KNOWLEDGE TRANSFER ACROSS GENERATIONS: THE IMPACT ON PRODUCT DEVELOPMENT PERFORMANCE IN THE AUTOMOBILE INDUSTRY

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ABSTRACT

Large manufacturing companies often have a range of product lines, and successively introduce new products over time. To adapt to changing customer needs, they may replace existing products at regular intervals and add new product lines. In most cases, these new products are not "completely" new for a company, both in terms of technologies and market concepts. A technology developed for one product may subsequently be used in a range of products. Knowledge about existing customers can also serve as a useful basis for interpreting current customer needs and translating them into technical parameters and physical products. Especially, due to intensive competitive pressures, a fast product development cycle has also become a critical source of competitiveness in industries such as automobile manufacturing. Under such circumstances, retaining and quickly utilizing knowledge across generations of projects, and learning from past development activities, may become particularly important both for avoiding redundant problem solving and for finding new solutions to problems in new product development. Few studies to date, however, have systematically dealt with this issue of knowledge retention and utilization.

This dissertation addresses the issue of the transfer and retention of knowledge as an essential element in product improvement. Drawing on examples from the Japanese automobile industry, this study investigates how companies retain product-related knowledge across multiple generations of products, and how differences in the ability to accumulate such knowledge, which we call *retention capabilities*, affect performance in developing a stream of new products. First, this dissertation examined relationships between knowledge types and appropriate knowledge retention mechanisms in Chapter 3. There, we specifically focused on knowledge of the interactions among fragmented functional domains, which we defined integrative knowledge. Based on descriptions of knowledge retention practices at Japanese automobile producers, we discussed that integrative knowledge may tend to be tacit and context-specific, and that its retention may require direct transfer of individual experience and intensive face-to-face interactions. Simple tests using data on 183 core members of new product development projects at seven Japanese automobile producers partially supported this. First, we found that project members responsible for integration activities tended to continue their positions in successive generations of projects. The second test showed that vehicle layout engineers tended to rely less on documents, reports, and standards to learn from past practices than do component engineers. We also found that design information stored in these archival facilities seemed to be more important to design individuals parts of component systems than whole component systems. These indicated that, the more knowledge becomes integrative, the less its retention depends on archival media.

Next, this study examined an impact of knowledge retention capabilities on performance of new product development. Using data on 83 key component engineers in 25 new product development projects, Chapter 4 explored relationships between knowledge retention capabilities and performance within well-established component system development areas, which we defined local performance. We found that retention of prior knowledge in articulated and generalized forms seems to be of great benefit to well-defined component system development. Results showed that dependence on documents and reports for knowledge retention had a positive impact on a range of local performance indicators; use of computer-stored design information improved product cost performance; use of computer simulation tools resulted in higher technical performance. However, organization-based and individual-based mechanisms for knowledge retention had either no association or negative associations with performance indicators.

Chapter 5 examined relationships between retention capabilities, and overall project performance or system performance at the project level. Data on 22 new product development projects at seven Japanese automobile producers suggested that retention of individual experience bases and face-to-face communication with previous project members had positive impact on several performance indicators at the entire project level. This was contrastive to results in Chapter 4. Especially, we found that these individual-based retention capabilities affected improvement of system performance derived from the complex interactions among different engineering and functional domains. Archival mechanisms for knowledge retention, on the other hand, did not seem to be critical to improvement of system level performance. However, we also found that an impact of experience-based retention capabilities on product development performance was moderated by project task characteristics. Results showed that benefit of experience-based retention is greater when projects utilize existing platform designs and introduce new products into a familiar customer base. We further found that retention of prior experience tends to cause problems when projects have to introduce new market concepts.

Results of this study imply that explicit management of the knowledge retention process in a sequence of new product development is important both to retain important prior experience and disregard unnecessary knowledge. In particular, the study suggests that different types of retention capabilities may require to improve local and system performance. While companies may greatly benefit from formalization of knowledge through documentation and computerization within well-established engineering domains, retention of individual experience may remain important as long as a new product is outcome of complex interactions among specialized knowledge domains.

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Introduction

Large manufacturing companies often have a range of product lines, and successively introduce new products over time. To adapt to changing customer needs, they may replace existing products at regular intervals and add new product lines. In most cases, these new products are not "completely" new for a company, both in terms of technologies and market concepts. A technology developed for one product may subsequently be used in a range of products (Cusumano, 1991; Meyer and Utterback, 1993; Meyer and Roberts, 1988; Nobeoka, 1993; Nobeoka and Cusumano, 1992, 1994; Sanderson, 1991; Uzumeri and Sanderson, 1995). Knowledge about existing customers can also serve as a useful basis for interpreting current customer needs and translating them into technical parameters and physical products (Christensen and Rosenbloom, 1995).

Successful new product development, therefore, at least partially may depend on the ability to understand technical and market knowledge embodied in existing products, and adapt this knowledge to support new product development (Iansiti, 1995; Iansiti and Clark, 1993). For example, new product development has been described as "a dynamic process of adaptation and transformation of the knowledge of prior experiences in order to accommodate them to the contingencies of the present." (Oxman, 1988). In addition, due to intensive competitive pressures, a fast product development cycle has also become a critical source of competitiveness in industries such as automobile manufacturing (Clark and Fujimoto, 1991; Nobeoka, 1993; Nobeoka and Cusumano, 1994; Sheriff, 1988). Under such circumstances, retaining and quickly utilizing knowledge across generations of projects, and learning from past development activities, may become particularly important both for avoiding redundant problem solving and for finding new solutions to problems in new product development.

Few studies to date, however, have systematically dealt with this issue of knowledge retention and utilization.[1] Most existing studies have tended to treat each new project as independent, and implicitly assume that each new product is the outcome of a self-contained and distinct problem-solving process (Kofman et. al., 1993). For example, various researchers have examined a wide range of factors for successful new product development, such as communication processes (Allen, 1970, 1977; Ancona and Caldwell, 1992), teams' compositional characteristics (Ancona and Caldwell, 1992; Katz and Allen, 1982), team structures and leadership (Clark and Fujimoto, 1991; Henderson and Cockburn, 1994; Imai, Nonaka and Takeuchi, 1985; Larson and Gobeli, 1988), and design of development processes (Clark and Fujimoto, 1991; Eisenhardt and Tabrizi, 1995; Iansiti, 1992). In particular, researchers have paid little attention to organizational and technological linkages across generations of projects. Although some recent studies explicitly deal with issues cutting across different projects (e.g., Cusumano, 1991; Cusumano and Selby, 1995; Iansiti, 1995 a, b; Meyer and Utterback, 1993; Nobeoka, 1993; Uzumeri and Sanderson, 1995), they are either case-based studies or limited to specific elements of knowledge transfer, such as particular components and design concepts. Broad-based empirical investigations exploring the impact of knowledge retention on organizational performance are rare. Compared to continuous improvement activities at the plant level (e.g., Kaizen, TQC), improvement of product development process over time has received less direct attention in academic research. As a result, we have little systematic understanding of the effects of managing multiple generations of products.

This dissertation addresses the issue of the transfer and retention of knowledge as an essential element in product improvement. Drawing on examples from the Japanese

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[1] Exceptions may be Iansiti and Khanna (1994) and Iansiti (1995 a, b).

automobile industry, this study investigates how companies retain product-related knowledge across multiple generations of products, and how differences in the ability to accumulate such knowledge, which we call *retention capabilities*, may affect performance in developing a stream of new products.

The automobile industry is an especially suitable setting for this study because automobile manufacturers continuously introduce new families of products while upgrading existing ones. Nobeoka (1993), for example, showed that, during the period between 1980 and 1991, 210 new automobile products were introduced worldwide, nearly 70 % of which were intended to replace existing models. Such characteristics of the automobile industry - successive introduction and replacement of multiple products - provide us with a favorable setting for this study because improvement of product performance through learning from past development activities and knowledge retention across generations of projects may be crucial to competitive advantage in rapidly changing markets where multiple new products are repeatedly introduced (Cusumano and Selby, 1995; Iansiti, 1995 b, d; Nobeoka, 1993, Wheelwright and Clark, 1992).

While the focus of this study on Japanese companies makes it difficult to generalize, it also eliminates the potential bias of a country effect, one of the strong performance predictors in several existing studies (e.g., Clark and Fujimoto, 1991; Iansiti, 1992; Nobeoka, 1993; Womack et. al., 1990). Brown and Eisenhardt (1995), through their extensive review of new product development literature, found that one of the shortcomings of existing studies is their extensive reliance on a Japanese viewpoint. It is not completely clear, for example, if strong reliance on supplier networks and projects led by so-called "heavy-weight project managers" (Clark and Fujimoto, 1991) has generalizable effects on performance, or whether this is simply a Japan effect. By exploring differences within Japanese projects, this dissertation attempts to extract explanatory factors independent of the country effect.

Retention of Integrative Knowledge

Of the several types of knowledge and information embodied in new products, this study has a particular emphasis on knowledge cutting across different technical and disciplinary areas, which we call *integrative knowledge*. As many researchers have pointed out, the design of new "systems" products (i.e., products that contain numerous components which must work together) invariably depends upon the complex interaction between potentially fragmented individual knowledge bases (e.g., Clark and Fujimoto, 1990; Henderson and Clark , 1990; Iansiti, 1995 a, b; von Hippel 1994) For example, Clark and Fujimoto (1991) suggested that the quality of such product systems is determined by the coherence between their discrete elements, which they called "product integrity." We define integrative knowledge as the knowledge that leads to an appropriate interaction between fragmented knowledge in multiple domains of organizations, so as to develop a coherent whole.[2] This may include knowledge about technical linkages between physical components (Henderson and Clark, 1990), user/design interfaces (von Hippel, 1994; Christensen and Bower; 1994, Clark and Fujimoto, 1991) and manufacturing/design interfaces (Sanderson, 1991; Womack et. al., 1990; Whitney, 1988).

Henderson and Clark (1990) identified two types of knowledge required to develop a new product: "component" and "architectural." Component knowledge refers to the knowledge required for each component to achieve its performance, independent of the other components. For example, the knowhow required to develop an automobile engine that achieves a certain level of horsepower performance is an aspect of the knowledge of one component, an engine. On the other hand, architectural knowledge refers to the

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[2] Iansiti and Khanna (1994) and Iansiti (1992, 1995 a, b) called the essentially same knowledge "system knowledge." Since, in automobile development, knowledge about the user / design interface is at least as important as knowledge about technical linkages, we avoided using the term "system," which may have a more technical connotation.

knowledge about the way several components are integrated to obtain high product performance as a whole. The ability to integrate an engine, suspension system, steering mechanism, and tires to achieve a stable ride is an example of architectural knowledge.

Knowledge about the user-design interface embodied in a product also characterizes a particular type of product system, as many studies have recognized (Christensen and Bower, 1994; Clark, 1985; Fujimoto and Clark, 1991; Henderson, 1991, von Hippel, 1994). One important activity in the development of a product with a complex user interface, such as the automobile, is to translate customer needs into an appropriate combination of a number of performance parameters. As customer needs have become increasingly sophisticated, the subtle balance between different performance parameters has become more critical (Fujimoto and Clark, 1991). As a result, companies have had to learn how customers evaluate different combinations of performance attributes. This is a task not only for the marketing function. Even if advanced marketing techniques precisely define future user needs, this knowledge has to be translated into a sophisticated description of which particular combinations of different performance parameters can satisfy user needs. Such understanding is essentially cross-functional knowledge.

Knowledge about the interface between manufacturing and design is another kind of integrative knowledge, related to the implementation of a product design. This problem has been widely discussed in the context of design for manufacturing (DFM) (e. g., Whiteney, 1988).

Several empirical studies of successful new product development have identified the importance of integrative knowledge (e. g., Clark and Fujimoto, 1991; Eisenhardt and Tabrizi, 1995; Imai, et al., 1985; Henderson and Cockburn, 1994). While these studies did not examine retention and accumulation of such knowledge, they have proposed normative mechanisms for instantaneous integration, such as cross-functional teams (e.g., Imai, Nonaka and Takeuchi, 1985) and heavyweight product managers (Clark and Fujimoto, 1991; Wheelwright and Clark, 1992).

In our view, performance of complex system products can be incrementally improved at a system level by continuously deepening such integrative knowledge across different generations of product families. It is especially difficult, however, to retain and transfer integrative knowledge, for two reasons. First, since integrative knowledge is essentially inter-disciplinary, there is no social support for its accumulation. We have professional communities, specific languages and educational institutions for disciplinary knowledge, but not for integrative knowledge. Through organizations, companies have to invent their own ways to create and accumulate integrative knowledge. Second, integrative knowledge tends to be context-specific, thus less codifiable and visible than disciplinary knowledge (Henderson and Clark, 1990; Iansiti, 1995c; Zander and Kogut, 1995; von Hippel, 1994). Since context-specific knowledge itself may not be applicable under different contexts, people need to retain information about numerous surrounding contingency factors in order to accumulate and utilize this knowledge (Oxman, 1990). Therefore, it may be difficult to transfer integrative knowledge in the form of archival information such as documents, reports and databases, because it is quite costly, if not impossible, to articulate all the contingency factors.

Accordingly, some researchers have suggested the transfer of context-specific knowledge as prototypical forms (Gero, 1987; von Hippel, 1994). Such difficulties imply, however, that accumulation of integrative knowledge may play a critical role in forming the firm-specific competencies that contemporary management studies emphasize as sources of competitive advantages (e.g., Barney, 1991; Teece, 1988; Prahalad and Hamel, 1990; Rumelt, 1991). As a result, we conjecture that variance in the effectiveness of managing integrative knowledge across generations of projects may contribute significantly to differences in product development performance. Accordingly, the underlying theme of this study is that appropriate learning from past development activities, especially the effective retention of integrative knowledge, is of fundamental importance to the improvement of product quality and the efficiency of new product development over time, and, in turn, to market competitiveness.

In summary, the study focuses on three broad research questions:

1. How do companies retain and transfer knowledge related to product development across different generations of projects?
2. How does the retention and transfer of product-related knowledge across product generations influence development performance? Especially, how does the retention and transfer of *integrative* knowledge across product generations influence development performance?
3. What mechanisms and what combination of mechanisms for knowledge transfer are associated with higher product development performance?

Chapter 1

The Research

1-1 New Product Development: Perspectives

This study pays particular attention to knowledge retention across generations of projects in new product development because the retention capability should be critical for companies that introduce successive series of new products. If so, why are there very few studies dealing with this issue? This is probably because most researchers of new product development and product innovation have neglected one aspect of new product development, the accumulation of integrative knowledge. It is when we focus on integrative knowledge that the issue of knowledge retention becomes critical, both theoretically and practically. More narrowly defined functional knowledge can be most effectively retained and accumulated under traditional functional organizations whose dysfunction has tended to be discussed in contemporary management studies.

Below, we first discuss what seems to be the existing dominant model of new product development and how this model ignores the importance of integrative knowledge retention. Although this description of a dominant model is stylized, this is done to more clearly highlight the unique assumptions on which many existing studies seem to be based. We then introduce an alternative perspective. In addition, we discuss why innovation research also has generally paid little attention to the issue of knowledge retention, despite its avowed interest in long-term technological evolution.

Models of New Product Development

Most existing studies of new product development seem to share common underlying assumptions, namely, that development projects are unique, short-lived, and oriented to producing a single product, and that their associated activities are more-or-less independent.[3] For example, a standard textbook illustrates a new product development project as a set of well-defined processes, starting with identification of the market opportunity, then proceeding to design and engineering, testing and product introduction (Urban and Hauser, 1993). Each project has its own agenda, and "the project ends when *its* specific objectives have been achieved or work is terminated " (Pessemier, 1982, pp.14) [emphasis added].

While advanced component technologies might be developed continuously and accumulated in each functional area, each product development project is assumed to independently integrate these fragmented technologies to make a coherent product system for particular customers. Although companies periodically develop some derivative products, these are generally cost-reduction versions, or contain relatively minor improvements. A new product development project generally represents a novel system solution (Wheelwright and Clark, 1992), utilizing both internally-stored and externally-acquired technologies (Figure 1-1).

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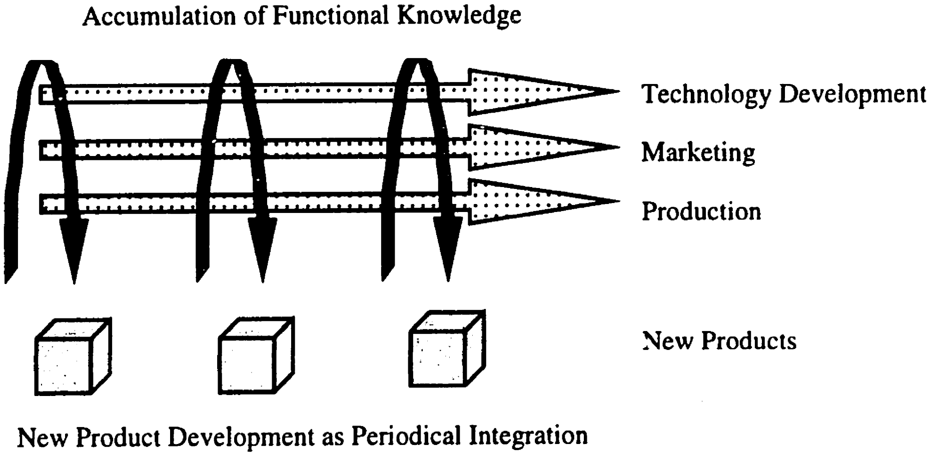
[3] There are studies dealing with linkages between different generations of products (e.g., Hamel and Prahalad, 1991; Meyer and Utterback, 1993; Uzumeri and Sanderson, 1995). However, while they discussed long-term product development strategy, they did not seriously consider organizational linkages between different generations of projects.

Figure 1.1: Dominant Conception of New Product Development: Continuous Accumulation of Functional Knowledge and Periodical Cross-Functional Integration



According to this common conception, product integration, as a primary task of a new product development project, takes place in a discrete way, unlike other functional activities such as technology development, marketing, and production. Projects are dependent on each other only to the extent that they access the same resources, such as specific sources of pooled technologies (Thompson, 1967). Thus, it is only narrowly defined technological knowledge that is subject to historical accumulation. Since a traditional functional organization can most effectively retain and transfer knowledge within narrowly defined technical and disciplinary areas (Allen and Hauptman, 1987), knowledge retention has not been a serious managerial issue. Rather, if anything, too much retention is regarded as problematic, preventing projects from introducing novel ideas (Allen and Marquis, 1964; Dougherty, 1992; Henderson and Clark, 1990; Christensen, 1992). In fact, technological knowledge accumulation and product integration have tended to be treated as having a trade-off relationship (e.g., Allen and Hauptman, 1987; Wheelwright and Clark, 1992). Therefore, co-located and autonomous cross-functional teams have often been recommended to achieve high product integration, which, in turn, may decrease the continuity of the knowledge flow (Sanderson, 1991; Meyer and Utterback, 1993).

However, new product development projects, in many cases, show more interdependence across generations than implicitly assumed in the traditional model. For example, Mr. Nakagawa, Toyota's Chief Engineer (project manager) for the Celica / ED / EXIV/ Carren project, mentioned during our interview:

> "When developing the Celica, we usually imagine that we shall also be involved in the next generation of the Celica project.... Projects are not something that are formed and disbanded by each generation.... For example, even when we want to enhance vehicle performance further in the current project, we stay with what we can do within a limited time, retaining what we cannot do as problems to be solved in the next project."[4]

Particularly in organizations that produce successive generations of the same or similar products, new product development can be regarded as a moment of time flowing from the past to the future within a sequence of new product development efforts. Although any project accomplishes its tentative objective with the introduction of a new product, the end of any project is a milestone which is followed by future project activities. For example, the introduction of a new product to market provides an opportunity to learn about user/design relationships which may be useful for product development (Hamel and Prahalad, 1991). People we interviewed at Japanese automobile companies often emphasized the importance of strict adherence to existing lead time schedules. While trying to achieve as much as they can within a limited time, they recognize opportunities for improvements in successive generations of projects. Mr. Kanazawa, an engineer at

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[4] Interview with Mr. Nakagawa, chief engineer of Vehicle Development Center II, Toyota Motor Corp., April 6, 1995.

Mazda, described this issue:

> "[D]evelopment has to finish within four years anyway. We cannot do everything. As a result, some project members are not fully satisfied with several parts of the current product. In that case, we let such engineers attend in the next model development, at least the early stages."[5]

In addition, new product development projects do not necessarily proceed in a sequential manner, from concept creation, vehicle planning, and detailed engineering to production. Some key activities often start before the creation of product concepts, based on experiences in the past generations of projects. For example, Mr. Ishidera, a chief engineer (project manager) at Toyota responsible for the third and the fourth generations of the Tercel, pointed out the following:

> "Before the CE plan ["Chief Engineer plan," a formal statement of the new vehicle development plan provided by the project manager] is proposed, body and engine design engineers start to coordinate with each other for the next model development. Since they understand the prior history of the Tercel development, there is a certain consensus about where the next Tercel should go in terms of technological and product concepts. Therefore, it's not often the case that decisions made in this early stage are seriously challenged by a chief engineer later."[6]

A similar observation was made by Mr. Umemoto, an engine design engineer at Honda responsible for the first and the second generations of the Acura Legend:

> "Based on the previous Legend, a couple of engineers from the engine, body and chassis engineering departments get together to discuss the direction of the next generations of the Legend. This discussion starts one to two years before the formal project starts. The LPL (Large Project Leader: a project manager

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[5] Interview with Mr. Kanazawa, senior manager in the chassis development department, Mazda Motor Corp., May 19, 1994

[6] Interview with Mr. Ishidera, chief engineer in Product Planning Div., Toyota Motor Corp., July 29, 1992

> responsible for the entire project) tends to be selected from members of such an early meeting. The LPL defines the total product concept and vehicle plan, based on decisions from this early discussion." [7]

These observations enable us to view new product development as a more continuous activity than assumed in the dominant model. At least in the Japanese companies studied, current development efforts depend on the knowledge created through the past product integration experiences. Just as each functional specialty, such as production, sales, marketing, and finance, is responsible for the accumulation of functional knowledge, the accumulation of integrative knowledge is one of the crucial tasks of new product development. In our view, new product development can be a continuous activity that gradually explores complex interactions between fragmented functional knowledge within and outside an organization.

We do not insist that this type of new product development is best in all cases. The traditional model may be more common when, for example, a firm wants to develop products for entirely new markets or businesses. The point is not which is better in an absolute sense, but that different perspectives or strategies magnify different aspects of new product development. As the traditional conception has shed light on instantaneous cross-functional integration and has driven researchers to explore mechanisms for more effective integration, our conception turns our attention to the issues of retention of integrative knowledge and of learning across generations of projects.

Knowledge Retention and Innovation Studies

While many studies of innovation have tried to explore general patterns of

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[7] Interview with Mr. Umemoto, chief engineer of the engineering design department No. 1, Honda R&D, May 23, 1994.

technological evolution (e.g., Abernathy and Utterback, 1978; Dosi, 1982; Tushman and Anderson, 1986; Anderson and Tushman, 1990), researchers have not extensively examined actual knowledge accumulation processes. This is partially because of their unique conceptualization of product innovation, as described below.

Traditionally, product innovation has been classified into two types according to the extent of change and departure from existing products: *radical* and *incremental* innovation[8] (Dewer and Dutton, 1986, Ettlie, et. al., 1984, Tushman and Anderson, 1986). Radical innovation is typically defined as being based on a dramatically new science, and shows a clear departure from existing products. It often involves entirely new product and market categories or production and delivery systems, and can create great difficulties for established firms (Henderson, 1995; Henderson and Clark, 1990; Anderson and Tushman, 1990). On the other hand, incremental innovation involves the adaptation, refinement and enhancement of existing products, production, or distribution systems.[9]

Studies focusing on a significant change involved in product innovation, that is, radical change rather than incremental change, tend to emphasize the negative impact of knowledge retention on the innovation process (Anderson and Tushman, 1990; Leonald-Barton, 1992; Christensen, 1992; Henderson and Clark, 1990). Emphasizing the routinized aspect of past knowledge, and the inevitable and automatic nature of knowledge retrieval, these studies tend to address issues such as how to break the automatic nature of this process, so as to create new knowledge. In comparison, the process of existing knowledge retention, application, and transfer has received little attention.

On the other hand, although incremental innovation has also received attention as

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[8] Some other researchers rather classified innovation along its impact on the existing organizational practices (see for example, Tushman and Anderson (1986) and Abernathy and Clark (1985)).

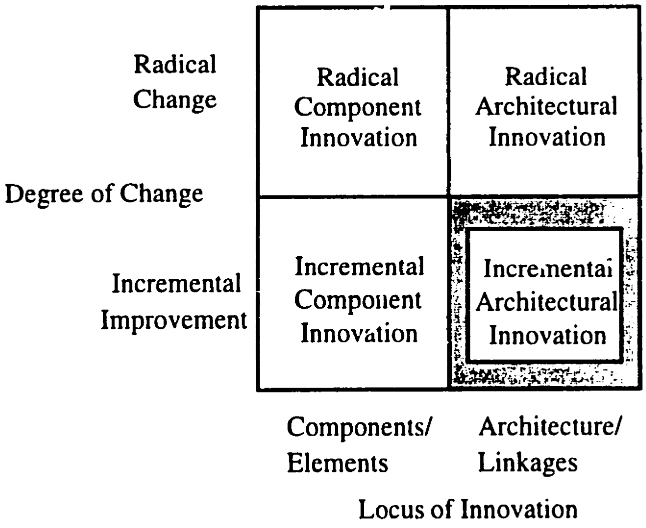
[9] Radical and incremental distinctions can be made both in an economic and an organizational sense (see, Henderson, 1994). In this section, we emphasize innovation's impact on organizations rather than economic performance.

having a significant cumulative impact on competition in the marketplace (Abernathy, 1978; Abernathy and Clark, 1985), it has tended to be treated as performance improvement derived from refinement within narrowly-defined technological functional areas. For example, the evolutionary perspective on innovation suggests that, as an industry evolves, knowledge about the product system is increasingly elaborated (Abernathy and Utterback, 1978; Abernathy, 1978). Especially, it suggests that the emergence of a dominant design significantly shifts the focus of innovation from the product architecture to the refinement and improvement of components (Clark, 1985; Henderson and Clark, 1990). Therefore, it has often been pointed out that the maturity of an industry is associated with the shift towards more hierarchical functional organizations (Abernathy, 1978; Wheelwright and Clark, 1992). Since incremental innovation requires a deeper understanding of the knowledge or technologies embodied in existing products, effective knowledge retention should be critical. However, as long as incremental innovation is characterized as derived from improvement within narrow functional domains, it does not create serious theoretical problems for academic researchers nor managerial problems for practitioners.

Beyond the traditional radical/incremental dichotomy, Henderson and Clark (1990) identified an intermediate category, architectural innovation. For them, since architectural innovation involves a significant departure from the existing ways in which components are linked together, it tends to render obsolete existing capabilities of firms. Therefore, they linked the focus on architectural innovation, similar to the case of radical innovation, to an argument that encourages the unlearning of existing organizational practices. For effective adaptation to architectural innovation, too much learning from past practices or knowledge retention may be avoided. On the other hand, they also conceived incremental innovation as the improvement of components (without a change in the fundamental technological approach) within an existing product architecture.

However, incremental improvement of an existing product can occur at an architectural level, as well as at the component level.[10] Product developers can improve ways in which components (or other elements of a product) are linked together as well as the component technologies. Figure 1.2 illustrates four attributes associated with product innovation, by using the architecture/component and radical/incremental dichotomies discussed above.

Figure 1. 2: Four Types of Product Innovation



For example, the upper-right cell indicates that product innovation may introduce changes in the product architecture. Innovation involving such changes without fundamental change in component technologies corresponds to architectural innovation in Henderson and Clarks' terms. However, any existing innovation category does not explicitly relate innovation to an attribute indicated in the lower-right cell, *incremental architectural innovation*. This is despite the fact that several studies have indicated the importance of performance improvement through the elaboration of knowledge about

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[10] Christensen (1992) defined incremental innovation as either improvements of component performance that build upon the established technological concept or refinements in system design that involve no significant changes in the technical relationships among components. However, the difference of these two types of incremental innovation was not the focus of his study. In this dissertation, I would rather emphasize the point that these two incremental innovations have quite different managerial implications.

linkages. For example, in his study of the rigid disk drive industry, Christensen (1992) found that companies perceive physical performance limits quite differently, so that even if there is an apparent limit at a component level, further improvement of the system design in a less mature part of the product system can advance the performance limit of a disk drive. Engineers at automobile companies also pointed out the importance of focusing on the product system for performance improvement. For example, Mr. Kuroda, LPL at Honda responsible for development of the current Accord, noted that:

> "Technologies involved in automobile development are becoming mature. For example, the suspension system of the Accord sedan, I think, has reached the performance level we had been aiming at.... [because of the maturity of component technologies]. We now need to compete on the basis of how to package different technologies."[11]

Mr. Kanazawa, an experienced chassis engineer at Mazda, offered a similar opinion:

> "It is certainly the point where different components intersect that frequently causes repetitive problems... typically, the section between a body and a chassis. In addition, ...in designing chassis, frequently occurring problems are mostly related to NVH [noise-vibration- harshness] and safety [for collision] performance because these [performance] are related to different parts [of a product system]. We call this 'neck-engineering'.... We recently started to spend much more time to significantly improve design accuracy at sections cutting across different functions."[12]

The reason we emphasize a difference between the notion of incremental innovation having more focus on improvement within narrowly defined functional areas, and improvement of linkages between product elements, is that they have quite different managerial implications. The former requires deepening specialized and disciplinary

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[11] Interview with Mr. Kuroda, LPL (project manager), Honda R&D, May 23, 1994.

[12] Interview with Mr. Kanazawa, a senior manager in Vehicle Design Department No. 2, Mazda Corp., May 19, 1994.

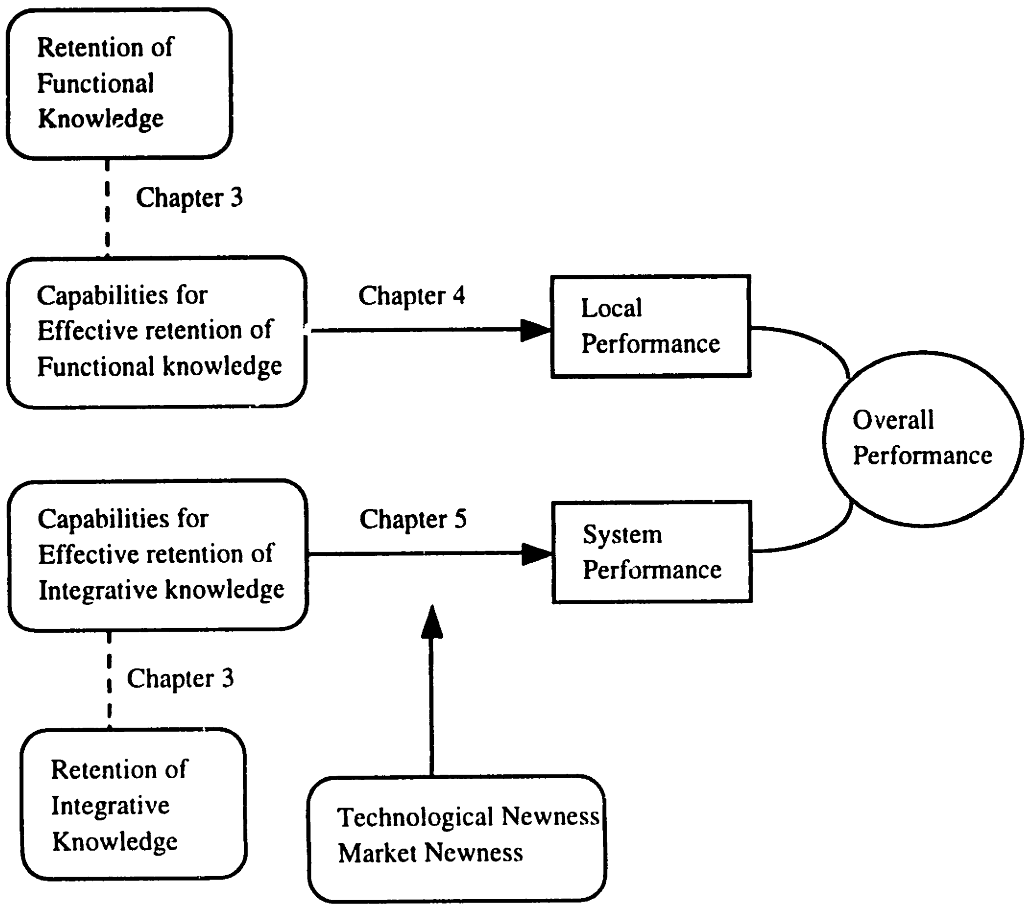
knowledge by, for example, hiring specialists, having close ties with universities, and strengthening organizational specialization. The latter requires the accumulation of integrative knowledge by linking different generations of product integration efforts and by facilitating post-project learning.

In this section, we have discussed why knowledge retention has received little attention in studies of new product development and of innovation by identifying implicit assumptions involved in dominant perspectives in these areas. In summary, researchers of new product development tend to conceptualize it as a discrete and temporally-bounded activity for cross-functional knowledge integration, and to neglect an aspect of integrative knowledge accumulation which makes knowledge retention a serious managerial and theoretical problem. On the other hand, innovation researchers tend to conceptualize incremental innovation as performance improvement within narrow functional areas, therefore, they often regard knowledge retention as either something to avoid (in the case of radical change) or take for granted (in the case of incremental innovation). This study, however, views new product development for complex system products as a historically continuous activity in which a deeper knowledge about the interaction between fragmented elements of product systems can improve product performance through refinement of a product architecture.

1-2 Research Framework

Figure 1.3 shows the research framework of this dissertation. The framework consists of three specific research questions corresponding to Chapters 3, 4, and 5.

Figure 1.3: General Framework



Knowledge Retention and Knowledge Retention Capability

Although one of our central research interests is the relationship between the degree of knowledge retention and development performance, it is not an easy task to empirically measure the amount of retained knowledge, especially because this study emphasizes less observable integrative knowledge. Instead, we focus on several possible mechanisms for knowledge transfer and specify boundary conditions as *capabilities* to facilitate knowledge transfer across generations of projects. These are:

1. the transfer of project members
2. communication with people who have substantial experiences in past development projects
3. the involvement by organizational units that coordinate development activities across generations.
4. the use of documents and reports describing past problematic and successful practices
5. the use of design standards, design tools and standard design/test procedures
6. the use of computerized information systems, such as CAD and CAE

If any of these mechanisms prove to be more appropriate to retain integrative knowledge than others, we can use a projects' dependence on such mechanisms as an indicator of the retention of integrative knowledge. Accordingly, the first research question, addressed in Chapter 3, is as follows:

Research Question 1

Through which mechanisms is integrative knowledge retained most effectively?

Knowledge Retention Capabilities, Local Performance, and Systemic Performance

The reason we have insisted on the importance of retaining integrative knowledge is that critical performance attributes of complex system products are often derived from interactions between different elements of product systems. For example, NVH (noise -vibration - harshness) is a critical performance attribute for automobiles. While NVH can be individually ascribed to particular technological elements, such as material technologies used in tires and bodies, engine systems, body shapes, and suspension systems, it also comes from the complex set of interactions among these elements. This study refers to the portion of overall performance reducible to particular technological elements as *local performance*, and that attributed only to interactive effects between them *system performance*.[13] Overall performance, then, consists of local and system performance.

The local and system distinction also applies to non-technical performance. For example, development lead time can be shortened either by compressing the lead time of technical and functional activities (local performance) or by creating overlaps between them through appropriate project adjustment (system performance). Since local performance may depend on effective access to high levels of functional or disciplinary knowledge, the retention of functional knowledge is critical. On the other hand, we hypothesize that the effective retention of integrative knowledge is of fundamental importance to improve system performance. Chapter 4 examines the former hypothesis; Chapter 5 deals with the latter.

> Research Question 2:
> What kind of retention capabilities (knowledge retention mechanisms) are associated with high local performance?

> Research Question 3:
> What kind of retention capabilities (knowledge retention mechanisms) are associated with high system performance?

By separately looking at factors affecting local performance and those affecting

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[13] Iansiti (1995c) made the same kind of distinction in a more precise way, and distinguished between fundamental potential and technological yield of the multi-chip module of mainframe computers. According to him, fundamental potential is the product's maximum potential performance give its fundamental technology bases. Technological yield is, on the other hand, the extent to which this potential is translated into realized system performance. For a related argument, see also Ulrich (1995).

system performance, we will be able to identify how retention of integrative knowledge affects product development performance.

Moderating Effects by Technological and Market Newness

Finally, our framework shows moderating effects by technological newness and market newness on knowledge retention and performance relationships. A negative effect of knowledge retention on innovation has been widely discussed in several studies (e.g., Leonald-Barton, 1992; Dougherty, 1992; Henderson and Clark 1990). A common claim in these studies is that prior technological knowledge is often not applicable in a novel situation characterized by innovation, and that it becomes an obstacle for bringing in new ideas. Thus, radical and architectural innovation have been described as posing a serious threat to established firms that tend to be bound to prior experiences.

However, other researchers suggest that prior experiences are important, and even help firms adapt to new environments. For example, researchers in design studies suggest that any design work is based on past experience and accepted tradition, and that past knowledge becomes critical even to non-routine and creative design work through its appropriate typification (Gero, 1990; Oxman, 1990). Iansiti (1992, 1995a, 1995b) also found, in his studies of the multichip module for mainframe computers, that system integrators' past experiences in developing the same type of product are positively correlated with development efficiency and technical performance.

Based on these contradictory claims, we examine whether knowledge retention has a positive effect on performance even when projects have to handle novel situations. The distinction between market newness and technological newness is also important. While many studies suggest that a technological discontinuity substantially changes market dominance from incumbents to new entrants (e.g., Henderson and Clark, 1990; Tushman and Anderson, 1986; Suarez and Utterback, 1991), others claim that change in a customer base and associated change in a product's functionality pose a more serious threat to incumbents than technological change (Christensen and Rosenbloom, 1995; Christensen and Bower, 1994; Iansiti and Khanna, 1994). This suggests that the impact of the retention of prior knowledge bases on performance may be differentially moderated by technological newness and market newness. We take this into consideration when examining our second and third research questions in Chapter 4 and Chapter 5.

1-3 Research Methods

This study used two approaches to address the research questions: a cross-sectional questionnaire survey and in-depth interviews. The cross-sectional questionnaire survey explores the relationship between capabilities for knowledge retention and product development performance. In common with most previous studies, the focal unit is an individual project, but the level of analysis (Rousseau, 1985) is the inter-project level. Therefore, the questionnaire has a particular emphasis on the transfer of product-related knowledge from past development activities, focusing on linkages between present and past development activities.

