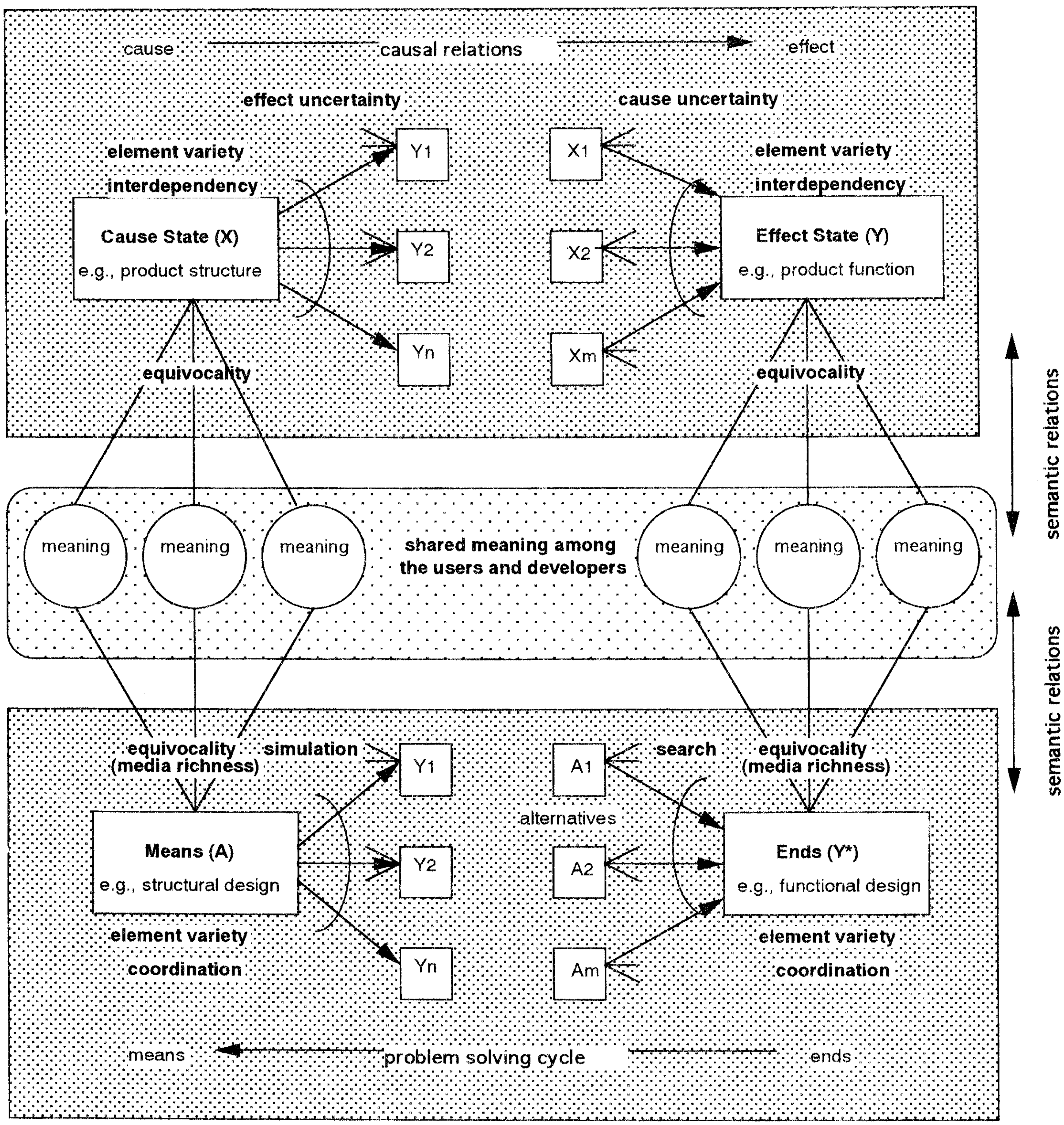
GH1: For a product with greater *equivocality* of production process, product structure, product function or customer satisfaction, the corresponding product development steps require *richer media* for information processing (e.g., face to face communication, physical prototypes, use of metaphors). This is a direct application of Weick's proposition that "organizational processes that are applied to equivocal inputs must themselves be equivocal" (**Weick 1979**, p.189. See also, **Daft and Lengel 1986**).

GH2: For a product with greater *cause uncertainty* (i.e., difficulty in estimation of causes for a given result event) of production process, product structure, product function or customer satisfaction, the corresponding product development steps require a higher degree of *search* activities. For a product with greater *effect uncertainty* (i.e., unpredictability of results for a given cause event) of production process, product structure, product function or customer satisfaction, the corresponding product development steps requires a higher degree of *simulation* activities. The concept of uncertainties and corresponding information processing efforts are discussed in the classic contingency theory works (**Lawrence and Lorsch 1967, Galbraith 1973**). These notions are also closely connected to Perrow's task variability and analyzability (**Perrow 1967**).

Note, however, that the intensity of searches and simulations is affected by the marginal costs and benefits of knowledge obtained through these activities (**Thomke 1998**). This implies that, given a level of uncertainty, patterns of search and simulation activities may be affected by their speed, fidelity and cost (**Thomke and Fujimoto 1998**).

Figure 4 Basic Logic of the Contingency Perspective

cause-effect chain of the value creation process



means-ends chain of product development process

GH3: For a product with a larger *number of distinctive elements* (or more changes) in the production process, product structure, product function or customer satisfaction, the corresponding product development steps require more problem solving cycles and organizational units. This is a direct application of Ashby's "requisite variety" concept (**Ashby 1956**): the variety within a product development process must be at least as great as the variety of the target value creation process.

GH4: For a product with greater *interdependency* among the elements of production process, product structure, product function and customer satisfaction, the corresponding product development steps requires a higher degree of *coordination* between problem solving units. This is also a straightforward application of Thompson's proposition (**Thompson 1967**). Note also that when applied to the context of product development, the notion of interdependency is closely related to the concept of task partitioning (**von Hippel 1990**), as well as modular/integral product architecture (**Ulrich and Eppinger 1994, Ulrich 1995**).

3.2 Specific Hypotheses

Based on the above generic hypotheses, let's move on to the specific propositions that we examine later in this paper. We propose in the following order a set of hypotheses relating to equivocality, uncertainty, variety and interdependence. Among numerous possible hypotheses, we paid particular attention to those propositions that have already been suggested in past literature, as well as to our own clinical studies.

3.2.1 Hypotheses on Equivocality: Since enactment and equivocality reduction tends to happen at earlier stages of product development (**Nonaka and Takeuchi 1995**), we focused in particular on the concept creation stage and the role of rich media (**Daft and Lengel 1986**) such as face-to-face communication, physical prototypes and metaphorical words.