It would be ideal to study multiple generations of projects as the unit of analysis, so as to more completely examine the long-term effect of knowledge retention.[14] However, it is difficult to obtain a large enough sample response to conduct a systematic analysis at the level of multiple generations of projects. In addition, asking questions about old development projects might substantially reduce accuracy of information obtained from the questionnaire. In-depth case studies may compensate for the weakness of cross-sectional surveys.

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[14] See for example Iansiti and Clark (1994)

The sample is limited to major new product development projects for *replacement models* that have direct predecessors. Although it may be interesting to look at how the relationship between knowledge retention and performance differs between different types of projects, for example, between projects for replacement models and those for entirely new product lines, the small sample size did not allow for such an analysis. Nonetheless, the focus on replacement models is still useful because nearly 70% of new models in the automobile industry are intended to replace existing models (Nobeoka, 1993). In addition, a close examination of the development of replacement models is especially appropriate for the theme of this study - the retention and transfer of knowledge - because replacement models have at least some continuity from past models in terms of target-customer characteristics and technologies embodied in the products themselves.

We distributed a questionnaire instrument between March and May 1995 to key members of projects at seven major Japanese automobile manufacturers. In distributing the questionnaires, we asked a contact person at each company to select recent new product development projects that satisfy the following two conditions. First, projects should be responsible for "major" new product development. The meaning of "major" is fairly clear among Japanese companies since they divide product development projects into "minor model change" projects, "full model change" projects, and "new model development" projects based on the common criteria. The latter two types are categorized as major new product development projects to which the Ministry of Transport imposes additional testing requirements not applicable to minor model changes. The second condition is that projects should develop new models that replace existing models, that is, "full model change" projects. Such models often have the same brand name as the previous model (e.g., Toyota Camry, Toyota Corolla, and Honda Accord).

The number of projects we requested varied from company to company depending on its size. We asked for a total of 29 projects and received data on 25 projects. Ten key members of each project were asked to respond. Those ten key members include a project manager, vehicle test engineers, layout engineers, body design engineers, chassis design engineers, exterior/interior designers, engine design engineers, electronic component design engineers, marketing planners, and production engineers. We tailored the questionnaire according to the needs of different team members to account for the uniqueness of their tasks. Having these ten different types of people is one of the advantages of this research design. Since people with different roles may require different types of knowledge, we can partially identify the relationship between knowledge types and required capabilities by looking at how different people rely on different mechanisms for knowledge retention.

We also conducted in-depth interviews with 14 project managers and 57 engineers from 14 new product development projects at six major Japanese companies to identify how they are actually retaining knowledge and information across generations of projects. Of the 14 projects, 10 projects participated in the questionnaire research as well. Therefore, we were able to use qualitative information obtained from in-depth interviews to interpret the survey results as well as to design the questionnaire instrument. It also enabled us to understand and compare different practices among different companies, and to clarify conditions affecting the effectiveness of knowledge retention, which is difficult to capture completely with a questionnaire.

1-4 Overview of the Following Chapters

Following the literature review in Chapter 2, Chapter 3 discusses relationships between knowledge types and retention mechanisms. In this chapter, we begin by illustrating actual examples of knowledge retention mechanisms observed in Japanese automobile companies. We describe how companies retain knowledge across generations of projects, and how different companies emphasize different mechanisms of knowledge retention, based on our interviews and publicly available information. We then show how integrative knowledge may be effectively retained by organic mechanisms, such as the direct transfer of people's experience bases and communication with people having substantial past experience, and that functional knowledge is more effectively retained in mechanistic ways, such as reports, documents, and technical standards.

In addition to a theoretical discussion combined with qualitative information obtained from the interviews, data from the questionnaire survey is also used to support this discussion. For example, we found that project members responsible for integration activities cutting across different functional areas, such as project mangers, layout engineers, and vehicle test engineers, tend to continue in their positions from previous projects more than components engineers. We also found that documents, reports, and design standards are more frequently used by component engineers than integrators, and that, even within the component design, those media are less frequently used for designing a whole component system than for designing its parts.

Building on the discussion in Chapter 3, Chapter 4 examines relationships between knowledge retention capabilities and local performance. Analyses in this chapter are conducted at the level of functional activities within vehicle development projects. Local performance is empirically-defined as performance within each technical functional area, according to ratings by project members representing that area. Our data show that the use of documents and reports and the use of computer-aided systems (CAE/CAD) are positively associated with development efficiency and technical performance. On the other hand, organic capabilities such as involvement of long-term planning groups, communication, and transfer of project members have either no association or a negative association with project performance, with the only exception of the relationship between transfer of project members and technical performance.

Chapter 5 examines relationships between retention capabilities, and overall project performance or system performance at the project level. Here, we statistically separate system performance from local performance. Since it is quite difficult to directly measure system performance, we derive this by looking at relationships between overall performance and local performance. We then regress overall project performance on performance within each technical and functional area, and then take a set of residuals from the regression model as an indicator for system performance.

Our analysis suggests that experience-based retention capabilities, indicated by transfer of project integrators and core project members, communication with the previous project members, and project members' past shared experiences, tended to be positively associated with system performance as well as overall performance. Especially, they show stronger relationships with performance improvement from the previous project.

On the other hand, archival-based retention capabilities, such as use of documents, reports, and standards, are less associated with system performance as well as overall performance. In addition, they are not associated with performance improvement from the previous projects.

The use of CAE simulation (computer aided engineering) has a significant impact on technical-related performance. However, its association with system performance is weaker. In addition, the use of CAE is not related to performance improvement from the previous projects. These results suggest that retention of integrative knowledge through transfer of individual experience bases is fundamental to achieve project level performance derived from complex interactions among different functional domains.

In addition, we find that newness of the target market moderates relationships between individual-based retention capabilities and performance indicators, implying that retention of past experiences may hurt new product development performance when projects introduce novel product concepts to new customer bases. On the other hand, technical newness does not have such moderating effects.

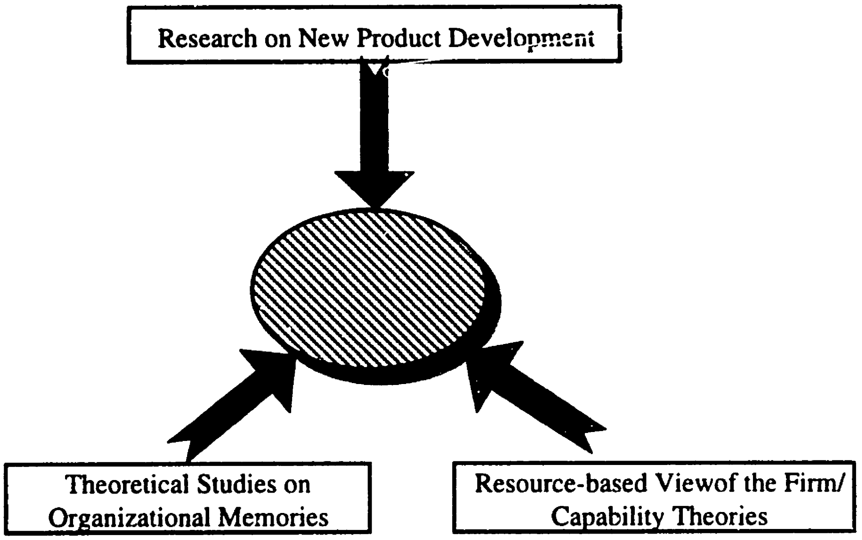
In Chapter 6, the conclusion, we discuss theoretical and managerial implications derived from this study as well as limitations of this research.

Chapter 2

Literature Review

This dissertation is related to three research areas as shown in Figure 2-1 below.

Figure 2.1: Related Research Areas



First, this dissertation is a study of new product development, a part of the broad area of innovation research. Innovation research has two streams. One is economic-oriented research that has long explored relationships among technological evolution, firm competition, industrial structures, and economic performance either at the industry level or at the country level (e.g., Abernathy, 1978; Arrow, 1962; Dosi, 1982; Nelson, 1993; Nelson and Winter, 1982; Penrose, 1980; Stobaugh, 1988). The other is organization-oriented research that has examined relationships among organizational processes, organizational structures, technological requirements, environmental characteristics, and performance at the organization and the group/project levels (e g., Woodward, 1965; Perrow, 1967; Allen, Tushman, and Lee, 1980; Katz and Allen, 1985; Clark and Fujimoto; 1991). Empirical studies in this latter stream, often associated with in-depth case studies within a particular industry, have generally tried to identify actual mechanisms that drive innovation which tended to be neglected by the economic-oriented research (e.g., Cusumano, 1991; Cusumano and Selby, 1995; Clark and Fujimoto, 1991; Iansiti, 1995 a, b; Imai, Nonaka and Takeuchi, 1985; Eisenhardt and Tabrizi, 1995). This dissertation is primarily oriented to organization-oriented empirical works that we will review in detail below.

Second, since the central theme of this dissertation is to explore the impact of knowledge retention across generations of projects on performance, it is useful to refer to theoretical studies in the area of organizational learning. Especially, we found it helpful to examine the recent discussion which has focused on the concept of organizational memory, which has a direct linkage to the issue of cross-generational knowledge retention (e.g . Cohen, 1991; Huber, 1988; Krippendorff, 1975; Walsh and Ungson, 1991). Although there are very few empirical studies in this area, it should be important to understand how organizational theorists have hypothesized the relationship between knowledge retention and organizational performance in order for us to construct specific hypotheses for this study.

Third, this dissertation also hopes to contribute to a recently developed theoretical perspective known as the resource-based view of the firm, or alternatively as a theory of organizational capability (e.g., Barney, 1991, Dosi, Teece, and Winter; 1991; Itami, 1987; Leonald-Barton; 1992; Peteraf, 1993; Prahalad and Hamel, 1990; Rumelt, 1984; Selznick, 1957; Teece, Pisano and Shuen, 1990; Wernerfelt, 1984). These theories conceive of organizations as sets of resources, routines and competencies, and emphasize the importance of historical accumulation of firm-specific capabilities as sources of competitive advantage. Their emphasis on the history-dependent nature of organizations inevitably turns our attention to the time dimension involved in any organizational activity. This dissertation deals with such time dimension by focusing on projects' cross-generational linkages in a sequence of new product development efforts, thus, it can be seen as an empirical extension of these theories.

An increasing number of studies has demonstrated rich conceptual discussions within this theoretical perspective. Some studies have discussed how firm-specific competencies affect competitiveness in the market place through case illustrations (e.g., Itami, 1987; Prahalad and Hamel, 1990). Others have tried to conceptually distinguish between different types of capabilities to specify a real source of firm competitiveness (Henderson and Clark, 1990; Henderson and Cockburn, 1994; Kusunoki, Nonaka and Nagata, 1995; Fujimoto, 1994). However, actual capability accumulation processes are yet to be explored (Henderson, 1994). Our study will be able to partially contribute to understanding such capability building processes by focusing on knowledge retention mechanisms in new product development.

Among these three related research areas, we review the first two in this chapter. Linkages with the resource-based view or the capability theory will be briefly discussed in Chapter 6, where we discuss several theoretical implications derived from this dissertation.

In the following sections, we begin by reviewing new product development studies (section 2.1). This review has three objectives. First, it summarizes factors that have been found to affect project performance. Those factors were considered in designing our empirical test concerning project performance. Second, the review highlights the fact that there are very few empirical studies that systematically address issues of linkages across different generations of projects. Third, it provides us with several important methodological lessons. Following the review, we particularly discuss two issues, performance measurement and project definition.

In section 2.2, we review theoretical studies discussing the utility of knowledge retention. We consider that somewhat contradictory hypotheses have been made by organization theorists regarding the relationship between knowledge retention and organizational performance: whereas some theorists have emphasized the positive impact of knowledge retention on organizational performance, others have pointed out its negative aspects. We also conclude that most innovation studies emphasize the negative influence of knowledge retention on innovation. This section next reviews the theoretical work regarding how knowledge is stored and retained within organizations.

2-1 New Product Development Studies

In reviewing existing studies of new product development, we divide them into two categories by the level of reference (Rousseau, 1985). Studies in the first category, which we call single-project studies, focus on management of individual projects, and explore factors affecting success of new product development within a single project (e.g., Allen, Tushman, and Lee; 1980, Clark and Fujimoto, 1991; Eisenhardt and Tabrizi, 1995; Ancona and Caldwell. 1992). Most existing empirical tests belong to this category.

The second set of studies has more emphasis on inter-project issues cutting across different projects or different generations of projects. Some of these studies explicitly shift the unit of analysis from the individual project to the product family, or to a product portfolio (e.g., Clark, Fujimoto and Aoshima, 1992; Uzumeri and Sanderson, 1995; Meyer and Utterback, 1992; Nobeoka, 1993; Nobeoka and Cusumano, 1994; Sakakibara and Aoshima, 1988; Sanderson, 1991; Uzumeri and Sanderson, 1995). Based on the recognition that new product development projects are interrelated in various ways regarding technologies, markets, resources, and strategies, they considered the performance of a group of new products rather than that of individual products. Empirical studies of this type are mostly case studies. However, some recent work tries to systematically explore the impact of inter-project factors, such as type of inter-project technology transfer (e.g., Cusumano and Nobeoka, 1992; Nobeoka; 1995) and cross-generational learning (e.g., Iansiti, 1995a, b). We first review single project studies, then move on to cross-project studies.

2-1.1 Single Project Studies

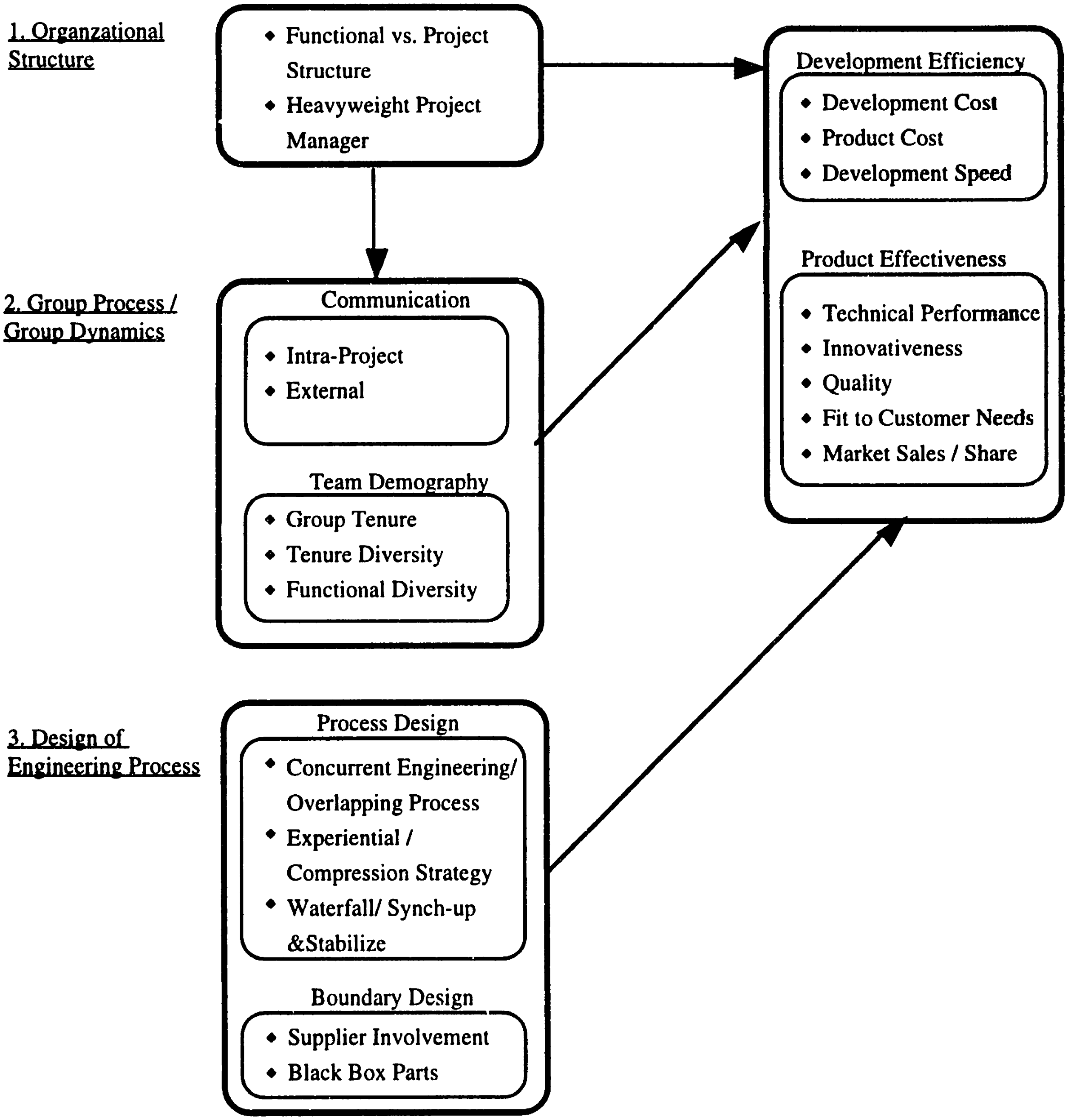
What makes a new product development project successful? To answer this question, different researchers have, to date, focused on different aspects of new product development. Broadly, three different aspects have been examined in the existing empirical studies, although researchers have often dealt with more than one aspect simultaneously.

First, many researchers have examined the impact of organizational structure on new product development performance from the perspective of an information-processing view of organizations (e.g., Allen and Hauptman, 1987; Clark and Fujimoto, 1991; Katz and Allen, 1985; Gupta, et al. 1986; Imai, Nonaka, and Takeuchi, 1985; Larson and Goberi, 1988; Marquis and Straight, 1965). The argument in these studies is mostly centered on the issue of tradeoffs between functional and project organizations. These studies, dealing with the structure-performance relationship, have their theoretical origin in the contingency model developed in the late 1960's in the area of organization theory (Child, 1972; Lawrence and Lorsh, 1967; Galbraith, 1977; Galbraith and Nathanson, 1978) . As the contingency model emphasizes the role of environmental characteristics as moderators of structure - performance relationship, this type of research on new product development also refers to several contingency factors, which we shall examine in due course.

Second, other researchers have viewed new product development activities as dynamic group processes. Beyond the structural properties of new product development projects, these researchers have emphasized detailed communication processes and compositional characteristics of groups (e.g., Ancona and Caldwell, 1992a, b; Allen, 1970, 1977; Allen, Lee, and Tushman, 1980; Katz and Tushman, 1981). For these studies, a new product development project is not merely an information-processing mechanism. It also has to handle its resource dependency on other parts of the organization, as well as the political context in which it is embedded. These studies commonly conduct questionnaire surveys aimed at multiple-respondents from each project so as to identify group characteristics of new product development projects.

Third, new product development has been examined from an engineering point of view. Researchers have investigated the effectiveness of different designs of engineering processes, such as concurrent engineering (e.g., Hartley, 1992; Smith and Reinersen, 1991; Stalk and Hout, 1990; Ward et. al., 1995), overlapping processes (Fujimoto and Clark, 1991; Iansiti, 1992; Imai, Nonaka and Takeuchi, 1985), the compression/experiential strategy (Eisenhardt and Tabrizi, 1995), and the synch-and-stabilize process (Cusumano and Selby, 1995). Some researchers have also examined the impact of alternative designs of project boundaries by looking at the involvement of suppliers and customers in new product development processes (Clark and Fujimoto, 1991; von Hippel, 1990). The role of information technologies, such as CAD/CAM, CAE and expert systems, have also received much attention recently. Figure 2.2 below summarizes factors affecting performance of new product development along the above three categories.

Figure 2.2: Determinants of New Product Development Performance Discussed in Existing Studies



Relationships between Organizational Structure and Project Performance

There is a near consensus among both theoretical and empirical researchers that new product development, especially for system products consisting of numerous components or subsystems, such as an automobile, aims to solve at least two fundamental process problems (Katz and Allen, 1985; Clark and Fujimoto, 1991; Marquis and Straight, 1965; Allen, 1986; Galbraith, 1977). First, product development should coordinate and integrate several subsystems often originating in different technological disciplines to create integrated final products. Second, it may try to develop advanced technologies in each functional area and attain a high level of functionality for each component. While, in general, the former can be achieved through a project organization organized around products with influential project managers, the latter favors a functional organizational structure, in which functional areas are directed by functional managers. Since these two types of organizational structures cannot exist simultaneously in their pure forms, the issue of deciding between a project or functional organization has historically been one of the central trade-offs or problems in the study of new product development.

Early researchers examined this issue in the context of R&D departments. Marquis and Straight (1965), by investigating 38 R&D projects under contract with a government agency, concluded that functional organizations tend to be more effective in technical results, while project organizations tend to be more successful in cost and lead time. Katz and Allen (1985) investigated 86 projects carried out in nine organizations, and demonstrated the relationship between the relative influence of project managers and functional managers, and project performance. They used subjective ratings to measure both independent and dependent constructs. Relative influences between project managers and functional managers were rated by project members. Project performance was rated by senior managers. Their data show that the highest performance is achieved when organizational influences are centered around project managers, and when influences on detailed technical work are centered around functional managers. Their study implies that an appropriate separation of roles between project managers and functional managers is more important than simply balancing their roles. Similarly, Allen et. al. (1988) conducted a questionnaire survey of 181 teams, including 2,000 subjects drawn from a wide variety of R&D organizations, and found effective role separation between project managers and functional managers. They concluded that, in successful projects, functional managers play an important role to keep up with state-of-art technology, while project managers help team members receive appropriate attention from the entire organization and to interact effectively.

Extending this traditional research, more recent studies consider activities outside the R&D department, and emphasize the importance of cross-functional integration that can be facilitated by the project type of structures. For example, Clark and Fujimoto (1991), by looking at 29 new product development projects in 22 automobile producers, examined the relationship between project performance and the type of organization classified along three dimensions: functional specialization, internal integration and external integration. Their data show that, while lower specialization and higher internal integration lead to higher development productivity and shorter lead time, the degree of external integration positively influences total product quality. Along these three dimensions, they obtained four idealized organizational structures for new product development: a functional structure, a light-weight project structure, a heavyweight project structure, and an autonomous project structure (see also Wheelwright and Clark, 1992). Their results suggest that, in general, projects with an influential project manager covering an entire development process -- the heavyweight project structure -- tend to perform better in every aspect of performance.

In another study, Larson and Goberi (1988) assessed the relative effectiveness of five different project management structures: 1) the functional organization, 2) the functional matrix, 3) the balanced matrix, 4) the project matrix, and 5) the project team. In comparing the performance of 540 development projects in terms of cost, schedule and technical performance, they found that both the balanced matrix and project matrix organization performed better in terms of cost, schedule, and technical performance. They found little support for the effectiveness of either the functional or functional matrix approach to project management.

Cross-functional integration appear to be important even in the development of non-assembly products. For example, Henderson and Cockburn (1994) examined 30 years' of research programs conducted in ten major pharmaceutical companies, and explored relationships between firm capabilities and drug discovery. They reported that firms whose research programs are organized either by cross-functional teams or around therapeutic areas outperform those whose programs are organized around disciplinary areas, with performance measured as the number of patents granted. The same result held at the research program level.

There are also several case studies directly dealing with the issue of the cross-functional interface (Imai, et al. 1985; Gupta, et al. 1986). These studies emphasize the importance of cross-functional integration for successful project performance. For example, Imai, et. al. (1985) examined seven product development efforts in five major Japanese companies, and found several common factors making them successful. As one of these factors, they discussed the importance of cross-functional team structures comprised of people with diverse backgrounds, in conjunction with intensive internal- and external-communications and role redundancy among project members.

One problem in these empirical studies may be a lack of clarity in distinguishing between cross-functional integration and project independence or autonomy, both of which are implied by project organizations. Although these two ideas are related, they are conceptually independent, since cross-functional integration, for example, through strong project managers and internal communication, can be achieved without co-located and dedicated teams. The existing empirical studies seem to be deficient in the measuring independence of projects. While people from different functional and disciplinary areas gather to form a project, they might be simultaneously in charge of other projects. However, very few studies have examined the impact of such project independence on performance.

Second, since organizational structures tend to be regarded as a pattern of contemporaneous interactions among organizational members (Walsh and Ungson, 1991), these studies deal only with organizational structures at a specific point in time. This overlooks the fact that various activities within the product development organization are spread out over time, and thus, erroneously de-emphasizes temporal inter-relationships as an element of organizational structures. Product development is not necessarily a momentary activity, but is usually continuous and calls for the inclusion of a time dimension to take account of this fact.

As indicated in the above review, recent empirical studies tend to show a strong support for the effectiveness of the project-oriented structure as facilitating cross-functional integration. However, some older studies conducted within the context of R&D departments show that the functional organization is also desirable for achieving technical excellence.[15] There are also contradictory findings regarding the role of project managers. For example, while Fujimoto and Clark (1991) suggested that project managers should be heavily involved in detailed technical work, Katz and Allen (1985) found that influences on technical work should be centered around functional managers for project

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[15] With regard to this, the existing studies show somewhat contradictory findings. For example, while Marquis and Straight (1965) found that a functional structure is desirable for achieving high technical performance, Larson and Gobeli (1988) reported that a project-oriented structure performs better in this area. Such an inconsistency can be also explained by contingency factors affecting structure-performance relationships.

success.

This contradiction suggests that the effectiveness of different organizational structures may depend on contingency factors, such as task characteristics, strategies and environmental conditions, as discussed in traditional organizational theories (Lawrence and Lorsch, 1967; Galbraith, 1974). In this respect, studies of product development organizations propose several factors that influence the relative effectiveness of different organizational structures.

For example, Allen and Hauptman (1987) discussed the impact of environmental conditions and the nature of the technology on the design of an effective organizational structure. They argued that project duration, the degree of technological change, and interdependence between subsystems are key determinants of whether a functional or a project organization is more appropriate. They hypothesized that, while faster technological change and longer project duration favor functional organizations, subsystem interdependence favors project organizations.

Clark and Fujimoto (1991) demonstrated that the relationship between organizational types and project performance is somewhat moderated by company strategies that reflect the nature of their task environments. They classified company strategies into two categories, volume producers and high-end specialists. They suggested that high internal and external integration are not necessarily important for the success of high-end specialized producers, but that a high degree of specialization is crucial. This is because products of high-end specialists have relatively stable technical architectures and user-interfaces, which means less interdependence between subsystems and between technical systems and user preferences.

Since most recent empirical studies have examined complex assembly products such as automobiles (Clark and Fujimoto, 1991; Imai, Nonaka, and Takeuchi, 1985; Womack et. al., 1990) and computers (Iansiti, 1992, 1995 a, b; Eisenhardt and Tabrizi, 1995), strong support for the effectiveness of project organizations might be explained by high subsystem interdependence in such products. However, contrary to Allen and Hauptman's projection, fast technological change, which also characterizes these products, did not seem to facilitate adoption of functional organizations. The type of technological change might explain this. When technological change involves inter-related change in different disciplinary areas, specialization through functional organizations might not be optimal (Henderson and Clark, 1990; Iansiti, 1992; Iansiti and Khanna, 1994). In general, however, empirical studies on new product development do not seriously consider the effect of these contingency factors on the structure - performance relationship; if anything, they tend to be included as control variables, not as moderators (Nobeoka, 1993).

Impact of Group Process on Performance

New product development is invariably a collective activity in which numerous people interact. This aspect of new product development, it being an interactive group process, has been emphasized by several researchers.

MIT (Massachusetts Institute of Technology) research groups have extensively examined team processes of new product development projects, especially by focusing on project members' communication processes (e. g., Allen, 1970, 1977; Allen, Lee, and Tushman, 1980; Tushman and Katz, 1980; Ancona and Caldwell, 1992a, b). An underlying hypothesis of their studies is that communication among project members (internal-communication) and with people outside project (external communication) has a positive impact on the performance of development projects. Pioneered by Allen (1970, 1977), some of these studies are characterized by an in-depth data collection method that obtained detailed sociometric communication data by directly asking laboratory members to recall each work related contact at the end of sampling day.

For example, Allen, et. al. (1980) carried out a 15-week longitudinal study at the

R&D facility of a large American corporation. They examined three types of R&D projects: research, development, and technical service. For each type of project, they explored the relationship between the frequency and distribution of project members' communication, and project performance rated by senior managers. They found that the development project can benefit both from intra- and inter-divisional communication within a laboratory, but research and technical service projects do not. They also found that, for product development projects, there are strong relationships between communication with people in other departments, such as marketing and production, and project performance. Finally, their data suggest that the technological "gate keeper" is important for development projects, but not for research projects. An issue of the technological gate keeper was more extensively examined by Allen at. al. (1979). They showed that, while research projects perform better when all project members maintain the same level of communication, product and process development projects show higher performance when external communication is monopolized by one or a few project members, implying the existence of the technological gate keeper.

Other studies have examined projects' compositional characteristics in conjunction with the communication-performance relationship. Katz and Allen (1982), for example, studied the 345 R&D professionals in 50 project groups. They examined such project characteristics as mean age, mean project tenure, project tenure diversity, and mean organizational tenure, and investigated their relationships with project performance. Their data suggest that mean project tenure and a project's tenure diversity have curvilinear relationships with performance, but mean organizational tenure and mean age do not. For example, they demonstrated that project performance reaches the highest at two or three years of mean group tenure, but significantly declines after five years. This relationship was explained by the negative influence of project tenure on important communication. For example, they reported that, for product /process development projects, communication with people outside the projects declines after 2.5 years of mean project tenure, which was found to be a critical contributor to project performance by Allen, et. al. (1979, 1980). Their results suggest that, while project tenure may have a positive impact on performance through a favorable team building process, it also prevents team members from communicating with key information sources, which they called the NIH syndrome.

Extending this study, Ancona and Caldwell (1992a) more specifically explored interactions among team composition, communication and performance. They collected questionnaires from 409 project members that comprised 45 new product development projects at five high technology companies. Their data on communication are subjective ratings by project members, and so do not measure frequency of communication, as in the earlier MIT studies. However, they examined both direct and indirect impact of team compositional characteristics on performance by using path-analysis. They found that diversity of team members' organizational tenure positively affects the internal group process defined by goal definition, developing workable plans, and prioritizing works, which, in turn, leads to high project performance rated by team members. On the other hand, communication with people outside the projects were found to be facilitated by diversity of team members' functional background since people tended to communicate with others having the same functional background. However, they found that both diversity measures have negative direct effects on performance, and that the overall impact of diversity on performance is negative. Based on the same sample projects, Ancona and Caldwell (1992b) found that project teams' specific strategies toward external communication, rather than just the amount of communication, affect project performance. They found that project teams engaged in so-called ambassadorial activities and task-coordinator activities showed the highest performance overall while the amount of external communication itself was only marginally associated with management-rated performance and negatively associated with team-rated performance.

In summary, this stream of studies identified the following factors affecting project performance:

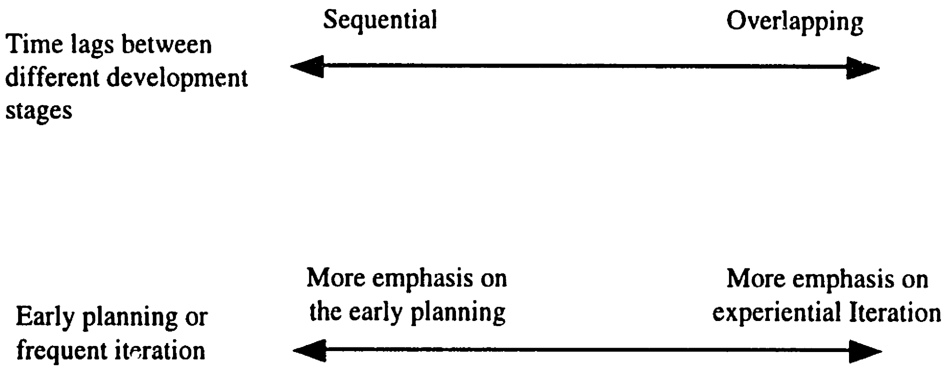
- External communication: project members' communication with people in outside projects has a positive impact on project performance.
- Gatekeeper: when external communication is monopolized by one or a few project members, projects show higher performance.
- Group tenure: projects show highest performance when mean project tenure is moderate, around two to three years.
- Diversity of group members: diversity of organizational tenure and of functional background have direct negative effects on performance

Notably, however, these studies neither examined project members' experiences in past projects, nor their communication specifically with people having experiences in past development projects. Considering the fact that many new products are aimed at replacing existing ones, it appears important to look at these factors.

The Impact of Development Process Design on Performance

From an engineering point of view, researchers have examined the impact of different designs of the development process on performance, most often, on development leadtime. Characteristics of development process design have tended to be captured along two dimensions, although different researchers have described it in different ways (Figure 2.3).

Figure 2.3: Characteristics of the Design of New Product Development Process



The first dimension is the degree of stage overlap. At one extreme, new product development can move through different phases in a step-by-step fashion, that is, upstream processes (e.g., product engineering) and downstream processes (e.g., process engineering) are conducted sequentially. This is often called the sequential approach (Imai, Nonaka and Takeuchi, 1985). At the other extreme, new product development can be conducted in such a way that activities at different stages are overlapped and move simultaneously. This is called an overlapping approach (Clark and Fujimoto, 1991) or a rugby process (Imai, Nonaka, Takeuchi, 1985). It is also a critical element of concurrent engineering (Hartley, 1992; Smith and Reinersen, 1991; Stalk and Hout, 1990). Overall development leadtime can be compressed by starting down-stream activities before up-stream activities end without reducing leadtime within each stage. However, for the down-stream phase to start early, it needs to acquire information from down-stream. Therefore, it has been theoretically hypothesized that the higher stage-overlap reduces development leadtime only when it is combined with intensive information exchange between up-stream and down-stream (Clark and Fujimoto, 1991; Hartley, 1992; Wheelwright and Clark, 1992).

There are several studies that empirically test the impact of stage-overlap on project performance. For example, the Harvard Business School automobile studies (e. g., Clark and Fujimoto, 1991; Clark, Chew and Fujimoto; 1987) found that Japanese projects show both higher performance characteristics and a higher stage-overlap ratio (especially between product engineering and process engineering stages). According to this research, the stage-overlap combined with frequent information exchange between upstream and downstream phases to account for a shorter average leadtime and higher engineering productivity (low engineering hours) for Japanese projects, compared to the U.S. and European projects.[16] Similarly, Iansiti (1992), in his study of the mainframe computer industry, showed that a high overlapping capability significantly reduces development leadtime, even after controlling for country effects. His measure of the overlapping capability consists of the degree of stage-overlap, the level of cross-functional information exchange, and the capability of prototype building.

However, Eisenhardt and Tabrizi (1995), in their study of computer industry projects, found that the degree of stage overlap has no significant effect on development leadtime for their sample, which included new product development projects from three different product segments - the mainframe computer, the microcomputer, and the personal computer/peripheral products. They also examined the impact of stage overlap by each product segment. Their results show that stage overlap reduces leadtime only for mainframe and microcomputer products, but that it has no effect on leadtime for personal computer and peripheral product development projects. They interpreted this result as implying that stage overlap can reduce leadtime only for predictable projects facing relatively stable environments.

Second, new product development has been characterized by whether it involves frequent and rapid iterative processes or it places more emphasis on pre-development

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[16] More recent research of the Harvard auto study group shows that Japanese advantages against the U.S. projects in terms of development leadtime disappeared as well as the degree of overlapping. They actually reported that a concept stage and an engineering stage are now more overlapped in the U.S. projects than Japanese projects (see, Ellison, Clark, Fujimoto, and Hyun, 1995).

planning (Eisenhardt and Tabrizi, 1995). On the one hand, product development may start with a very ambiguous product concept, then gradually crystallize through numerous experiential and iterative processes (Eisenhardt and Tabrizi, 1995; Cusumano and Selby, 1995; Imai, Nonaka, and Takeuchi, 1985; Wheelwright and Clark, 1992; von Hippel, 1994; Ward, 1995). In this process, the design specification is only loosely or incompletely defined at the early stages, but it gradually converges through continuous modification to adapt to changing customer needs. This process, which we might call the iterative approach, has been given different labels in different studies, such as the experiential strategy (Eisenhardt and Tabrizi, 1995), the synch-and-stabilize process (Cusumano and Selby, 1995), and the rapid prototyping process (Clark and Fujimoto, 1991; Wheelwright and Clark, 1992). Since frequent iteration facilitates designers' learning by doing, designers can improve their chances of creating a successful design and gain intuitive understanding for the sensitivity of design parameters and the design robustness (Eisenhardt and Tabrizi, 1995). Therefore, it has been hypothesized that the more iterative approach results in shorter development leadtime.

Related to this iterative approach, Cusumano and Selby (1995), in their in-depth case study of Microsoft, labeled Microsoft's product development style the synch-and-stabilize process, which they contrasted with the more conventional waterfall process. According to their description, Microsoft teams begin by making a vision statement and outline specification of features to guide projects. In this early stage, they define the strategic vision of the new product, but avoid writing a complete product specification and detailed design document. Projects retain sufficient flexibility for the product specification to be refined and evolved throughout development process, so as to adapt to user inputs and fast changing consumer needs. Projects are organized into small feature teams that work in parallel. These teams synchronize, debug, and integrate their work daily, weekly, and at major milestones. They found that the establishment of this synch-and-stabilize process has significantly contributed to a reduction in the delay in the shipment of new Microsoft products.

Eisenhardt and Tabrizi (1995) empirically tested how the iterative approach reduces development leadtime in the computer industry. They first identified two approaches to new product development -a compression strategy and an experiential strategy- and then tested how these two approaches affect development leadtime. The compression strategy is characterized by its emphasis on the early planning phase, use of CAD, supplier involvement, multi-functional teams, and phase overlapping. On the other hand, the experiential strategy is identified by frequent design iteration, more time spent on testing, less time between milestones, and powerful project managers. Their results show that all four variables indicating the experiential strategy significantly reduce development leadtime. However, among four variables composing the compression strategy, only the multi-functional team was significantly associated with shorter development leadtime. Surprisingly, more use of CAD and more time spent on planning slowed the pace of product development.

Taking a different perspective, several researchers have emphasized the importance of pre-development planning. They suggest that people from different functional areas should be involved in the early planning stage to prevent problems from occurring at later stages of the development process (Wheelwright and Clark, 1992; Clark and Fujimoto, 1991; Iansiti, 1992; Womack et. al., 1991). Spending more time in the pre-development phases, or the up-front loading, can eliminate potential problems, especially those derived from interaction between different components and functions. Since the costs of design changes significantly increase in the later stages, predicting and fixing problems as soon as possible should improve efficiency of product development (Wheelwright an Clark, 1992).

For example, data from the software industry indicates that fixing a bug late in a project or after delivering is about 100 times more expensive than fixing the bug when it occurs (Boehm, 1981).