SH1.1: *Successful use of rich communication media (e.g., face-to-face communication and metaphorical words) in equivocality of concept creation tends to bring about project success in a product for which equivocality of market needs (e.g., sensibility and industrial design intensity) is higher.*

SH1.2: *Successful use of unequivocal media (e.g., block diagrams, layout drawings) in concept creation tends to bring about project success in a product when its* *structure, function and customer needs can be articulated in a numerical or geometrical manner.*

SH1.3: *Successful use of physical prototypes (i.e., the richest media for expressing the product itself) in product engineering tends to bring about project success in a product for which equivocality of market needs (e.g., sensibility and industrial design intensity) is higher.*

SH1.4: *Successful use of unequivocal media for expressing product structures and functions (e.g., computer simulations or CAE) tends to bring about project success in a product when its structure, function and customer needs can be articulated in a numerical or geometrical manner.*

3.2.2 Hypotheses on Uncertainty: For this aspect, we paid particular attention to uncertainty caused by technological novelty (SH 2.1, 2.2, 2.3), system complexity (H2.4, 2.5, 2.6), and customer characteristics (SH 2.7, 2.8).

SH2.1: *Successful use of intensive search for new technology (e.g., parallel technology development) in advanced engineering tends to bring about project success in a product which involves novel technology, and thus has high cause-effect uncertainty relating to product structure.*

SH2.2: *Successful use of intensive simulation for new technology (e.g., intense coordination between technology and product development) tends to bring about project success in a product which involves novel technology, and thus has high cause-effect uncertainty relating to product structure.* The above two propositions (SH2.1, 2.2) are essentially reinterpretations of Iansiti's studies on technology integration and a system-driven approach in technology-intensive industries (**Iansiti 1993, 1997**). High technological novelty in this case leads to high causal uncertainty between product structure and function.

SH2.3: *Successful use of trial-and-error search (experimentation) of many alternatives in product engineering tends to bring about project success in a product which involves novel technology, and thus has high cause-effect uncertainty relating to product structure.* This proposition seems to be consistent with the experiential approach that **Eisenhardt and Tabrizi** (1995) identified in their study of the computer industry.

SH2.4: *Successful use of accurate or realistic simulation tools (test equipment and methods) in product engineering tends to bring about project success in a product when its product function and customer needs are complex (i.e., many elements and* *high interdependency) and the corresponding technology and market uncertainty is high.* In other words, when Y is complex and the effect uncertainty of the causality X -> Y is high, the corresponding simulation (X -> Y) requires fidelity.

SH2.5: *Successful use of commercial process equipment or methods at earlier stages of product development (e.g., product engineering and pilot) tends to bring about project success in a product when its production processes are complex (i.e., many steps and high interdependency) and the corresponding uncertainty is high.* This relation is typically predicted for complex process industries, where so-called "scale-up" problems create causal uncertainty between product and process. Early search of process equipment and recipe should facilitate subsequent process simulations.

SH2.6: *Successful search of feasible production processes for the product at earlier stages of its development (e.g., product engineering) tends to bring about project success in a product when its production processes are complex (i.e., many steps and high interdependency) and the corresponding uncertainty is high.* This relation is also typically predicted for complex process industries for the same reason as in SH2.5.

SH2.7: *Successful early freeze of product concept tends to bring about project success in a product when its customer needs are less uncertain.* This is related to Iansiti's argument that concept freeze should be late where customer expectations change very rapidly and are thus highly unpredictable. (**Iansiti 1997. See also, Cusumano and Selby 1995**). Where customer needs are reasonably predictable, however, early concept freeze tends to facilitate product integrity (**Clark and Fujimoto 1990**), as well as faster and more efficient product development, other things being equal.

SH2.8: *Successful use of direct customer inputs (e.g., customers' instructions and voices) for product concept creation tends to bring about project success in a product when its customers possess higher product knowledge.* This may typically be the case in industrial goods (e.g., capital equipment and components). If the customers have a more complete cause map than the developers, having accurate information about their expectations would be the key to product success. To the extent that the customers can articulate their own needs, direct instruction of product specifications by the customers themselves would be important. For example, von Hippel's classical study of scientific instruments (**von Hippel, 1976**) is quite consistent with this hypothesis.

3.2.3 Hypothesis on Element Variety: Unlike other areas, it is difficult to derive specific hypotheses about the number of elements. For example, it is reasonable to predict that development of the automobile (typically a few thousand functional parts) involves a larger number of engineers and problem solving cycles than that of cameras (typically a few hundred parts), but this does not mean that, within each industry, larger projects are associated with higher project success. **Clark and Fujimoto (1991)**, for example, showed that smaller project teams in their sample tended to outperform larger ones in project speed and efficiency. Thus in this paper, we focused only on a hypothesis about project leadership, which seems to avoid the above problem.

SH3.1: *Successful leadership by project managers tends to bring about project success in a product with a larger number of product and process elements.* It would be appropriate to use a music analogy here: An orchestra, with more instruments and players, needs an effective conductor integrating their activities, whereas a chamber music group would not need such a leader -- mutual adjustment would be enough.

3.2.4 Hypotheses on Interdependence: Here we directly apply Thompson's proposition that higher task interdependency requires a higher level of organizational coordination. We also predict that interdependency in a certain stage of the value-creation process requires coordination at the corresponding stages of product development. We propose three hypotheses dealing with the upstream, midstream, and downstream of the development process respectively.

SH4.1: *Successful coordination between product planning and product engineering units tends to bring about project success in a product when its functions or customer needs are interdependent.* This refers to the upstream interdependence of the value creation process in relation to upstream coordination of problem solving cycles.

SH4.2: *Successful coordination within the product engineering group (e.g., among the engineering design units; among design, prototyping and testing units) tends to bring about project success in a product when its structures and functions are interdependent.* This refers to midstream interdependence of the value creation process in relation to midstream coordination of problem solving cycles.

SH4.3: *Successful coordination within the production-related group (e.g., factories, pilot group, manufacturing engineers) tends to bring about project success in a product when its production processes are interdependent.* This refers to downstream interdependence of the value creation process in relation to downstream coordination of problem solving cycles.

SH4.4: *Successful coordination of project members through rich media (e.g., face-to-face communication, physical prototypes) tends to bring about project success in a product when its product structures, functions and production processes are interdependent.* This is based on an assumption that face-to-face communication is the most intense mode of coordination.

We have now identified 17 specific hypotheses derived from our analytical framework and generic hypotheses. Before testing these hypotheses, we will explain our research methods and variables in the next section.

4. Research Method

4.1 Basic Direction: A Short-Cut Approach

The research method that we adopted in this paper may be called a "short cut approach" for inter-industry analysis of effective product development. In theory, we can design "full scale" research by measuring performance indicators, routine (activity) variables, and product characteristic variables. For example, we can estimate coefficients of multiple regressions either as a generic model or an industry-specific model. Suppose that Y_i is the product development performance for the i-th product (project), X_{ij} is the level of j-th product development routine for project i, and Z_{ik} is the k-th product trait for the i-th project for controlling the data for product differences. For simplicity of discussion, let us assume linear relationships between the independent and dependent variables. We can then conduct a generic empirical study by collecting data from various projects in multiple industries (i = 1 ~ n) and fit the data with the following regression model.

$$Y_i = b_{i0} + b_{ij} X_{ij} \qquad \text{where } b_{ij} = c_{i0} + c_{ik} Z_{ik}$$

In such a case, we pool all the data across the industries and estimate the regression coefficients b_{ij}, which represent the impact of routine j in the industry (product type) i. In reality however, it is very difficult to find appropriate indicators for performance and product content common to all the industries. For example, it is practically impossible to compare product development lead time (Yi) for an automobile and that for an ice cream cone and tell which is shorter after adjusting for product content variables. It is extremely difficult to find control variables for such inter-industry adjustment.