Iansiti (1992) has also provided empirical evidence. In his study of the multi-chip module for mainframe computers, he found that the ratio of concept leadtime to development leadtime is substantially higher for Japanese projects (average = 0.94) than U.S. and European projects (average = 0.55), and that Japanese projects spend less than half of the engineering resources spent by U.S. and European projects. He explained that this is because emphasis on the early concept stage enhances a product's system-level integration and leads to less rework in later stages.

Whether the continuous iteration, or early planning, is optimal may be partially dependent upon the degree of task uncertainty involved in product development. For example, while products for which researchers suggest more iterative approaches, such as software and personal computers, can be characterized as fast changing environments both in technologies and user requirements, products for which researchers suggest early planning may be desirable, such as automobiles and mainframe computers, might be in less uncertain technologies or markets. There are also physical constraints on the adoption of iterative approaches in some industries. For example, since automobile development inevitably involves time-consuming die development, there is a certain limit for the number of iterative cycles even with advanced CAD/CAE technologies.

Another interpretation, one related more closely to this dissertation, is that the effectiveness of pre-development planning may depend on a project's capability for bringing past experiences to the current projects (Iansiti, 1995 a, b, c). While task uncertainty may decrease the effectiveness of the early planning, the uncertainty can be reduced by intensively learning from the past project experiences (Aoshima, 1994). Thus, it may be interesting to look at differences in the relationship between development process design and performance between projects with and without linkages to past projects.

Supplier Involvement

Another issue in designing the development process is the degree of supplier involvement. Theoretically, when product architectures allow the design problems to be decomposed into de-coupled subproblems, product development can better exploit supplier capabilities (Ulrich, 1995; von Hippel, 1990). Supplier involvement reduces task complexity that focal projects have to handle (Clark and Fujimoto, 1991), and also exploits suppliers' specialized knowledge and economies of scale.

Empirical evidence mostly supports the effectiveness of supplier involvement. For example, as a part of the Harvard automobile studies, Clark (1989) reported that, despite higher unique parts ratio, Japanese projects showed fewer engineering hours because of their extensive use of suppliers to reduce the in-house new design ratio (project scope). Clark and Fujimoto (1991) found, in particular, that Japanese firms relied on components whose functional specifications are developed by assemblers and detailed engineering is conducted by suppliers. They called such components "black-box parts" [17] According to these studies, greater supplier involvement appears to account for approximately one-third of the Japanese advantage in engineering hours and four to five months of their advantage in lead time.

In summary, these studies provide ample information to predict the performance of a single project. However, they tend to neglect issues that cut across different generations of projects. Whenever new products are developed to replace existing products, linkages between different generations of projects in terms of technology and organization should have some impact on performance of the current project.

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[17] For the historical description of the black-box parts practice in Japanese companies, see Fujimoto (1994).

2-1.2 Performance Measurement and Project Definition

While the above review allows us to identify factors for successful new product development, which will be considered in our empirical work, it also provides several methodological lessons. We now discuss two of these issues: performance measurement and project definition. .

Performance Measurement

One of the critical issues in studies of new product development is how to measure project performance. Existing studies vary in this regard. Some use relatively objective measures, such as development leadtime (Clark and Fujimoto, 1991; Iansiti, 1992; Eisenhardt and Tabrizi, 1995), engineering hours (Clark and Fujimoto, 1991; Iansiti, 1992, 1995a; Nobeoka, 1995), market share (Clark and Fujimoto, 1991; Nobeoka, 1993; Nobeoka and Cusumano, 1992), and the number of patents granted (Henderson and Cockburn, 1994). Others use subjective ratings by project members (Ancona and Caldwell, 1992a; Nobeoka; 1993), senior managers (Allen et. al. 1979, 1980; Katz and Allen, 1982, Dougherty, 1992), or industry experts (Clark and Fujimoto, 1991). Based on such diverse ways of measuring performance, it should be important to recognize potential biases and difficulties involved in these performance measures both in interpreting results and in designing another empirical study.

Subjective measures are subject to several inherent problems. For example, when subjective responses both for performance and for independent constructs come from the same questionnaire (e.g., Ancona and Caldwell, 1992a; Larson and Gobeli, 1988; Kusunoki, Nonaka and Nagata, 1995), the common method bias may distort real relationships. Especially if the respondents are familiar with the results of past studies, they may attribute their success to factors identified in those studies. In addition, when individual ratings are aggregated to form project-level constructs, an aggregation bias might be a problem (Rousseau, 1985). Furthermore, it may not be appropriate to treat data obtained by using the Likert-type scale as interval data.

Objective measures also have problems. Below we discuss these problems by focusing on two popular performance measures observed in the existing studies: development leadtime and engineering hours. The discussion is primarily based on information we obtained during our interviews at seven Japanese companies.

First, there is a problem of comparability. For example, despite increasing interest in development speed, it is not an easy task to acquire comparable leadtime data across different companies, especially because the time of project start is often unclear. Existing studies handle this problem by providing a description of pre-defined development phases. For example, the Harvard automobile studies (e.g., Clark and Fujimoto, 1991; Ellison, Clark, Fujimoto and Hyun, 1995; Clark, Chew and Fujimoto 1987) devised such pre-defined development phases as concept creation, vehicle planning, detailed engineering, and process engineering. This helps respondents to specify leadtime. However, concept studies in automobile development usually start before the formal management approval, and the very initial stage of concept studies may involve only a few people. Total development leadtime may significantly differ whether or not respondents include this early activity. For example, one Nissan engineer mentioned that some Japanese projects may show longer leadtime for concept studies because of the projects' continuity across generations.[18] For project members who continue their positions from the earlier generation of a project, they start to imagine the next product right after the launch of the previous product, and this tends to be included as a part of the concept phase.

Eisenhardt and Tabrizi (1995) tried to solve this problem by defining the start of a project as the time when the first meeting was held to consider the development of the focal

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[18] Based on remarks made by Mr. Sasabe, senior manager, Nissan Motor Corp., during IMVP sponsors meeting held in Tokyo, May 29, 1995.

product. However, since there are often a lot of informal meetings before an initial product plan is proposed, it seems difficult to obtain first meeting date that is comparable across different companies.

There are also difficulties in obtaining comparable engineering hours. For example, during our field study, we found that one company did not keep track of engineering hours. Even when companies have formal records, differences in the definition of a project's boundary may influence the calculated number. For example, many components, such as an engine and a suspension system in the case of automobiles, are developed for more than one product. Companies differ in the way they allocate engineering resources used to develop these components to a particular project. Some project managers told us that they calculate total engineering cost assuming that no other projects share the same components.[19] Managers in other companies said that they allocate engineering hours for a particular component development to all related projects using that component. It is quite difficult, if not impossible, to take this difference into consideration. In addition, some portion of engineering resources may not show up in the formal records. For example, one project manager we interviewed mentioned that, sometimes, he asked engineers informally to work for his projects without using budgeted engineering resources.

To take into account the shared engineering resources, the Harvard automobile studies excluded engineering resources used to develop power-trains, including engines and transmissions, since the development of power-train units takes much more time than each model development. However, when multiple projects develop technologically-related products in parallel, exclusion of engineering resources shared across projects becomes much more difficult. For example, the Domani project at Honda is reported as spending only one fifth of a more typical project's engineering hours.[20] This is because

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[19] Interview with Mr. Ishidera, chief engineer, Toyota Motor Corp., July 29, 1992.

[20] "Nihongata Re-engineering (Japanese Re-engineering)", p. 102, Nikkei Business, Nihonkeizai-shinbunsha,

the Domani project developed its new product in parallel with the Civic project, whose platform was rapidly transferred to the Domani project (Nobeoka, 1993). Since the Domani project shared many engineers with the Civic project, some of the shared engineering resources were probably assigned to the base project, which developed the Civic.[21] In this case, we cannot understand real development efficiency without examining both the base and derivative projects.

Second, there is a problem of construct validity. For example, development leadtime may not always be an appropriate measure for development speed. Since development leadtime is crucial, projects tend to give the highest priority to this. Under such a circumstance, leadtime becomes what they must follow, but it may not appropriately reflect performance of their activities. For example, if project managers realize, during a development process, that they may not be able to follow the projected leadtime while achieving the product quality they want, they tend to compromise technical performance and technological novelty to avoid delay of the product launch. For example, a project manager at Mazda, who was responsible for development of Eunos 800 (called Millenia in the US), discussed this problem:

> "We wanted to introduce it [Eunos 800] by fall 1993. However, development of the mirror cycle engine [a completely new engine for the Eunos 800] would take until this fall [1994] or next spring [1995]. It was quite difficult to bridge this one year difference. What I proposed is to maintain the uniqueness of the engine system, but to simplify components by using existing ones. For example, although if we had incorporated VVT (Variable Valve Timing), we could have achieved much higher performance, we did not do that because, within the planned leadtime, we could not achieve the required reliability. In this sense, this engine has a great potential for future improvement."[22]

Tokyo, 1994.

[21] As Nobeoka (1993) found, a portion of reduced engineering hours is attributed to the effective inter-project management through the rapid design transfer strategy.

[22] Interview with Mr. Uchiyama, Shusa, Mazda Motor Corp., May 19, 1994.

Although it is possible to adjust leadtime by controlling, for example, for technological newness, as existing studies have shown (e.g., Clark and Fujimoto, 1991; Nobeoka; 1993), such adjusted leadtime are far from perfect when there is strong influences from a standard development schedule. All seven companies we interviewed have standard cycle plans for new product introduction. It is not often the case that overall development leadtime substantially deviates from this standard schedule. For example, when we asked one manager at Nissan about the leadtime of projects, he first gave us the standard development schedule and said that all projects basically follow this schedule though there are some differences. Under such a circumstance, total development leadtime may not be a good indicator for development speed because of its low variance. In other words, most projects do not try to go faster or slower than their schedules.

Third, there is a difficulty in selecting control variables. Objective measures such as development leadtime and engineering hours are influenced by several factors, such as task complexity, technological newness, supplier involvement, and component sharing. Results may be strongly influenced by the selection or omission of these control variables. For example, Eisenhardt and Tabrizi's study examines development leadtime of quite diverse projects in the broadly defined computer industry including mainframe computers, micro computers, personal computers and peripheral products. However, their model includes only a few control variables, project size and industry segment, both of which have only two categories. If they had included other control variables, more specifically describing product characteristics, the results might have changed. The Harvard auto studies made substantial efforts to incorporate a full set of appropriate control variables. Their original studies, conducted in the late 1980's, included model price, degree of supplier involvement, country dummies, the number of body types, degree of body change, unique parts ratio, and in-house component ratio, as control variables. In addition to these variables, their recent study (Ellison, Clark, Fujimoto and Hyun, 1995) added even more sophisticated control variables, such as platform complexity, badge (brandname) complexity, and component/process innovation indices.

If we can completely ensure comparability, construct validity, and appropriate control variables, the objective measures are probably much better than subjective ratings. However, it is costly to ensure this because it would require in-depth observation. On the other hand, subjective ratings, though less reliable, can implicitly reflect these factors. For example, when respondents are asked to rate their development speed and development efficiency, they probably take many control variables into account, such as task complexity, technological newness, and supplier involvement. If they had unexpected troubles in their design work and had to compromise on technical performance, they might report low performance in adherence to schedule even if projects finish within target leadtime. Respondents tend to have a common reference point, at least, within the same companies. In the case where there are substantial differences across companies in terms of reference points, we can re-code subjective ratings by subtracting company-level mean values (e. g., Ancona and Caldwell, 1992 a, b).

Although we think there are pros and cons both for subjective and objective measures, few empirical studies use both types of measures simultaneously.

Definition of Projects

New product development involves numerous people. For example, in the case of automobile development, some projects include between 500 and 800 or more people at the peak. Some people are full-time, and others are part-time. Boundaries of projects are not always clear. However, when we are interested in group-level constructs whose measurement requires multiple respondents from each project, definition of the project boundary becomes critical. For example, if we want to measure average frequency of communication among project members, we need to specify who we include as project members.

There are two ways to define project members. First, researchers may rely on a company's own definition. For example, Ancona and Caldwell (1992 a, b) defined a project team by obtaining a list of team members from company records. They then verified this information with team members, including people whom a majority of team members considered to be on the team. This method can remove the possibility of a researcher's arbitrary selection.

However, the definition of a project team may be different from company to company, and even from project to project. For example, when we asked the number of core project members at the Japanese automobile projects, this ranged from 10 to 50, which implies that different projects counted core project members differently. The word "team" may thus have different meanings for different companies. For example, engineers at Toyota mentioned that they do not feel like team members since they formally belong to a technical functional department. Another related problem is that people may define project boundaries based on factors that are of interest to researchers. For example, they may define project members by considering frequency of communication. They may also define them according to those who are substantially influenced by project managers. In this case, it becomes less meaningful to compare frequency of communication and relative power of project managers among sample projects, since the project definition already includes it.

Alternatively, researchers can define project members *a priori*. In this dissertation, for example, we tentatively define core project members as including project managers and representatives from technical and functional areas. By doing so, we control for the functional background of team members, which means that we are unable to examine functional backgrounds as characteristics of the project team. On the other hand, this does enable us to appropriately compare other characteristics, such as frequency of communication, other compositional background characteristics, and experience bases, because these are independent of the project definition.

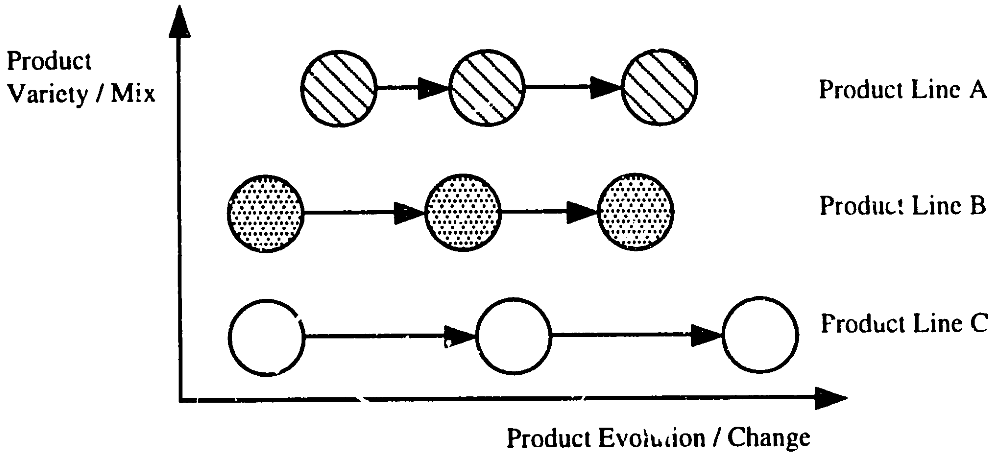
2-1.3 Cross-Project Studies: Studies Focusing on the Level above Individual Projects

Even though many empirical studies focus on the individual project level, some recent studies have emphasized the need for product development processes and strategies that go beyond the consideration of individual projects so as to explicitly deal with the inter-project relationships as a key element of a new product development process.

Multi-Product Strategy

Most studies of this category to date have focused on strategic issues associated with introduction of multiple related products. Two strategic dimensions have often been considered (Figure 2.3).

Figure 2.3: Dimensions for Multi-Product Strategy



*Each circle stands for an individual product.

The first is a strategy for product evolution that includes decisions regarding the extent of product change, timing, frequency and sequence of new product introduction, the extent of technological carry-over, and similar elements. The second is a strategy for product portfolios and product variety. It includes decisions regarding product mix, relative positioning, technology sharing, and manufacturing flexibility.

Sanderson and Uzumeri (1990) and Sanderson (1991) discussed the importance of an evolutionary perspective in the management of product families in a highly competitive environment, which requires the continuous upgrading and improvement of existing products. In analyzing the development of Sony's Walkman, they described how Sony introduced more than 160 product variations between 1980 and 1990, based on existing platforms, while continuously improving and renewing these platforms. They proposed a specific strategy for such product improvement, which they called "design-based incrementalism." Design-based incrementalism is a strategy to effectively leverage core design resources to make numerous derivative and modified products within a short period of time. According to them, a new capability, called "virtual design," enables this fast product renewal. The virtual design is the "capability in information processing and computer-aided design (CAD) to store information about product design and function and to reuse that information in designing new products for model changeover" (Sanderson 1991, pp. 296). Their model shows that the use of virtual design is particularly effective when new products incorporate many component designs that are modified from the existing ones.

Meyer and Utterback (1993) analyzed the role of the evolution of product families in the development of a core capability, which was applied in subsequent development work. They mapped the chronology of three product families in a large corporation engaged in the electronic imaging business, and demonstrated how the evolution of product families is related to the development of a company's core capabilities and, in turn, performance.

They found a positive association between core capabilities and the success of product families, both of which were subjectively rated by ten product developers and divisional managers, respectively. Based on this result, they suggested that management should avoid single-product funding, and that they should invest in core capabilities from the viewpoint of product family evolution.

Similarly, Wheelwright and Sasser (1989) discussed inter-product linkages from the technological point of view. By examining the evolution of the vacuum cleaner in two firms, they developed a product generation map as a tool for analyzing the evolution of a product family over time. They categorized new products into new platform and derivative products, which were further categorized into "enhanced," "customized," "cost-reduced" and "hybrid." In a related study, Wheelwright and Clark (1992) discussed the concept of the aggregate project plan, designed to ensure that a set of projects accomplish the companies' product development objectives. They classified product/process development projects into the following four types along the degree of product and process change: research/advanced development projects, breakthrough/radical projects, platform/next generation projects, and derivative projects. They suggested that management has to make an appropriate plan for the project mix by considering both benefits from each type of project and expected resource requirements.

In another study, Kusunoki (1992) investigated the evolutionary pattern of new product development in the facsimile industry. He classified companies' product strategies along two dimensions: frequency of new product introduction and magnitude of change in products' functional performance. By examining 185 new products developed during a period between 1973 and 1987 by four major facsimile producers, he found that the four companies took distinctive strategies labeled either as a discrete or an incremental approach. He described, for example, that Matsushita Denko, taking a strategy of frequent change and the incremental approach, failed to shift to new digital technologies because of excessive investment in analog technologies.

In a study with greater emphasis on the issue of product variety, Cusumano (1991, 1992) discussed several examples of both single and multiple project styles of management in the US and Japanese computer software industries. He analyzed the evolution of software production systems from craft or job shops to flexible design and production systems. This study demonstrated that a flexible deign and production system can produce a variety of semi-customized products at relatively low cost through the creation of components, tools and processes for reuse across different projects.

Clark, Fujimoto and Aoshima (1992), by illustrating cases in the automobile industry, discussed the concept of product-line management, as opposed to individual project management. Their basic focus was on how to manage the trade-off between product-line integrity and individual product integrity; in so doing, they identified several types of product-line strategy, and argued that these correspond to different organizational types. For example, they discussed two elements of analyzing a product line in the static case: relative positioning and identity. They then identified four distinctive product-line strategies: product-driven, identity-driven, position-driven, and total product-line driven. They also proposed a framework to analyze a dynamic aspect of product line strategy in which they emphasized continuity, relative change, and timing and sequence as building blocks for a dynamic product line strategy

Despite a rich conceptual discussion in this area, systematic empirical investigation of the relationships between multi-product strategies and performance is rare. Nobeoka and Cusumano (1992) and Nobeoka (1993) are among the few exceptions. They investigated 210 new car products introduced during a period between 1980 and 1991 at 17 automobile producers and demonstrated how alternative inter-project strategies influence the rate of new product introductions. They classified inter-project strategies into four categories with respect to types of platform transfer (new design, rapid design transfer, sequential design transfer and design modification) and showed that companies which adopted a rapid design transfer strategy tended to perform better in terms of market share growth. Rapid design transfer strategy is defined as one transferring a base platform within two years after the start of the base project. Their results suggest that firms can create competitive advantage in the market by transferring core technologies and designs quickly across multiple projects.

Compared to studies that clarify strategy-performance relationships at an inter-project level, organizational processes that implement such strategies have, to date, received less attention. However, some existing studies partially deal with organizational issues, as discussed below.

Organizational Issues at Cross-Project Levels

Regarding processes to facilitate an appropriate product evolution, a set of studies are focused on processes of learning between different generations of projects. For example, Cusumano and Selby (1995), in a case study of Microsoft, described how product development projects at Microsoft have benefited from knowledge learned from past development activities. They pointed out that Microsoft institutes a variety of mechanisms to learn from past and on-going projects, such as through postmortem reports, process audits, retreats and benchmarking. They showed how such mechanisms have contributed to substantial improvement of product quality of Microsoft's products through successive version upgrades. They also described how Microsoft tends to rely on people or "mentors" to transfer knowledge about product designs and development processes to new engineers, rather than formal rules, compulsory training programs or detailed documentation.

Wheelwright and Clark (1992) also suggested that systematic efforts are required to learn from past projects because issues in new product development can be very complex and involve many different people in different groups and functions. As one mechanism, they proposed the project audit, a systematic project review conducted by a cross-functional team, and demonstrated an actual implementation of the project audit for the development of a high-performance portable computer.

In a study showing the pitfalls of not learning from the past, Watkins (1991) conducted an in-depth longitudinal case study of the development of front and rear body closures of automobiles at a large European firm. He found that several quality problems not only showed up late in programs, but often were not new, and had already been resolved in previous programs. He found that the program was losing its memory of past problems because of the rapid turn-over of engineers, driven by narrow job content, and explained that this loss of memory led to the occurrence of the repetitive problems.

These studies have opened new research areas in the study of new product development by conceptualizing this as a set of historically-continuous and interrelated activities that continue to generate product development knowledge.[23] Especially, the case-based studies demonstrate actual knowledge accumulation processes and provide insight to identify possible mechanisms for retaining knowledge across generations of projects. As a next step, systematic studies need to explore how learning across generations of projects actually affects performance and what kinds of mechanisms are appropriate for such learning.

As for the management of inter-project strategies, Nobeoka (1993, 1995) examined organizational capabilities required for rapid inter-project technology transfer. He conducted a questionnaire survey of 256 design engineers at 10 major automobile manufacturers in the U.S. and Japan, and explored cooperation requirements and organizational mechanisms to manage interactions between concurrent projects. He classified component design into two categories, one with and without inter-project

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[23] For more discussion of this perspective on new product development, see Kofman, et. al. (1993) and Iansiti and Clark (1993)

interdependency and interaction, and found that the organizational cooperation required to manage these two types of component designs significantly differed. He reported that component designs with inter-project interdependency requires both strong intra-project and inter-project (functional) cooperation.

As for cross-generational linkages, Iansiti (1995 a, b) investigated 27 development projects of multi-chip modules for the mainframe computer, and found that projects that took a system focus approach, and which emphasized technology integration capabilities, tended to perform better in terms of lead time and engineering resources. He found that system focused projects 1) emphasize detailed knowledge about product systems rather than elements, 2) focus on the early generation of knowledge of the potential impact of individual decisions on the broad characteristics of the existing product systems, and 3) retain past knowledge of related technology integration efforts. For example, when integration groups work on a consistent stream of products with continuity in members, projects attain higher performance. He explained that integration groups "specify the scope of the tasks and are the focus for retention of knowledge of the complex interaction between the individual disciplinary bases involved in a sequence of development projects." (Iansiti, 1993: 29) However, he focused only on integration groups as a primary mechanism for knowledge retention We need to examine a broader range of mechanisms for knowledge transfer to fully understand the impact of knowledge retention on product development performance.

In summary:

- Most systematic empirical studies have focused on the management of a single project. While they examined numerous organizational factors to predict project performance, factors cutting across different projects and different generations of projects have largely been neglected.

- Although some recent work shows consideration of relationships among multiple products or projects across product lines and generations, systematic empirical investigations are very few. Especially, the discussions tend to center on strategic issues. Organizational mechanisms implementing strategies at multiple and multiple generations of projects have received little attention.

2-2 Studies of Organizational Memories: Knowledge Retention and Performance

Does knowledge retention from past activities have a positive impact on performance? Theoretical studies of organizations have somewhat contradictory conclusions on this question. On the one hand, successful organizations embed their adaptation activities as organizational routines. Such routines, often reflected in the standard operating procedures, programs, stable communication channels, and organizational structures, form a critical part of organizational memories. Since organizational memories stored as such routines are automatically retrieved, organizations can reduce costs associated with search and experimentation and thus increase task efficiency (March and Simon, 1959; Nelson and Winter, 1982; Thompson, 1967).

On the other hand, it has been suggested that knowledge about the past can blind decision makers to new aspects of environments and thereby compromise an organization's effectiveness (March, 1972; Nystrom and Starbuck, 1984; Walsh and Fahey, 1986). Memory retention facilitates a single-loop learning (Argyris and Schon, 1972) and, thus, enhances the existing routines that may not be appropriate for the new situations. Studies of technological innovation tend to emphasize this negative impact of knowledge retention on innovation performance (Henderson and Clark, 1990; Christensen, 1992; Leonard-

Barton, 1992). Emphasizing the routinized aspect of the past knowledge, and the inevitable and automatic nature of knowledge retrieval, studies of innovation tend to address the issues of how to break the automatic nature of this process so as to create new knowledge. In comparison, processes of existing knowledge retention, application, and transfer have received little attention.

This contradiction is partially explainable by considering differences in organizations' environmental characteristics. Memory retention may increase organizational performance only when organizations are facing stable and certain environments that call for repetitive problem solving. Routines in the form of standard operating procedures and programs can most effectively facilitate organizational members' learning for such problem solving. People who emphasized positive aspects of knowledge retention may primarily look at organizations facing relatively stable environments. On the other hand, those who underscored negative aspects of past knowledge might pay attention to organizations facing novel and uncertain situations. This is why studies of innovation tend to emphasize problems associated with knowledge retention.

That studies of organizational memories have too much emphasis on routinized knowledge and its automatic retrieval (Huber, 1991) further enhances such interpretation. In the literature of organizational learning, two types of learning are often distinguished: search /exploration of new possibilities, and exploitation of old certainty (March, 1991). The argument is that organizational memories tend to be linked to the latter type of learning. Thus, it is said that a distinctive property of organizational memories, as opposed to individual memories, is seen in the *routinized* portion of shared knowledge that is maintained despite the personnel turnover (Cyert and March, 1963; Levitt and March, 1988; Nelson and Winter, 1982). If past experiences are completely stored as routinized knowledge that is automatically retrieved into current settings, relevance of knowledge retention totally depends on environmental conditions because organizational members cannot influence knowledge retrieval processes.

However, past knowledge is not fully routinized, reflected in standard operating procedures, and a stable channel of an organization's communication (Walsh and Ungson, 1991) There is non-routine knowledge that may be partially stored in individuals and archives (Huber, 1991). Such knowledge can be subject to intentional management. Even if no management action is taken, at least part of the knowledge is likely to be automatically retrieved. Therefore, the intentional management of an appropriate retention process may be important both from the point of view of retaining important knowledge, as well as disregarding unimportant knowledge. Thus, Walsh and Ungson (1991) hypothesized that if past knowledge is intentionally and critically considered as it bears on the present, it increases the effectiveness of organizations. If carefully managed, retention of past knowledge is not necessarily problematic even under novel and uncertain situations characterized, for example, by innovation. Some researchers suggested that prior experiences are rather critical for adaptation to new environments. For example, researchers in design studies suggested that any design work is based on past experiences and accepted traditions, and that past knowledge becomes critical to non-routine and creative design work through its appropriate typification (Gero, 1990; Oxman, 1990). Iansiti (1992, 1995a, 1995b) found, in his studies of the multi-chip module for mainframe computers, that system integrators' past experiences in development of the same type of product were positively correlated with development efficiency and technical performance. He argued that retention of past knowledge is crucial to adapt to new technological opportunities since the essence of innovation resides in appropriate combinations between existing technological capabilities and new opportunities.

The above discussion identified two critical issues that we have to consider in examining the relationship between knowledge retention and organizational performance. First, we must take into account differences in environments to which organizations have to adapt. This implies that an actual effect of knowledge retention on organizational performance may be moderated by environmental novelty. The second is the distinction between intentional and automatic retrieval of past knowledge. While automatic retrieval of past knowledge may prevent organizations from appropriately adapting new environments, organizations might be able to overcome this problem by intentionally managing knowledge retention and retrieval processes. We shall take into account these two factors in conducting our study. The environmental condition will be captured by technological and market newness involved in each new product development. Our focus on manageable mechanisms for knowledge retention, such as personnel transfers, communication processes, and information technologies, will distinguish intentional from automatic knowledge retention.

Knowledge Retention Mechanisms

Researchers focusing on organizational memories have explored how memories are stored and retained within an organization. They provide us with helpful hints of how we can empirically observe retention of knowledge across generations of projects.

For example, Kenippendolf (1975) identified three types of organizational memories, each of which is stored and retained differently. First, he proposed the concept of temporal memory. Although each person has only limited capacities to store information, if such information is successively transmitted to other persons with delays, a resulting long chain of people can be sufficient to maintain a significant quantity of temporally coded (or mis-coded) information. Thus, for example, observed intensive communication between older and newer organizational members, and that between people engaged in current problem solving activities and those engaged in past activities, may be a reasonable indication of knowledge retention.

Second, Kenippendolf discussed memory involving records. The basic way to store information is to rely on semi-permanent media that carry past histories. This is intentionally employed by individuals, sometimes, with help of information technologies. Thus, for example, the existence of well-organized databases, documents, and reports can indicate knowledge retention in organizations. Third, he argued for a structural memory. The difference between memory involving records and structural memory is similar to the difference between data and computer algorithms, and between words and grammar. That is, the structural memory stores not just past events, but relationships, structures and rules abstracted from past events. "The defining feature of a structural memory is that past information is represented in the organization of interacting parts into a dynamic whole" (pp. 28). He suggested that an organizational structure, as a reflection of the way organizational members are related to each other and standard communication channels are described, can be said to memorize something structurally to the extent that they are explainable as adaptive responses to past environmental opportunities and threats. In summary, his discussion identified three mechanisms for knowledge retention: a communication chain, archives or formal records, and organizational structure.

Walsh and Ungson (1991) defined organizational memory broadly as "stored information from an organization's history that can be brought to bear on present decisions" (pp. 61). Then, they suggested that it is embedded in systems and artifacts as well as individuals. They identified five retention facilities composing the structure of organizational memory: 1) individuals, 2) culture, 3) transformations, 4) organizational structures, and, 5) ecology.

Information stored in individuals can be retained either by retaining those individuals or by transferring information through communication chains. Organizational members also develop a shared way of understanding, thinking about, and perceiving problems. Walsh and Ungson called this "culture," and suggested that it collectively retains an organization's past experiences. Transformations embed the logic that guides the processing of any kind of input into an output. The standard operating procedures, programs, and rules may be examples. Ecology means the physical structure or workplace environments. In addition to these five facilities, they also pointed out the importance of external archives for memory retention, such as company reports, documents, and retired people, though they claimed that these are not a part of an organization's memory per se.

Walsh and Ungson further argued that these retention facilities have different properties. For example, they suggested that only individuals have the cognitive capability to understand " the 'why' of a decision in the context of an organization's history." (pp. 67) This implies that effective retention of context-specific and tacit knowledge may require direct and intensive interaction between individuals. Not only individuals *per se* but also an aggregation of individuals may also be able to house context-specific past information. When an organizational member helps other members to evoke their past experiences, it can be said that a group of people have collective memories. Such collective memories may comprise complex contingency information behind past decisions they made.

On the other hand, Walsh and Ungson discussed that transformations, structures, and ecology may not be able to store information about "why." While these mechanisms can retain information about an organization's past responses to environmental stimuli, they are not effective to retain information regarding reasons for such responses. Moreover, information stored in these facilities, as opposed to individuals and groups, tend to be subject to automatic retrieval, and not prone to effortful retrieval.

In yet another study, Huber (1990, 1991) emphasized the importance of computer-based organizational memory. He argued that memories that reside in individuals are being increasingly transformed to computer-based expert systems, and that these expert systems increase the accessibility and reliability of information. Table 2.1 summarizes the knowledge retention mechanisms discussed above.

Table 2.1: Knowledge Retention Mechanisms

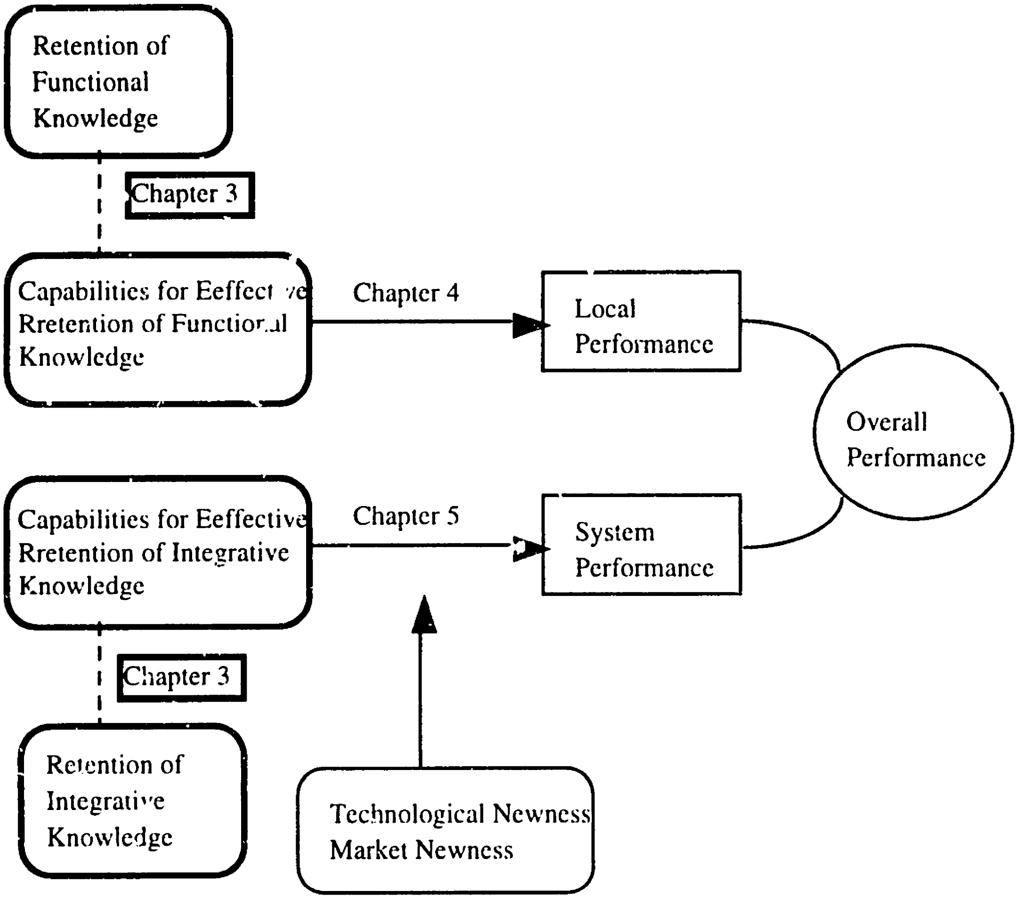
	Memory Retention Mechanisms	Intentional Retrieval?
Individual-based Mechanisms	Continuity of Organizational Members	Possible
	Communication Chains	Possible
	Continuity of Groups and Cohorts	Possible
Structural (or Organizationally- embedded) Mechanisms	Organizational Structure	Difficult
	Ecology (Physical Working Environment)	Difficult
	Standard Operating Procedures, Rules, Programs	Difficult
Archival Mechanisms	Computer-based Memories	Possible
	Documents, Reports, Databases	Possible

Although it is difficult to directly observe how much past knowledge is retained within organizations, observation of these mechanisms may provide us with a reasonable approximation. For example, some researchers suggested that a long and stable history of tenured individuals, existence of dominant cohort groups, and low personnel turnover may indicate higher ability to retain knowledge (Huber, 1991, Walsh and Ungson, 1991, March and Levitt 1988). Similarly, more frequent reference to documented information by organizational members may indicate more knowledge retention.

Since we are interested in intentional management of knowledge retention processes in new product development efforts, we have placed more emphasis on mechanisms less subject to automatic retrieval, such as individual-based mechanisms and archival mechanisms. In the next chapter, we will discuss knowledge retention mechanisms involved in new product development projects more specifically. There, we will also offer several hypotheses about the relationships between knowledge types and appropriate retention mechanisms.

Chapter 3

Mechanisms for Knowledge Retention Across Generations of Projects



In this chapter, we examine the capabilities required to retain knowledge effectively across generations of projects. One of the central themes in this dissertation is to explore how the retention of knowledge obtained from past development experiences influences subsequent product development performance. However, it is difficult to observe actual knowledge retention directly. Instead, we set boundary conditions that indicate the existence of knowledge retention. In section 2.2 in Chapter 2, we discussed several possible mechanisms to retain knowledge, such as continuity of organizational members, inter-temporal communication chains, organizational structures, and archives. Project dependence on these knowledge retention mechanisms should enable us to reasonably infer the existence of knowledge retention.

In the following sections, we begin by describing these knowledge retention mechanisms in detail, and illustrate them with actual practices in the major Japanese automobile producers (section 3.1). Section 3.2 then considers relationships between knowledge types and appropriate knowledge retention mechanisms, and generates a set of propositions. Since this dissertation has a particular focus on the impact of *integrative knowledge* retention on product development performance, we attempt to identify which mechanism is most appropriate for retention of integrative knowledge. Once the association between a particular mechanism and integrative knowledge retention is identified, dependence on such a mechanism can be used as a reasonable approximation of integrative knowledge retention. Section 3.3 empirically tests propositions regarding knowledge retention mechanisms, using data obtained from 229 core project members from a sample of 25 new product development projects in seven Japanese automobile producers.

3-1 Mechanisms for the Retention of Product-Related Knowledge: Case Descriptions

The literature review in section 2.2 of Chapter 2 identified three broad types of retention mechanisms: individual-based, structural-based, and archival-based. Using on this classification, field observations enabled us to examine the following six mechanisms that appear to be critical for knowledge retention across generations of automobile development projects:

1. transfer of project members
2. communication with people who have substantial experience in past development projects
3. involvement by organizational units that coordinate development activities across generations
4. use of documents and reports describing past problematic and successful practices
5. use of design standards, design tools and standard design/test procedures
6. use of computerized information systems, such as CAD and CAE

Below we describe these knowledge retention mechanisms by drawing on examples from six Japanese automobile producers: Toyota, Nissan, Mitsubishi, Honda, Mazda, and Daihatsu. Qualitative information in this section was obtained mainly through interviews with key project members responsible for new product development at these companies. We conducted interviews between 1992 and 1995.