Alternatively, we may do a series of industry-specific studies based on a common format and estimate the inter-industry differences of effective routines by two steps: We divide the data set into industries and estimate the effectiveness coefficient b_{ij} separately for each industry, and then regress b_{ij} further by Z_{ik} to estimate the impact of the product-industry characteristics on the effectiveness of the routines. This type of multiple-industry study would require enormous resources and time, which is beyond our current research scope.

For the present project, we chose a "short cut" approach. That is, we skipped the first step of the above "full scale" analysis and directly asked experienced product development practitioners how successfully each of the development routines were executed in successful projects that were executed recently (S_{ij} for i-th project and j-th routines). We also asked the same respondents their subjective estimation of the product-industry characteristics (Z_{ik} for i-th project and k-th product trait). Then we did a simple correlation analysis between S_{ij} and Z_{ik} to show how product characteristics affect effective patterns of product development.

As discussed later, this short-cut method has some potential problems in measurement and validity. Measuring the variables of both sides of the equation by subjective Likert scale is also a somewhat risky approach. On the other hand, according to our framework mentioned earlier, it is valid to measure perceived (not objective) patterns of the product-industry characteristics in this way, because the project members are assumed to create effective problem solving routines based on their cause map (i.e., the perceived value creation process).

Thus, notwithstanding the significant difficulty of measurement discussed later in this paper, we believe that, given our limited time and resources, this study is a good first step toward more developed inter-industry studies of effective product development.

4.2 Data Collection

In this study, we combined clinical field studies and statistical data collection. The former was used for hypothesis building. We visited over 30 product development organizations of manufacturing firms in such industries as **apparel, food, pharmaceutical, toiletry, industrial materials, software, electronics equipment and components, office equipment, automobile, mechanical parts, and construction equipment,** covering virtually all the industrial sectors studied in our questionnaire survey. We combined our knowledge from both our literature survey and field research for developing the hypotheses, selecting variables and designing the questionnaire. We then moved on to the questionnaire survey.

We collected data through a questionnaire survey mailed to 700 business units or research laboratories in July 1997. We received 203 answers (response ratio of 29%) by October 1997, which we then analyzed for this study. The unit of analysis is an individual *project* of product development. Some of the multi-divisional companies gave us more than one response.

For the purpose of our study, we distributed the questionnaire to many different industries. As a result, the 203 responses were spread across a variety of industries: textile and apparel (n=14); food and beverage (n=15); pharmaceutical and biological (n=10); consumer chemical and toiletry (n=9); industrial chemical and material (n=35); software and telecommunication systems (n=11); consumer electronics and appliances (n=23); electronic parts (n=21); precision machines for offices (n=25); passenger car and motorcycle (n=7); machinery parts (n=7); industrial machines and equipment (n=26).

Each respondent to the questionnaire was asked to select a relatively successful project that he or she experienced in recent years, and to answer the questions consistently about this particular project.

4.3 Variables

Following our framework, we measured two sets of main indicators in our analysis: effective routines and product-industry characteristics.

4.3.1 Effective Product Development Routines: We selected **32** routines that may affect project performance based on our understanding of existing work, case-based field studies that the authors conducted in more than twenty projects and industries, and the problem solving framework that we adopted for this study. That is, we developed about **thirty** statements, each of which describes a routine that we thought may potentially be effective for certain types of products. For each routine, the respondents were asked if that routine was executed **relatively successfully** in the successful project that they chose. More specifically, they were asked how successfully each of the following routines was executed relative to average projects in the same product category, using a 5 point Likert scale (5 = very successful; 3 = neutral; 1 = failure).

We also asked the respondents if each of the routines was **important** for the success of the project (binary choice). This "importance" indicator was also used as a supplementary measure for the analysis. As discussed later on, this measure was not used directly in our main analysis, but was used as a validity check of the success indicator.

The list and basic statistics of this set of variables is shown in **Table 1.** Note that the mean (column 3) for almost all of the routine variables is over 3.0, which means that these development routines tended to be executed relatively successfully.

Table 1 around here.

In order to check if there are significant inter-industry differences in average development practices, ANOVA was applied for these variables. The results (column 6) show that significant inter-industry differences existed in 13 of these routine variables. Thus our basic hypotheses BH3 was at least partially supported by our data.

4.3.2 Product-Industry Characteristics: We also selected **20** product-industry characteristics along the main steps of the value-creation process (i.e., market needs, product function, product structure, production process),

Table 1 Product Development Routines

category	development routine	mean	st. dev.	# of respond - ents	inter-industrial difference	rank correlation with checking assessment of critical routines
1. Media for Product Concept and Engineering	1-1. Product concept was evaluated by actively using key-word (metaphor) or scenario methods.	3.20	1.08	187	**	***
	1-2. Product concept was evaluated by actively using layout drawings.	3.42	1.05	182	***	***
	1-3. Product concept was evaluated by actively using functional design charts (e.g., diagrams)	3.13	1.02	180	***	***
	1-4. Coordination was made and problems were shared among project participants through the use of physical prototypes (parts interference checks, etc.).	3.67	1	183	***	***
2. Advanced Engineering	2-1. Alternative core technologies were compared and analyzed using prototypes in order to realize the product's concept and specifications.	3.65	1	188		***
	2-2. Development of core technologies was carried out in advance separately from product development.	3.75	1.13	187		***
	2-3. The period of core technology development was overlapped with the period of product concept/specification development.	3.79	0.91	190		***
	2-4. Actual development activities started before the product concepts and specifications were approved by senior management group.	3.81	0.89	193		***
	2-5. Effective coordination and communication were made at the stage of advanced development of core technologies.	3.50	0.88	186		***
3. Product and Process Engineering	3-1. Many alternative designs were prototyped and screened by trial-and-error in order to achieve target specification and performance.	2.99	0.89	185	**	***
	3-2. Product functionality and performance were enhanced by developing testing equipment and methods that would represent user experiences and situations more accurately.	3.44	1.01	183		***
	3-3. Product functionality and performance were enhanced by raising measuring accuracy of testing equipment and methods.	3.41	0.91	182		***
	3-4. Mass (commercial) production equipment was actively used for pilot runs (tests of production equipment's functionality).	3.75	1.12	181	***	***
	3-5. Mass production methods were almost fixed at the product engineering stage. Mass production quality and productivity was enhanced by refining them.	3.89	0.94	187		***
	3-6. Engineering prototypes (working prototypes using representative design and materials) were made by using commercial (mass) production facilities.	3.47	1.02	182	***	***
	3-7. Engineering prototypes (working prototypes using representative design and materials) were made by using the same production methods (recipes) as commercial production.	3.64	1.04	189	***	***
	3-8. Physical prototypes were actively used for revealing manufacturing-related problems.	3.91	0.79	190	**	***
	3-9. Exterior models directly liked to CAD (e.g., rapid prototyping) were actively used for revealing manufacturing-related problems prior to product design and prototyping.	2.92	1.05	170	***	***
	3-10. Inter-departmental coordination mechanisms (e.g., early design reviews involving manufacturing) were actively used for revealing manufacturing-related problems prior to product design and prototyping.	3.67	1.03	189		***
4. Target Definition	4-1. Once approved by senior management group, the product concept and specifications were not changed throughout the development period.	3.51	1.04	191		***
	4-2. The product was developed based on concept and specifications specified concretely by the customers themselves.	3.39	0.96	187	**	***
	4-3. Product concept and specifications were made following actual voice of the customers and retail stores obtained through direct contact with them.	4.02	0.88	195		***
5. Control and Coordination	5-1. Product development leader demonstrated his/her individual ability of project management and coordination.	3.88	0.84	190		***
	5-2. Product development leader demonstrated his/her individual technological ability.	3.81	0.88	190	**	***
	5-3. Product development leader demonstrated his/her individual ability for creating product concept (market imagination).	3.74	0.88	190		***
	5-4. Effective coordination and communication were made between product planning / marketing and product development departments.	4.04	0.84	197		***
	5-5. Effective coordination and communication were made between product design departments within the product engineering group.	4.03	0.74	189		***
	5-6. Effective coordination and communication were made between product design departments and prototyping/testing departments.	3.91	0.79	188		***
	5-7. Effective coordination and communication were made between product engineering (product technology) departments and process engineering (production technology) departments.	3.88	0.8	194		***
	5-8. Effective coordination and communication were made between engineering prototype shops and pilot plants.	3.50	0.89	180	**	***
	5-9. Effective coordination and communication were made between pilot plants and commercial (mass) production plants.	3.32	0.93	176		***
	5-10. Effective control and coordination among participants were made through their daily contacts.	4.01	0.78	197		***

1. Inter-Industrial difference is tested by ANOVA. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$.
2. About rank correlation (Kendoll's) with checking assessment of critical routines. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$; blanck, not significantly correlated.

focusing on uncertainty, variety (i.e., complexity in terms of the number of distinctive elements), interdependence, equivocality, and so on.

The respondents of the questionnaire were asked if each of the following descriptions fits a characteristic of the product in question, compared with other products in general, using a 5 point Likert scale (1 = correct; 3 = neutral; 5 = wrong). Considering the potential problem of having both development routine indicators and product characteristic indicators reported on the subjective Likert scale, we asked the latter by reversed scale. The list and basic statistics of this set of variables is shown **in Table 2.**

<u>**Table 2 here**</u>

We applied ANOVA to these variables in order to check if average characteristics are different across the industries. The result (column 7) shows that this was the case for the majority of the characteristics variables. The list of the industries with high average scores (column 6) also seems to make sense in most cases. Thus, our basic hypothesis BH3 was generally consistent with our data.

4.4 Issues of Validity: Do the Indicators Reflect the Constructs?

Although 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 routine effectiveness and product characteristics across industries. Thus, we have to check the validity of our indicators before analyzing the data.

4.4.1 Validity of "Effective Routines" Variables: There is difficulty in measuring the effectiveness of the routines for each product. For example, one could query the respondents about the construct directly by asking a question such as, "Do you think this routine raises the chance of project success, other things being equal?" Whereas there may be no validity problem in this case, there is a problem of measurement reliability -- the response, even by experienced project managers, would involve too many factors of subjective judgment.

Another popular method is a pair approach: asking the responding firms to give us a pair of projects, a successful and an unsuccessful one from their

Table 2 Product Characteristics

category	product-industry characteristics	mean	st. dev.	# of respond -ents	high score industries	inter -industrial difference	correlation with objective assessment of product-industry character -istics
Equivocality	1. The product's form and structure were difficult to describe by engineering drawings.	3.67	1.18	190	softwares and systems		/
	2. It was difficult to specify required product functions and specifications numerically.	3.06	1.25	194	consumer chemical and toiletry, textile and apparel	*	/
	3. It was difficult to describe numerically customer needs for this product.	2.90	1.3	196	textile and apparel, customer electronics and appliances	***	/
	4. Customers of this product emphasized its exterior designs.	3.15	1.37	198	customer electronics and appliances, passenger cars and motorcycles	***	/
	5. This product emphasized the aspect of human sensibility and ergonomics.	2.95	1.35	198	passenger cars and motorcycles, textile and apparel	***	/
Uncertainty	6. The product included completely new technological elements.	2.31	1.3	199	electronic parts, passenger cars and motorcycles		
	7. The basic technologies (technological elements) had to be developed for this product.	2.37	1.29	198	machinary parts, electronic parts		***
	8. It was difficult to develop technology elements that can achieve the product's target specifications.	2.43	1.16	197	electronic parts		/
	9. It was difficult to forecast customer needs for this product.	3.47	1.26	197	passenger cars and motorcycles, textile and apparel	*	/
	10. Customers of this product requested an extremely high or advanced levels of performance.	2.57	1.28	198	electronic parts, industrial chemical and material	***	***
	11. Customers possessed a high level of knowledge about this product and its technologies.	2.66	1.08	197	electronic parts, industrial chemical and material	**	/
Variety	12. The product consisted of many components or ingredients.	2.88	1.31	195	passenger cars and motorcycles	**	***
	13. Many functions were required for this product.	2.60	1.13	196	passenger cars and motorcycles, electronic parts	***	***
	14. There were many production processes (production steps) for this product.	3.15	1.08	193	passenger cars and motorcycles	**	***
	15. More engineering person-hours were needed for developing the process than developing the product.	3.80	1.12	197	industrial chemical and material	***	***
	16. Customers requested many functions from this product.	2.76	1.17	196	softwares and systems, passenger cars and motorcycles		***
Interdependency	17. The layout of the product's components or ingredients was severely constrained.	2.59	1.24	191	consumer electronics and appliance	***	/
	18. It was difficult to achieve the product's multiple functions simultaneously.	2.51	1.08	193	electronic parts, industrial chemical and material		/
	19. A coherent quality control was needed from the upstream to the downstream production process in order to achieve the required product functions and specifications .	2.47	1.19	195	passenger cars and motorcycles,textile and apparel	***	/
	20. Customers emphasized a certain balance between different functions of this product.	2.80	1.1	193	precision machines for offices		/

1. Inter-Industrial differences are tested with ANOVA. *p <0.1; **p <0.05; ***p <0.01; blanc, no significant difference.

2. About correlations (Pearson's) with objective assessment of product-industry characteristics, *p <0.1; **p <0.05; ***p <0.01; blanck, not significantly correlated;

Cells filled with / means not applicable.

point of view, and to evaluate the level of adoption of each routine (**Rothwell, et al. 1974**). If the levels are significantly different between the pairs for a given routine, we could say that it is an effective routine. In reality however, it is rather difficult to get questionnaire responses about failed projects from companies (This is particularly the case in Japan).