3-1.1 Transfer of Project Members

Knowledge obtained through past development activities may be partially stored in individuals. Therefore, bringing persons who have appropriate experience in past development into current projects is one way to transfer knowledge across generations (Roberts, 1979). One of the advantages in knowledge retention through people is that individuals have the cognitive capability to fully understand the "why" of the past development decisions (Wong and Weiner, 1981). For example, although engineers can easily transfer the prior design itself through drawings, "it's difficult to understand why previous engineers chose such designs only from drawings."[24] Information about the

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[24] Interview with Mr. Ozaki, Group Leader in the Engineering Planning Group, Mitsubishi Motor Corp.,

reasoning behind decisions may be particularly important to improve existing designs. In addition, when past knowledge includes tacit and context-specific components, storing information on documents and blueprints in the form of facts and propositions may miss important surrounding contingency information, which may lead to misuse of the past knowledge (Garud and Nayyar, 1994; Spender, 1994; Walsh and Ungson, 1991).

Since individuals can be effective knowledge containers, how to manage the flow of people across product development projects within organizations may be of fundamental importance not only for individuals' career tracks, but also for knowledge accumulation at the organization level as a critical element of the capability building process (Kusunoki and Numagami, 1994). Our observations at Japanese automobile companies revealed some examples that indicate explicit management of the consistent flow of people across generations of projects, as described below.

Continuity of the Project Management Group

First, in companies such as Toyota, Mitsubishi, and Daihatsu, project management groups tend to maintain a continuity of people across generations of projects for development within the same product line.

A project management group in these companies is involved both in engineering work and in other functional activities such as cost management, marketing strategy, sales promotion, and production, and integrates an entire project throughout a development process. Although project managers (called "chief engineers" in Toyota) usually do not have formal authority over engineering personnel beyond their direct staff, typically between three and 15 people, they have strong informal authority over the entire new product development process. As one Toyota's engineer put it, "the CE [chief engineer] is

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May 30, 1994.

absolute. The final decision is always in CE's hand."[25] Their strong informal power seems to be derived from their prominent ability to integrate all project activities, obtained from long-standing experiences as project coordinators.

For example, in Toyota, project mangers and their staff used to belong to the Product Planning Office.[26] Typically, engineers with seven to 10 years of experience in body design or chassis design move to the Product Planning Office at around the age of 30. They then become responsible for particular vehicle development projects as staff members of project managers. There used to be three ranks within the Product Development Office, from Shusa (a project manager) and Shusa-tsuki (a sub-project manager) down to Shu-tantoin (a lower-ranked sub-project manager).[27] New entrants to the Product Planning Office start from the Shu-tantoin. They are then promoted to the Shusa-tsuki and Shusa, most often within the same product line. They are trained as candidates for future project managers and learn how to coordinate and integrate the entire product development process. Once they become Shusa (called CE since the late 1980s), they tend to be responsible for two successive product generations. Appendix 1 shows successive project managers for the selected major product lines at major Japanese producers. In this way, Toyota has retained knowledge to integrate all project activities needed to develop new products through people. The example below specifically illustrates how continuous management groups have managed development projects for the Celica/Carina/Corona series at Toyota.

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[25] Interview with Mr. Kodera, Manager in the Technical Administration Div., Toyota Motor Corp., April 6, 1995.

[26] Toyota re-organized its product development organization in 1992, in order to divide it into three vehicle centers and one advanced engineering center. The Product Planning Office was disbanded and absorbed into each of three vehicle centers.

[27] In the late 1980s, Toyota changed these titles. Since then, a former Shusa has been called CE (Chief Engineer); the former Shusa-Tsuki are called Shusa.

Example: History of Celica/Carina Projects at Toyota[28]

Toyota introduced the first generation of Celica/Carina in 1970. The Celica and Carina were variations derived from the same platform design (the same under-floor panels, suspension systems, braking systems and engines systems) with different upper bodies. Toyota characterized the Celica as an affordable sporty vehicle; the Carina was a sub-compact sedan intended to fill a market segment between the Corona (first introduced in 1957) and Corolla (first introduced in 1966). Introduction of the Carina meant the completion of the first stage of Toyota's full-line policy. Although the Celica/Carina used the basic platform design derived from the existing Corona, their suspension systems, transmissions, and one type of the engine systems (T-Engine) were newly designed.

Mr. Nishida, the former director of the Body Design Department, was primarily responsible for the first generation of the Celica/Carina project as a project manager or Shusa (although Mr. Hasegawa, the former project leader for the Corolla project, lead this project for the first year, he left the project early due to a promotion). He continued his position as Shusa after introduction of the first Celica/Carina series, and led the second generation of the project until 1973. During the period when Mr. Nishida was Shusa, Mr. Wada, as a sub-project manager or Shusa-tsuki, played a critical role in supporting Mr. Nishida. He then took over Mr. Nishida's position in 1976, and led a project for the second generation of Celica/Carina, which Toyota introduced in 1977.[29] In this second generation, the Celica/Carina platform design became completely independent of the Corona series.

While Mr. Wada continued in his position until 1986, responsible for the three

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[28] The description here is based on a company internal document and interviews with Mr. Nakagawa, Chief Engineer, Toyota Motor Corp., May 31, 1994, and April 6, 1995.

[29] Although the second generation of Celica/Carina series was planned to be introduced around 1973-74 according to the cycle plan, this was canceled because of the Oil Shock. Partially because of this, Mr. Moriya, Director of the Product Planning Office were directly in change of the Celica/Carina project during the period between 1973 and 1976.

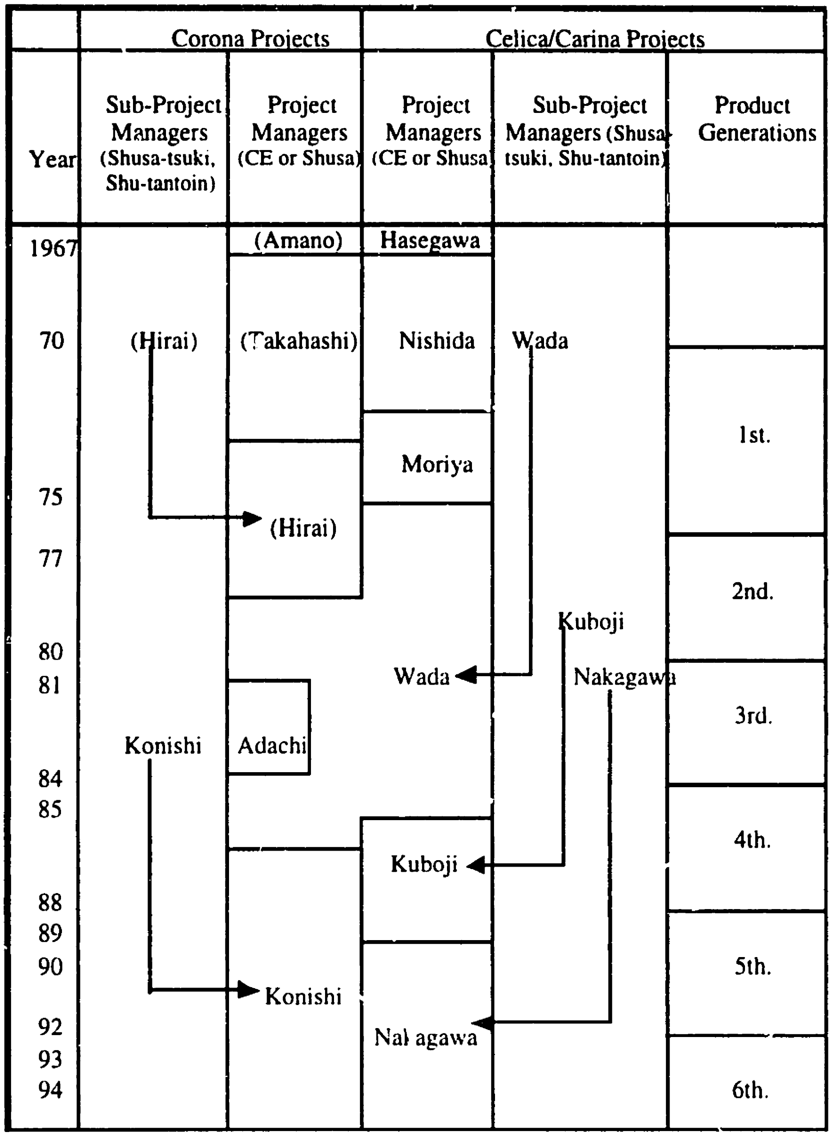
successive Celica/Carina projects, he also became Shusa for the Corona project in 1979. Since Mr. Wada became responsible for both the Celica/Carina and the Corona series, his teams gradually integrated the two series in platform design. For example, when Toyota introduced the third generation of the Carina/Celica in 1981 (Carina in June and Celica in September), project teams integrated a coupe version of the Corona to the Celica/Carina series while it still shared a part of floor-panels with the Corona sedan.

Toyota introduced the fourth generation of Carina in 1983 with major technological changes. The project team completely renewed its platform design from the rear-wheel-drive (FR) to the front-wheel-drive (FF) platform. At the same time, it totally integrated the Cairn's platform design with that of the Corona sedan, that is, the Corona and Carina sedan became "sister" cars. On the other hand, the Celica became technologically independent of the Corona/Carina sedans. Instead, the project team added a coupe version of the Corona (called the Corona Coupe, later re-named EXIV) and of the Carina (called Carina ED, later re-named ED), to the Celica series in 1985 to maintain required economies of scale.

While Mr. Wada was responsible both for the Celica/Carina and Corona projects, several sub-project managers took charge of individual model development. For example, Mr. Adachi was assigned to Shusa specializing in the Corona project in 1981 and led this project to develop the eighth generation of the Corona introduced in 1983. He continued this position until 1984. Mr. Konishi supported Mr. Adachi as a sub-project manager, who took over for Mr. Wada and became Shusa for the Corona project later in 1987. On the other hand, Mr. Kuboji, who joined the Carina/Celica project in its third generation, was specifically responsible for development of the Celica series as a sub-project manger or Shu-tantoin. In addition, Mr. Nakagawa, formerly responsible for the vehicle test of the third generation of the Celica series, coordinated the Carina project as Shu-tantoin.

The fifth Carina series was introduced in 1988; the Celica in 1989. Mr. Kuboji, the former sub-project manager under Mr. Wada took charge of this Celica/Carina project as a project manager. Under Mr. Kuboji, Mr. Nakagawa specifically took care of development of the Carina ED and the Corona EXIV as a part of the Celica series. Then, Mr. Nakagawa took over for Mr. Kuboji to develop the sixth generation of the Celica/Carina projects. The project introduced the sixth generation of Celica/Carina/ED/EXIV in October 1993 with a newly designed platform. As a part of this series, it added Carren (Celica Coupe in the US) in February 1994. Figure 3.1 below shows the project management groups on the Celica/Carina/Corona projects.

Figure 3.1 Project management groups of the Celica/Carina/Corona projects



October 1970 (Celica/Carina)

- A platform was derived from the Corona.

August 1977 (Celica/Carina)

- A platform became independent of the Corona.

July1981 (Celica), September 1981 (Carina)

May1984 (Carina)
August 1985 (Celica, Carina ED, Corona Coupe)

- The Carina and the Corona was integrated (FF). The Celica became independent.

May1988 (Carina)
August 1989 (Celica, Carina ED, Corona EXIV)

May 1992 (Carina)
October 1993 (Celica, ED, EXIV)
February 1994 (Carren)

People in parentheses are not in the text.

As this example shows, the Celica/Carina and Corona series at Toyota has evolved historically with a clear continuity of the project manager group. Most project managers for these projects were promoted from their former positions as sub-project managers within the same series development. For example, Mr. Nakagawa, a project manager for the sixth generation of the Celica series, first, entered the Product Planing Office at the age of 35, transferred from a test department. Then, he experienced the third, the fourth, and the fifth generation of development projects as one of the project coordinators before he became CE (equivalent to Shusa) for the sixth generation of the Celica/Carina series.

Why should project manager groups maintain continuity? Mr. Nakagawa commented on this:

> "Even if the present Celica uses a different technological concept from the past, the characteristics of users have some commonalty. To understand the characteristics of users needs long experience [therefore, a project manager tends to stay in the same project for a long time]. For example, although the current Celica shares basically the same 2.2 liter engine, 5SAF, with the Camry, we did not use the balance shaft for the Celica engine, because I knew that Celica users require more power at the cost of noise. Also, when we decided to carry over a part of the under-floor panels from the previous model, I learned from the past project several issues such as what kinds of problems occurred in previous projects both in technical and user characteristics."[30]

This comment indicates that continuity of project members may be required to deepen the understanding of linkages between user needs and required design features. In fact, in the history of the development of the Celica/Carina/Corona series, project managers and sub-managers tended to be assigned according to targeted segments rather than platform design. For example, even if the Corona and the Carina shared the same platform design, different project managers develop these products after 1986. On the other hand, major technological change indicated by, for example, change from the FR platform to the FF platform in 1983, did not seem to affect the continuity of the flow of people in the project manager group.

Mr. Nakagawa further mentioned that, in the case of the Celica/Carina project,

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[30] Interview with Mr. Nakagawa, Chief Engineer, Toyota Motor Corp., May 31, 1994.

approximately ten key engineers among 200 to 300 project members have stayed in the same project for more than 10 years. According to him, continuity of these key people greatly helped him to coordinate an entire project:

> "It's really easy to work with such people [long-staying engineers]. I could quickly understand, for example, 'His word is completely reliable' or 'What he is saying is half joking.'... Although most of the engineers move to another model development project after the project completion, key people tend to stay for a long time.... Since I cannot drive all test vehicles, vehicle evaluation must proceed through many interactions with test drivers or vehicle evaluators. In such cases, if I understand, for example, 'What he is saying approximately corresponds to this level of my feeling,' I can make a decision just by taking to him [without driving]."[31]

As this comment implies, important knowledge retained by continuing individuals might be related to the need for a specific language to communicate with people of different backgrounds.

Continuity of project manager groups is not unique to Toyota. For example, Mitsubishi's project management groups tend to have similar continuity. At Mitsubishi, project manager groups are located together in the Product Development Office. There are four ranks in this office, from Tantoin, Shunin and PE (a project engineer) up to PM (a project manager). While a PE is responsible for individual model development, his span of responsibility is limited to design and engineering departments. On the other hand, a PM is responsible for multiple related projects simultaneously, and coordinates various functional departments such as production, marketing, sales and cost management as well as design and engineering. Tantoin and Shunin work for projects as PE's staff members.

Similar to the case of Toyota, Mitsubishi's engineers typically enter the Product Development Office around the age of 30, having already obtained experience in body or chassis design. There, they are trained, under PEs and PMs, on how to coordinate projects.

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[31] Interview with Mr. Nakagawa, Chief Engineer, Toyota Motor Corp., May 31, 1994.

Although some PEs and PMs are directly transferred from positions as group leaders (section chiefs) in other engineering departments such as body, chassis, and functional testing departments, approximately 90% of PEs are promoted within the Product Development Office. Shunin and Tantoin may experience different projects, but it is rare for PEs to move across different projects.

Continuity of project manager groups is related to the fact that project integration requires complex human skills that may not be fully replaced by computerized systems. For example, Mr. Ushiro, responsible for the two successive generations of the Minica projects, characterized his task as project coordinator as follows:

> "Most important information for automobile development still depends on person-to-person connections. A computer as a *tool* is increasingly coming into our world. However, human factors are still crucial for us to coordinate development projects."[32]

Mr. Fukui, who led the first and the second generations of the Pajero project, offered a similar opinion:

> "In setting the direction of a new model development project, we rely on our personal knowledge of how users feel about different product features and performance dimensions.... Although we gather as much data as possible both from inside and outside the company [to learn from the past development practices], in my opinion, information related to user feelings should be retained by continued key persons. Although I told you that we have recently started to facilitate rotation across different functional areas, we are also trying to train people knowledgeable in the fundamentals [such as particular model development and particular component development]...."[33]

Mr. Usui at Daihatsu, responsible for coordination of the Mira projects for 14 years,

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[32] Interview with Mr. Ushiro, Group Leader in the Product Development Office, Mitsubishi Motor Corp., April 12, 1995.

[33] Interview with Mr. Fukui, Project Engineer, Mitsubishi Motor Corp., April 12, 1995.

also recognized the importance of a certain continuity of project coordinators. He especially emphasized that staying in successive generations of projects was helpful for him to gain knowledge about the subtle balance between product cost and user requirements:

> "Particularly important is knowledge about the appropriate balance between product features and product cost. For example, such information as 'although we spent a lot of development cost in this feature in the past, customers did not realize benefits from it' seems to be very important. Especially in the case of micromini-car development, the relationship between design features and cost is a critical issue.... Of course, we receive several detailed proposals from the related engineering departments. It is Shusa's [project manager] specific responsibility to deal with decision about human feeling that cannot be expressed by hard data...."[34]

However, not all companies maintain such continuity of project manager groups. Some companies, such as Nissan and Honda, rather explicitly promote the discontinuity of project managers by each major model development in some product lines. For example, Nissan in the 1980s brought various people with diverse backgrounds into positions of project managers.

Before 1980, Nissan's development organization was built around technical functional departments, each of which was in charge of the development of components for a particular set of product lines. For example, Vehicle Design Department No. 1 was responsible for Cedric, Bluebird (Stanza), Sunny (Sentra), Silvia (240 SX), and Fairlady Z (300 ZX) (Ikari, 1985). In those days, there was no project manager equivalent to Toyota's Shusa who coordinated different functional areas. Project managers were typically senior managers in the chassis/body design departments who often continued their positions through two or three successive generations. In addition, they were sometimes responsible

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[34] Interview with Mr. Usui, manager in the Product Planning Department, Daihatsu Motor Corp., May 9, 1995.

for the development of multiple projects. For example, the project manager for the development of the third to fifth generations of the Sunny (Sentra) was also simultaneously responsible for development of the Violet/Stanza and Silvia (240 SX) models.

This development system experienced substantial change from 1980 to 1983. Under the new development system, Nissan stressed strong cross-functional coordination within individual model development projects. Nissan grouped project managers, called "Shukan," into a newly established Shohin-Honbu (Product Planning & Marketing Division) and gave them strong responsibility for the entire development process from concept generation to manufacturing and marketing. Nissan then seemed to emphasize the discontinuity and freshness of project managers and project members, so as to emphasize the uniqueness of each development project. Some project managers, such as those who were responsible for the first Cima projects, the seventh Sunny (Sentra) project, and the fifth Laurel project, were converted from the sales department, which is rare in the case of Japanese automobile companies. While Nissan in the 1980s strongly emphasized cross-functional coordination within each project, it tried to prevent project members from learning too much from past projects (See Appendix 1 for the successive project managers for major product lines.).

Mr. Fukai, a project manager ("Shukan") for the eighth Sunny project, for example, mentioned the following during our interview:

> "Many present Shukans [project managers] were directly assigned from other departments without experiences as previous Shukan's staff members. I was responsible for the previous Sunny project for three years as a staff member. My case is exceptional. I guess, currently, there is no Shukan except me who has experienced the previous model development as staff members.... I was surprised when talking to a project manager for development of the current Corolla [Mr. Honda]. I remember, Mr. Honda mentioned that he has been in charge of the Corolla project for 16 years. I have been staying in the Sunny project for longer

than usual. But this is still 7 years. Even 7 years are exceptional in Nissan...."[35]

According to Mr. Fukai, however more recently, Nissan has changed this policy so as to make project management groups responsible for longer periods. This occurred, for example, in the case of the project for the 1995 Cedric/Gloria, which was one of Japan's best selling domestic cars in 1995.

Whether the continuity of project managers is desirable or not may depend upon various factors, such as company strategies, nature of technology, and market conditions. We will examine this question in later chapters.

Continuity of Engineers

Continuous assignment of component engineers such as body design engineers and electronic component engineers may also facilitate knowledge retention across product generations. In the case of component design, there are at least two types of knowledge or knowhow subject to historical retention.

First, new product development organizations develop and accumulate the specialized and generic component development knowhow independent of a particular vehicle development. For example, engineers can apply fundamental knowledge to develop the multi-link suspension to many different type of vehicles. Second, organizations accumulate knowledge of how to apply such generic knowhow to particular model development. For example, applying multi-link suspension systems to the front suspension of the FF platform model is quite different from applying it to the rear suspension of the FR platform model. Especially when development of one component

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[35] Interview with Mr. Fukai, General Manager in the Product Planning & Development Division, No. 2, Nissan Motor Corp., April 11, 1995.

system depends upon that of other components in the entire product development process, engineers may have to retain various product-specific knowhow for component development.

Organizations can retain specialized and generic component development knowledge by making engineers stay in particular component development for a relatively long period of time. On the other hand, they can retain product specific knowhow by successive assignment of engineers to the same series of development projects across product generations.

In the Japanese automobile companies where we interviewed, both types of continuity seem to be limited to some types of engineers. Although the pattern of continuity differs across different engineering areas, most design engineers tend to frequently change the design parts for which they are responsible. While it is rare for design engineers to rotate across different engineering areas, such as body design, chassis design, and engine designs, engineers rotate across different component development tasks within these engineering areas, such as steering systems, suspension systems, and braking systems in the chassis engineering department. Most design engineers also move around different vehicle development projects.

For example, Mr. Hori, manager in a body design department in Daihatsu, explained how body design engineers move around:

> "Although our body design department is divided into three sections, in fact, there is no wall between these sections. For example, in the case of major model change projects, 20 to 30 engineers are involved at the peak. The peak period lasts for six months or so. After the peak, most engineers move to the other projects and the other component development. That is, the engineers' responsibility for parts design within a body design department changes every six months."[36]

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[36] Interview with Mr. Hori, Manager in the Body Design Department, Daihatsu Motor Corp., May 9, 1995.

Similarly, in the case of the 1990 Tercel, only one engineer out of 30 body engineers involved had experience in the previous generation of the product. Mr. Ezaki, responsible for the body design of this Tercel, mentioned:

> "Engineers move across different projects according to the fluctuation of required manpower in different projects. Body design engineers can design any type of vehicle. Their ability is not bound to a particular model type."[37]

While most design engineers move around different models, key engineers, in some cases, stay in the same project in successive generations. Mr. Hori at Daihatsu discussed this:

> "We do not start the next Mira project from the scratch. Our project is not like 'breaking up the past' or 'replacing all members.' As a development project proceeds for several years, key persons are spontaneously recognized. Those key persons tend to stay for the next project. For example, 20 to 30 body engineers involved at the peak usually decrease to three to four people at the end of project. Those remaining people become a core for the next development to retain prior design solutions and problems."[38]

Engineers have to move around different projects and component design tasks to efficiently and flexibly utilize engineering resources. In fact, several interviewees pointed out that they have actively encouraged engineers to rotate across different technical areas, especially after the economic boom in the late 1980s, when it became difficult to hire new people.

On the other hand, engineers need to accumulate particular knowledge both about

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[37] Interview with Mr. Ezaki, Senior Manager in Body Design Department, No. 1, Toyota Motor Corp., July 29, 1992.

[38] Interview with Mr. Hori, Manager in the Body Design Department, Daihatsu Motor Corp., May 9, 1995.

generic component development and about specific vehicle development. Companies achieve these seemingly conflicting requirements by assigning different engineers to different roles: while most engineers move around across projects and component development, a few key engineers stay in their positions for a relatively long time. In addition to this role differentiation among engineers, individual engineers also seem to take different roles in different stages on their career path. For example, while younger engineers tend to move frequently, senior engineers tend to stay in a project for a longer time.

3-1.2 Communication with People Who Have Substantial Experiences in Past Projects

Project members may communicate directly with persons who have substantial knowledge and experience to learn what occurred in the past. Communication with persons recognized as "experts" in particular technological and functional areas is one way to transfer and retrieve past knowledge. While some experts are informally recognized as such by people within a department, others are formally appointed, based on their knowledge and experience. For example, several engineers are formally registered as experts within the power-train department of Mazda. They take a lead in several types of design reviews held with the other relevant departments in the early stages of the development process. Although experts reside in each engineering department, they have substantial knowledge about problems potentially occurring in inter-functional areas, based on their experiences in past projects. Thus, experts in the production department are familiar with what kinds of designs may cause problems in actual production stages, considering the existing line layout and tact time.

When knowledge is specific to a particular model type and there is no member in the current project who experienced the previous model development, current project members often communicate with people from the preceding project. Since all automobile companies where we interviewed have separate functional units where engineers meet, part of the prior design knowledge may be easily retained through communication within engineering departments. In addition, each engineering department tends to be divided into component development groups and vehicle development groups. While the former concentrates on the development of generic component technologies, the latter accumulates knowledge about specific model development from the perspective of their component development. For example, a test department in Honda includes ten groups. One of these ten groups is called "project task," where 20 to 30 engineers responsible for vehicle development projects get together. Honda organizes other groups by functional testing areas, such as handling, body strength, and durability.

Project managers and their staff also frequently talk to people with relevant experience in the preceding model's development. Mr. Fukui, a project manager for the Pajero project at Mitsubishi, discussed this:

> "Although various information is kept in drawings and documents, it's impossible to understand why such designs and decisions were made in the past without directly talking to people previously responsible for those designs and decisions. Sometimes I go to ask and sometimes I am asked by others, not only for information about direct predecessor models but also for other products."[39]

3-1.3 Organizational Units That Coordinate Development Activities Across Generations

Companies may leverage past knowledge effectively by establishing independent organizational units with a span of control that cuts across different generations of new product development. Clark, Fujimoto and Aoshima (1992) termed this a "dual-matrix." Since almost all of the major automobile companies have matrix-like forms around project managers at the level of individual projects (Clark and Fujimoto, 1991), establishment of

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[39] Interview with Mr. Fukui, Project Engineer, Mitsubishi Motor Corp., April 12, 1995.

independent organizational units cutting across different projects and different generations of projects repeats the matrix form, resulting in a dual matrix structure (matrix in matrix).

A department in charge of cycle planning is one example of such an organizational unit. This links different generations of projects from the perspective of customer concepts. Another example is a department or a group responsible for long-term technology development planning. This integrates different generations of projects from a technological point of view.

In Mitsubishi, the former is called the Product Planning Department, located in Tamachi, Tokyo. Approximately 40 people are working in this department. Two-thirds of these people have non-engineering backgrounds. On the other hand, the group responsible for the long-range technology development planning is called the Engineering Planning Group in the Engineering Administration Department located in Okazaki, Aichi, and was set up in 1987.

Mitsubishi has two types of long-range cycle plans. The first is the LRPP (Long Range Product Planning) that the Product Planning Department mainly create. The LRPP includes new vehicle introduction plans for the next eight years or so. It also includes a long-range platform carry-over plan across generations of products. Although it mainly reflects a marketing perspective, members in the Product Planning Department intensively gather information from the engineering departments to incorporate engineering conditions into the plan.

The second is the LRCP (Long Range Component Planning) that includes long-term component development plans such as for engines, transmissions, bodies, and anti-lock-braking systems (ABS). The Engineering Planning Group creates this. Although the Product Planning Department used to create both the LRPP and LRCP, the Engineering Planning Group was established in 1987 to make plans reflect engineering perspectives more closely. Mr. Ozaki, a manager in the Engineering Planning Group, talked about these long-range plans:

> "[These plans] are like the constitution in the Office of Passenger Car Development & Engineering [a product development organization]. We started to make these plans 20 years ago. We have renewed them once every six months. The current version is the 42nd...."[40]

Other Japanese automobile companies also have similar departments or groups. For example, at Nissan, while the Product Planning Office makes long-range cycle plans for product introduction, the Technological Development Planning Office makes plans for the development of major component systems and platforms, and for their carry-over. A project manager, Shukan, has a direct staff in Product Planning Office, implying that individual product development projects are coordinated from the perspective of the long-term and company-wide product portfolio evolution.

Some companies also have independent organizational units that consider the design implications for manufacturability, such as the Production/Design Section in the Engineering Department No. 3 in Nissan. This section was established in 1991. Approximately 150 people belong to this section; half come from design departments, and the other half are production engineers. Approximately 120 engineers are engaged in standardization, component sharing, reduction of the number of parts, and cost reduction to prepare for new model development. Twenty engineers specialize in the accumulation of knowhow to develop designs that are easy to manufacture and incorporate high production quality.

The Automobile Production Planning Office at Honda is similarly responsible for design for manufacturability, and engineers of this office are involved in the very early stages of the development process to incorporate manufacturing requirements into the

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[40] Interview with Mr. Ozaki, Group Leader in the Engineering Planning Group, Mitsubishi Motor Corp., May 30, 1994.

initial drawings. These organizational units share the function of continuously gathering information from on-going projects to improve design for manufacturing.

Knowledge transfer across generations of projects may also be facilitated by forming hierarchical structures above individual project managers. Under such a hierarchical structure, *super-project managers*[41] may be assigned above the level of the individual project manager in charge of the development of a specific single product. The super-project manager may often take charge of the development of several different products simultaneously, and also manage the general product evolutionary trajectory.

For example, in Mitsubishi, each project has its own project manager, called a "project engineer (PE)." This individual project engineer is directed by a group project manager, called a "project manager (PM)," who looks at multiple products as a group.[42] There are six product groups in Mitsubishi - middle, compact, sporty, recreational vehicle, commercial and mini car - each of which is directed by a single project manager. Each project manager coordinates multiple projects within his group from the viewpoint of administration, cost management, technical issues, and commercial value. The project manager is involved in the individual product development in the early stage of the product development process, and manages key project activities with the project engineer. The project manager is usually promoted from project engineers within the same group.

Honda's example is more illustrative from an historical perspective. Honda's product development teams have traditionally been very autonomous with strong project managers, called "LPLs" (Large Project Managers). Although Honda's development organization maintains functional units, such as an engine department or a chassis department, these departments are in turn subdivided into several groups, by product. Even the engine

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[41] This is different from the so-called heavy-weight project manager identified by Clark and Fujimoto (1991), which refers to strong project managers for individual projects. A super-project manager, in contrast, is responsible for the coordination of activities among multiple individual project managers.

[42] Interview with Mr. Hosono, Project Engineer, Mitsubishi Motor Corp., July 30, 1992.

department includes different groups, each of which is devoted to developing an engine for a specific new product. Since a new LPL is assigned each time a new project starts, coordination between different models and different generations has been relatively de-emphasized. In this sense, Honda's development organizations have been close to an autonomous project team structure (Aoshima 1989, Clark and Fujimoto 1991). Issues across different models and different generations have been partially managed by a "series LPL." The series LPL is an integrator located above the LPL, but only for some specific products. For example. while both the Civic and CR-X (Del-sol) teams each have their own LPL, a series LPL looked at these products as a whole. There has also been a series LPL above the LPL in the Accord and Prelude projects. Unlike the LPL, the series LPL has responsibility for multiple generations of products, so as to manage the product family evolution.[43]

Around 1989, Honda set up an LPL office where all LPLs could meet. The LPL office has a director who coordinates, although loosely, various LPL activities (Aoshima, 1989). More recently, Honda has set up a new organizational unit consisting of five chief engineers, called RADs (Representatives of Automotive Development). Each RAD is in charge of multiple products and manages strategic issues across different products. The RAD also looks at the continuity of product development across different generations. All RADs are promoted from the level of LPL. Honda's product development has been managed by a so-called SED system, where S represents sales; E is production engineering; D is development (Aoshima, 1989; Ikari, 1986). The SED system is essentially a mechanism for maintaining cross-functional integration. Before setting up the RAD, the SED system was managed by an LPL who was a representative of development. The RAD took over this role from the LPL. Since, unlike the LPL, the RAD has responsibility for

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[43] Interview with four executive chief engineers, Honda Motor Corp., July 31, 1992.

multiple products across generations, this facilitates the transfer of knowledge about cross-functional integration beyond individual projects. The Honda example illustrates how the product development organization can evolve by acknowledging, and adapting to, the needs for inter-temporal and cross-project management.[44]

3-1.4 Documents, Reports, and Standards

Companies can store knowledge obtained from past development activities in various types of documents. Our interviews revealed that Japanese automobile companies use documentation extensively as a means to store knowledge about past practices. Although engineers are not obliged to record information, it seems to a common practice for them to write down information obtained from their development activities.

Such documents and reports vary in terms of their formality. They can be broadly classified into the following categories, in the case of Japanese automobile producers (although boundaries between these categories somewhat differ across companies):

1. Company-wide technical standards
2. Department-level design standards, standardized design (test) procedures, and design (testing) tools
3. Formal reports and documents storing non-standardized knowhow, such as process and design knowhow documents, testing reports, and user claim reports
4. Informal documents and memos to retain past problematic and successful cases

The first two documents describe standards and rules which engineers must follow. The last two documents are more flexible, and describe design knowhow, testing results,

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[44] Interview with four executive chief engineers, Honda Motor Corp., July 31, 1992.

and other problematic and successful cases found in previous development activities.

Technical Standards

The company-wide technical standards are called, for example, "Toyota Technical Standards" and "Daihatsu Technical Standards." These determine the most basic requirements, including material standards, testing criteria, standard design procedures, which engineers mush follow. In the case of Toyota, the Toyota technical standards were established beginning in the 1940s right after management set up an engineering department.[45] The standards have been periodically revised in approximately 10 yearly intervals. In addition to the periodical revision, Toyota has renewed the standards whenever any problems arose. As Mr. Kodera at Toyota mentioned, "Toyota's knowhow is condensed in the technical standards" and forms its critical design capabilities.

Based on the company-wide technical standards, each design and test department keeps its own technical standards, standard design tools, and standard testing methods. For example, the body design department at Daihatsu has a formal document called "Before-Check-List". Before-check-list describes more concrete design tools than does the company-wide technical standard. It includes, for example, standard design procedures, design evaluation procedures and criteria, structural standards, performance standards, and material standards.

At Mitsubishi, an equivalent formal document is called the Design Guideline ("Sekkei-Gaidorain"). The Design Guideline at an engine design department, for example, determines "the choice of materials, specific mass and size to achieve required performance levels, an appropriate parts list for proper engine cooling and noise reduction, and so

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[45] Cusumano (1985, Chapter 6) describes that, after the World War II, Nissan actively started to create its technical standards as part of the QC program.

on."[46]

At Toyota, such department level standards and tools have been sophisticated since the 1970s. According to Mr. Nakagawa, the original objective was to break down the company-wide technical standards so as to make them usable even for technicians at the department level:

> "It was our generation that actively started to make such standards, first to make manuals to teach design procedures to technicians. Then we established them to make design processes more efficient."[47]

Some documents describe standardized design interfaces between different design and engineering departments. For example, a body design department in Honda keeps a document named Feasibility-Standard Document ("Furekishibiriti-Kijun-Sho"), which specifies appropriate interfaces between the body design and the exterior styling. Exterior designers proceed with their design work while referring to the Feasibility-Standard Document to avoid having conflicts later with body engineers. They also have a Layout-Check List which determines several basic rules in designing a vehicle layout to prevent conflicts with other component designs. For manufacturing-design interfaces, engineers maintain a Manufacturability-Guide List ("Seigisei-Gaido-Risuto"), which specifies available design solutions that are applicable with existing manufacturing facilities. Table 3.1 below summarizes these examples of standards.

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[46] Interview with Mr. Kato, Group Leader in the Engine Design Department, Mitsubishi Motor Corp., April 12, 1995.

[47] Interview with Mr. Nakagawa, Chief Engineer, Toyota Motor Corp., April 6, 1995

Table 3.1: Examples of technical standards, design (test) standards, standard design (testing) procedures

Name	Company	Department	Content
Company-wide			
Toyota Technical Standards ("Toyota-Gijutsu-Hyojun")	Toyota	-	The most basic requirements for materials, designs, and design and testing procedures
Daihatsu Technical Standards ("Daihatsu-Gijutsu-Hyojun")	Daihastu	-	The same as the above
Department-level			
Technical Standards ("Gijusu-Hyojun")	Nissan Toyota	Design and test departments	Design standards, design (test) tools, standard design (test) procedures
Before-Check List ("Bifo-Chekku-Risuto")	Daihatsu	Body design department	Design tools, past problematic cases
Design-Guideline ("Sekkei-Gaidorain")	Mitsubishi	Design departments	Design standards, design tools, standard design procedures
Design-Procedure Document ("Sekkei-Tejun Sho")	Mazda	Design and test departments	Design standards. Items, methods, and criteria for the design evaluation
Feasibility-Standard Document ("Fijibiriti-Kijun-Sho")	Honda	Body design and design (styling) departments	Interface information between exterior/interior designs and body designs
Layout-Check List ("Reiauto-Chekku-Risuto")	Honda	Body design departments	Standard rules for the vehicle layout design
Manufacturability-Guide List ("Seigisei-Gaido-Risuto")	Honda	Body design and production departments	Available design solutions applicable with existing manufacturing facilities

Reports and Documents for Non-Standardized Knowhow Retention

Organizations can retain knowledge and knowhow that cannot be expressed as technical standards through more flexible documentation. For example, each design department at Mitsubishi has a document called the "Knowhow Document" ("Nou-Hau-Shu"). The know-how document describes "problematic designs that engineers should avoid, which has been identified as problematic in the past development activities."[48] It states, for example, "In the case of such a material, this system was not applicable.... Then, we tried three alternatives. Each alternative has the following problems...." Information stored in the knowhow document is summarized by components, which indicates that each

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[48] Interview with Mr. Kato, Group Leader in Engine Design Department, Mitsubishi Motor Corp., April 12, 1995.

engineering department accumulates knowhow in the component base, although engineers can also call up these documents by inputting key words indicating vehicle project names.

At Honda, various types of information is written down in the "Know-how Document" ("Nou-Hau-Shu"). For example, in the testing department, the knowhow documents describe specific test results, such as, "the relationship between front-grill and bumper shapes, and water temperature in radiators."[49] It also simply describes past design solutions and problematic cases.

Another important document used for the past knowledge retention is the test report, which sometimes composes part of the knowhow document. The test report is the primary output of test engineers. There are two types of test reports. First, test engineers make reports that describe test results obtained from their advanced engineering efforts, independent of particular vehicle development projects. Second, test engineers write down test results and problems that they found during specific vehicle development projects. In most companies, it is a test engineer's responsibility to summarize problems found during each vehicle development project.

In Toyota, a document called "Technical Report" ("Gijutsu-Hokokusho") includes these test results. One technical report contains approximately 30-40 pages. Engineers submit thousands of reports for each new vehicle development project. Although the technical report includes several advanced test results, it is a report primarily about each product development project. All the technical reports are maintained by the Technical Administration Division. Engineers can get access to these reports from computer terminals located in the library named "Gijutsu-Shiryo-Shitsu".

At Mitsubishi, results of advanced engineering efforts are distributed by the Functional Testing Department to related design engineering departments as the

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[49] Interview with Mr. Ikeno, Chief Engineer in the Research Block, No. 7, Honda R&D, May 23, 1994.

"Guideline" which become a basis for the "Design Guideline" ("Sekkei-Gaidorain") within each design department. The Functional Testing Department also summarizes problems which occurred during vehicle development projects and distribute these as the "Problem Handling Document" ("Mondaiten-Shori-Hyo"). The Problem Handling Document specifies project names and types of components in which problems were found.