Considering the above problems, we decided to let each respondent select a recent successful project, and to ask if a given routine was executed more successfully than the average case in the past. Our assumption, based on our field research, was that experienced project managers would have reasonably accurate judgment about whether they had better than average practices. In other words, our approach in this project was a quasi-pair comparison, which let the respondents compare their actual successful projects with imaginary "average" projects. In this way, we tried to measure the effectiveness of each routine without asking about failed projects.

One problem of this quasi-pair method is that the respondent may answer "more successful" in the case of unimportant routines that happened to be better executed than average. In order to check this possibility, we correlated the "relative success" indicator and the "importance" indicator mentioned earlier for each routine to see if successful ones tend also to be important. The result generally showed that relatively successful routines are also regarded as important: for all the variables that we investigated in this paper, rank correlation coefficients between the two indicators were positive and significant (See **Table 1, column 7**).

To sum up, our approach in measuring relative perceived success of each routine in a successful project vis-a-vis the average seems to reflect the construct of "effective development routine" reasonably well.

4.4.2 Product-Industry Characteristics: Now let's turn to the side of perceived product-industry characteristics. Note, again, that what we measure in this study are the perceived patterns of the value creation process for the product in question. There is a fundamental trade-off here between accuracy and comparability of measurement, though.

Suppose, for example, that we want to measure the "complexity of a product" and compare it across the industries. One straight-forward way to get such data is to ask directly, "Is your product in question complex?" However, there is no guarantee that what a software programmer thinks is complex can be compared with what an automobile engineer thinks is complex. Alternatively, to get an answer we can ask a car engineer about the number of components, a programmer about the number of lines, and a chemist about the number of process steps or molecular weight. The answer may be more accurate when we ask such industry-specific questions, but then we cannot compare these answers directly across industries. Thus, we face a dilemma between accuracy and comparability of the product characteristics data.

There is no ultimate solution to this fundamental trade-off. After trying various methods, we decided to use the subjective measures as the main yardsticks and hoped that the respondents would have a broad perspective in evaluating their products in an unbiased way, and we supplemented the respondants by giving them some objective measures. Fortunately, the correlation coefficients between selected pairs of the subjective and objective measures of product-industry characteristics were generally positive and significant, which indicates that the former is reasonably unbiased in evaluating products in a broad context (See **Table 2, column 8**). With these validity checks, we will now present our results of the correlation analysis between the development routine variables and product-industry variables.

5. Results

The results of the correlation analysis are summarized in **Table 3**. Each column shows an effective development routine indicator; Each row contains a product-industry characteristics indicator. The shaded cells are the combinations related to our hypotheses. The statistical significance of each correlation coefficient is also indicated in the table. Note that the two variables are measured in reversed ways, so that negative signs of the coefficients mean positive correlation.

Table 3 here

Considering the somewhat preliminary nature of this research, we used the measured indicators directly, rather than summarizing them into underlying factors (e.g., factor analysis), in order to minimize the risk of ad hoc interpretation. Also, for simplicity of analysis, we used Pearson's correlation

correlation

Table 3 Correlation between Product-Industry Characteristics and Product Development Routines

Product Development Routines — 1. Media for Product Concept and Engineering; 2. Advanced Engineering

Product-Industry Characteristics	Variable	1-1 Evaluate concept by using key-word or scenario methods	1-2 Evaluate concept by using layout drawings	1-3 Evaluate concept by using functional design charts	1-4 Coordinate and share problems among project participants through the use of physical prototypes	2-1 Compare and analyze alternative core technologies using prototypes	2-2 Carry out development of core technologies in advance separately from product development	2-3 Overlap the period of core technology development with the period of concept/spec development	2-4 Start actual development activities before the product concepts and specifications were approved	2-5 Effectively coordinate and communicate at the stage of advanced development of core technologies
Equivocality	1 The product's form and structure were difficult to describe by engineering drawings	0.079	0.192**	0.205***	0.027	-0.073	0.087	-0.01	-0.024	0.06
	2 It was difficult to specify required product functions and specifications numerically	-0.036	0.132*	0.126*	-0.063	0.034	0.031	-0.031	-0.042	0.169**
	3 It was difficult to describe numerically customer needs for this product	0.085	0.244***	0.074	-0.137*	0.07	-0.041	0.074	-0.043	0.116
	4 Customers of this product emphasized its exterior designs	-0.18**	-0.032	-0.114	-0.167**	0.03	0.103	0.027	-0.076	0.124*
	5 This product emphasized the aspect of human sensibility and ergonomics	-0.249***	-0.122	-0.121	-0.248***	-0.062	-0.004	0.074	-0.039	-0.018
Uncertainty	6 The product included completely new technological elements	-0.124	-0.007	-0.161**	-0.061	-0.052	-0.287***	-0.252***	-0.241***	-0.181**
	7 The basic technologies (technological elements) had to be developed for this product	-0.119	0.061	-0.022	-0.102	-0.206***	-0.337***	-0.198***	-0.182**	-0.282***
	8 It was difficult to develop technology elements that can achieve the product's target specifications	-0.032	0.01	0.026	-0.043	-0.238	-0.277***	-0.194***	-0.221***	-0.286***
	9 It was difficult to forecast customer needs for this product	0.029	0.134*	0.066	-0.004	0.014	0.008	0.033	0.058	0.106
	10 Customers of this product requested an extremely high or advanced levels of performance	0.056	-0.067	-0.106	-0.07	-0.082	-0.157**	-0.107	-0.106	-0.237***
	11 Customers possessed a high level of knowledge about this product and its technologies	-0.003	-0.243***	-0.185**	-0.125*	0.101	-0.003	0.039	-0.05	-0.07
Variety	12 The product consisted of many components or ingredients	-0.043	0.06	-0.078	-0.126*	-0.069	0.009	0.081	-0.057	-0.03
	13 Many functions were required for this product	-0.088	-0.039	-0.084	-0.118	-0.147	-0.229***	0.024	-0.015	-0.116
	14 There were many production processes (production steps) for this product	-0.037	0.065	0.042	-0.181**	0.011	-0.003	0.005	0.003	-0.141*
	15 More engineering person-hours were needed for developing the process than developing the product	-0.06	0.122	0.125*	0.105	0.035	-0.063	-0.132*	-0.074	-0.03
	16 Customers requested many functions from this product	-0.009	0.074	-0.018	-0.127*	-0.113	-0.149**	-0.025	-0.029	-0.213***
Interdependency	17 The layout of the product's components or ingredients was severely constrained	0.04	-0.066	0.01	-0.214***	-0.147**	0.078	-0.143	-0.015	0.033
	18 It was difficult to achieve the product's multiple functions simultaneously	0.038	0.008	0.061	-0.228***	-0.2***	-0.007	-0.094	-0.048	-0.026
	19 A coherent quality control was needed from the upstream to the downstream production process in order to achieve the required product functions and specifications	-0.047	0.082	-0.025	-0.347***	-0.146**	-0.188**	-0.23***	0.02	-0.218***
	20 Customers emphasized a certain balance between different functions of this product	-0.138*	-0.06	0.008	-0.099	-0.083	-0.077	-0.061	0.033	-0.003
	related specific hypothesis	SH1 1	SH1 2	SH1 2	SH1 3, 4 4	SH2 1, 4 4	SH2 1	SH2 2	SH2 2	SH2 2