Information about quality problems found by customer is often maintained by a quality assurance department and stored in documents called, for example, the "User-Claim Report" ("Shijou-Kureimu-Sho"), or the "Quality Problem Report" ("Fuguai-Sho"). In Toyota, the quality assurance department keeps details of past quality problems, and draws engineers' attention to these problems at the Pre-Product-Clinic (PPC) stage of each development project.

In Mitsubishi, user claim information is maintained by the Technology Information Department. Information is stored by products, components, sales areas, and distribution channels, and can be retrieved from computer terminals. Information is distributed to related design and test departments.

In addition to these formal documents, there are various types of informal documents that warn of problematic situations. Such documents are called, for example, the "Problem Information Memo" ("Mondaiten-Renraku-Hyo") and the "Communication Memo" ("Renraku-Memo"). In most cases, information described in these memos does not includes scientific evidence. Engineers voluntarily write down what they think is useful for future development activities. Compared to making the formal reports, it takes much less time to write in these informal memos, which results in the fast transmission of updated information.

In Daihatsu, these kinds of memos have become circulated through an on-line computerized system. In this system, whenever engineers find problems during development processes, they input that information through computer terminals in their own department, which can be referenced at any other department. They also write down the same information in documents called the "Problem Information Memos" ("Mondaiten-Renraku-Hyo"). Mr. Hori explained how this system works:

> "It takes time to make formal reports. We want to deal with problems earlier, say, within two weeks. Thus, when we find problems during the development process, we input identified problems in our computers as well as write them down in the Mondaiten-Renraku-Hyo. Contents of problems, proposed design solutions, and realized effectiveness of those solutions are registered in computers. Therefore, engineers can check progress even daily. This information stored by computer is also used to make several proposals in the PPC (Pre-Product Clinic) phase for the next model development."

These examples of standards, documents and reports are intensively examined at the start of development projects. Most companies have a specific development phase that is devoted to gathering feedback about problems in existing products from various departments. The PPC phase on Toyota and Daihatsu is an example. During this phase, many departments such as for quality assurance, sales, and test, make proposals to improve existing models. A project team checks thousands of quality problems and test items during this phase.

Reference to these documents and reports are also important means for individual engineers to learn from past practices. For example, Mr. Hori at Daihatsu explained this:

> "I started this in development of the previous Mira project.... First, right after I was assigned to a particular component design task, I gathered all the Problem-Handling Documents and Test Reports regarding that component development. Then, I wrote down everything I need to understand what happened in the past development. Based on this understanding, I brought in engineers who designed that component for the previous model. We put past drawings on a big table, which indicated problematic parts, and wrote in how those parts were previously designed.... This is, I think, the most efficient way [to understand past design problems]. In addition to these documents, there is the Before Check List, which describes more general problems found in these 10 years. Although I referred to Before Check List, I use the three ways [Problem-Handling Document, Test Report, and listening to the previous engineers] to obtain information about the direct

predecessor model. These ways, combined with technical standards, enable even inexperienced engineers to make an acceptable design."[50]

Our interview generally revealed that test engineers and component design engineers strongly depend on these documents and reports as sources of information about the past development activities. Table 3.2 below summarizes examples of various types of documents and reports described above.

Table 3.2: Examples of Reports and Documents for Non-Standardized Knowhow Retention

Name	Company	Department	Content
Knowhow Document ("Nouhau-Shu")	Mitsubishi	Design departments	Information about problematic design cases identified in the past
Knowhow Document ("Nouhau-Shu")	Honda	Test departments	Specific test results and problematic cases
Technical Report ("Gijutsu-Hokoku-Sho")	Toyota	Test departments	Specific test results obtained through vehicle projects and advanced testing activities.
Test Report ("Shiken-Houkokusho")	Daihatsu Nissan	Test departments	The same as the above
Guideline ("Gaidorain")	Mitsubishi	Functional testing department	The same as the above
Problem-Handling Document ("Mondaiten-Shori-Hyo")	Mitsubishi	Functional testing department	Information about problems occurring during vehicle projects
User-Claim Report ("Shijo-Kureimu Sho")	Mitsubishi	Maintained by the technology information department	Quality problems found by customers
Quality-Problem Report ("Fuguai-Shu", "Fuguai-Jirei-Shu")	Toyota Daihatsu	Maintained by the quality assurance department	The same as the above
Problem-Information Memo ("Mondaiten-Renraku-Hyo")	Daihatsu	Design design departments	Problematic cases found in previous vehicle development
Communication Memo ("Renraku-Memo")	Toyota	Design departments	For simple communication

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[50] Interview with Mr. Hori, Manager in the Body Design Department, Daihatsu Motor Corp., May 9, 1995.

3-1.5 Knowledge Retention though Computer-Aided Design Systems[51]

Most Japanese automobile producers started to use design CAD systems in the 1970s. Currently, all companies that we interviewed use the three-dimensional CAD system for body design processes. Some companies such as Toyota and Nissan use it for interior/exterior styling design as well. Although the two-dimensional CAD is still dominant in designing other component units, such as engines and suspension systems, all companies are currently shifting to three-dimensional CAD in these areas.

Simulation abilities by CAE (computer-aided-engineering) systems also has dramatically increased during this decade because of advances in super computers. Companies are making efforts to develop CAE models with topological data to make digitized mock-up, which reduce time-consuming prototyping steps and may eliminate them in the future.

These CAD systems serve, not only as tools to help design and test, but also as facilities to retain prior knowledge obtained through design and testing experiences.

Data stored in the design CAD system can be directly re-used in future design work. For example, since an automobile body consists of several separate body panels (e.g., front, center and rear floor panels), each of which has a particular drawing stored in the CAD, designers often reuse and edit designs from existing body panels and re-combine them with newly designed panels to develop the entire body design. In the design of engine-control systems at Mazda, for example, an electronic circuit is modularized into sub-circuits, each of which is described by computer language such as C. Thus, engineers can simply edit the existing design in the computer language.

Advances in three-dimensional CAD enabled engineers to retain design information that cannot be expressed in two-dimensional drawings. Especially important is the fact that

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[51] The description in this section is based on the interview reports by Prof. Nobeoka at Kobe University.

it became possible for engineers to easily examine and store design information related to interference between different components, for example, in the engine compartment (before, engineers had to make several drawings from the different angles).

However, some interviewees also pointed out problems associated with the use of CAD data. Those problems were commonly related to use of CAD data without knowing contextual information behind the original design. Mr. Ushiro at Mitsubishi described this:

> "Introduction of CAD enables engineers to copy [existing designs]. For example, they sometimes copy an entire design and modify just a part of it. In such a case, engineers sometimes change a design that should not be changed since they do not know how the original design was made. We have several such cases in the small parts design."

Mr. Nakagawa at Toyota also made a related comment:

> "The number of design items that design engineers write in drawings has significantly decreased since the introduction of CAD... Before, engineers wrote in many things on drawings, such as what they focused on in the previous development, what remains problematic, and what we have to pay attention to in the next development... This kind of information is very useful for us [product planners].... Current CAD systems do not have enough room for this kind of description."

On the other hand, CAE models reflect knowledge obtained from the prior prototype testing. Whether companies develop their own CAE models or use commercial packages, it is critical to incorporate their experience of actual prototype testing into CAE models to make it usable.

As a part of the computer-aided design systems, companies are actively creating design information databases which were previously stored in the form of documents. Such a database not only enables engineers to more efficiently access available parts information. The drawings can also be automatically produced from the component parts in the parts list system and CAD data. Complete parts data is also required to make a digitized mock-up for the CAE simulation.

3-2 Knowledge Type and Knowledge Transfer Mechanisms: Propositions

Integrative Knowledge

As many existing researchers have pointed out, the design of new "systems" products (i.e., products that contain numerous components which must work together) invariably depends upon the complex interaction among potentially fragmented individual knowledge bases (e.g., Clark and Fujimoto, 1991; Henderson and Clark, 1990; Iansiti, 1995 c, d ; von Hippel, 1994). On the one hand, knowledge required for new product development comes from various domain-specific, functional, and specialized disciplinary areas. On the other hand, new product development calls for knowledge to integrate this specialized knowledge to apply to specific contexts, which we call integrative knowledge.

Recent studies of innovation and new product development have increasingly emphasized the importance of knowledge cutting across different functional and disciplinary domains as having particular implications for competitiveness in the market place.

Henderson and Clark (1990), for example, specifically discussed knowledge about the interactions between physically distinctive components, which they defined "architectural knowledge." They found, in their study of innovation in the photolithographic alignment equipment, that lack of explicit management of the architectural knowledge created serious threats to incumbent firms.

Our interviews at Japanese automobile companies also revealed that understanding about appropriate linkages between different components or component systems is one of the critical development issues, which is difficult to capture by existing rules and standards. One engineer at Mazda pointed out, for example, that nearly 70% of design changes occurring during the development process are derived from interference between different components such as that within the engine compartment and at intersection between the body and the suspension systems. A system engineer also mentioned that the most difficult problem in making the three-dimensional digitized mock-up for the CAE simulation is to incorporate relational data to link different components or component systems.

The work of Iansiti has broadened the concept of architectural knowledge (Iansiti, 1995 a, b, c, d). He defined technological integration as activities to evaluate novel technical approaches and apply them to detailed design and development contexts. His series of empirical studies in the computer industry showed that capabilities for technological integration and retention of such capabilities through individual experiences resulted in better R&D performance indicated by higher development speed and R&D productivity.

Integrative knowledge is not limited to the relationships between physical components and technological elements. Knowledge about the user-design interface embodied in a product also characterizes a particular type of product system. Several researchers thus have focused on knowledge to link customer environments and product design (Clark, 1985; Christensen and Bower, 1994; Clark, 1985; Fujimoto and Clark, 1991; Henderson, 1991, von Hippel, 1994). For example, Clark (1985) showed that interactions between a hierarchy of customer concepts and that of product design have driven technological evolution in the automobile industry. Christensen and Rosenbloom (1995) found failure of incumbent firms in the disk drive industry to be explainable by lack of ability to adapt to changing linkages between user contexts and product design. Clark and Fujimoto (1991) found that external integration through strong project managers, integration between customer concepts and product designs, led to shorter development lead-time, higher development efficiency and higher overall product quality in the world automobile industry.

Qualitative information that we obtained from interviews also revealed difficulties involved in understanding an appropriate customer-design interface and the importance of retention of such knowledge. For example, Mr. Ikeno, responsible for the second Legend project as LPL (a project manager), mentioned how difficult it was to interpret luxury in technological terms:

> "Since Honda did not have long experiences in luxury car development, it was most difficult to interpret taste and quality for a luxury car, which customers required, into a [physical] design. In this respect, we tried to learn a lot from the first generation of development [most project members continued from the first generation]. "[52]

The discussion about continuity of project manager groups in the previous section also suggested that one of the reasons project coordinators tend to continue across generations lies in the fact that some critical knowledge about user-design interfaces is difficult to transfer by other media, such blueprints and standards.

Knowledge about interactions between components, user needs and product design, and process and product design, may all be particular cases of complex sets of integrative knowledge involved in new product development (Iansiti, 1995d). Integrative knowledge can also be both technical (i.e., knowledge about appropriate linkages between body design and suspension design), or managerial knowledge (i. e., knowledge about appropriate coordination between body and suspension engineers). New products are the result of complex interactions among different knowledge domains, each of which includes

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[52] Interview Mr. Ikeno, Chief Engineer, Honda R&D, May 23, 1994.

particular engineering know-how, underlying scientific knowledge, customer needs, marketing techniques, manufacturing environments, and other knowledge. In cur view, the ability to achieve appropriate interactions cannot be instantaneously acquired, but should be retained and accumulated historically.

Mechanisms for Retaining Integrative Knowledge

One of the reason researchers have paid significant attention to knowledge cutting across different specialized domains is that such knowledge tends to be less articulable, thus, it may form the foundation of firm-specific competencies.

There are a couple of reasons why integrative knowledge tends to be less articulable. First, there is no established language to communicate integrative knowledge. Domain-specific and scientific knowledge is often supported by particular disciplinary areas with well-established languages for teaching and communication. We have social mechanisms for accumulating disciplinary knowledge, such as professional communities and educational and research institutions. On the other hand, there is no universal language to communicate integrative knowledge. There is no social support for its accumulation. Each company, thus, has to invent its own ways to create and accumulate integrative knowledge. In particular, since integrative knowledge involves knowledge to translate different languages between different thought worlds, it tends to be difficult to articulate.

Development of the Nissan Primera (G20) illustrated this point. In development of the Primera, a specific vehicle evaluation group, called the Yazaki group, played critical role in pursuing vehicle technical performance.[53] The Yazaki Group is a group of people who are capable of making evaluations from a broad perspective and in terminology

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[53] Description here is based on interview with Mr. Sakai responsible for the Primera project as s sub-project manager (Shutan), April 18, 1991. See also "Case of Nissan Motor Co., LTD," Nomura School of Management, 1992.

appropriate to design engineering. Good vehicle evaluators should be able to make judgments based on a deep understanding of the environment of the target markets, including not only external conditions and driving style, but also customs, habits and other user contexts, and relay their evaluation to design engineers in appropriate terms. However, this kind of knowledge is difficult to capture by rule-like procedures. Therefore, Nissan sent several evaluators overseas for about a year to directly experience unfamiliar user environments. Then, these evaluators were schooled by Mr. Yazaki. As a result of intensive personal contacts and mutual-experiences within the Yazaki school, about ten evaluators were produced (at the point of 1991) as a core group of vehicle evaluators who can understand different worlds.

Second, integrative knowledge tends to be context-specific: "it is knowledge of the particular circumstances of time and place" (Hayek, 1945). It may also be embedded in specific personal relationships (Badaracco, 1991; Spender, 1994). Thus, it may be difficult to express it in the form of facts and propositions. For example, in the case of automobile development, while the best vehicle styling to solely maximize aerodynamic performance can be theoretically determined and generalizable, appropriate linkages between the styling, the body structure, the engine shapes, and the suspension types may be different among vehicle types with different sizes, platforms, and customer bases.

Regarding the context-specific natures of integrative knowledge, von Hippel and Tyre (1995) found that field problems occurring in the introduction of new process technology were often discovered through learning by doing by field engineers after process introduction. Since they are invariably caused by subtle and specific interactions among particular attributes of machine design and the user environments, they are difficult to predict in advance. von Hippel and Tyre also found that discovery of field problems depended on a particular type of learning, which they called "templating." Templating is a form of pattern recognition. Since field problems in production machines depend upon context-specific factors, scientific investigation to specify universal cause-effect relationships may not work properly. For context specific-knowledge to be usable in other settings, people need to retain and transfer information about numerous surrounding contingency factors behind easily observable facts and results. Therefore, it may be quite costly, if not impossible, to articulate context-specific integrative knowledge. von Hippel (1994) called such knowledge, which is costly to transfer, "sticky information."

The most direct way to transfer and retain less-articulable and context-specific integrative knowledge may be to transfer to or retain individuals with first-hand experience in appropriate decision settings. For example, Cohen (1991) pointed out that the concept of procedural memory proposed by Anderson (1983), which refers to methodological knowledge in use as opposed to facts and propositions, may be better transferred by means of personnel rotation.

When knowledge is embedded in specific relationships between people, it might be required to make a group of people active for long time. For example, Wilson and Hlavacek (1984) found that firms which benefited from technologies created in past projects kept knowledge alive by the active presence of a core group of people.

However, there are obvious limitations in completely depending on a particular individual or group: when people leave, knowledge disappears. If integrative knowledge can be shared with, and transferred to, other people and groups, firms can more effectively leverage that knowledge. In this respect, Nonaka (1994) suggested that tacit knowledge embedded in individuals can be transferred among individuals by having shared and common direct experiences. He called this type of knowledge transfer (conversion) "socialization." Thus, if companies can create a chain of overlapped common experiences among people, tacit knowledge can be retained for a long time. The example of Toyota's project manager groups described in the previous section illustrated this type of knowledge retention. At Toyota, sub-project managers acquired knowledge to integrate an entire project by working together with a project manager of particular model development for a relatively long time.

Direct face-to-face interactions may help individuals share integrative knowledge. Although fully embedded knowledge may not be directly expressed by words, direct interactions lead to gradual understanding of contextual factors behind artifacts, providing better ways of knowledge retention than documents or blueprints.

Accordingly, we hypothesize that integrative knowledge is most effectively retained through individual-based retention facilities, such as the direct transfer of individuals and a group of people, shared experiences among individuals, and intensive face-to-face interactions among individuals.

On the other hand, domain-specific and functional knowledge tends to be more articulable and generalizable. Therefore, retention of such knowledge will most benefit from the use of archival mechanisms, such as documentation, standardization, and computerized systems.

This leads to the following set of propositions:

> Proposition 1: Integrative knowledge is most effectively retained across generations *by individual-based mechanisms*, either through the direct transfer of individuals or cohort groups, or through communication with past project members.

> Proposition 2: Domain-specific and functional knowledge is most effectively transferred by *archival mechanisms*, such as reports, documents, standards, and computerized media.

The initial results of our survey to 22 project managers in Japanese automobile projects provided some evidence related to the above propositions, although it was not an empirical test. Table 3.3 below summarizes the survey results. In the survey, we asked project managers how different knowledge retention mechanisms were effective to retain different types of knowledge in their automobile development projects. The number shown in this table indicates the percentage of project managers who answered "effective" for each of the mechanisms (respondents were allowed multiple responses).

Table 3.3: Mechanisms for different types of knowledge retention

	Effective Mechanisms for Knowledge Retention					
Knowledge about.......	Direct transfer of people from the past projects	Communication with people having experience in the past projects	Independent organizational units responsible for long-range planning	Documents and reports that describe solutions and problems in the past projects	Standards such as design standards, test code, standard design procedures, and standardized parts	Computer-aided systems, computerized databases
Concept making	45.45%	77.27%	40.91%	36.36%	0.00%	4.55%
User needs	18.18%	59.09%	45.45%	50.00%	0.00%	22.73%
Vehicle layout	54.55%	50.00%	13.64%	45.45%	27.27%	27.27%
Target performance	22.73%	50.00%	13.64%	59.09%	31.82%	31.82%
Available new technology	9.09%	50.00%	45.45%	36.36%	13.64%	9.09%
Carry-over of component systems	18.18%	36.36%	27.27%	27.27%	54.55%	27.27%
Re-usable parts	9.09%	27.27%	13.64%	0.00%	54.55%	31.82%
Detailed engineering of component systems	45.45%	59.09%	18.18%	36.36%	40.91%	31.82%
Problem-solving cutting across different technical areas	18.18%	81.82%	13.64%	31.82%	18.18%	13.64%
Conflict resolution between performance parameters	18.18%	77.27%	13.64%	36.36%	9.09%	9.09%
Management of product development	31.82%	77.27%	18.18%	36.36%	13.64%	0.00%
Design prototype test	22.73%	45.45%	22.73%	59.09%	40.91%	4.55%
Production prototype test	18.18%	50.00%	22.73%	50.00%	36.36%	4.55%
Ramp-up	31.82%	54.55%	22.73%	50.00%	27.27%	9.09%
Total	25.97%	56.82%	23.70%	39.61%	26.30%	16.23%

The number shown in the table indicates the percentage of project managers who answered "effective" for each of the mechanisms to retain knowledge listed in the first column.
22 respondents. Multiple answers were allowed.

This table shows that, based on our sample of Japanese projects, communication with people having experience in past projects was the most effective way to retain prior knowledge about new product development. This was followed by the use of documents and reports describing past development practices. These results indicate that, while projects tended to depend heavily on face-to-face communication as a way to retain knowledge, they also used documentation extensively. Among the other four mechanisms, respondents regarded computer-based systems as least effective. The remaining three mechanisms, namely direct people transfer, the involvement of independent organizational units, and the design/process standards seemed to play almost equally important roles: . However, the importance of different retention mechanisms was found to differ substantially across knowledge types.

Communication seems effective particularly for knowledge retention about concept making, problem-solving cutting across different technical areas, and conflict resolution between performance parameters. This implies an association between integrative knowledge retention and intensive communication.

Documentation seemed to play an important role within activities in which test engineers were heavily involved, such as target performance setting and design prototype test. This is understandable since test reports are the primary outputs of test engineers.

More than half the respondents answered that continuity of project members was an effective way to retain knowledge about vehicle layout design. Since vehicle layout design involves key decision-making for platform designs, basic component configuration, and major physical dimensions with consideration of customer requirements, it significantly influences interfaces between different component systems and user environments. Thus, this result may be one indication that retention of integrative knowledge depends upon the direct transfer of people.

The table also shows two other types of knowledge whose retention seems to depend upon personnel transfer: knowledge about concept making and knowledge about detailed engineering of component systems. High dependence on personnel transfer to retain detailed engineering knowledge of component systems seem to contradict our proposition.

However, the table shows that this knowledge retention also tends to be carried out through archival mechanisms as well, such as documents, standards, and standards. Some detailed engineering knowledge involves subtle knowhow to adjust component designs to be compatible with other component designs and production processes. Our interviews revealed that this type of knowledge tends to be held by functional experts.[54] We speculate that retention of this portion of detailed engineering know-how may require personnel transfer.

Standards seem to be important to carry over component systems and reuse existing parts as well as retain detailed engineering knowledge. This suggests that retention of knowledge through standards may tend to be limited to activities within well-defined component engineering areas. The use of a computer-aided system also seems to be an effective way to retain knowledge within each individual engineering area, reflected in relatively high percentages for carry-over parts, reusable parts, and detailed engineering.

Although all these are tentative results, they more-or-less indicate that integrative knowledge retention may be dependent upon individual-based mechanisms such as direct people transfer or face-to-face communication. In the next section, we conduct more focused empirical tests to examine the propositions.

3-3 Test for Relationships between Knowledge Type and Retention Mechanisms

To examine the above propositions empirically, we compared different types of project members in terms of their reliance on knowledge retention mechanisms.

Automobile development projects involve numerous people with different

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[54] The description is based on interview with Mr. Morioka, Mazda Motor Corp., May 19, 1994.

engineering roles and functional backgrounds. Different people invariably require different types of knowledge to accomplish their tasks. For example, for project members primarily responsible for integration and coordination of dispersed functional activities, integrative knowledge should be more critical. In the case of automobile development, project managers or coordinators, vehicle layout engineers, and vehicle test engineers may be examples of such integrators. On the other hand, functional knowledge should be more important for people whose primary task is to design particular component systems, such as suspension systems, braking systems, under-floor panels, and engine components.

If there is a difference in reliance on knowledge retention mechanisms between integrators and component engineers, we should be able identify the mechanism appropriate for the retention of integrative knowledge.

Below, we first examine how these two types of project members differ in terms of experience in previous projects (related to Proposition 1) and use of documents, reports, and standards (related to Proposition 2). The former is examined in Section 3.3.1; the latter is discussed in Section 3.3.2.

We also examine Proposition 2 in another way. Automobile component systems further decompose into lower levels of components and parts. For example, engine systems consists of engine blocks, cylinders, pistons, fuel injectors, and exhaust systems. Similarly, suspension systems consist of springs, insulators, shock absorbers, and suspension members. Engineers often design both entire component systems and their individual parts. If Proposition 2 is correct, engineers will be more dependent upon documents, reports, and computer-aided systems for retaining past design information for the design of lower levels of parts than for the design of the component systems.

3-3.1 Continuity of Project Members from the Previous Project

Proposition 1 implies that transfer of integrative knowledge will be associated with direct personnel transfers. Thus, we expect to observe that project members primarily responsible for integration among different functional and technical areas are more likely to continue in their position for successive generations of projects than those responsible for functional activities.

In the case of automobile development, we define the following three types of project members as integrators: project managers, vehicle layout engineers, and vehicle test engineers.

The role of project managers as system integrators has been discussed in existing studies (e.g., Clark and Fujimoto, 1991; Imai et. al, 1985). Although project managers' span of responsibility differs from project to project, our interviews in Japanese automobile companies revealed that all project managers were at least responsible for concept making, the basic vehicle plan, and coordination of development processes. In addition, several interviewees pointed out that project managers should have a broader view, and be familiar with all project activities, including numerous different areas.

> "The PE[title of project manager at Mitsubishi] is a person who can look at an entire project.... [It] is crucial for the PE to have close personal relationships with engineers in different design areas."[55]

> "Although we refer to quantitative data, the most important activity is [person to person] adjustment between related functional departments. Inside each design and testing department, the worlds are becoming computerized. However, there is still a lot we cannot understand without having actual products [which calls for human coordination] since user feelings are changing even daily."[56]

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[55] Interview with Mr. Ushiro, Project Engineer (project manager) for the Minica project, Mitsubishi Corporation, April 12, 1995.

[56] Interview with Mr. Fukui, Project Engineer (project manager) for the Pajero project, Mitsubishi Motor Corp., April 12, 1995.

Vehicle layout design is another activity that involves complex adjustments between conflicting engineering areas. The vehicle layout basically refers to the design of space distribution for mechanical components, body structures, luggage, and passengers. It involves key decision making for platform designs, basic component configuration, and major physical dimensions (e.g., wheel-base, tread, hip point). The vehicle layout determines the basic architecture of an automobile, which expresses total vehicle concepts in physical terms (Clark and Fujimoto, 1991). Accordingly, design of the vehicle layout significantly influences interfaces among different component systems, for example, between suspension systems and under-floor panels, between engines and engine mount. Layout engineers thus require broad-based experience encompassing different engineering areas.

Although layout engineers typically have backgrounds as body designers, there seems to be no common place where they belong organizationally, reflecting the inter-disciplinary nature of their tasks. At some companies, such as Toyota, Daihatsu, and Mitsubishi, project coordinators who reside in product planning groups as staff of the project manager play key roles in designing the vehicle layout with the help of body engineers. At Honda, engineers in the body design department take a primary responsibility for layout design. On the other hand, Mazda and Nissan have separate departments for layout engineers. At Mazda, layout engineers belong to the Basic Design Department, which is separated from the Product Centers responsible for product development. At Nissan, layout engineers belong to departments called ZRB (layout for rear-wheel drive vehicles) and ZFB (layout for front-wheel drive vehicles), which are located under the Product Planning & Development Division, No. 1 and No. 2, respectively.

Vehicle test engineers, as opposed to component test engineers, can also be regarded as engaged in extensive coordination activities cutting across different component development areas. Since the overall performance of automobiles, as indicated by, for example, NVH (Noise-Vibration-Harshness), safety, body strength, and driving stability, is derived from many complex interactions among individual components, a vehicle test engineer has to interact with related component engineers to achieve targeted performance levels. For example, at Nissan, a leader of the vehicle test engineers, called "Jikken-Shutan" (Testing Leader), is formally assigned as the No. 2 manager for a particular model development project, and plays a critical role in helping the project leader (Sasabe, 1993).

Based on this discussion, we can extend Proposition 1 as the following working hypothesis:

> Hypothesis 1: The probability that project managers, vehicle layout engineers, and vehicle test engineers are transferred from the previous generation of project is higher than that of the other project members.

Methods:

To test this hypothesis, we obtained data on project members' experiences in the previous generation of projects by a questionnaire survey. The sample contains 223 project members representing 25 new product development projects at seven Japanese automobile producers, carried out between 1987 and 1995. We distributed a questionnaire to the following 10 project members for each project, who represented their own activity areas for that project. Below we call these members *project core-members*.

1. A Project manager
2. A Representative of Vehicle Layout Designers /Planners
3. A Representative of Vehicle Test Engineers
4. A Representative of Chassis Design Engineers
5. A Representative of Body Design Engineers
6. A Representative of Exterior/Interior Designers
7. A Representative of Engine Design Engineers
8. A Representative of Electronics Component Design Engineers
9. A Representative of Production Engineers
10. A Representative of Marketing/Product Planners

While we obtained all 10 responses from 17 projects, there is some missing data for the remaining eight projects, since we were unable to obtain responses from some project core members. As a result, the sample comprises 229 core members. Out of these, 223 responses included usable answers with respect to experiences in the previous projects.

We identified whether or not respondents had experience in the previous project by asking them to list the names of past new product development projects on which they spent more than an average of 30% of their time, for at least six months. When the name of the direct predecessor model is on this list, we regarded them as members in the previous generation of projects. Even wnen the respondents participated in the previous model development, we did not count them as previous project members unless they had devoted more than 30% of their time for at least six months.[57]

Table 3.4 below shows the number and the percentage of project core-members transferred from the previous project by each category of people.

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[57] This way of defining project members needs to be treated with care. Since some components, such as electronics components, are often designed for multiple projects, engineers might not spend more than 30% of their time even on their principal project. We therefore considered these people as not having worked for the preceding project, unless they explicitly indicated otherwise in the questionnaire.

Table 3. 4: Transfer of project members from the previous generation of project

	Project members in the previous generation of project ?		Total
	Yes	No	
Project Managers**	12 (50.0%)	12 (50.0%)	24
Layout Engineers****	15 (75.0%)	5 (25.0%)	20
Vehicle Test Engineers**	11 (50.0%)	11 (50.0%)	22
Exterior/Interior Designers	5 (20.8%)	19 (79.2%)	24
Chassis Engineers	4 (17.4%)	19 (82.6%)	23
Body Engineers	10 (43.5%)	13 (56.5%)	23
Engine Design Engineers	9 (37.5%)	15 (62.5%)	24
Electronics Component Engineers	4 (19.0%)	17 (81.0%)	21
Production Engineers	9 (47.4%)	10 (52.6%)	19
Marketing/Product Planners	4 (17.4%)	19 (82.6%)	23
Total	83 (37.2%)	140 (62.8%)	223

Asterisks indicate results of the chi-square tests of independence between being each of three integrators, as opposed to the other functional/component engineers, and being the previous project members (**$p < .05$, ***$p < .01$, ****$p < .001$).

Out of the 223 respondents, 83 project core-members had experience in the previous generation of projects. Out of 10 different types of core-members, layout engineers were more likely to be transferred from previous projects (15 out of 20 layout engineers), followed by project managers (12 out of 24), and vehicle test engineers (11 out of 22). Being layout engineers, vehicle test engineers, and project managers, as opposed to the other functional engineers, makes a significant difference as to whether or not they are transferred from the previous generation of projects. This appears to support our hypothesis that integrators are more likely to be in charge of the same model development in successive generations.

It is tempting to suggest that this may be because these integrators' tasks are more product-specific than others. However, Table 3.4 shows that representatives of exterior/interior designers and of marketing/product planners tend not to be transferred from the previous projects (only 5 out of 24, and 4 out of 23, respectively), implying that product-specific tasks cannot explain project membership in successive generations.

Among representatives of component engineers, body engineers tend to have experience in the previous project compared to chassis engineers, electronics components engineers, and engine engineers. This also seems to be consistent with our hypothesis, because "Body engineers need a broader view than do other engineers because body design is strongly inter-related to the other component design both functionally and structurally"[58]

To examine the validity of the above finding more precisely, we conducted a logistic regression analysis. In this model, we considered the following three explanatory variables as predictors for whether or not project core-members had experience in previous project generations:

SYSINTEGR: A dummy variable indicating system integrators (set to 1 if respondents are either project managers, vehicle layout engineers, or vehicle test engineers; set to 0 otherwise).

TASKNEW: % of design change from the previous model

LINENUM: The number of available projects at the time of start of the focal project.

We divided ten project core-members into two categories, system integrators or functional engineers. As already defined, system integrators include project managers, vehicle test engineers and vehicle layout engineers. SYSINTEGR was set equal to 1 if respondents are system integrators, and 0 otherwise.

In addition to SYSINTEGR, we included two control variables. The first control variable is a percentage of new design, TASKNEW, that indicates the degree of change in

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[58] Interview with Mr. Kanazawa, a chassis engineer, Mazda Motor Corp., May 19, 1994.

engineering tasks from the previous project. The previous project members might be assigned to the current project because the required engineering works are similar between two successive projects. For example, we may expect that the project members continue in successive generations when the current project activity involves minor modification of the previous design. Our tentative finding in Table 3.4 may be due to the fact that vehicle platforms tend to be relatively stable across generations, compared to the design of each component system. The novelty of integrators' tasks is presumably determined by the degree of platform change. As one engineer at Mitsubishi explained:

> "The PE [project manager] and group-leaders [project manager or sub-project manager] in vehicle planning groups may stay in successive generations since a platform design tends to be carried over across successive generations. On the other hand, since body design [upper-body design] and other functional components tend to be renewed by each generation, engineers responsible for these design tasks move around between different model development projects in accordance with the fluctuation of required engineering resources by those projects."[59]

Project managers assessed the degree of novelty of the design for their new products. Answers encompassed 10 different component systems, including exterior/upper-body, interior/trim, steering, floor-panels, braking systems, suspension systems, transmissions, engine, engine control, and instrument panels. Newness of each design was measured on a 4-point scale: 1 = minor modification of less than 20% of the existing design, 2 = major modification involving 20 to 80% new design, 3 = new design involving more than 80% new design, and 4 = entirely new technology not applied to any model before. This scale was conceived to capture the theoretical distinction between component system designs which are purely "carry-over," involved substantial redesign, or were entirely new designs.

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[59] Interview with Mr. Ozaki, Manager in the Engineering Administration Department, Mitsubishi Motor Corp., April 12, 1995.

We calculated novelty involved in activities of component engineers by averaging newness of appropriate component designs. We measured newness of system integrators activities by the newness of the platform design indicated by newness of suspension systems and under-floor panels (Nobeoka, 1993). The extent of novelty in the design activities of production engineers was measured by the percentage of new production equipment. Appendix 2 explains these novelty indicators in more detail. We excluded marketing/product planners from the analysis since we could not obtain indicators for their task newness comparable with those for the other core-members. As a result, values of TASKNEW were assigned to 192 project members.

The second control variable, LINENUM, is the number of available projects at the time of the current project's start. We expect that the greater the number of simultaneous ongoing projects in a company, the lower the probability of project members being transferred within the same model line.[60] Therefore, we included LINENUM as a control variable.

Tables 3.5 to 3.7 below summarizes descriptive statistics of the dependent variable, the explanatory variables, and two control variables.

Table 3.5: Descriptive statistics for experience in the previous project generation

	Frequency	Cumulative Frequency	Cumulative Percent
0 = not members of previous generation of project	107	107	58.5%
1 = members of the previous generation of projects	76	183	100.0%

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[60] If we could have obtained complete responses from 10 project core-members of all 25 projects, we would not have to include this as a control variable because of complete independence between LINENUM and SYSINTEGR variables. However, the number of effective respondents is 223, implying 27 project members are missing. Besides, only 192 core-members can be included in our analysis considering the TASKNEW variable.

Table 3.6: Descriptive statistics for the system integrator dummy variable (SYSINTEGR)

	Frequency	Cumulative Frequency	Cumulative Percent
0 = functional engineers (exterior/interior designers, chassis engineers, body engineers, engine engineers, electronics component engineers, production engineers, and marketing/product planners)	122	122	66.7%
1 = system integrators (project managers, vehicle test engineers, layout engineers)	61	183	100.0%

Table 3.7: Descriptive statistics for the control variables (TASKNEW and LINENUM)

	N =	Mean	Std Dev.	Min.	Max.
a percentage of new design (TASKNEW)	183	0.54	0.27	0.05	1.00
the number of available projects at the time of the project start (LINENUM)	183	15.64	5.63	5.00	22.00

Results:

Table 3.8 below, shows the results of a fitted logistic regression analysis.

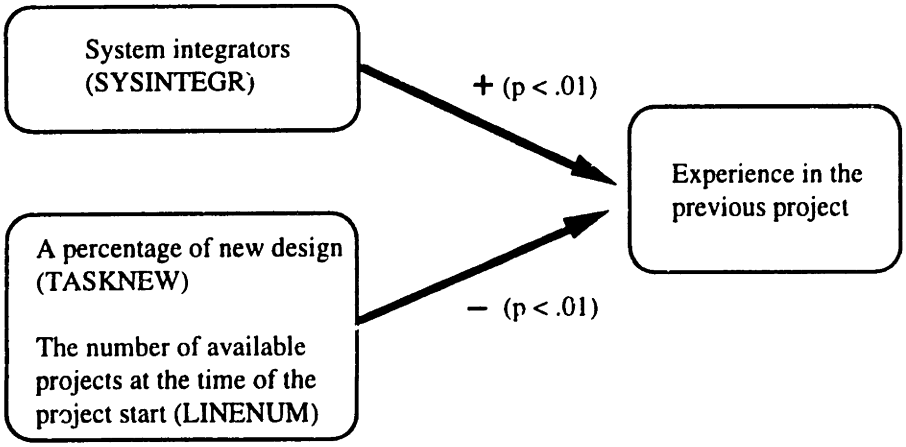
Table 3.8: Fitted regression models describing the relationship between experience in the previous generation of project and type of project members.

		Predictors			-2logL
Model #	Intercept	TASKNEW	LINENUM	SYSINTGR	(Chi-square)
I	(incl.)				248.42
II	1.37	-0.66	-0.09		238.11
III	0.86	-0.38	-0.09	1.10	227.13

The second row of this table shows the result of the fitted logistic regression model, Model 2, including TASKNEW and LINENUM as independent variables. Parameter estimates for TASKNEW and LINENUM are negative, -0.66 and -0.09, respectively, which may indicate a negative relationship between these variables and transfer of core-project members, as we expected. The chi-square goodness of fit statistic for this model is 238.11, which is decreased by 10.31 from that of Model 1 without any predictor, 248.42. An associated decrease of degree of freedom is two. Since 10.31 is greater than the critical value of the chi-square distribution with alpha = 0.01 and df = 2, we conclude that TASKNEW and LINENUM, taken together, are negatively related to the transfer of project core-members from the previous project, which is consistent with our expectation.

Model 3, in the third row of Table 3.8, adds SYSINTEGR as a predictor. The parameter estimate of SYSINTEGR is 1.10, which indicates a positive relationship between SYSINTEGR and previous experience, as we expected. The chi-square goodness of fit statistic for this model is 227.13, a reduction of 10.98 from 238.11 in Model 2. Since 10.98 is greater than the critical value of the chi-square distribution with alpha = 0.01 and df = 1, the null hypothesis was rejected at the 1% level, and we conclude that SYSINTEGR is positively related to previous experience, after controlling for the effect of TASKNEW and LINENUM. Figure 3.1 below indicates these results graphically.

Figure 3.1 Relationships between system integrators and their experience in previous projects



Therefore, we conclude that being system integrators significantly increased the probability of being responsible for the successive generations of the same product development. This suggests that prior knowledge about integration activities may tend to be transferred by individuals, consistent with our hypothesis.

3-3.2 Differences in the Use of Document, Reports, and Design Standards

First, Proposition 2 implies that component engineers may use documents, reports, design standards, and computerized media to retain past knowledge more frequently than do integrators. This leads to the following working hypothesis.