Product Development Routines — 3. Product and Process Engineering

Product-Industry Characteristics	Variable	3-1 Prototype and Screen many alternative designs by trial-and-error to achieve target specification and performance	3-2 Enhance product functionality and performance by developing testing equipment and methods that would represent user experiences and situations	3-3 Enhance product functionality and performance by raising measuring accuracy of testing equipment and methods	3-4 Use commercial production equipment for pilot runs	3-5 Almost fix mass production methods at the product engineering stage	3-6 Make Engineering prototypes by using commercial production facilities	3-7 Make engineering prototypes by using the same production methods as commercial production	3-8 Use physical prototypes for revealing manufacturing-related problems	3-9 Link exterior models directly to CAD for revealing manufacturing-related problems prior to product design and prototyping	3-10 Use inter-departmental coordination mechanisms for revealing manufacturing related problems prior to product design and prototyping
Equivocality	1	0.003	0.1	0.031	-0.065	0.052	-0.125*	-0.09	0.003	0.045	0.125*
	2	-0.096	0.062	0.11	-0.063	0.101	-0.04	0.012	0.048	-0.139*	0.133*
	3	-0.05	0.124*	0.075	0.029	0.117	0.135*	0.156**	-0.043	-0.106	0.153**
	4	-0.102	0.088	0.07	-0.076	0.154**	-0.076	0.092	-0.058	-0.28***	-0.136*
	5	-0.082	-0.051	0.036	-0.084	0.053	-0.057	0.143*	-0.091	-0.297***	-0.11
Uncertainty	6	-0.134*	-0.176**	-0.181**	0.029	-0.165**	-0.042	-0.069	0.057	-0.093	0.16**
	7	-0.151*	-0.136*	-0.152**	-0.033	-0.004	0.037	0.008	-0.041	-0.011	0.132*
	8	-0.15**	-0.13*	-0.085	-0.049	-0.111	0.001	-0.044	-0.085	-0.078	0.088
	9	-0.106	-0.005	0.019	0.038	0.159**	0.092	0.131*	-0.031	-0.151**	0.078
	10	-0.099	-0.266***	-0.301***	-0.294***	-0.106	-0.133*	-0.163**	-0.087	-0.5	0.006
	11	0.000	-0.135*	-0.282***	-0.108	-0.091	0.066	-0.055	-0.124*	-0.043	-0.156**
Variety	12	-0.115	-0.084	-0.142*	-0.064	-0.015	0.036	0.099	-0.067	-0.176**	-0.062
	13	-0.099	-0.181**	-0.182**	-0.04	-0.034	0.088	0.035	-0.07	-0.118	0.016
	14	-0.101	0.004	-0.141*	-0.188**	-0.012	0.032	0.009	-0.197***	-0.154**	-0.13*
	15	-0.071	0.154**	0.043	-0.045	0.059	-0.196***	-0.195***	-0.138*	0.054	0.095
	16	-0.158	-0.078	0.043	-0.127*	-0.018	-0.009	0.014	-0.15**	-0.084	-0.005
Interdependency	17	0.011	-0.073	-0.136*	-0.036	0.071	0.242***	0.174**	-0.201***	-0.078	-0.103
	18	-0.177**	0.095	-0.246***	-0.191**	0.065	0.103	0.007	-0.045	-0.065	-0.623
	19	-0.227***	-0.041	-0.242***	-0.273***	-0.244***	-0.181	-0.158**	-0.205***	0.102	0.096
	20	-0.077	-0.3**	-0.087	-0.106	-0.018	0.015	0.072	-0.199***	-0.035	-0.051
	related specific hypothesis	SH2 3	SH2 4	SH2 4	SH2 5	SH2 5	SH2 5	SH2 5	SH2 6	SH2 6	SH2 6

Product Development Routines — 4. Target Definition; 5. Leadership, Control and Coordination

Product-Industry Characteristics	Variable	4-1 Not change the product concept and spec throughout the development period	4-2 Specify the product concept and spec by the customers themselves	4-3 Make product concept and spec following actual voice	5-1 Product development leader for project management and coordination	5-2 Product development leader technological ability	5-3 Product development leader for creating product concept	5-4 Effectively coordinate and communicate between product planning / marketing and product development departments	5-5 Effectively coordinate and communicate within the product engineering group	5-6 Effectively coordinate and communicate between product design departments and prototyping/testing departments	5-7 Effectively coordinate and communicate between product engineering departments and process engineering departments	5-8 Effectively coordinate and communicate between engineering prototype shops and pilot plants	5-9 Effectively coordinate and communicate between pilot plants and commercial (mass) production plants	5-10 Effectively control and coordinate through their daily contacts
Equivocality	1	0.05	0.158**	0.033	0.058	-0.113	-0.111	0.06	0.143*	0.056	0.011	0.014	0.048	-0.077
	2	0.163**	0.051	0.066	0.057	-0.011	-0.066	-0.032	0.16**	0.094	0.063	0.075	0.027	0.01
	3	0.113	0.218***	0.117	-0.059	0.063	-0.105	-0.039	0.095	0.045	0.133*	0.084	0.08	-0.133*
	4	0.054	0.014	-0.027	-0.032	0.119	0.025	-0.16	0.043	-0.028	0.006	0.042	-0.012	-0.01
	5	0.016	0.039	-0.017	-0.029	0.102	-0.016	-0.141**	-0.058	-0.088	0.023	-0.005	-0.022	-0.078
Uncertainty	6	-0.029	-0.061	-0.068	-0.129*	-0.076	-0.101	-0.048	-0.118	-0.083	-0.075	-0.08	-0.026	-0.128*
	7	0.021	-0.095	-0.042	-0.037	-0.095	-0.013	-0.044	-0.062	-0.078	-0.094	-0.204***	-0.165**	-0.135*
	8	-0.031	-0.074	-0.091	0.007	-0.122*	0.017	-0.072	0.025	-0.078	-0.014	-0.197***	-0.086	-0.104
	9	0.146**	0.101	0.138*	0.031	-0.01	-0.03	-0.057	0.128*	0.077	0.123*	0.069	-0.001	0.043
	10	-0.047	-0.274***	-0.174*	-0.151**	-0.153**	-0.095	-0.112	-0.155**	-0.177**	-0.046	-0.102	-0.154**	-0.142**
	11	-0.058	-0.292***	-0.322***	-0.228***	-0.199***	-0.233***	-0.011	-0.173**	-0.108	-0.06	-0.07	-0.101	-0.059
Variety	12	0.048	-0.106	-0.063	-0.0778	-0.13*	-0.116	-0.06	-0.158**	-0.171**	0.016	-0.019	0.016	0.097
	13	0.103	-0.112	-0.158**	0.107	0.029	-0.029	-0.077	-0.034	-0.075	0.053	-0.003	0.003	-0.045
	14	0.073	-0.076	-0.042	-0.114	-0.01	-0.149**	-0.041	-0.157**	-0.157**	-0.032	-0.102	-0.113	-0.116
	15	-0.005	-0.058	0.045	0.045	-0.075	0.07	0.039	0.108	-0.001	-0.057	-0.101	-0.13*	0.031
	16	0.112	-0.092	-0.105	-0.048	-0.035	-0.055	-0.148**	-0.14*	-0.179**	0.022	-0.048	-0.02	-0.094
Interdependency	17	-0.003	0.055	-0.21***	-0.007	0.034	-0.038	-0.024	-0.015	-0.171**	-0.031	0.013	0.002	-0.134*
	18	0.134*	-0.102	-0.173**	0.003	-0.182**	-0.087	-0.161**	-0.106	-0.198***	-0.099	-0.203***	-0.215***	-0.15**
	19	0.025	-0.112	-0.115	-0.165**	-0.051	-0.123*	-0.044	-0.279***	-0.351***	-0.807***	-0.309***	-0.33***	-0.175**
	20	0.032	-0.166**	-0.116	-0.103	-0.059	0.016	-0.143**	-0.112	-0.155**	-0.158**	-0.109	-0.192**	0.013
	related specific hypothesis	SH2 7	SH2 8	SH2 8	SH3 1	SH3 1	SH3 1	SH4 1	SH4 2	SH4 2	SH4 3	SH4 3	SH4 3	SH4 4

1 About correlations (Pearson's) between product-industry characteristics and product development routines, *p <0.1; **p <0.05; ***p <0.01

2 Shaded cells are related to our specific hypotheses.

coefficients, although strictly speaking there may be better tools for this type of data (e.g., rank correlation).

5.1 Results Relating to Equivocality:

SH1.1: Relative success in evaluating product concept by "key word and scenario methods" (1-1) was significantly and positively correlated with the product's emphasis on "sensibility and ergonomics" (5) and the customer's emphasis on exterior design (4), but it was not significantly correlated with needs equivocality in terms of numerical expression (3). The hypothesis between rich concept media and needs equivocality was partially consistent with the data.

SH1.2: Relative success in evaluating product concept by "layout drawings" (1-2) was significantly correlated with the product structure's geometric equivocality (1), product function's numerical equivocality (2), and customer needs' numerical equivocality (3). Relative success in functional diagrams (1-3) was also correlated with the same equivocality variables except the last one. The hypothesis between unequivocal media and product-market equivocality was partially consistent with the data[5].

SH 1.3: Relative success in problem solving through physical prototypes (1-4) was significantly correlated with the product's emphasis on "sensibility and ergonomics" (5), customer's emphasis on exterior design (4), and needs equivocality in terms of numerical expression (3). The hypothesis between rich media for engineering and needs equivocality was generally consistent with the data[6].

5.2 Results Relating to Uncertainty:

SH2.1: Relative success in advanced engineering of element technologies (2-2) and parallel development of element technologies by prototypes (2-1) were significantly correlated with technological novelty (6), requirements for developing basic element technologies (7), and difficulty of element technology development (8) in most of the combinations. The hypothesis between

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[5] We also found that both layout and functional diagram indicators were significantly correlated with customer knowledge, which may imply that knowledgeable customers are involved in the articulation of product concepts by using these unequivocal media.

[6] As discussed later, effective use of physical prototypes is also correlated with complexity of the product and process.

technological uncertainty and technological search (**Iansiti 1993, 1997**) tended to be consistent with the data.

SH2.2: Relative success in overlapping advanced engineering and product development (2-3), overlapping product conception and engineering (2-4), and communication in advanced engineering stage (2-5), were significantly correlated with technological novelty (6), requirements for developing basic element technologies (7), and difficulty of element technology development (8) in most of the combinations. The hypothesis between technological uncertainty and advanced technological simulation and coordination (**Iansiti 1993, 1997**) tended to be consistent with the data[7].

SH2.3: Relative success in trial-and-error search and screening of many alternatives in product engineering (3-1) was significantly correlated with technological novelty (6), requirements for developing basic element technologies (7), and difficulty of element technology development (8). The hypothesis between technological uncertainty and intensity of search was generally consistent with the data[8].

SH2.4: Relative success in enhancing testing representativeness (3-2) and testing accuracy (3-3) was significantly correlated with technological novelty-uncertainty (6, 7, 8), number of product elements (12), required product functions (13), customer needs (16), and process elements (14), as well as trade-off or interdependency between product's structural elements (17), functions (18), customer needs (20), production processes (19) and difficulty in achieving customer requirements (10) in most of the combinations. The hypothesis between complexity of needs and functions and intensity of corresponding simulations tended to be consistent with the data.

SH2.5: Relative success in using commercial process equipment or recipes earlier, at the pilot run stage (3-4) or the product engineering stage (3-5, 3-6, 3-7), was significantly correlated with relative process engineering efforts vis-a-vis product engineering (15) and in most of the combinations interdependency among process steps (19), but was not significantly correlated with the number of process steps (14). The hypothesis between process

[7] Note that the routines variables in both SH2.1 and 2.2 are significantly correlated with some of the variety and interdependency variables, which may indicate that a source of such technical uncertainty is product-process complexity.

[8] The prototype indicator is also correlated with product function interdependency and process interdependency, which may imply that a source of the technical uncertainty is the product-process complexity.

complexity and uncertainty and the intensity of early process search was partially consistent with the data[9].

SH 2.6: Relative success in early search for a feasible production process through physical prototypes, rapid prototypes, CAE and design reviews (3-8, 3-9, 3-10) was significantly correlated with the number of process steps (14) and in most of the combinations interdependency among process steps (19), but was not significantly correlated with relative process engineering efforts vis-a-vis product engineering (15). The hypothesis between process complexity and uncertainty and early process feasibility of search and simulation was partially consistent with the data[10].

SH2.7: Relative success in earlier freeze of product concept (4-1) was significantly correlated with unpredictability of customer needs (9, reversed scale). The hypothesis between market certainty and early concept fix was basically consistent with the data.

SH2.8: Relative success in following customers' concrete instructions about product concept and specification (4-2) was significantly correlated with the level of customer's product knowledge (11) and performance requirements (10). This routine variable was also significantly correlated with unequivocality of customer needs and product structure (1, 3; reversed scale), which indicates that the customers can themselves articulate the needs and specifications for this type of product (**von Hippel, 1976**).

Relative success in utilizing customers' "voice" (4-3) was significantly correlated with the level of customer's product knowledge (11) , but not with the level of performance requirements (10). The hypothesis between customer knowledge and customer inputs tended to be consistent with the data.

5.3 Results Relating to Element Variety:

SH3.1: Relative success in project leadership in coordination, technological ability, and concept creation (5-1, 5-2, 5-3) was not significantly correlated with the number of product structural elements (12), product

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[9]The routine variables for early process search tended also to be correlated with difficulty in achieving customer satisfaction (customers' expectations of high performance).