> Hypothesis 2: Component engineers refer to documents and reports, and use design standards and standard design procedures more frequently than do integrators.

As a partial test of this, we asked engineers to rate, on a 5-point Likert scale (from 1 = not refer at all to 5 = refer very frequently), the frequency with which they referred to documents and reports that described design knowhow and design solutions and problems identified in the past development activities. Similarly, respondents rated how important were the roles design standards and standard design procedures played in their project activities, on a 5-point Likert scale, from 1 = not important at all to 5 = played a very important role.

Second, If Proposition 2 is correct, we would expect more a frequent use of documents and reports, and greater significance attached to design standards for design of parts of component systems than for design of entire component systems. This leads to the further working hypothesis:

Hypothesis 3: Component engineers refer to documents and reports, and use design standards and standard procedures more frequently for design of parts of component systems than for design of entire component systems.

To test this, we asked component engineers to rate frequency of use of documents and reports, and importance for design standards and standard design procedures, separately for design of component systems as a whole, such as engine and a suspension system, and for design of their parts, such as a cylinder, a drive-shaft, and a suspension member. They rated both in the same 5-point Likert scales as described above.

Results

Table 3.9 shows how two types of integrators, layout engineers and vehicle test engineers, differ from the other component engineers (and production engineers) in terms of their dependence on documents, reports, and standards.

Table 3.9: Frequency of reference to documents and reports, and importance of standards rated by project members

	Frequency of Reference to Documents and to Documents and Reports		Importance of Standards (desig standards and test codes)	
	1 = Not at all 5 = Very Frequently	S. D.	1 = Not important at all 5 = Played Very Important Role	S. D.
Exterior/Interior Designers (21)	3.16	1.09	3.59	1.15
Chassis Engineers (23)	3.80	0.82	4.06	0.77
Body Engineers (23)	4.00	0.82	4.17	0.73
Engine Engineers (25)	4.12	0.58	4.14	0.87
Electronics Engineers (23)	3.74	1.12	4.06	1.09
Production Engineers (N = 20)	3.90	0.91	4.40	0.82
Layout Engineers (N = 21)	3.38	0.92	3.55	0.82
Vehicle Test Engineers (N = 25)	4.04	0.97	4.40	0.95
Total (N = 180)	3.78	0.95	4.06	0.94

First, the table shows that layout engineers tended to rate lower the frequency of reference to documents and reports, and to rate lower the importance of standards in their development activities, than did most of component engineers. Table 3.10 below which shows the results of a series of independent t-tests indicates this difference more specifically.

Table 3.10: Results of independent t-test for difference in reference to documents and reports and in the use of standards between layout engineers and other component and production engineers

	Layout Engineers (N = 21)	
	Frequency of Reference to Documents and to Documents and Reports	Importance of Standards (desig standards and test code)
Exterior/Interior Designers (N = 21)		
Chassis Engineers (N = 23)	*	**
Body Engineers (N = 23)	**	***
Engine Engineers (N =25)	***	**
Electronics Engineers (N =23)		*
Production Engineers (N =20)	*	***

*p < .1, **p < .05, ***p < .01 (two-tailed siginificance)

Component engineers and production engineers reported significantly more frequent reference to documents and reports to learn from the past design activities except for exterior/interior designers and electronics engineers. As for importance of design standards and standard design procedures, component and production engineers reported higher importance than did layout engineers. This seems to suggest that knowledge regarding vehicle layout design is less likely to be transferred through documentation and standardization. Considering our findings in the previous sections that layout engineers tended to continue their positions in successive generations of projects, knowledge to design the total vehicle layout may be less codifiable, and its retention may tend to depend on personal experiences. For example, Mr. Morioka, responsible for vehicle layout design in the four successive Familia (323) projects at Mazda, explained why it is important for layout engineers to continue their positions in successive generations:

> "Since "Kikaku-sekkei" [Basic design, which means the layout design in Mazda] is related to the all engineering areas, it's important to gain broad experiences [within the same product line] to be able to capture a whole [complex relationships between different engineering domains].... Thus layout engineers tend to stay in the same product line for long time."[61]

Although we found no significant difference between layout engineers and exterior/interior designers either in reference to documents/reports or importance of standards, this is not surprising because most exterior/interior designers are not engineers but industrial designers. [62]

Contrary to our proposition, Table 3.9 shows that both documentation and standardization seem to be important means to capture prior practices in vehicle test engineering. Results indicate that vehicle test engineers tended to depend upon documents , reports, and standards more than did component engineers although a series of independent t-tests showed that there are no significant differences between them either in reference to documents/reports or the importance of standards. (However, two-tailed independent t-tests showed a significant difference between exterior/interior designers and vehicle test engineers with reference to documents and reports at the 1% level, and in importance of standards at the 5% level.)

This may be partially because that documents and reports have particular meaning or usefulness to test engineers. While drawings are the primary outputs for design engineers, testing reports are the primary outputs for test engineers. Test engineers summarize test results in various forms of reports which they distribute to related engineering and design departments. Table 3.3 in section 3.2 also indicated that knowledge related to testing

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[61] Interview with Mr. Morioka, Mazda Motor Corp., May 19, 1994.

[62] Among exterior/interior designers in our sample, five people have engineering backgrounds, and were responsible for interior designs and interior component designs.

activities, such as that about target performance setting, design and production prototype evaluation, were thought to be transferred through documentation. In this respect, for example, Cusumano and Selby (1995) described that software testers at Microsoft rely heavily on various types of checklists and scripts.

They also seem to depend on standards more than do component engineers. This suggests that existing testing methods and established test codes become a critical basis for testing new vehicles. Compared to design work, testing work may require more consistency and thoroughness than creativity. Thus, standards and documents may become important. Although we assumed that vehicle test engineering involves complex integrative efforts across many different component system development, testing function itself may be an well-established discipline.

Table 3.11 shows how differently components engineers use documents, reports, and standards to retain past design information for a whole component system and for its parts. Since responses both to reference to documents and reports and to use of standards came from the same respondents, we conducted paired-sample t-tests to examine differences.

Table 3.11: Frequency of reference to documents and reports and importance of standards for designing a whole component system and its parts

	Frequency of Reference to Documents and Reports		Importance of Standards (design standards, test code)	
	Component Systems (Whole)	Parts of Components	Component Systems (Whole)	Parts of Components
Component engineers (N = 114)	3.70 (1.04)**	3.87 (1.00)**	3.96 (1.01)**	4.02 (0.94)**
Exterior/Interior Designers (21)	3.09 (1.26)	3.23 (1.04)	3.47 (1.28)	3.71 (1.10)
Chassis Engineers (23)	3.73 (0.81)	3.86 (0.96)	4.00 (0.85)	4.13 (0.75)
Body Engineers (23)	3.82 (1.02)	4.17 (0.88)	4.17 (0.83)	4.17 (0.71)
Engine Engineers (25)	4.12 (0.67)	4.12 (0.78)	4.08 (0.91)	4.20 (0.86)
Electronics Engineers (23)	3.60 (1.19)	3.86 (1.09)	4.04 (1.09)	4.09 (1.15)

Standard deviations shown in parenthesis
**p < .05 (Paired t-test, two tailed)

Results show that component engineers tended to refer to documents and reports that described past design solutions and problematic cases more frequently for designing parts of component systems than designing whole component systems ($p < .05$, two tailed paired t-test). In addition, design standards tended to played more important roles in designing parts of component systems than designing whole component systems ($p < .05$, two tailed paired t-test).

Qualitative information obtained from interviews also indicates this difference. They tended to point out that, while knowhow of parts-level design can be easily stored as written documents and standards, knowledge to develop entire component systems sometimes may have to depend on individual experience as the following comment by one engineer at Honda illustrates:

> "Once we divide the entire design work in to component [parts] levels, anyone can design them [because of standard design procedures]. But, as for design and plan of an entire engine configuration, it may be necessary for a specific person to continue in multiple generations"[63]

Mr. Ikeda, responsible for development of engine control systems at Mazda, also pointed out the distinction between knowhow to design a whole engine unit and its sub-system or parts:

> "To systematically retain engine development knowhow, we intensively spent 3 to 4 years to formalize standard design procedures. However, these standard procedures are more or less for retaining knowledge at the subsystem level, mainly focusing on parts design processes.... I do not know whether we have formalized documents to store knowledge to design an engine as a whole unit."[64]

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[63] Interview with Mr. Umemoto Chief Engineer in the Design Block No. 1, Honda R&D, May 23, 1994.

[64] Interview with Mr. Ikeda, manager in the PT Design Department No. 1, Mazda Motor Corp., May 19, 1994.

These comments combined with our survey results seem to indicate that, the more knowledge becomes integrative, the less its retention depends on archival media.

3-4 Summary

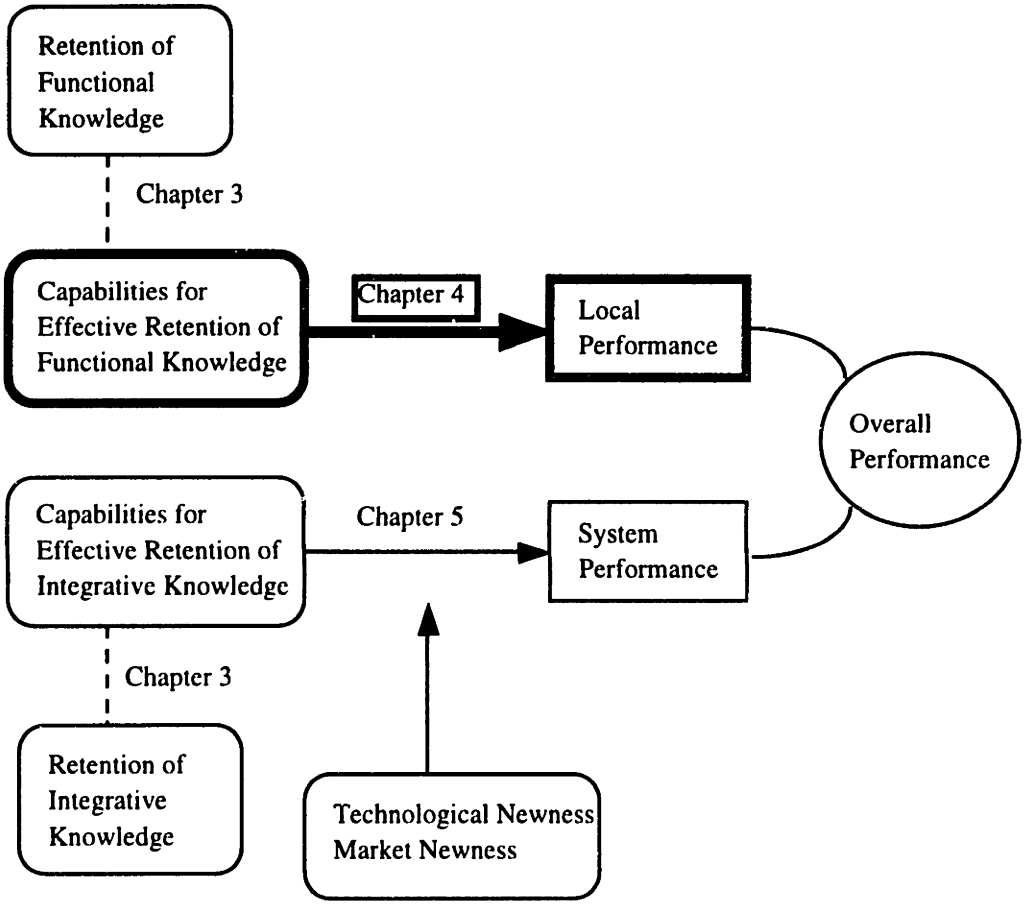
The main objective of this chapter was to explore how knowledge of the interactions among fragmented functional domains, which we defined integrative knowledge, is retained across generations of product development projects. After describing several knowledge retention mechanisms, we proposed that retention of integrative knowledge may require transfer of individual experience bases since it may be less codifiable and teachable, and more context-specific.

We then conducted two simple empirical tests to examine this proposition. In these tests, first, we found that project members responsible for integration activities cutting across different functional domains tend to continue their positions in successive generations of projects. This implies that knowledge for integration may tend to be associated with transfer of people. On the other hand, component engineers were less likely to responsible for successive generations of the same product development projects.

In the second test, we found that layout engineers tend to rely less on documents, reports, and standards to learn from past design practices than do component engineers. In addition, we found that component engineers placed less importance on past design information stored in documents, reports, and standards to design a whole component system than their individual parts. These results also imply that archival mechanisms alone are not enough to retain knowledge regarding interaction and integration among different design domains.

Chapter 4

Impact of Knowledge Retention Capability on Local Performance



In the previous chapter, we discussed six mechanisms for knowledge retention across generations of new product development. We discussed that, while some mechanisms are more appropriate for the retention of integrative knowledge, others seem to retain functional knowledge more effectively. For example, our discussion and analyses suggested that, while direct transfer of individual experiences might be required for the retention of less-codifiable integrative knowledge, archival-based retention capabilities, including documentation, standardization, and computer-aided design systems, can be an effective means for retaining knowledge within well-defined component development activities.

Building on the previous discussion, this chapter examines how knowledge retention capabilities affect new product development performance within each component engineering area, which we call *local performance.* While we attempt to empirically examine whether or not retention of prior knowhow affects performance within well-defined component development, we also try to identify which retention capability is more likely to be associated with higher local performance. We shall examine the relationship between knowledge retention capabilities and product development performance *at the entire project level* in Chapter 5.

4-1 Knowledge Retention Capabilities for Local Performance: Propositions

Complex system products like automobiles consist of several relatively well-defined subsystems, which often, in turn, involve numerous components. Correspondingly, new product development processes for such system products involve several distinctive engineering activities. An automobile development process involves, for example, body design, chassis design, exterior/interior design, engine design, manufacturing process design, and prototype testing processes. Although a sum of performance in these individual engineering activities is not necessarily equal to the entire product development performance, especially in the case of integrated system products (Ulrich, 1995), each of these specialized activities should make an important contribution to total product development performance, as indicated by measures such as product quality, development speed, and development efficiency. For example, the mileage of automobiles is directly related to combustion efficiency in engine systems, although it also depends upon interactions between vehicle weight, body shape, and other factors. Similarly, total product development speed can be improved by independently reducing the lead time required for either exterior design, body die making, prototype testing, or production ramp-up. In this chapter, we examine the effect of knowledge retention on performance within relatively well-defined functional and engineering areas.

Achieving high local performance may require specialized or domain-specific technological or functional knowledge, often based on fundamental scientific understanding. No chassis engineer, for example, would join a company without a mechanical engineering background (though engineers of suspension control systems may require electronic backgrounds). While based on fundamental scientific knowledge, development of actual component systems requires a more substantial engineering knowhow that goes beyond what is learned from university education. Such knowhow may be gradually accumulated within companies through long-standing development experiences. Current component system development should benefit from such historically accumulated knowhow, as one body engineer mentioned during our interview: "Without our [body] engineering knowhow long accumulated in the Knowhow Documents, newly assigned engineers cannot start their development work."[65] We thus conjecture that differences in local performance, at least partially, depend upon how engineers effectively retain and utilize specialized or domain-specific engineering know-how obtained from prior development activities.

In Chapter 3, we discussed that, compared to inter-disciplinary or integrative knowledge, functional or component knowledge may tend to be more articulable and communicable, and less context-specific (Iansiti, 1995d). Although component system

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[65] Interview with Mr. Takahashi, Chief Engineer, Honda R&D, May 23, 1994.

development also involves subtle engineering knowledge which is retained only by internal experts, benefits of articulating and formalizing experiential knowledge may be considerable within well-defined component system engineering areas. For example, one chassis design engineer at Mazda told us:

> "Recently we have actively tried to incorporate design knowhow embedded in experts into design tools and technical standards. There is a lot more knowhow that <u>we can and we should</u> accumulate as standardized tools to more efficiently leverage our design knowhow."[66]

We hypothesize that efforts to retain engineering knowhow in *articulated and generalized forms* will significantly contribute to local performance, particularly in automobile development in which technological concepts for component system development is fairly stable and mature.

As we demonstrated in the previous chapter, three mechanisms may be particularly useful to retain knowledge in articulated forms: documentation, standardization, and computerized mechanisms. This leads to the following set of propositions:

> <u>Proposition 1:</u> High local performance, defined as development performance within well-established component system engineering areas, will be associated with retention of domain- specific technological knowledge in well-articulated forms.

> <u>Proposition 2:</u> The use of archival mechanisms for knowledge retention, such as documents, reports, standards, and computer-aided design systems, will be associated with high local performance.

A direct benefit of standardization may be reflected in the reduction of component

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[66] Interview with Mr. Kanazawa, Manager in the Chassis Design Group No. 2, Mazda Motor Corp., May 19, 1994.

costs through reuse and sharing existing components. Standardization also leads to efficiency in the component design process, first because it helps engineers find well-established and reliable designs, materials, and parts, and second because it prevents them from spending time in repetitive problem solving. While standardization may significantly increase the availability of existing knowledge, however, it may adversely affect performance when not updated to adapt to changing environments. The reason several studies pointed out the negative aspect of retention of standardized knowledge is that it tends to be inflexible to changing environmental situations. Frequent re-examination of standards will prevent knowledge stored in standards from being obsolete. For example, in his study of the Japanese software industry, Cusumano (1991) referred to this as "dynamic standardization." Fujimoto (1994) also described that, while Toyota depends on manuals, tools and standards to maintain and distribute manufacturing experience within the organization, standards are frequently revised by shop floor supervisors.

Documentation may be a more flexible way to retain existing knowledge in articulated forms. As described in the previous chapter, Japanese automobile companies have several types of documents and reports available in which they store non-standardized prior knowledge, ranging from the knowhow documents and the problem-handling documents to the user claim reports Intensive reference to such documents and reports at the early stage of development should enable engineers to prioritize their engineering tasks, which leads to more efficient component system development processes. These documents and reports also highlight established technological solutions and unsolved important technological problems to develop technically reliable component systems. Thus documentation as a way to retain knowledge will lead to improvement of both functionality and development efficiency of component systems.

Companies also increasingly store codified and generalized knowledge in computer-based systems. This enables rapid design, testing, and redesign work, without the need to build actual prototype models during the early stages of the product development process through the usage of advanced design systems, such as CAD and CAE. CAE simulation tools, by embodying a huge amount of scientific and engineering principles and knowhow, not only accelerate the computation processes, but also enable engineers to get fast feedback at the very early stages from various people including production engineers and suppliers to improve the quality of component systems. Thus, the use of CAE tools may be associated with both high development efficiency and technical performance of component systems.

Since CAD stores all past designs in electric forms, it enables engineers to quickly edit (e.g., cut and paste) existing designs. A standardized parts' database also contributes to fast access to available and reliable parts. These will results in more efficient development processes.

Other Ways to Retain Functional Knowledge

We have emphasized the roles of archival and computerized mechanisms in the retention of domain-specific technical knowledge, and hypothesized that knowledge retention within well-established component areas may be most effectively achieved in articulated forms. However, there are several other mechanisms related to retention of specialized technological knowledge, some of which have been extensively discussed in existing studies. Therefore, when we empirically examine the effect of knowledge retention on local performance in the next section, we will consider the following mechanisms as well.

The first is the role of organizational structure. Existing studies have pointed out that functional organizations may be most suitable for the retention or transfer of knowledge for component development (Allen and Hauptman, 1987; Clark and Fujimoto, 1991; Wheelwright and Clark, 1992). Allen and Hauptman (1987) argued that, under a project-based organization, engineers would likely fall behind in state-of-the-art technology. In order to accumulate advanced technologies, and to disseminate them across different products, engineers with similar technical specialties should be grouped together, implying a functional type of organization. Wheelwright and Clark (1992) used a similar rationale to explain the advantage of functional organizations in new product development. As they put it: "the functions and subfunctions capture the benefits of prior experience and become the keepers of the organization's depth of knowledge while ensuring that it is systematically applied over time and across projects" (Wheelwright and Clark, 1992: 193). These arguments suggest that the traditional functional unit, managed by functional managers, can play an important role in transferring and retaining knowledge about each component development.

Knowledge retention in component development can also be facilitated by independent organizational units that plan component technology carry-over across projects. As we explained in Chapter 3, one such organizational unit in automobile companies is a long-term technology planning group. They make long-term plans for component transfer across projects, such as engine and suspension systems. They also participate in decision-making processes with project managers and functional managers for important components in the early stages of development. They may have a role complementary to the functional units in terms of effective component knowledge transfer across generations over time.

Second, communication among engineers within the same functional units may also play an important role in the transfer and retention of domain-specific technological knowledge. This is one reason why traditional functional units have been emphasized for component knowledge accumulation. For example, Allen et. al. (1980) found that new product development projects significantly benefit from communication among engineers, both within the laboratory and outside it. However, effective knowledge retention may require not only general intra-functional communication. It also requires a more specific type of communication between individuals who previously developed a particular component system and those who intend to improve that component system.

Retention of specialized component knowledge can be also retained through individual experiences An example of this is to assign engineers to develop the same type of component systems over time.

Although some knowledge may be best transferred through individuals (Allen and Hauptman, 1987), dependence on individual-based retention mechanisms has some drawbacks. First, dependence on individual experience may be costly, compared to archival mechanisms. For example, making engineers responsible for successive generations within a particular type of component (e. g., V6 engines) and within a specific product line prevents engineering resources from being efficiently utilized across different projects. In addition, if there is past design information available in documents and computerized database, which is easily accessible, talking to people may also be wasteful.

Second, knowledge stored as individual experience may sometimes be too context-specific and inapplicable in different settings. As long as knowledge is articulable and generalizable (in other words, important information is not missed by its articulation and formalization), emphasis on archival and computerized mechanisms is of great benefit to firms. The knowledge of how to develop well-defined component systems may be of this type.

4-2 Sample Characteristics and Measurements

To investigate the relationships between capabilities for knowledge retention and functional performance, we used a sample of 83 project members in 25 new product development projects in seven Japanese automobile producers. They were all key project members, representing five different engineering or design areas, exterior/interior design, chassis design, body design, engine design, and electronics component design.

As explained in the previous chapters, we distributed 250 questionnaires to 10 different project members involved in 25 new product development projects. Two-hundred twenty-nine completed questionnaires were returned. In this chapter, we used a portion of this data set, related only to component engineers. We excluded project managers and layout engineers from analyses because their performance is directly linked to overall project performance, and thus cannot be ascribed solely to their own efforts. We also excluded test engineers, production engineers, and marketing/product planners, since some of explanatory and performance variables examined below were not applicable to these project members.

The resulting sub-data set includes 118 component engineers. However, because of missing values for some explanatory variables, the final sub-sample analyzed here includes 83 engineers.[67] Among the 83 engineers, 16 are chassis engineers; 18 are body engineers; 17 are engine engineers; 15 are electronics component engineers; and 17 are exterior/interior designers. The average age of these project members at the time of project end was 39.07 (s.d. 5.26); the average length of their service in the project was 35.10 months (s.d. 14.20).

4-2.1 Performance Measurement

In the questionnaire, we asked respondents to assess performance derived only from design activities within their engineering areas, as opposed to the performance of overall product development projects. Using 5-point Likert scales, they rated their satisfaction in

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[67] Missing values were observed especially for the ratio of engineers involved in the previous generation of project, as described later.

development cost performance, component cost performance, adherence to schedules, manufacturability of component systems, novelty of component systems, and technical performance of component systems. Table 4.1 below shows summary statistics for these performance indicators.

Table 4.1: Descriptive statistics for performance indicators

N = 83	Mean	S.D.	Min.	Max.
Component cost performance	3.33	1.04	1.00	5.00
Development cost performance	3.04	0.90	1.00	5.00
Adherence to schedule	3.13	1.01	1.00	5.00
Manufacturability of component systems	3.14	0.70	1.00	5.00
Novelty of component systems	3.21	1.01	1.00	5.00
Technical performance of component systems	3.74	0.74	2.00	5.00

5-point Likert Scales, from 1 = not satisfactory, to 5 = very satisfactory.

4.2.2 Explanatory Variables

Reference to Documents, Reports, and the Use of Standards

As described in Chapter 3, automobile companies use documentation extensively as a mechanism for storing past practices. In Chapter 3, we described various documents and reports that Japanese automobile companies use to retain knowhow by classifying them into four types. The first two types of documents described standardized knowhow such as technical standards, standard design procedures, and standard test methods, which "engineers must follow."[68] These were stored either at the company-level or at each engineering department level.

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[68] Interview with Mr. Kato, Group Leader in the Engine Design Department, Mitsubishi Motor Corp., April 12, 1995.

Non-standardized knowhow or lessons obtained from past activities were retained through several other formal and informal reports. Examples of formal documents were, for example, the test reports, the knowhow documents, and the user-claim reports. Companies also flexibly used various informal memos or reports, such as the problem-handling document and the communication memos, to transfer information about past problematic cases to current project activities.

Although the boundary between standards and non-standardized knowhow is not clearly defined, we tried to separate them in the questionnaire. First, we asked respondents to rate how frequently they referred to documents and reports that described design solutions and problems identified in the past development activities on a 5-point Likert scale, from 1 = not refer at all, to 5 = refer very frequently. The exact question (in English translation) was:

> How frequently did you refer to documents that describe problem-solving methods for design and its evaluation and other unsolved problems found through the past development activities (for example, technology reports and problematic case reports) during this project?

Second, respondents rated the importance of standards in designing components during the project on a 5-point Likert scale, from 1 = not important at all, to 5 = very important. The exact question was:

> How do you rate the importance of design standards, standard design procedures, and standard design tools in development of component systems in your area for this project?

Table 4.2 below shows summary statistics for these two indicators.

Table 4.2: Summary statistics for the use of documents/reports and standards

N = 83	Mean	S.D.	Min.	Max.
Reference to documents and reports	3.78	0.91	1.00	5.00
Importance of standards	3.92	0.99	1.00	5.00

Use of Computer-aided Systems

We requested respondents to rate the importance of computer-aided systems within six different areas: CAE simulation (vehicle performance), CAE simulation (structural analysis), CAD/CAM with direct creation of parts programs, sharing of design information among engineers by CAD/CAE, standardized parts database, and reuse and edit of past design information stored in CAD/CAE. Respondents rated the importance of each of these according to a 5-point Likert scale, from 1 = not important at all, to 5 = very important.

Some of these six variables are conceptually distinct. For example, the first two variables together indicate the use of CAE simulation tools; the last two variables indicate the use of computer-stored past information. To verify an underlying pattern, we conducted a principal component analysis. Two factors emerged. The first two variables, CAE simulation (structural analysis) and CAE simulation (performance), formed one cluster. Since this is a conceptually related cluster, we averaged values for the two variables to indicate the use of CAE simulation (alpha = 0.83).

The second factor consisted of the last three variables. However, the last two variables presumably indicate computer-based past design retention, which is conceptually different from design information sharing. Therefore, we excluded the information sharing variable, and then averaged scores for the remaining two variables, the standardized database and the reuse and edit of past design information, to construct an indicator for computer-based design retention (alpha = 0.78). Since a variable of CAD/CAM with direct creation of parts programs was almost equally loaded on the two factors, we preserved this as a separate variable. This grouping is appropriate since the resulting three measures for use of computer-based information systems are conceptually distinct. Table 4.3 below shows summary statistics.

Table 4.3: Summary statistics of variables for computer-based systems

N = 83	Mean	S.D.	Min.	Max.
Computer simulation	3.22	1.25	1.00	5.00
Reuse of computer-stored design information	3.63	0.90	2.00	5.00
Direct creation of parts program by CAD/CAM	3.48	1.32	1.00	5.00

Continuity of Engineers Across Product Generations

Each respondent provided the total number of engineers in his or her area involved in the project. They were then asked for the number of these engineers who also had been responsible for the previous generation of a project. Based on these numbers, we calculated the percentage of engineers having experience in the previous project generation. Because of confidentiality issues, some respondents did not provide us with these numbers. We obtained data only from 90 out of 118 respondents, which significantly decreased our sample size.[69] While we could have examined the previous experiences of respondents themselves, in the same way as in Chapter 2, we chose not to do this since knowledge retention within functional areas should be more appropriately captured by

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[69] One participating company refused to provide the number of engineers involved in projects. As a result, most engineers in this company did not give us this data. Since almost all missing values for this variable systematically came from one company, we had no way to replace them.

looking at all engineers. The average percentage of engineers having experience in the previous projects as estimated by the engineers themselves was 18% (s.d., 0.14).

Communication

Respondents estimated how often, on average during projects, they communicated with the following nine types of individuals.[70]

Table 4.4: Types of communication reported

(measured in approximate days per year, N = 83)

Communication with Project Members belonging to	the same project	another project	the previous generation of the project
the same engineering area	(1) Mean: 193.2 S.D.: 72.9	(2) Mean: 113.1 S.D.: 91.1	(3) Mean: 84.83 S.D.: 94.11
different engineering areas within the product engineering department	(4) Mean: 58.7 S.D.: 29.8	(5) Mean: 17.2 S.D.: 19.2	(6) Mean: 18.0 S.D.: 15.8
different functional departments and suppliers	(7) Mean: 36.0 S.D.: 19.1	(8) Mean: 15.1 S.D.: 17.9	(9) Mean: 15.1 S.D.: 16.5

Cells, 1, 2, and 3, in the first row of Table 4.4 refer to communication within each engineering area; for example, communication among body engineers, and communication among chassis engineers. We included six engineering areas, namely exterior/interior design, body design, chassis design, electronics component design, engine design, and vehicle test engineering. Cells, 4, 5, and 6, in the second row refer to communication which occurs between different engineering areas. Communication between body

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[70] Although our specific concern is the impact on local performance of communication with individuals who previously developed the same component systems, we also considered other types of communication, since the existing studies deal with both intra- and inter-functional communication with people within/outside project boundaries as important performance predictors (e.g., Allen, et. al., 1979; Ancona and Caldwell. 1992a).

engineers and chassis engineers, and between vehicle test engineers and engine designers, are examples. The other functional departments shown in the third row include production, marketing/product planning, sales, quality insurance, purchasing, cost management, long-term planning groups, and suppliers. Cells, 7 , 8, and 9, refer to communication with people who belong to these different departments.

Respondents rated the frequency of communication on 6-point scales, with 1 = two to three days per year or less, 2 = once a month, 3 = two or three days a month, 4 = once a week, 5 = two or three days a week, and 6 = every day. Based on a 240-day working year, each score was transformed to the number of days in the following way: 1 → 2.5 days; 2 → 12 days; 3 → 30 days; 4 → 52 days; 5 → 120 days; and, 6 → 240 days. Then, we calculated scores for the above nine types of communication, if required, by averaging the number of days for communication with appropriate individuals. The means and standard deviations are shown in the table 4.4 above.

To identify an underling pattern, we subjected these nine indicators to a principal components analysis. Four factors emerged. Communication with other project members, (cells 4, 5, and 6) was clustered, as well as communication with the previous generation of project members (cells 7, 8, and 9). Communication within the current project was divided into two factors, intra-functional communication and cross-functional communication (which includes communication both with individuals in different engineering areas and those in different functional departments). Based on this analysis, we constructed four measures for different types of communication by averaging corresponding communication scores. These are intra-functional and within-project communication, cross-functional and within-project communication, inter-project communication, and communication with the previous project members (cross-generational communication).[71] The means and standard

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[71] However, these measures are not completely independent, since some project members might be transferred from the previous generation of projects, or have worked on multiple projects simultaneously. In

deviations for these measures are as follows.

Table 4.5: Summary statistics of communication variables

N = 83	Mean	S.D.	Min.	Max.
Intra-functional communication	193.2	72.9	12.0	240.0
Cross-functional communication	47.0	19.7	4.0	110.8
Communication with other project members	22.7	18.4	2.5	94.32
Communication with previous project members	21.0	18.4	2.5	67.1

Organizational Influences

Respondents rated the influences of functional managers, long-term technology planning groups, and project managers in technology selection decision-making, on 5-point Likert scales, from 1 = not involved at all to 5 = played a very important role. Based on these answers, we constructed indicators of the relative influence between project managers, functional managers, and long-term planning groups, by subtracting scores for project managers' influences from scores for the other two influences. As a result, we obtained two indicators for relative influences: one indicates the influence of a functional manager relative to that of a project manager; the other refers to the influence of a long-term technology planning group relative to that of a project manager. The table below shows summary statistics.

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such cases, communication within the project is more-or-less overlapped with inter-project and inter-generational communication.

Table 4.6: Summary statistics of variables indicating organizational influence relative to project managers

N = 83	Mean	S.D.	Min.	Max.
Relative Power of Functional Managers	-0.24	1.23	-3.00	2.00
Relative Power of Long-term Planning Groups	-1.55	1.56	-4.00	3.00

The table suggests that the influence of functional managers is slightly weaker than that of project managers on average, and that the influence of long-term planning groups is much weaker than that of project managers. The difference between means of these two variables is statistically significant ($p < .001$, paired t-test, two-tailed).

4-2.3 Control Variables

In addition to the above explanatory variables, we considered several control variables. The first is a dummy variable that indicates whether or not projects ended before 1992. Japan experienced a record-breaking economic boom in the late 1980s, later called the "Bubble economy." During this period, Japanese automobile producers, without exception, shifted attention to more luxury features of automobiles, reflecting their perception of changed consumer preferences. One example of this was the establishment of the Lexus and Infinity channels in the U.S. by Toyota and Nissan, respectively. New product development during the Bubble economy was significantly different from that in the 1990s. Relative to the preceding period, automobile producers spent lavishly on development costs to upgrade product performance. For example, Mr. Takahashi, a body engineer at Honda, contrasted development of the 1990 Accord with that of the 1994 Accord:

> "In the development of the 1990 Accord, we could do anything we wanted. We made as many new attempts as possible. We spent any amount of money to improve attractiveness of a new model.... In those days, we had about 30 types of trunk hinges company-wide [converging to one type for currently developing new products]. However, this atmosphere had gradually changed when we were developing the 1994 Accord. We changed our way of thinking in order to make money. In body design, for example, we tried to fully utilize the existing production facilities."[72]

Generally, all people we interviewed reflected on what they retrospectively considered to be wasteful development expenditure during the Bubble economy. Thus, we would expect that efficiency-related performance for development projects conducted during this period would be very low, and that novelty of component systems would be higher.

There are four projects out of 25 that could be regarded as mainly conducted during the period of the bubble economy. All these four projects introduced new models in 1991.[73] Respondents involved in the four projects were coded as 1: otherwise they were coded as 0. There are 16 engineers coded as 1.

The second control variable indicates whether or not respondents were responsible for the development of micro cars. Micro cars are characterized by an engine displacement of less than 660cc. There are also size limits for micro cars determined by law. Since most micro cars had already reached these limits, opportunities for fundamental design changes were quite restricted. In addition, since micro cars sold at very low prices, starting from around $5,000, cost targets inevitably received the highest priority in development. Because of this distinctive nature of micro car development, we included this as a dummy

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[72] Interview with Mr. Takahashi, Chief Engineer, Honda R&D, May 23, 1994.

[73] Our sample did not include any project that introduced its product during 1992, implying that all the other projects introduced their models in 1993, 1994, or 1995. Although some of these projects started during 1989, we believe that they had had enough time to adjust to economic conditions after the bubble economy.

variable. Respondents who worked on micro car development were coded as 1; 0 otherwise. There were 11 engineers coded as 1.

The third control variable is design newness, which indicates the percentage of change of the component from the existing design. This variable is the same as that used in Chapter 3. Finally, we considered two dummy variables which indicate engineering areas and companies.

4-3 Results and Discussion

Table 4.7 below shows the correlations among performance variables and explanatory variables.

Table 4.7: Correlation Matrix

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Communication :Functional																	
2	:Cross-functional	0.06																
3	:Inter-project	0.09	-0.07															
4	:Cross-generation	0.24 ••	0.24 ••	0.40 •••														
5	Relative Power of functional manager	-0.02	-0.03	0.02	0.16													
6	Relative Power of Long-term Planning Group	-0.04	0.00	0.08	0.00	0.22 ••												
7	Reference to Documents and Reports	-0.01	0.00	0.07	0.28 •••	0.20 •	-0.10											
8	Use of Design Standards	-0.02	-0.06	-0.02	0.02	0.16	0.01	0.58 •••										
9	Use of CAE Simulation	0.14	-0.10	-0.23 ••	-0.03	0.14	0.00	0.20 •	0.26 ••									
10	Use of Computer-stored Past Design Information	-0.07	0.02	0.09	0.07	0.04	-0.09	0.32 •••	0.38 •••	0.16								
11	Direct Parts Program through CAD/CAM	0.03	-0.12	-0.21 ••	-0.26 ••	-0.06	0.05	0.09	0.20 •	0.23 ••	0.27 ••							
12	% of Previous Project Members	-0.03	0.00	-0.05	0.22 ••	0.09	-0.06	0.12	-0.03	0.03	-0.20 •	-0.17						
13	Component Cost Performance	-0.13	-0.08	-0.18 •	-0.17	0.22 ••	-0.08	0.33 •••	0.25 ••	0.17	0.31 •••	0.21 ••	0.01					
14	Development Cost Performance	-0.05	-0.04	-0.02	0.04	0.08	0.12	0.24 ••	-0.05	-0.18	0.14	0.06	0.05	0.56 •••				
15	Adherence to Schedule	-0.05	-0.04	0.19 •	0.06	0.06	0.17	0.19 •	0.03	0.02	0.04	-0.03	0.12	0.19 •	0.51 •••			
16	Manufacturability	-0.10	-0.03	-0.18	-0.06	0.17	-0.04	0.17	-0.03	0.05	0.12	0.18	-0.10	0.44 •••	0.41 •••	0.14		
17	Novelty	-0.12	0.09	-0.17	0.17	0.01	-0.27	0.11	0.08	0.17	0.03	-0.02	0.11	0.02	-0.06	0.06	0.07	
18	Technical Performance	-0.17	0.03	-0.04	0.09	0.18 •	-0.23	0.44 •••	0.12	0.32 •••	0.04	-0.06	0.25 ••	0.24 ••	0.14	0.25 ••	0.38 •••	0.43 •••

*p < .1, **p < .05, ***p < .01

This table shows relatively strong relationships among several performance indicators. The relationship between development cost performance and component cost performance is particularly strong ($r = 0.56$, $p < 0.01$). This might be because respondents were not responsible for managing development costs for their engineering works. Since either functional managers or project managers typically manage development cost, respondents might not be able to distinguish development cost from component cost performance. The relationship between technical performance and innovativeness was also strong ($r = 0.41$, $p < 0.01$). Despite the high correlations among performance variables, we retained each indicator as separate in later analyses because of conceptual distinctiveness.