[10] In addition to this finding, these routine variables on design for manufacturability tended to be significantly correlated with different types of product characteristics, apparently reflecting the nature of the media: traditional physical prototypes (3-8) with product interdependency, rapid prototypes (3-9) with design intensity, and early coordination (3-10) with product-market unequivocality, which were consistent with SH1.1, SH1.2 and SH1.3.

functional elements (13), production process steps (14), and product structural interdependency (17), but it was partially correlated with product function interdependency (18) and process step interdependency (19). Overall, the hypothesis between project leadership and product-process complexity was not very consistent with the data.

We also found that the project leadership indicators tended to be significantly correlated with level of customer knowledge and customer expectations, to which our present framework could not give appropriate explanations. Overall, the results relating to project leadership were difficult to interpret.

Also, generally speaking, the indicator for the number of product elements (**12**) was not particularly correlated in a meaningful way with effective development routines. This may be caused partly by our way of measuring this construct, but we need to investigate further the reason why product complexity in terms of element variety does not affect successful development patterns.

5.4 Results Relating to Interdependence:

SH4.1: Relative success in coordination between product planning and product engineering units (5-4) was significantly correlated with interdependency of product functions (18) and customer needs (20). The hypothesis between upstream interdependence and upstream coordination was basically consistent with the data. This coordination variable was also correlated with the number of customer needs (16). Thus, more broadly, the upstream coordination tended to be correlated with complexity (element variations and interdependency) of market needs and product functions.

SH4.2: Relative success in coordination within product engineering units (5-5) was not significantly correlated with interdependency of product structures (17) and functions (18), but was correlated with process interdependency (19). Relative success in coordination between engineering design and prototyping/testing (5-6) was significantly correlated with interdependency of product structures (17), functions (18), and process steps (19). The hypothesis between midstream interdependence and midstream coordination was partially consistent with the data.

More broadly, the routine variables tended also to be correlated with the number of product and process elements (12, 13, 14), which implies that midstream coordination is associated with product-process complexity (element variations and interdependency)[11].

SH4.3: Relative success in coordination between process engineering and product engineering (5-7), between pilot plant and prototype plant (5-8), and between commercial plant and pilot plant (5-9) was significantly correlated with interdependency of production process steps (19). The hypothesis between downstream interdependence and downstream coordination was basically consistent with the data[12].

SH4.4: Relative success in coordination through daily contact (5-10) and physical prototypes (1-4, 3-1) was significantly correlated with interdependency of product structures (17) and functions (18), as well as structure-function relations (21, reversed scale) and manufacturing process (19). The hypothesis between midstream interdependence and coordination intensity and richness was basically consistent with the data.

These "intense coordination" variables tended also to be correlated with the number of product-market-process elements (12, 13, 14, 16). Thus, more broadly, the degree of rich coordination tended to be correlated with product-process-market complexity (element variations and interdependency).

To sum up, in a majority of the cases that we investigated, our data were at least partially consistent with the hypotheses we derived from the analytical framework.

It should be noted that, as is obvious in Table 3, there are many combinations of the variables where significant correlation was observed outside our hypotheses. Many of these correlations can still be explained by our basic framework reasonably well, which we tried to do in the above analysis. There are many others that are difficult to interpret from our point of view, however. Some of the puzzling combinations might be caused by simple measurement problems (e.g., poor wording of our questions), but they may also be ascribed to high correlation among some of our routine variables,

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[11] The midstream variables tended also to be correlated with customer needs complexity (16, 20).

[12] Unlike the former two hypotheses, these downstream coordination variables were not significantly correlated with the number of process elements (14), although the signs of the coefficients were consistent with our predictions.

as well as among the product indicators. In such a situation, it is quite possible that a variable captures some construct that we did not expect. Thus, for future research we may have to supplement our simplistic analyses with more sophisticated approaches such as multiple regressions and factor analysis.

6. Implications

The present paper explored a contingency perspective of effective product development by analyzing data from 203 projects in multiple industries in Japan. Although we need to further improve the system for measuring and analyzing inter-industry differences of successful product development patterns, the hypotheses we derived from our framework were at least partially supported by our data. First, we identified significant inter-industry differences in the patterns of the value creation process in most of the characteristic indicators on the one hand, and the patterns of effective product development routines on the other hand. Second, many of the predictions derived from our contingency framework were consistent with our data, according to our correlation analysis.

The result of our study has some practical and theoretical implications. To the practitioners of product development, the present study seems to provide useful insights as to how we learn from successful product development practices in other industries. Whereas the most useful information to the practitioner tends to come from competitors within the same industry, we also know that practices in other industries sometimes give rich insights on new ways to compete through product development. Without a reliable framework for inter-industry comparative studies, the practitioner may end up in one of two polar stances: either to blindly follow other industries' "best practices" without taking product-market differences into account, or to overlook potentially useful information from other sectors by simply saying "we are different."

A more constructive approach is to know how, why and where the effective development routines are different and thereby learn more efficiently from not only direct competitors but also best practices in other sectors. The present research provides only rough-cut pictures in this regard, but when combined with in-depth case studies and industry-specific surveys, it may give practitioners additional learning opportunities. We hope the present study will be a first step toward this goal.

There are also some theoretical implications that we can draw from the present study. While the empirical research on product innovations started with studies seeking generic prescriptions for effective product-technology development, which was followed by more industry-specific, international and competition-oriented research, there have been growing research opportunities in recent years for inter-industry comparative studies of successful innovations. Given that researchers have accumulated product-specific case studies and data analyses in a growing number of industries since the late 1980s, this relative shift in research agenda seems to be a natural consequence of the research which has come before. Although there are many difficulties in conducting this type of research, which we have discussed in this paper, this line of research seems to deserve further exploration both in content and methodologies.

The present study seems to indicate the possibility that some theoretical concepts which many people may regard as outmoded, such as the "problem solving perspective" and "contingency approach" may still have strong power to explain quite contemporary issues like competition thorough product development. In this sense, the present study has been our attempt to make the best use of classical and proven concepts in new contexts, which we believe generates rich insights to both researchers and practitioners. The product development project, to us, is a bundle of interconnected problem solving cycles, by which the firm tries to construct and articulate a cause map for a value creation process despite incomplete causal knowledge. Successful project organizations tend to be able to prepare a set of routines that can build such cause maps more accurately, speedily and efficiently than their rivals. How effectively these projects can articulate the map depends partly on the organizational capabilities of the companies in question, but it also depends partly upon the nature of the value creation processes of the industries in question.

In this paper, we tried to take a first step toward inter-industry empirical analyses of effective product development. This type of study is still at an exploratory or preliminary stage. We need to improve our measurement system, and we also need to introduce additional statistical analyses such as factor analysis and multiple regressions. We have to derive more testable hypotheses and thereby strengthen the tie between our conceptual framework and the empirical data. Furthermore, we need to back up our statistical results with the clinical data we obtained from the field studies. Again, we are still taking the initial steps in this research area.

Finally, we also need to make our research more international in the future, as some of our findings may reflect country-specific patterns of effective product development. For instance, the fact that routines of cross-functional coordination are used successfully in more or less any industry (see **Table 1**, column 6, variables 5-4 to 5-10) may be a typical pattern that is somewhat specific to Japan. In other words, what we need for future research in this direction is not only further inter-industry studies, but also international collaboration among the researchers of product development and innovations.

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