Among the explanatory variables, the reference to documents and reports, and the use of standards, are highly correlated ($r = 0.58$, $p < 0.01$). As we see in later analyses, this high correlation seems to cause problems in parameter estimates for some of the fitted regression models. However, we preserved these two as separate because we are interested in how differently knowledge retention in standardized forms affects performance from that in non- standardized forms. Instead, we look at results by removing either of these two variables from the fitted regression models in turn to avoid a problem of multi-collinearity.

Results in Table 4.7 appears to support our proposition that local performance is positively associated with archival-based knowledge retention capability. For example, component cost performance was positively correlated with the reference to documents and reports ($r = .33$, $p < .01$), the use of standards ($r = .25$, $p < .05$), and computer-based design retention ($r = .31$, $p < .01$). Development cost performance has a positive association with the reference to documents and reports ($r = 0.27$, $p < 0.05$). Technical performance was positively related with the reference to documents and reports ($r = .44$, $p < .01$), and the use of CAE simulation ($r = .32$, $p < .01$).

On the other hand, organization-based and individual-based mechanisms tended not to be associated with performance indicators. First, none of the communication-related variables was significantly associated with performance. Second, among the organizational influence variables, the functional manager's relative power against a project manager had a positive association only with component cost performance ($r = .22$, $p < .05$). Third, the percentage of engineers who worked on the previous project was found to be positively related with technical performance ($r = .25$, $p < .05$), but has no association with any efficiency-related performance indicator.

Table 4.8 below shows the results of fitted regression models for each performance dimension. Model 1 includes only control variables for each performance indicator. When sets of dummy variables indicating engineering areas and firms were not significantly associated with performance, we excluded them in the subsequent models.[74] Model 2 includes variables related to archival-based retention mechanisms in addition to control variables; Model 3 includes variables for organizational capabilities. Model 4 for each performance indicator shows the full fitted regression model. However, we found that the observed high correlation between the reference to documents and reports, and the use of standards ($r = 0.58$), seemed to cause some problems in parameter estimates, so we excluded either of these variables in turn from Model 5 and Model 6, respectively.

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[74] We conducted the increment-to-R-square test to examine the impact of sets of dummy variables. When either the firm or area dummy variables together did not significantly increase values of R-square (5 % level), we excluded them in the subsequent regression models.

Table 4.8: Results of the fitted regression analyses for local performance indicators

	Product Cost Performance						Development Cost Performance					
	I	II	III	IV	V	VI	I	II	III	IV	V	VI
Bubble Economy	-0.44 •••	-0.50 •••	-0.47 •••	-0.51 •••	-0.47 •••	-0.48 •••	-0.30 ••	-0.35 •••	-0.29 •••	-0.33 •••	-0.27 •••	-0.27 ••
Micro Car	0.16	0.24 •••	0.15 •	0.19 ••	0.19 ••	0.21	0.26	0.13	0.15	0.12	0.12	0.12
Design Newness	0.07	0.08	-0.06	0.02	-0.03	0.03	-0.11	-0.10	-0.11	-0.14	-0.24	-0.23 •
Firm	Not Sig.						Not Sig.					
Engineering Area	Sig.	Inc.	Inc.	Inc.	Inc.	Inc.	Not Sig.					
Reference to Documents		0.20 ••		0.28 ••		0.19 •		0.43 •••		0.45 •••		0.24 ••
Use of Design Standards		-0.09		-0.16	-0.02			-0.39 •••		-0.39 •••	-0.17	
Computer-based Design Retention		0.17 •		0.21 ••	0.21 ••	0.18 •		0.15		0.15	0.18	0.08
Direct Parts Program by CAD/CAM		0.16		0.06	0.11	0.06		0.01		-0.02	0.04	-0.03
Use of CAE Simulation		0.02		0.05	-0.01	0.02		-0.15		-0.17 •	-0.19 •	-0.23 ••
Relative Power: FM			0.10	0.08	0.09	0.07			0.04	0.04	0.08	-0.02
Relative Power: Long-term Plan			-0.07	-0.02	-0.07	-0.04			-0.18 •	-0.10	-0.15	-0.13
Communication: Functional			-0.12	-0.04	-0.05	-0.03			-0.03	0.02	0.00	0.05
:Cross-Functional			-0.02	0.03	0.01	0.03			0.03	0.00	-0.01	0.00
:Cross-Generation			-0.04	-0.19	-0.17	-0.16			0.08	-0.05	0.11	0.00
:Inter-Project			-0.19 •	-0.12	-0.07	-0.13			-0.04	-0.09	-0.13	-0.10
% of Previous Members			[illegible]	0.01	0.02	0.01			0.01	-0.06	-0.03	-0.05
d. f. of residuals	69	75	68	68	69	69	69	75	68	68	69	69
Adjusted R-square	0.41 •••	0.46 •••	0.38 •••	0.47 •••	0.44 •••	0.47 •••	0.12 •	0.27 •••	0.09 •	0.23 •••	0.11 •	0.15 ••

	Adherence to Schedule						Manufacturability					
	I	II	III	IV	V	VI	I	II	III	IV	V	VI
Bubble Economy	-0.06	-0.01	0.01	-0.04	0.00	0.02	-0.31 •••	-0.36 •••	-0.26 •••	-0.34 •••	-0.27 ••	-0.27 ••
Micro Car	0.41	0.04	0.08	0.02	0.02	0.08	0.39 ••	0.09	0.12	0.11	0.11	0.16
Design Newness	-0.31 ••	-0.26 ••	-0.28 ••	-0.22 •	-0.26 ••	-0.22	0.06	0.11	0.00	0.05	-0.03	0.06
Firm	Not Sig.						Not Sig.					
Engineering Area	Not Sig.						Not Sig.					
Reference to Documents		0.17		0.19		0.10		0.34 •••		0.40 •••		0.21 •
Use of Design Standards		-0.14		-0.18	-0.08			-0.32 ••		-0.36 ••	-0.15	
Computer-based Design Retention		0.05		0.07	0.08	-0.03		0.02		0.03	0.04	0.06
Direct Parts Program by CAD/CAM		-0.02		-0.01	0.02	0.05		0.12		0.06	0.12	0.03
Use of CAE Simulation		-0.01		0.02	0.01	0.04		0.11		0.08	0.05	-0.18
Relative Power: FM			0.01	0.00	0.02	-0.01			0.06	0.05	0.09	0.03
Relative Power: Long-term Plan			0.09	0.15	0.13	0.12			-0.01	0.02	-0.04	-0.01
Communication: Functional			-0.09	-0.11	-0.12	-0.11			-0.03	-0.01	-0.03	0.01
:Cross-Functional			0.00	0.02	0.02	0.01			-0.03	-0.01	-0.02	-0.02
:Cross-Generation			0.03	-0.04	0.03	0.01			0.09	-0.03	0.11	0.02
:Inter-Project			0.14	0.14	0.13	0.17			-0.21 •	-0.16	-0.19	-0.16
% of Previous Members			-0.03	0.10	0.11	0.03			-0.15	-0.18	-0.15	-0.18
d. f. of residuals	69	75	68	68	69	69	69	75	68	68	69	69
Adjusted R-square	-0.01	0.01	0.02	-0.02	-0.03	-0.02	0.13 ••	0.14 •••	0.05	0.12 •	0.03	0.05

*p < .1, **p < .05, ***p < .01

Table 4.8: Continued

	Technical Novelty						Technical Performance					
	I	II	III	IV	V	VI	I	II	III	IV	V	VI
Bubble Economy	0.16	0.19 •	0.20 •	0.19 •	0.19 •	0.18	-0.09	-0.03	0.08	-0.05	0.04	0.01
Micro Car	0.23	-0.05	-0.14	-0.12 ••	-0.12 ••	-0.13	0.24	0.04	-0.06	-0.06	-0.06	-0.01
Design Newness	0.13	0.11	0.00	0.11	0.12	0.11	-0.07	0.00	-0.30	-0.04	-0.15	-0.03
Firm	Not Sig.						Not Sig.					
Engineering Area	Not Sig.						Not Sig.					
Reference to Documents		0.08		-0.04		0.02		0.55 •••		0.50 •••		0.38 •••
Use of Design Standards		0.05		0.11	0.09			-0.22 •		-0.24 •	0.02	
Computer-based Design Retention		0.03		-0.09	-0.09	-0.08		-0.06		-0.07	-0.05	-0.15
Direct Parts Program by CAD/CAM		-0.05		0.09	0.08	0.11		-0.13		-0.09	-0.02	-0.07
Use of CAE Simulation		0.13		0.27 ••	0.27 ••	0.30 ••		0.32 •••		0.38 •••	0.35 •••	0.38 •••
Relative Power: FM			0.07	0.04	0.04	0.05			0.19 •	0.11	0.16	0.09
Relative Power: Long-term Plan			-0.29 •••	-0.35 •••	-0.34 •••	-0.34 •••			-0.28 •••	-0.25 ••	-0.31 •••	-0.27 •••
Communication: Functional			-0.22 ••	-0.25 ••	-0.25 ••	-0.25 ••			-0.17	-0.19 •	-0.22 ••	-0.18 •
:Cross-Functional			0.00	0.05	0.05	0.05			0.04	0.12	0.11	0.10
:Cross-Generation			0.10	0.07	0.06	0.07			0.13	-0.11	0.06	-0.06
:Inter-Project			0.17	0.30 ••	0.30 ••	0.30 ••			-0.10	0.08	0.04	0.09
% of Previous Members			0.05	0.08	0.08	0.07			0.13	0.14	0.18	0.12
d. f. of residuals	69	75	68	68	69	69	69	75	68	68	69	69
Adjusted R-square	-0.04	-0.01	0.11 ••	0.13 ••	0.14 ••	0.15 ••	0.12 •	0.25 •••	0.12 ••	0.32 •••	0.17 ••	0.29 •••

*p < .1, **p < .05, ***p < .01

Results from the regression analyses are mostly consistent with those from the correlation analyses. First, as shown in the full models (Model 4), data suggest that the more frequently engineers referred to documents and reports, the higher performance they reported, in general. Specifically, this variable was positively associated with component cost performance ($p < .05$), development cost performance ($p < .01$), manufacturability ($p < .01$), and technical performance ($p < .01$). This implies that reference to documents and reports to learn from past component development practices has a broad impact on local performance dimensions, both in terms of development efficiency and technical performance, as hypothesized.

However, contrary to our proposition, the full regression models show that the use of standards is negatively related to development cost performance, manufacturability, and technical performance. Although all these negative relationships were no longer significant after excluding the use of documents and reports as shown in Model 5, indicating a problem of multi-collinearity, the signs of regression coefficients were still negative. It might be that there is some real negative influence from the use of standards on performance. Qualitative information obtained from interviews provided some hints to interpret this result.

Problems of dependence on technical standards generally arise when engineers use outdated technical standards and take it for granted. New products were introduced after 1993 in 21 out of the 25 projects in our sample. This means that most projects developed new products after the record-breaking economic boom in the late 1980s. As we mentioned in the previous section, engineers had to significantly change the way to develop component systems to adapt to much more price-conscious customers in the 1990s. For example, engineers were required to dramatically reduce component costs and the number of parts. In such circumstances, companies had to revise many existing technical standards that had tended to put too much quality on component systems by sacrificing cost performance (Fujimoto, 1994), as several interviewees pointed out. Thus too much reliance on existing technical standards during this period might lead to low performance, particularly in efficiency-related performance dimensions, at least, in the engineer's subjective evaluation.

Second, computer-based design retention was positively associated with component cost performance at the 5% significance level. Since a high score for this variable also indicates the high degree of reuse of previously-designed parts, this result is understandable. However, computer-based design retention was not significantly related to any other performance indicators. Although it was consistently positively associated with efficiency-related performance indicators, the relationships were not statistically significant.

In the additional analysis which excluded exterior/interior designers from the sample, we found that both computer-based design retention and the CAD/CAM variables were significantly associated with manufacturability at the 5% level. Table 4.9 below shows this. Since manufacturability is not a main concern to exterior designers (for styling), this result of the additional analysis may reflect reality more appropriately.

Table 4.9: A result of the fitted regression analysis for manufacturability. Exterior/interior designers were excluded from the sample.

	Manufacturability					
	I	II	III	IV	V	VI
Bubble Economy	-0.32 ***	-0.30 **	-0.28 **	-0.30 **	-0.25 *	-0.25 *
Micro Car	0.11	0.10	0.20	0.15	0.15	0.15
Design Newness	0.13	0.18	0.10	0.16	0.11	0.17
Firm	Not Sig.					
Engineering Area	Not Sig.					
Reference to Documents		0.20 *		0.28 *		0.20
Use of Design Standards		-0.15		-0.21	-0.11	
Computer-based Design Retention		0.06		0.04	0.09	0.01
Direct Parts Program by CAD/CAM		0.29 **		0.21	0.28 *	0.24 *
Use of CAE Simulation		0.13		0.13	0.10	0.10
Relative Power: FM			0.04	0.02	0.04	0.01
Relative Power: Long-term Plan			-0.05	-0.04	-0.08	-0.04
Communication: Functional			0.05	-0.02	-0.02	-0.03
:Cross-Functional			-0.10	-0.10	-0.11	-0.08
:Cross-Generation			-0.04	-0.08	0.04	-0.05
:Inter-Project			-0.15	-0.07	-0.10	-0.06
% of Previous Members			-0.26 **	-0.21	-0.18	-0.17
d. f. of residuals	62	57	57	50	51	69
Adjusted R-square	0.08 **	0.20 ***	0.07	0.15 *	0.11	0.13 *

*p < .1, **p < .05, ***p < .01

Third, the use of computer simulation tools was significantly associated with technology-related performance: novelty of component systems and component technical performance. However, it was negatively associated with development cost performance. This result may suggest that the use of CAE tools results in higher technical performance at the cost of development efficiency. Qualitative information that we obtained from interviews at Japanese companies also seems to support this result. Several engineers pointed out that, while CAE tools significantly improved quality of the first design prototype, it had not yet achieved projected development efficiency improvement. For example, the following remarks indicate this:

> "[By introducing CAE tools] the number of prototypes decreased by 20 to 30 % for these five years although we were told to reduce it by 50%. But, I think, an

> advantage of CAE lies not in reducing the number of prototypes but in increasing the number of testing cycles before the first prototype. The CAE tools enabled us to consider testing items that we used to give up because of limited time and budget.... Improving accuracy of the first prototype is the most important contribution of CAE."[75]

> "Although we planned to reduce engineering hours by introducing CAE tools, engineering hours have not decreased actually. This is because we are spending a lot of engineering resources to improve [technical] performance. Introduction of the CAE increased the number of technical items we had to consider because the CAE easily found them. As a result, performance and quality have certainly improved. But we may be spending too much time for marginal performance improvement."[76]

Contrary to archival mechanisms and computerized systems, organization-based and individual-based knowledge retention mechanisms did not show any positive impact on performance indicators: some were actually found to have a negative impact.

Among the communication-related variables, communication with the previous project members had no significant association with any performance indicator.

Surprisingly, communication with engineers in the same engineering area was negatively associated with technical-related performance such as novelty of component systems and technical performance of components. This may indicate the inherent problems in communication studies: the more problems occur, the more frequently engineers have to communicate with the other engineers to solve problems. That is, the observed negative association might be spurious, implying that more engineering problems simultaneously increases the frequency of communication and lowered technical performance.

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[75] Interview with Mr. Morita, Section Manger in the Test Department, Daihatsu Motor Corp., May 9, 1995.
[76] Interview with Mr. Nakagawa, Chief Engineer, Toyota Motor Corp., May 31, 1994.

On the other hand, communication with the other project members was positively associated with performance in novelty of component systems ($p < 0.05$). This may indicate that engineers successfully brought in new technological ideas by communicating with individuals outside their projects. There is another interpretation. Since technologically-new components are typically developed for multiple projects, newness of component systems might require engineers to communicate with other project members to adjust component development activities across projects (Nobeoka, 1993).

Organizational influence variables also had no positive impact on any performance indicators. Although correlation analyses showed that a stronger influence by functional managers than project managers is associated with better component cost performance, this association was no longer significant in the regression analysis.

Involvement of long-term planning groups had a significant negative impact on technology-related performance such as novelty of component systems ($p < 0.01$) and technical performance ($p < 0.01$). Since long-term technology planning groups often play a critical role in facilitating carry-over of existing component systems, it is understandable why their involvement may lead to less novel component systems.

Finally, continuity of engineers in successive generations of projects had no significant association with any performance indicators. Although the correlation analysis in Table 4.7 showed a relatively strong association between continuity of engineers and technical performance, this association was no longer significant in the regression analysis though the sign was still positive. This result implies that knowledge retention through people may not be critical to improve local performance.

However, since continuity of engineers here means continuity within the development of the same product across generations, it did not indicate retention of generic technological knowledge for component system development, but, rather, retention of knowledge to apply to a particular product. Therefore, the result here does not necessarily suggests that retention of generic component knowledge through people has no effect on local performance. To explore this point further, the future study needs to examine how the depth of engineer's experience in a particular component development affects local performance.

4-4 Summary

In this chapter, we examined how different knowledge retention capabilities affect performance within well-established component system development areas. We hypothesized that retention of prior knowledge *in articulated and generalized forms* is of great benefit to component systems development since specialized and domain-specific knowledge required for development within well-defined engineering areas may be more articulable and less context-specific.

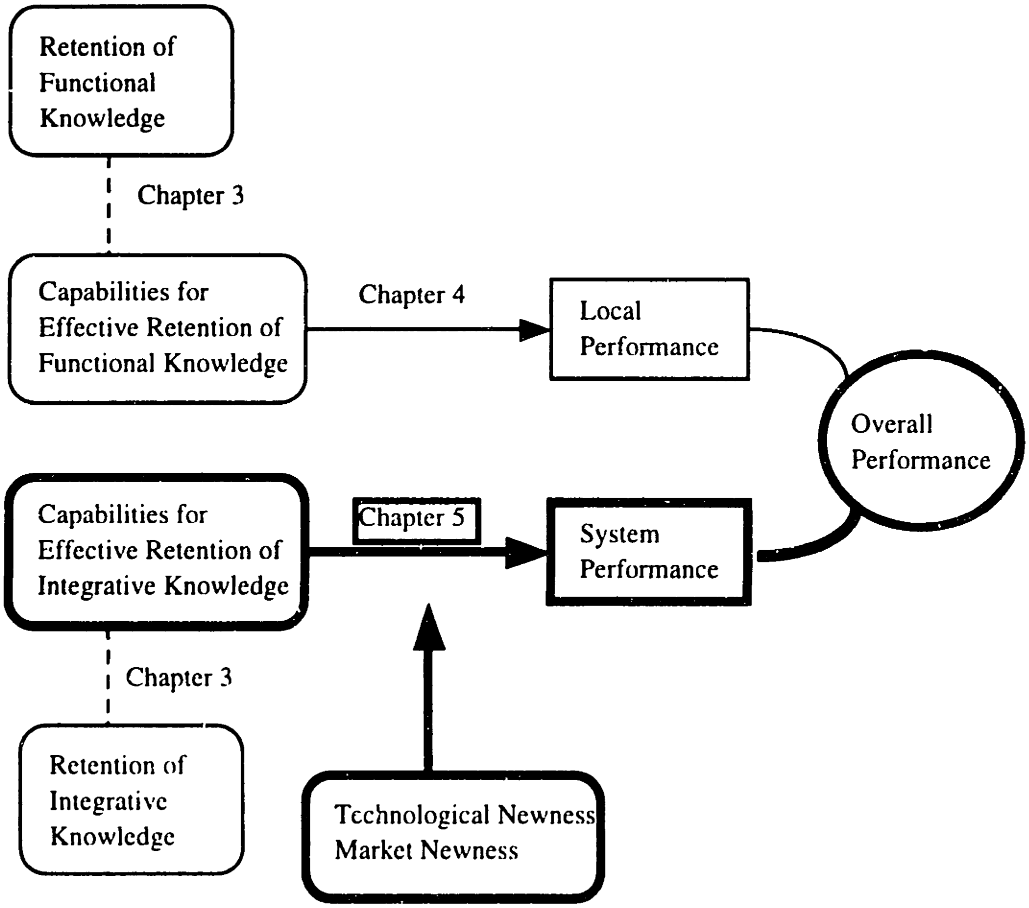
Our survey results partially supported this hypothesis. We found that dependence on documents and reports for knowledge retention had a broad positive impact on local performance; dependence on computer-stored prior design information improved product cost performance; and use of computer simulation tools was associated with higher technical performance of component systems. On the other hand, organization-based and individual-based mechanisms for knowledge retention had either no association or negative associations with performance indicators.

These results imply that investment in formalizing and articulating knowledge may be critical to improve performance within well-defined component system development areas. In the next chapter, we examine the impact of knowledge retention capabilities on the performance of entire product development projects and on performance derived from the interaction between different engineering and functional domains.

The analyses in this chapter have limitations. Since all the data for explanatory and performance indicators came from the same questionnaire survey, observed relationships might be created by common questionnaire methods. In addition, our measures of local performance may not be reliable enough since they depend on subjective self-evaluations. We discuss these limitations in more detail later in Chapter 6.

Chapter 5

The Impact of Knowledge Retention Capability on Overall Project and System Performance



This chapter examines the relationship between knowledge retention capabilities and product development performance *at the project level.* In the previous chapter, we explored how knowledge retention capabilities affect performance within individual engineering areas, which we defined as local performance. For example, we found that dependence on archival mechanisms for knowledge retention, such as documents, reports, and on computer-aided design systems, tended to be positively associated with local performance. However, overall project performance, whether the product's technical performance, development process efficiency, or resulting market sales, cannot be solely attributed to such local performance. It also depends upon the ability to manage complex interactions among different engineering and functional domains. Each engineering activity must be integrated to form a coherent whole, which is, in turn, integrated into user environments (Christensen and Rosenbloom, 1995; Iansiti, 1995 b, c; von Hippel, 1994).

In Chapter 3, we defined the knowledge base required for such integration as integrative knowledge. Effective retention of integrative knowledge may lead to improvement of product development performance since it enables projects to benefit from deeper understandings of complex interactions between different technical and functional domains (Iansiti, 1995b; Henderson, 1995). Since integrative knowledge tends to involve context-specific and tacit components, archival mechanisms such as documents and blueprints may not work as well for its retention as it does for functional knowledge. Instead, individual-based retention mechanisms, such as direct transfer of individuals and face-to-face communication, might be required to effectively retain integrative knowledge. Therefore, if integrative knowledge retention is critical for product development performance at the project level, we should observe a positive association between individual-based retention capability and product development performance. The main objective of this chapter is to empirically examine this conjecture.

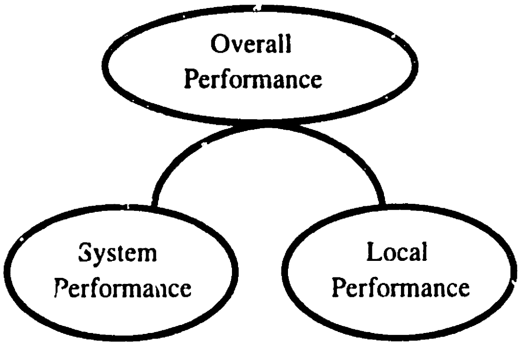
In the following sections, we begin by suggesting how the effective retention of integrative knowledge leads to improvement of project level performance through its impact on system performance. We then hypothesize that dependence on individual-based knowledge retention mechanisms, transfer of a project member's experience base, and cross-generational communication, will be positively associated with performance derived from interaction among different functional domains, which we define as *system* *performance*. Especially, we hypothesize that such retention capabilities affect the degree of *improvement* in new product development performance from previous generations of projects. However, we also hypothesize that integrative knowledge retention through individual-based mechanisms may have a negative impact on product development performance when projects face novel technical requirements and market environments. We then test these hypotheses by using data obtained from 22 new product development projects at seven Japanese automobile producers.

5-1 Knowledge Retention Capabilities for System Performance: Propositions

In the conceptual scheme used in this thesis, overall performance of new product development consists of two factors: local performance and system performance (Figure 5.1). We have discussed that local performance arises only from the local region of product or of product development process, and corresponding development efforts within particular technical and functional areas (Iansiti, 1995b; Henderson and Cockburn, 1995; Ulrich, 1995). For example, the aerodynamic performance of automobiles, as indicated by an air drag co-efficient (Cd), is almost solely determined by the exterior body shape developed by exterior body designers.

On the other hand, system performance characteristics arise from many related elements of a product or a product development process, and their interaction. It is thus the outcome of interactive activities among people in different functional and disciplinary areas. For example, NVH (noise-vibration-harshness) is a critical performance metric for automobiles. While NVH can be individually ascribed to particular technological elements, such as material technologies used in tires and bodies, engine systems, body shapes, and suspension systems, it also comes from the complex set of interactions between these elements.

Figure 5.1 Overall performance, system performance, and local performance



We define local performance as the portion of overall performance reducible to particular technological and functional elements, and system performance as the portion attributed to interactive effects among these elements. The local and system distinction is also applicable to non-technical performance. For example, development lead time may be shortened either by compressing the lead time of each technical and functional activity (local performance) or by facilitating overlaps among them through appropriate adjustments (system performance). Similarly, in some cases, superior engine technology or effective advertising may become a primary driver for automobile sales in the market-place (local performance); in other cases, an appropriate combination among a product concept, component performance, and manufacturing quality may become critical for sales performance (system performance).

Local performance may depend on effective and efficient access to high levels of functional or disciplinary knowledge (Iansiti, 1995c). As we discussed in Chapter 3 and 4, functional knowledge may tend to be less tacit and context-specific than cross-functional knowledge. Thus, it may be effectively retained and transferred in the articulated form, such as data, equations, and formal records. Although our interviews revealed that some of detailed engineering know-how is still kept by functional experts in Japanese automobile companies, a greater portion of component engineering knowhow has been retained through design standards and computerized design systems. We thus hypothesized in Chapter 4 that an emphasis on archival mechanisms and computer-aided systems may lead to higher performance within narrowly defined engineering areas. Analyses in Chapter 4 partially supported this hypothesis, suggesting that the reference to documents and reports, and the use of computer simulation tools, tended to be positively associated with local performance indicators.

On the other hand, system performance may primarily depend on integrative knowledge that goes beyond functional and technical boundaries. In the case of automobile development, for example, body design must be integrated with suspension system design to minimize the noise level and to improve body strength; product design must be integrated into process design to achieve smooth ramp-up and high manufacturability; and the whole product design must be integrated into user contexts to satisfy user needs. All these require knowledge to integrate different functional domains.

Some recent studies have realized the importance of such integrative knowledge in the development of complex system products, and have proposed normative mechanisms appropriate for cross-functional and inter-disciplinary coordination, such as co-located cross-functional teams (Imai et. al., 1985), the heavyweight project manager system (Clark and Fujimoto, 1991; Wheelwright and Clark, 1992), and project organizations (Allen and Hauptman, 1987, Allen, 1987). However, it seem that these structural solutions are easy to imitate (Kusunoki et. al., 1995; Henderson, 1995). Thus, we doubt that they become sustainable sources of difference in new product development. In our view, a capability for cross-functional integration is, rather, a historical product (Fujimoto, 1994), and effective retention of integrative knowledge is of fundamental importance to form a project's ability to solve cross-functional problems.

As we discussed in Chapter 3, since integrative knowledge tends to be less codifiable, and more context-specific than domain-specific functional knowledge, its retention may need direct transfer of individual experiences or intensive face-to-face communication between individuals responsible for different generations of projects. Especially, effective retention of integrative knowledge will affect product development performance derived from complex interaction among different functional domains. This leads to the following proposition:

> Proposition 1: Individual-based retention capability, reflected in continuity of project members across generations of projects and communication among project members in successive generations of projects, will be associated with high system performance in new product development.

System performance shares a critical portion of overall performance especially in the case of complex system products like automobiles, which involve numerous interrelated components and complex user interfaces (Clark and Fujimoto, 1991; Fujimoto, 1994). Therefore, in the case of automobile development, we also expect to observe a positive association between overall performance at the project level and a project's ability to effectively retain integrative knowledge. However, since overall performance is also influenced by local performance characteristics, we conjecture that the impact of individual-based retention capability on overall performance will be weaker than it is on system performance alone. This leads to another proposition:[77]

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[77] The importance of integrative knowledge retention in new product development may depend upon the degree of uncertainty involved in interfaces among different elements in product development, such as component design interface, a manufacturing and design interface, and a user and design interface. For example, when product designs are completely modularized industry-wide, implying standardized interfaces between component designs, there may be no room for each individual company to improve system design. In this case, overall product performance is directly linked to each component performance; thus, firm-level efforts for integrative knowledge retention may have little effect on performance improvement of final

> Proposition 2: Individual-based retention capability, reflected in continuity of project members across generations of projects and communication among project members in successive generations of projects, will be associated with high overall product development performance at the project level. However, this association will be weaker than that with system performance.

Effective retention of past solutions enables a project to start from the level that the previous project reached. That is, projects can avoid redundant problem-solving. Furthermore, knowledge retention may result in an appropriate project focus, since it helps project members prioritize their work so that they focus on critical problems unsolved in the past development activities.

Through these processes, effective knowledge retention is likely to result in consistent performance improvement (Fujimoto, 1994; Iansiti and Clark, 1994).[78] Thus, utility of integrative knowledge retention is more likely to be reflected in change in project performance from that of the previous generations of projects than in the current performance level. This leads to the following proposition:

> Proposition 3: Individual-based retention capability, reflected in continuity of project members across generations of projects and communication between project members in successive generations of projects, will be positively associated with the degree of improvement in product development performance at the project level.

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products. Similarly, if consumer needs are stable and predictable, product development projects can focus solely on technological issues, without explicitly considering user-design interfaces. Integrative knowledge retention capability may not be critical in this case as well. However, throughout this dissertation, we are assuming that the development of automobiles involves uncertainty, both in component design interfaces and in user design interfaces (though the latter interface is probably more uncertain).

[78] As a related concept to retention capability, Fujimoto (1994) defined the ability of the development - production system to consistently and quickly achieve improvement in competitive performance as "improvement capability." Iansiti and Clark (1994) also argued that the same ability is an example of dynamic capabilities.

Contrary to these propositions, innovation studies have tended to discuss a negative effect of knowledge retention on innovation performance (e.g., Allen and Marquis, 1964; Leonard-Barton, 1992; Dougherty, 1992; Henderson and Clark, 1990). A common claim in these studies is that prior technological knowledge is often not applicable in a novel situation characterized by innovation; rather, it becomes an obstacle for bringing in new ideas (e.g., Anderson and Tushman, 1990; Henderson and Clark, 1990; Christensen and Bower, 1994).

Especially, some researchers have pointed out that continuity of project members in multiple generations of projects may cause problems in innovative activities because it increases project homogeneity and project tenure. While project homogeneity may contribute to team cohesiveness, it may prevent project members from bringing in new ideas, especially those created in other development projects (Ancona and Caldwell, 1992b; Katz and Allen, 1982). For example, in their study of 50 R&D projects, Katz and Allen (1982) found that project performance increased up to, and was highest when, project tenure was one and a half years, with a noticeable decline by five years of tenure. Considering that it normally takes more than three years to develop a new car model, continuity of project members in successive generations might be negatively related to project performance depending on the extent to which projects require novel technological ideas and new product concepts. This leads to the following proposition:

> Proposition 4: The relationship between individual-based retention capability and product development performance will be moderated by the degree of task newness involved in new product development activities.

There is counter-argument to this proposition, however. Some researchers have suggested that prior experiences are important, and even help firms adapt to new environments (Cusumano, 1991; Cusumano and Selby, 1995; Neustadt and May, 1986; Huber, 1991; Walsh and Ungson, 1991). Recent theoretical argument in the area of design studies also tend to assume that any design work is based on past experiences and accepted tradition, and that past knowledge becomes critical, even to non-routine and creative design work (Gero, 1990; Oxman, 1990). As an empirical study, Iansiti (1995 a, b, d) found that system integrators' past experiences in developing the same type of product are positively correlated with development efficiency and technical performance.

Furthermore, different types of task newness may differentially moderate the relationship between knowledge retention and product development performance. While some studies found that technological discontinuity substantially changes market dominance, from incumbents to new entrants (e.g., Henderson, 1991; Tushman and Anderson, 1986; Suarez and Utterback, 1991), others claimed that a change in the customer base and associated changes in product functionality pose a more serious threat to incumbents than technological change (Christensen and Rosenbloom, 1995; Christensen and Bower, 1994; Iansiti and Khanna, 1994).

Whether retention of prior knowledge is beneficial or not is still controversial. In section 5.3, we attempt to provide some empirical analyses to this question while examining Proposition 4. In doing so, we shall consider the above alternative hypotheses.

5-2 Sample Characteristics and Measurements

5-2.1 Sample Characteristics

We again analyzed data obtained from the same questionnaire survey. We distributed the questionnaire to 250 project core-members in 25 new product development projects at seven Japanese companies. All projects were responsible for development of new models that replaced the previous generation of models. We asked ten project core-members to be respondents, and represent each project. Those ten core-members included a project manager and representatives of the vehicle test engineers, layout engineers, body design engineers, chassis design engineers, exterior or interior designers, engine design engineers, electronics component engineers, marketing planners, and production engineers. We obtained 229 responses (a response rate of 91.6%).

While each individual was a unit of analysis in the previous chapters, for this chapter, we analyze data at the project level. Some project-level data was obtained directly from questionnaires specifically designed for project managers; other data was constructed by aggregating project members' responses, as described below. Because of 21 missing responses, we could not include all 25 projects in our analyses. We excluded the three projects from the analyses which lacked responses from the project managers, resulting in a usable sample of 22 projects. Table 5.1 below shows characteristics of new models developed by these 22 projects.

Table 5.1: Characteristics of new models developed by sample projects

Number of Organizations	7
Number of Projects	22
Year of Product Introduction (includes one model to be introduced in early 1996)	1991-1996
Average Price ($ 1= 100 yen)	$25,712 Min. $8,475 Max. $57,200
Vehicle size (# of projects):	
micromini	3
subcompact	3
compact	6
mid-large	10
Geographical market (# of projects):	
Domestic Only	3
Foreign and Domestic	19

5-2.2 Analysis Strategy

Because of the small sample size, we could not utilize fully multivariate techniques to specify the relationships between project performance and knowledge retention capabilities. Instead, we take the following steps in the subsequent analyses.

First, we explore the bivariate relationships between project performance and performance predictors. In the analyses, we consider both overall performance and system performance. System performance is statistically separated from overall performance as described below. One of the objectives of this correlation analysis is to explore whether there is any difference between factors affecting overall performance and system performance, as described in Proposition 5.2. The correlation analysis also identifies important control variables which should be considered to specify the relationships between project performance and knowledge retention capabilities.

Additionally, we examine the fitted regression models to further confirm results of the correlation analyses. Since we have only 22 sample projects, these models include only selected control variables and indicators for knowledge retention capabilities.

Finally, we examine Hypotheses 5.4, which refers to an interaction effect between individual-based knowledge retention capability and task newness. We fit regression models including interaction terms between a technical or a market newness indicator and individual-based knowledge retention capability indicators, and examine how newness indicators moderate the relationships between individual-based retention capabilities and product development performance.

5-2.3 Measurement

Performance Measurement

Selected project members rated each of the following seven project performances in a 5-point Likert scale, from 1 = not satisfactory to 5 = very satisfactory. They also rated this performance relative to the previous generation of projects in a 5-point Likert scale, from 1 = the same level or worse than the previous project (model) to 5 = much better than the previous project (model). In the questionnaire, we clearly requested them to rate *overall project performance*, as opposed to performance of activities within each engineering area. Scores obtained from multiple respondents were averaged for each project to construct project level performance measures. Performance ratings encompass seven areas: product cost performance, development cost performance, adherence to schedule, manufacturability, technical performance, technical novelty, and degree of match to customer needs. Table 5.2 shows summary statistics for these performance indicators. In the following analyses, we call a set of indicators shown in the third column of this table, which relate to the current project only, as *performance satisfaction*, and another set of indicators in the fourth column, which compare performance to the previous project, as *performance improvement*.

Table 5.2: Summary statistics for performance indicators rated by selected project members

		Performance Satisfaction		Performance Improvement from the Previous Projects	
Indicators	Description	Mean	S.D.	Mean	S.D.
Product cost performance	Rated by project managers, layout engineers, and marketing planners	3.21	0.81	3.18	1.03
Development cost performance	Rated by Project managers	3.02	1.01	3.25	1.41
Adherence to schedule	Rated by project managers, layout engineers, and marketing planners	3.15	0.61	2.83	0.69
Manufacturability	Rated by project managers and production engineers	3.39	0.81	3.23	0.97
Match to customer needs	Rated by project managers, layout engineers, and marketing planners	3.54	0.69	3.34	0.77
Technical Novelty	Rated by project managers.	3.46	1.14	3.23	1.38
Technical Performance	Rated by project managers with respect to 15 technical performance items[79]	3.97	0.37	3.78	0.59

In addition, we considered market performance, measured by the ratio of realized average monthly sales volume to the targeted volume announced at the time of introduction. Although sales volume is affected by numerous factors that go beyond the new product development process, such as company size, quality of distribution channels, advertising, and general economic conditions, we assumed that companies take these factors into account to some extent when setting target sales volumes. We calculated sales achievement ratios only for the first year of model introduction so as to maintain data comparability across sample projects.[80] The mean score of this indicator across sample

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[79] The 15 items are: space utility, comfortability, noise - vibration - harshness, driving stability, acceleration, braking performance, engine performance, handling response, safety, painting quality, body strength, exterior/interior styling, aerodynamics, and vehicle weight.

[80] However, when projects introduced new products after September 1994, we could not obtain sales data for all 12 months (the latest sales data available was for September 1995). In this case, we averaged available monthly sales volumes after adjusting for a seasonal effect and a new model introduction effect as explained in Appendix 3.

projects was 1.01 (s.d. = 0.36).

Decomposition of overall performance

To separate system performance from local performance, we regressed each of the six indicators for overall performance (product cost performance, development cost performance, adherence to schedule, manufacturability, technical novelty, and technical performance) on corresponding local performance indicators. For example, overall product cost performance was regressed on component cost performances, as rated by component engineers representing body, chassis, electronics component, engine, and exterior/interior design areas. Indicators for local performance were the same as used in Chapter 4. As explained there, representatives of engineering areas rated performance *within* their areas on a 5-point Likert scale, from 1 = not satisfactory at all to 5 = very satisfactory. Since two market-related performance indicators, "degree of match to customer needs" and "sales achievement," have no corresponding local performance indicators, we did not make a system and local distinction for these two.

From the fitted regression models, we used the sets of residuals as indicators for system performance. We thus conceptualize system performance as the portion of overall performance that cannot be explained by performance reducible to the outcome of activities within each engineering and functional area. Since residuals capture all the variance not explainable by selected local performance variables, our system performance indicators may include more than the exact system performance. However, they reflect system performance more accurately than do original performance indicators. Thus, the comparison between factors affecting original overall performance indicators and those affecting residuals enables us to identify factors that have a stronger association with system performance than with local performance. Appendix 4 shows the results of regression models. The results indicate that efficiency-related performance is strongly related to performance within body engineering, implying that the body design may be a critical path in automobile development. Among these overall performance indicators, product cost performance and technical novelty were most explained by local performance. This implies that these two performance indicators have fewer system performance characteristics.

Experience-Based Knowledge Retention Capability

We considered four indicators for experience-based knowledge retention capability, as shown in Table 5.3 below. These four indicators are particularly related to integrative knowledge retention as explained below.

There may be two ways to retain integrative knowledge through individuals. First, integrative knowledge may reside in particular individuals primarily involved in integration activities between different technical and functional areas. Direct transfer of these individuals from the previous generation of projects thus indicates a project's ability to capture integrative knowledge embodied in the past product. As defined in Chapter 3, we regarded project managers, vehicle layout engineers, and vehicle test engineers as such integrators in automobile development. Therefore, we took a percentage of integrators transferred from the previous generation of projects to indicate experience-based knowledge retention capability.[81]

Second, integrative knowledge can be also stored in multiple people as collective memories (Badaracco, 1991; March, 1988; Huber, 1991; Spender, 1994; Walsh and Ungson, 1991). In this case, knowledge retrieval may be triggered when members with common experiences in a specific past project get together (Walsh and Ungson, 1990). Especially, when project members have common experiences in developing the direct

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[81] As explained in Chapter 4, only when project members spent an average of a minimum of 30% of their time for six months in the previous project did we count them as previous project members.

predecessors, product-specific knowledge may be effectively retained. We thus considered a percentage of project core-members responsible for the previous generations of a project to be the second indicator for experience-based retention capability.

Common past experiences among project members, however, may not be limited to a particular type of model development. If they have common experiences in any past development project, relevant knowledge from experiences of cross-functional problem solving activities may be brought into the current project. To measure the degree of common experiences among project core-members, we asked them whether or not they had worked with the other project core-members in <u>any past</u> major development project. Based on this information, we made a 10 by 10 matrix that demonstrated the combination of project core-members who had worked for the same project before. Since 10 project core-members were included in each sample project, the maximum number of combinations was 45. We divided the observed number of combinations of people with common experiences by 45, which gave us an appropriate indicator for degree of common past experiences at the project level.

Fourth, we considered how much project members had expected to be assigned to the focal project before their actual appointment. The idea here is that people who have a high expectation of assignment to a particular project may store usable information for that project in advance, and that transfer of such people will be associated with retention of <u>useful</u> prior knowledge. Respondents were asked to rate how much they had expected the appointment to the focal project on a 5-point scale, from 1 = 0% sure, 2 = 25% sure, 3 = 50% sure, and 4 = 75% sure to 5 = 100% sure. Obtained percentages were averaged for each project. Table 5.3 below shows summary statistics for these four indicators.

Table 5.3 Summary statistics for experience-based knowledge retention capability indicators

Indicators	Mean	S. D.
Percentage of integrators who have experience in the previous generation of projects	0.59 (59%)	0.29
Percentage of core members who have experience in the previous generation of projects	0.34 (34%)	0.19
Degree of common project experience among project core- members	0.61	0.14
Degree of expectation of being assigned to the project (0 to 100% sure)	0.51 (51%)	0.17

We subjected the above indicators to a principal component analysis to identify an underlying pattern. One factor emerged (eigenvalue = 2.38).[82] We thus used the first factor as a composite measure for experience-based knowledge retention capability.

Communication-Based Retention Capability

We examined the frequency of project members' cross-functional communication with members in the previous generation of projects as an indicator for the communication-based retention capability. Since we are interested in the retention of integrative knowledge, we distinguished this from communication with the previous project members within the same engineering areas. Respondents rated frequency of communication with previous generations of project members outside their engineering areas on a 6-point scale, from 1 = two to three days per year or less, to 6 = every day. Then, we converted each point to an estimate of the number of days, as explained in Chapter 4. Scores obtained from these project members were averaged to form project level measures.[83] The mean

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[82] Factor loadings are 0.82 for the integrators' experience variable, 0.79 for the core-members' experience, 0.74 for the common experience, and 0.75 for the expectation for assignment.

[83] Although we distinguished retention capability as either communication-based or experience-based, it was hard to distinguish between these two categories empirically. When most core-project members were transferred from previous projects, communication within the current project overlapped with communication

score across sample projects was 15.7 days per year (s. d. = 7.02).

Archival and Computer-Aided Mechanisms for Knowledge Retention

We examined five indicators for archival-based knowledge retention capability, as shown in Table 5.4 below. The first is frequency of reference to documents and reports that describes design solutions and problematic cases identified in past development activities. Engineers rated the frequency of reference to such documents and reports on a 5-point Likert scale, from 1= not at all to 5 = very frequently.

Second, engineers rated the importance of standards on a 5-point Likert scale, from 1 = played no role to 5 = played very important role. "Standards" means design standards and standard design procedures for component, layout, and production engineers; and test codes and standard testing methods for vehicle test engineers.

Third, we included indicators for three types of computer-aided system usage: the reuse or editing of computer-stored information (including the use of a standardized parts database), the use of computerized simulation tools (CAE), and the creation of direct parts programs by CAD/CAM.

Engineers rated the importance of the reuse or editing of past design data (test data) stored in CAD/CAE on a 5-point Likert scale, from 1 = played no role to 5 = played very important role. In addition, component engineers and production engineers rated the importance of a standardized parts database on the same scale. They also rated the importance of CAE simulation in their development activities.[84] Finally, component

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with previous members. Since communication within the current project is, in general, much more frequent than with members in previous and other projects, an observed high frequency of communication with previous project members tended to indicate high continuity of project members across successive generations. Because of this, a composite measure for experience-based retention capability and a communication indicator are highly correlated each other ($r = 0.51$, $p = 0.12$). A principal component analysis that includes four experience-based indicators and a communication-based indictor yielded one factor. However, a factor loading for a communication-based indicator was less than 0.7. Therefore, we followed the original conceptual distinction, and kept the communication-based indicator separate.

[84] Component engineers and layout engineers rated the importance of both structural and performance

engineers and production engineers rated the importance of creating parts programs directly through CAD/CAM systems on the same scale. Project managers rated the importance of these archival and computer-based systems for several design and testing activities on behalf of the entire project. For each of the above five indicators, scores obtained from these project members were averaged to construct project level measures. Table 5.4 below shows summary statistics for these five indicators.

Table 5.4: Summary statistics for archival-based knowledge retention capability indicators

Indicators	Mean	S. D.
Use of documents and reports	3.72	0.22
Use of standards	3.86	0.31
Use of computer-stored information.	3.65	0.40
Use of computer simulation	3.53	0.41
Use of CAD/CAM	3.67	0.46

Using a principal component analysis, these indicators yielded two factors. The first three indicators, all of which are directly related to knowledge retention, seemed to be clustered: the use of documents and reports, the use of standards, and the use of computer-stored information. However, a factor loading for the use of documents and reports was less than the 0.7 cut-off line, and it is also conceptually distinct from the other standard-based retention mechanisms, so we kept it as a separate variable. We averaged scores for the use of standards and the use of computer-stored information to measure the standard-based retention capability (mean = 3.76, s. d. = 0.31, alpha = 0.69).

While the use of computer simulation was clearly loaded on the second factor, the

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simulation; test engineers rated the importance of performance simulation; production engineers rated the importance of CAE simulation in process design.

use of CAD/CAM was almost equally loaded on two factors. We kept only the use of computer simulation as a separate variable for the later analyses to indicate degree of the use of computer simulation.

Involvement of Independent Organizational Units

The discussion in Chapter 3 revealed several independent organizational units that coordinate new product development activities across generations of projects. In the questionnaire, we asked project managers about the degree of influence of the following organizational units or individuals: the long-term technology planning group, the long-term product planning group, the design for manufacturing group, the long-term layout planning group, and the senior managers located above individual project managers (we called them *super-project managers* in Chapter 3). Project managers rated the degree of influence of these groups or individuals across a range of development activities and decision making, in on a 5-point Likert scale, from 1 = played no role to 5 = played a very important role. When there is no corresponding group or individual, we considered that it played no role (set equal to 1). Table 5.5 below shows summary statistics.

Table 5.5: Summary statistics for influence independent organizational units

Indicators	Mean	S. D.
Long-term Technology Planning Group	1.77	1.17
Long-term Product Planning Group	1.71	1.00
Design for Manufacturing Group	2.34	1.18
Layout Planning Group	1.77	1.68
Super-project Manager	2.86	1.69

A principal component analysis yielded two factors. The first four indicators were clustered. We thus averaged scores for these four indicators to generate a measure of the degree of involvement by long-term planning groups (mean = 2.06, s. d. = 0.79, alpha = 0.70). We kept an indicator for involvement by super-project managers as a separate variable.

Cross-functional Integration

We also considered the degree of cross-functional integration that has been identified as a critical factor for project success (e. g., Allen et. al., 1980; Clark and Fujimoto, 1991; Imai et. al., 1985; Iansiti, 1995a). One of the mechanisms to achieve cross-functional integration is the heavyweight project manager system proposed by Clark and Fujimoto (1991). As they described, the distinctive characteristics of the heavy-weight project managers lie not only in their formal authority but also in their extensive involvement in a wide range of development activities, from concept generation, technical problem solving, and production ramp-up, to marketing strategies. Similarly, other researchers have pointed out that project-type organizations, where project managers are more influential than functional managers, facilitate cross-functional coordination (Allen *et al.*, 1979; Larson and Gobeli, 1988, Wheelwright and Clark, 1992). Based on this existing argument, we included the following four indicators to measure degree of cross-functional integration.

The first is a project manager's span of responsibility. Project managers answered whether or not they had formal responsibilities in the following seven development phases: concept creation or vehicle plan, product engineering, vehicle test engineering, process engineering, pilot production, production ramp-up, and modification or improvement after product introduction. The number of responsible phases was regarded as an index for cross-functional integration.

Second, project managers rated the degree of involvement in 17 development activities or decisions in on a 5-point Likert scale, from 1 = not involved at all to 5 =

played very important role. Scores for the 17 activities were averaged.[85]

Third, component engineers and production engineers assessed the degree of involvement by project managers. They rated the degree of a project manager's involvement in the decision of technology selection on a 5-point Likert scale, from 1= not involved at all to 5 = very influential. Scores obtained from these engineers were averaged to form a project-level measure.

Fourth, project managers rated their authority relative to functional managers in 15 engineering and functional areas on a 5-point scale from 1 = a project manager was very influential to 5 = a functional manager was very influential.[86] Scores for these 15 areas were reversed and then averaged for each project. Table 5.6 shows summary statistics for these four indicators.

Table 5.6: Summary statistics for cross-functional integration indicators

Indicators	Mean	S.D.
Project managers' span of responsibility	4.09	1.65
Project managers' involvement (PM rated)	3.98	0.52
Project managers' involvement (Engineer- rated)	3.81	0.50
Project managers' influence relative to functional managers	2.91	0.61

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[85] The 17 activities or decisions are: concept creation, advanced development of new technology, decision of vehicle layout, selection of major components, selection of carry-over components, selection of suppliers, detailed engineering, development of design prototype, analyses and feedback of vehicle test results, development of production prototypes, management of development cost and engineering manpower, management of production cost, marketing strategies, management of development schedule, management of development target, coordination between design and test engineers, and coordination among design engineering departments, the production department, and the marketing department.

[86] These 15 engineering and functional areas are: exterior/interior design, body design, chassis design, electronics component design, vehicle test, engine design, process engineering, production and plant operation, marketing or product planning, sales, quality assurance, cost management, schedule management, and advanced technology development.

These four indicators were subjected to a principal component analysis. One factor emerged (eigenvalue = 2.41). Therefore, we used the first factor as a composite measure for cross functional integration.

Whereas the above four indicators primarily indicate structural mechanisms for cross-functional integration, cross-functional communication among project members may facilitate cross-functional integration through on-going processes. We thus considered the frequency of the cross-functional communication of project members. Each respondent was asked to rate frequency of communication with project members in different engineering areas on a 6-point scale. Then, these scores were averaged to form a project level measure (mean = 48.6 days per year, s.d. = 10.3).

Another way to achieve cross-functional integration may be to form dedicated cross-functional teams that are independent of the other project activities (Wheelwright and Clark, 1992). GM's Saturn project and Chrysler's platform teams are examples of such independent and autonomous project teams (Scott, 1994). To measure a project's independence, project core-members were asked to indicate the average percentage of their time devoted to the focal project. We averaged obtained percentages for each project to construct a measure for project independence. The mean score across sample projects was 0.69 (s.d. = 0.12).

Technical Content, Supplier Involvement, and Other Possible Control Variables

Finally, Table 5.7 shows the other variables we considered in the analyses, which include technical content, the degree of supplier involvement, and economic conditions.

Table 5.7: Summary statistics of indicators for technical content, supplier involvement, and economic conditions.

Indicators	Description	Mean	S. D.
Bubble Economy	A dummy variable that indicates project ended before 1992	-	-
Micro Car	A dummy variable that indicates projects are micro car project.	-	-
New Parts Ratio	Percentage of newly designed parts (in number of parts).	0.69	0.17
New Platform Ratio	Percentage of new design in under-floor panels and suspension systems (obtained from the questionnaires)	0.43	0.27
New Platform Ratio 2	Newness of platform design based on Nobeoka's classification scheme (Nobeoka, 1993)	New (code =1) 9	Old (code =0) 16
Assembly Proprietary Parts	Percentage of parts developed entirely by assembly makers (see Clark and Fujimoto, 1991 for the definition)	0.39	0.23
Black Box Parts	Parts whose basic engineering is done by car makers and whose detailed engineering is done by parts suppliers (see Clark and Fujimoto, 1991)	0.45	0.25
Supplier Engineering Parts	Parts developed entirely by parts suppliers (see, Clark and Fujimoto, 1991)	0.16	0.15

5-3 Results and Discussions

5-3.1 Correlation Analyses

Technical Content and Task Characteristics

Table 5.8 and 5.9 below show correlations between control variables explained in the previous section and indicators for overall performance satisfaction or overall performance improvement.

Table 5.8: Bivariate relationships between indicators for overall performance satisfaction, and indicators for technical content, task characteristics, and other control variables

	Product Cost Performance	Development Cost Performance	Adherence to Schedule	Manufacturability	Match to Customer Needs	Technical Novelty	Technical Performance	Sales Achievement
Bubble Economy	-0.53 **	-0.25	-0.18	-0.26	0.09	0.44**	0.15	-0.09
Micro Car	0.34	0.39 *	0.41 *	-0.03	0.01	-0.16	-0.15	-0.20
New Platform	-0.55 ***	0.06	-0.23	-0.09	-0.10	0.32	0.34	0.27
New Platform 2	-0.36 *	0.07	0.15	-0.06	0.11	0.42**	0.43**	0.30
New Parts	-0.34	-0.25	-0.30	-0.06	0.22	0.06	-0.03	0.41 *
Assembler Parts	0.00	-0.31	-0.53 ***	-0.39 *	0.43 **	0.10	-0.27	0.36*
Blackbox Parts	-0.05	0.23	0.26	0.33	-0.36	0.03	0.30	-0.29
Supplier Parts	0.09	0.10	0.36 *	0.04	-0.06	-0.19	-0.06	-0.07

Table 5.9: Bivariate relationships between indicators for overall performance improvement and indicators for technical content, task characteristics, and other control variables

	Product Cost Performance	Development Cost Performance	Adherence to Schedule	Manufacturability	Match to Customer Needs	Technical Novelty	Technical Performance
Bubble Economy	-0.44 **	-0.13	-0.14	-0.02	0.02	0.53 ***	0.32
Micro Car	0.19	0.22	0.38 *	-0.09	-0.01	-0.07	-0.27
New Platform	-0.54 ***	-0.25	-0.33	-0.39 *	-0.14	0.22	0.34
New Platform 2	-0.20	0.08	-0.17	0.08	-0.07	0.55 ***	0.49 **
New Parts	-0.25	-0.20	0.12	-0.05	-0.08	0.03	0.26
Assembler Parts	-0.18	-0.07	0.25	-0.27	0.37 *	0.06	0.11
Blackbox Parts	0.07	0.01	-0.35 *	0.09	-0.23	0.11	0.11
Supplier Parts	0.15	0.09	0.19	0.24	-0.18	-0.26	-0.32

*p < .10
**p < .05
***p < .01

First, these tables show that projects during the late 1980s, indicated by "bubble economy," demonstrated lower performance satisfaction in product cost ($p < .05$) while they showed higher performance satisfaction in technical novelty ($p < .01$). This is consistent with our observation that Japanese automobile producers spent lavishly to upgrade product features during this period. Similarly, new platform ratios were negatively associated with product cost performance and positively associated with technical novelty, implying the trade-off relationship between product cost performance and innovativeness. In addition, a new platform ratio measured by the Nobeoka's classification (Nobeoka, 1993), "new platform 2", was positively related to both technical performance satisfaction and technical performance improvement This result is consistent with Nobeoka (1993) , which found that a new platform design strategy resulted in fresh technology at the cost of development efficiency.

Second, an assembler proprietary parts ratio was negatively related to schedule performance, while it showed positive association with market-related performance such as "match to customer needs" and "sales achievement." While this result is consistent with existing studies that showed the importance of supplier involvement for efficient development processes (e.g., Clark and Fujimoto, 1991; Imai, et. al., 1985), the data also indicates that a detailed control for new parts development by assembly makers might be required to effectively adapt to customer needs.

Retention Capability, Overall Performance, and System Performance

Tables 5.10 to 5.13 below show results of correlation analyses between sets of explanatory variables and indicators for overall performance satisfaction and performance improvement. Table 5.12 and 5.13 specifically show results for system performance that we statistically separated from local performance to indicate performance characteristics derived from interactions among individual engineering domains.

Table 5.10: Correlations between explanatory variables and indicators for overall performance satisfaction

	Product Cost Performance	Development Cost Performance	Adherence to Schedule	Manufacturability	Match to Customer Needs	Technical Novelty	Technical Performance	Sales Achievement
Experience-Based Retention	0.11	0.35	0.41 **	-0.08	0.47 **	0.16	0.06	-0.12
X-Generational Communication	-0.09	-0.17	0.04	0.15	0.47 **	0.47 **	0.23	-0.15
Long-Term Planning Groups	-0.32	-0.13	-0.07	0.08	-0.45 **	0.23	0.29	-0.32
Super-Project Managers	0.27	-0.03	0.06	-0.08	0.35	0.07	-0.05	0.07
Standards & Computer-Stored Information	0.14	-0.11	-0.08	0.35 *	-0.07	0.43 **	-0.04	-0.13
Documents and Reports	0.19	0.01	0.13	0.26	0.10	0.22	-0.02	0.07
Computer Simulation (CAE Tools)	0.19	0.28	0.38 *	0.50 **	-0.05	0.29	0.60 ***	-0.06

Table 5.11: Correlations between explanatory variables and indicators for overall performance improvement

	Product Cost Performance	Development Cost Performance	Adherence to Schedule	Manufacturability	Match to Customer Needs	Technical Novelty	Technical Performance
Experience-Based Retention	0.17	0.36*	0.44**	0.05	0.13	0.01	0.47**
X-Generational Communication	-0.01	0.01	0.19	0.21	0.22	0.26	0.56***
Long-Term Planning Groups	-0.30	-0.24	-0.55***	-0.11	-0.08	0.31	-0.09
Super-Project Managers	0.14	-0.02	0.29	0.10	0.16	0.02	-0.20
Standards & Computer-Stored Information	-0.05	0.04	-0.06	-0.14	0.39*	0.30	0.17
Documents and Reports	0.09	0.14	0.15	0.01	0.11	0.17	0.08
Computer Simulation (CAE Tools)	0.22	0.37*	0.04	0.28	-0.20	0.26	0.22

$*p < .10$
$**p < .05$
$***p < .01$

Table 5.12: Correlations between explanatory variables and indicators for system performance

	Product Cost Performance	Development Cost Performance	Adherence to Schedule	Manufacturability	Technical Novelty	Technical Performance
Experience-Based Retention	0.17	0.50**	0.35*	0.08	0.32	-0.01
X-Generational Communication	0.17	-0.09	0.03	0.16	0.60***	0.18
Long-Term Planning Groups	0.14	-0.17	-0.08	-0.26	0.22	0.10
Super-Project Managers	0.33	-0.08	-0.04	0.09	0.18	-0.07
Standards & Computer-Stored Information	0.22	-0.06	-0.08	0.08	0.44**	-0.09
Documents and Reports	0.09	0.03	0.27	0.37*	0.24	-0.16
Computer Simulation (CAE Tools)	0.31	0.13	0.47**	0.48**	0.20	0.33

Table 5.13: Correlations between explanatory variables and indicators for system performance improvement

	Product Cost Performance	Development Cost Performance	Adherence to Schedule	Manufacturability	Technical Novelty	Technical Performance
Experience-Based Retention	0.56***	0.48**	0.37*	0.25	0.00	0.39*
X-Generational Communication	0.54***	0.38*	0.19	0.28	0.28	0.52***
Long-Term Planning Groups	0.09	0.00	-0.52**	-0.30	0.44**	0.12
Super-Project Managers	0.07	-0.21	-0.01	-0.12	0.00	-0.08
Standards & Computer-Stored Information	-0.04	0.05	-0.17	-0.17	0.39*	0.24
Documents and Reports	-0.06	0.09	0.08	0.02	0.31	0.06
Computer Simulation (CAE Tools)	0.26	0.32	-0.11	0.29	0.39*	0.11

*p < .10
**p < .05
***p < .01

Although we found in Chapter 4 that individual-based knowledge retention, such as transfer of engineers and communication with the previous project members, had no significant relationship with performance within individual engineering areas, results here indicate that both experience-based retention capability and cross-generational communication are positively related to several performance variables at the project level.[87] Specifically, experience-based retention was positively associated with two performance satisfaction variables - adherence to schedule ($r = .41$, $p < .05$) and match to customer needs ($r = .47$, $p < .05$) - and three performance improvement variables - adherence to schedule ($r = .44$, $p < .05$), development cost performance ($r = .36$, $p < .1$), and technical performance ($r = .47$, $p < .05$). This suggests that retention of experience affects broad performance dimensions ranging from development process efficiency and customer satisfaction to technical performance at the project level.

Cross-generational communication was positively related to performance satisfaction in technical novelty ($r = .47$, $p <.05$) and in match to customer needs ($r = .47$, $p < .05$), and technical performance improvement ($r = .56$, $p < .01$). This implies that cross-functional communication with the previous project members may be an important source both for technological and market knowledge. However, cross-generational communication has no association with any efficiency-related performance.

Tables 5.12 and 5.13 also show several positive correlations between experience-based retention and cross-generational communication and system performance indicators. In particular, we found that they have broader relationships with <u>improvement</u> of system performance, which is consistent with Proposition 3. Specifically, the experience-based retention variable was positively associated with improvement of product cost performance ($r = .56$, $p < .01$), development cost performance ($r = .48$, $p < .05$), adherence to schedule (r

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[87] <u>Appendix 5</u> shows correlations among individual indicators for experience-based retention capability and performance indicators.

= .37, p < .1), and technical performance (r = .39, p < .1); cross-generational communication was associated with improvement of product cost performance (r = .54, p < .01), development cost performance (r = .38, p < .1), and technical performance (r = .52, p < .01). These results are consistent with our expectation that the retention of integrative knowledge has a particular contribution to improvement of system performance derived from complex interactions among different functional domains.

Compared to the impact of individual-based retention capabilities, the impact of archival-based retention on product development performance seems to be limited. For example, although the analyses in Chapter 4 identified the use of documents and reports for knowledge retention as the most important contributor to local performance, results here show that it has no significant association with any performance indicator, except for its modest relationship with the system performance indicator on manufacturability. This suggests that, while retention of articulated knowledge has a significant impact on local performance, it may not be related to system performance at the project level.

The impact of knowledge retention through standardized information, such as technical standards and CAD/CAE for design and parts reuse, seemed to be limited as well. It was only positively associated with both performance satisfaction and performance improvement in technical novelty (r = .43, p < .05), and moderately related to satisfaction in manufacturability (r = .35, p < .1). A positive association with manufacturability may reflect recent significant efforts that Japanese automobile producers have made to formalize knowledge about manufacturable designs. As discussed in Chapter 3, our interviews at Japanese companies revealed that both product and process designs for easy manufacturing have been increasingly stored as standards. In addition, since reuse of existing parts designs generally increased the reliability of component systems, it may lead to fewer problems in manufacturing. The result may also imply that knowledge about a design-manufacturing interface might be more articulable than we expected.

On the other hand, the positive relationship between knowledge retention through standardized information and performance on technical novelty seems to suggest that efficient design reuse for mature parts of the product design enabled projects to focus on new technical solutions in less mature parts. For example, one engineer at Honda pointed out:

> "We used to upgrade product features in every aspect of a product. This resulted in higher cost and price in every major model change . Now we try to upgrade products at the same cost as before, which means that we focus our new technological investment on particular parts while saving money in other part designs. That is, we make products evolve without increasing the cost."[88]

Most of our sample projects, which came after the Bubble economy period, built from a realization of the wasteful development styles of this period of opulence. Eighteen out of the 22 sample projects introduced new products after 1993, which implies that most sample projects tended to be cost conscious. If these cost conscious projects had to add innovative features to their products, they probably would have to compensate for the associated additional cost by reusing existing designs for other parts. The above result may indicate this effect.

Additional analyses indicated that communication with previous project members <u>within</u> the same engineering area was also moderately related to both performance satisfaction on technical novelty ($r = .40$, $p < .1$) and manufacturability ($r = .40$, $p < .1$). This may suggest that performance on technical novelty and manufacturability is related more to retention of functional knowledge than integrative knowledge.

On the other hand, the use of computer simulation was positively associated with several overall performance indicators, especially those for technical-related performance.

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[88] Interview with Mr. Takahashi, Chief Engineer at Engineering Department No. 6, Honda R&D, May 1994.

For example, it was related to performance satisfaction in manufacturability ($r = .50$, $p < .05$) and technical performance ($r = .60$, $p < .01$). Engineers we interviewed also pointed out that use of CAE simulation has a particular contribution to technical performance and product reliability or quality, not to development efficiency.

However, data suggest that the use of computer simulation only has a moderate relationship with improvement in development cost performance ($r = 0.37$, $p < .1$). In addition, despite its significant relationship with overall technical performance satisfaction, Table 5.13 shows that the use of computer simulation is not significantly related to a system performance indicator on technical performance. This implies that the use of computer simulation tends to affect local technical performance more than system performance.

Contrary to our expectation, the involvement of long-term planning groups was negatively related to some performance indicators. Especially, this had a significant negative impact on performance improvement in adherence to schedule ($r = -.55$, $p < .01$). This may simply indicate that long-term planning groups do not work properly from a project member's point of view, as one project manager at Toyota pointed out during our interview:

> "The "Sokatsu" group in the Product Planning Office and the Technology Planning Department make plans for the platform sharing and carry-over. However, from the CE's point of view, these organizations do not seem to work properly "[89]

Since the long-term planning groups play critical role in coordination among different projects as well as across generations, the strong involvement of these groups may indicate that projects needed to adjust development activities with other related projects,

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[89] Interview with Mr. Ishidera, Chief Engineer, Toyota Motor Corp., July 29, 1992.

which might cause problems in adherence to the schedule (Nobeoka and Cusumano, 1994; Nobeoka, 1993, 1995).

The result may also indicate a potential conflict between the autonomy of individual projects and inter-project coordination by the long-term planning groups (Clark, Fujimoto, and Aoshima, 1991). The long-term planning groups usually impose several constraints on individual project activities. For example, in our sample of projects, their involvement had a strong negative correlation with the new parts ratio ($r = -.67$, $p < .01$), implying that it prevented engineers from designing new parts from scratch. Since "engineers usually hate to use parts and components designed by the other engineers"[90] and "project managers have tendency to always try something new,"[91] project members might have complaints about the involvement of long-term planning groups. As a result, they may have tended to ascribe low project performance to the long-term planing groups.

Tables 5.14 and 5.15 below highlight differences among factors affecting overall performance and those affecting only system performance. These tables show clearly that experience-based retention and cross-generational communication, in particular, have positive associations with indicators for improvement of system performance. On the other hand, archival-based retention and computer simulation tended not to be associated with those indicators.

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[90] Interview with Mr. Hosaka, Director in the Product Planning Office, Honda R&D, May 23, 1994.
[91] Interview with Mr. Kodera, Manager, Toyota Motor Corp., April 6, 1995.

Table 5.14: Summary results of the correlation analyses for overall and system performance satisfaction and sales achievement

	Experience-Based Retention		X-Generational Communication		Long-Term Planning Group		Standards & Computer-Stored Information		Documents and Reports		Computer Simulation (CAE Tools)	
	Overall	System	Overall	System	Overall	System	Overall	System	Overall	System	Overall	System
Product Cost												
Development Cost		**				*(-)						
Schedule	**	*									*	**
Manufacturability							*			*	**	**
Tech. Novelty			**	***			**	**				
Tech. Performance											***	
Match to Customer	**		**									
Sales Achievement												

*p < .1, **p < .05, ***p < .01

Table 5.15: Summary results of the correlation analyses for overall and system performance improvement

	Experience-Based Retention		X-Generational Communication		Long-Term Planning Group		Standards & Computer-Stored Information		Documents and Reports		Computer Simulation (CAE Tools)	
	Overall	System	Overall	System	Overall	System	Overall	System	Overall	System	Overall	System
Product Cost		***		***								
Development Cost	*	**		*							*	
Schedule	**	*			*(-)	**(-)						
Manufacturability												
Tech. Novelty								*				*
Tech. Performance	**	*	***	***								
Match to Customer							*					

*p < .1, **p < .05, ***p < .01

Consistent with Proposition 2, the tables also seem to indicate that experience-based retention and cross-generational communication are related more to system performance than overall performance indicators, although this difference for performance satisfaction indicators is not as clear as for performance improvement indicators.

5-3.2 Regression Analyses

To further examine the results from the above correlation analyses, we fitted the regression models including selected control variables and indicators for archival-based and individual-based knowledge retention capabilities. We excluded other explanatory variables because of the small sample size. Appendix 6 and 7 shows results of regression analyses.

For each performance indicator, Model 1 includes only control variables. We selected these control variables by considering both conceptual reasoning and results of correlation analyses shown in Tables 5.6 and 5.7. All the Model 2s include control variables and indicators for the standard-based retention capability, the use of documents and reports, and the use of computer simulation. Model 3s include control variables and individual-based retention capability indicators. Model 4s include all these explanatory variables except for the use of documents and reports which showed no significant relationship with any performance indicator in Model 2s. Model 5s and 6s exclude either the experience-based capability or the cross-generational communication indicator to avoid multi-collinearity, which seemed to be caused by a high correlation between these two indicators ($r = 0.51$, $p < .01$).

Tables 5.16 and 5.17 below summarize the results shown in Appendix 6 and 7. Results for the standard-based retention and the use of computer simulation come from Model 4s. Results for the experience-based retention and cross-generational communication are obtained from Model 5s and 6s, respectively, to eliminate problems of multi-collinearity.

Table 5.16: A summary table for the results of regression analyses for relationships between knowledge retention capabilities and <u>performance satisfaction</u>

	Standard-based retention	Computer simulation	Experience-based retention	X-generational communication
Product cost performance				
Development cost performance			*	
Adherence to schedule			***	
Manufacturability				
Technical novelty	*			**
Technical performance		***		
Match to customer needs			**	*
Achievement of sales target				

*p < .1, **p < .05, ***p < .01

Results from Models 4s in Appendix 6 for the standard-based retention and computer simulation. Results from Models 5s in Appendix 6 for the experience-based retention; Model 6s for the cross-generational communication

Table 5.17: A summary table for the results of regression analyses for relationships between knowledge retention capabilities and <u>performance improvement</u>

	Standard-based retention	Computer simulation	Experience-based retention	X-generational communication
Product cost performance				
Development cost performance		*	**	
Adherence to schedule			**	
Manufacturability		*		
Technical novelty				
Technical performance			**	***
Match to customer needs				

*p < .1, **p < .05, ***p < .01

Results from Models 4s in Appendix 7 for the standard-based retention and computer simulation. Results from Models 5s in Appendix 7 for the experience-based retention; Model 6s for the cross-generational communication

Results shown in Appendix 6 and 7 as well as Tables 5.16 and 5.17 generally supported the results of the correlation analyses, and indicated even stronger relationships between experience-based retention and overall performance indicators. Especially, an experience-based retention variable was significantly associated with development process efficiency. For example, Model 4s, the full regression models, shows that experience-based retention is related to performance satisfaction both on development cost and on adherence to schedule, at the 1% significance level. It was also related to performance improvement in development cost and in adherence to schedule at the 5% level. Although the full models show no more significant associations between the experience-based retention and the match to customer needs or technical performance improvement, which was found to be significant in the correlation analyses, this might be due to multi-collinearity caused by a high correlation between the experience-based retention and the cross-generational communication variables. In fact, Model 3s for these two performance indicators show that inclusion of experience-based retention and cross-generational communication variables significantly increased the adjusted R-squares, and Model 5s which excluded the cross-generational communication variable, also showed positive and significant relationships between the experience-based retention and satisfaction on match to customer needs and improvement in technical performance at the 5% levels.

The finding that experience-based retention capability tends to be positively associated with development process performance may indicate that critical experiences retained from the past development activities is related to knowhow or knowledge to effectively manage the development process by the mutual adjustment of working relationships. For example, Mr. Uchiyama, Project Manager at Mazda, made the following comment:

"In the case of the RX-7 projects, the same [major] project members have tended to

> be responsible for all three generations.... Since our minds worked the same way [and shared a common language], we could immediately transform what we imagined to substantial forms, and required information also immediately came to a person who needed it... although I do not think this is always good.[92]"

As this comment implies, consistent retention of experiences in cross-functional problem solving develops a common understanding among project members despite different functional backgrounds (Kofman, et. al., 1993). In turn, this may improve efficiency of the development process.

In contrast, the cross-generational communication variable was specifically related to technical- and market-related performance indicators, such as satisfaction on technical novelty and improvement in technical performance, and satisfaction on the match to customer needs, but not to efficiency-related performance indicators. In fact, Model 4s show that cross-generational communication was negatively associated with satisfaction in development cost performance. However, this negative relationship is probably due to multi-collinearity since results in Model 6s no longer showed significant negative relationship between cross-generational communication and satisfaction in development cost performance, though the sign was negative. Similar to results of the correlation analyses, this result indicates that cross-functional communication with the previous project members is an effective way to acquire technological and market knowledge.

The results in Appendix 6 and 7 are also consistent with the correlation results for retention capabilities indicated by archives, standards and computerized systems. For example, the standard-based retention variable had only a moderate relationship with satisfaction in technical novelty, as indicated in Model 4 ($p < .1$).

The use of computer simulation was strongly related only to satisfaction in technical

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[92] Interview with Mr. Uchiyama, Project Manager (Shusa), Mazda Motor Corp., May 19, 1994.

performance (at the 1% level). It had moderate relationships with improvement in development cost performance and in manufacturability (at the 10% level).

In summary, the above correlation and regression analyses seem to support our propositions at least for some performance dimensions. Contrary to the results in the previous chapter regarding local performance, the above analyses generally indicate that individual-based knowledge retention capabilities are required to improve product development performance at the project level, which is consistent with Proposition 1. Particularly, we find that their impact is stronger, or broader, on system and improvement performance rather than on static and local performance (consistent with Proposition 2 and 3). On the other hand, we found that archival-mechanisms for knowledge retention tended not to have a substantial influence on product development performance at the project level.

5-3.3 Moderating effects by task characteristics on relationships between project performance and individual-based retention capability

Proposition 4 suggests that task newness may have moderating effect on the relationship between individual-based retention capability and product development performance. To examine this possibility, we fitted regression models including interaction terms between individual-based retention capability indicators and either technical or market newness involved in new product development.

New platform ratios, shown in Appendix 6 and 7, were used to indicate technical newness involved in the project tasks. Market newness was identified by considering project managers' self-evaluations, brand name changes, and market class changes, as described below.

First, project managers were asked to choose the most appropriate description of their products from the following three descriptions: "(a) mainly targeted to the existing customer base;" "(b) targeted both to the existing customer and the new customer base;" and "(c) mainly targeted to the new customer base." When a project manager chose (c), we categorized his project as "new market"; when he chose (a), we categorized this as an "existing market." As a result, four projects were categorized as "new market" and five projects as "existing market." For remaining 13 projects, we further classified four models as "new market" since these products were given different brand names from the predecessor models with substantial price differences.[93] Finally, we classified one product as "new market" since this new model was clearly positioned in a different market class from the previous model.[94] As a result, seven projects were classified as "new market," and 15 projects as "existing market" (see Appendix 8 for a further explanation of this classification process).

Appendix 9 shows results of regression analyses that examine the moderating effects either of technical or market newness on performance satisfaction, while Appendix 10 shows results for their moderating effects on performance improvement. All the Model 1s include interaction terms for the experience-based retention variables, while Model 2s include those for the cross-generational communication variable.

Proposition 4 implies that we should expect negative signs on the regression coefficients for interaction terms. Indeed, we found significant negative coefficients for the interaction terms in the regression models. This implies that projects tends to benefit from retention of prior experience bases when they develop new products based on existing platform designs toward familiar customers. Especially, the results seem to suggest that *market newness is more likely to moderate relationships between individual-based*

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[93] A predecessor of one model was sold in the market place as a derivative of another product, and the old brand name included the brand name of that base product. The name of this base product line was removed from the new model, which became independent of the previous base model.

[94] The predecessor of this new model had the FR platform and was targeted only to the domestic market. Although the current version has the same brand name as this predecessor, its basic design was integrated into the other export-based product in the different product class, which is based on the FF platform. As a result, this new model was positioned in a different market class from the predecessor model.

retention capabilities and product development performance than technical newness.

Tables 5.18 and 5.19 below summarize the results in Appendix 9 and 10.

Table 5.18: Effects of interactions between the individual-based retention and the task characteristics on performance satisfaction.

	Experience-based retention X		X-generational communication X	
	Market newness	Technical newness	Market newness	Technical newness
Product cost performance				
Development cost performance	** (-)		** (-)	
Adherence to schedule				
Manufacturability			* (-)	
Technical novelty				
Technical performance				*** (-)
Match to customer needs				
Achievement of sales target	* (-)		*** (-)	

*p < .1, **P < .05, ***p < .01

Asterisks mean that interactions between retention mechanisms and task newness have significant negative impacts on performance indicators.

Table 5.19: Effects of interactions between the individual-based retention and the task characteristics on performance improvement.

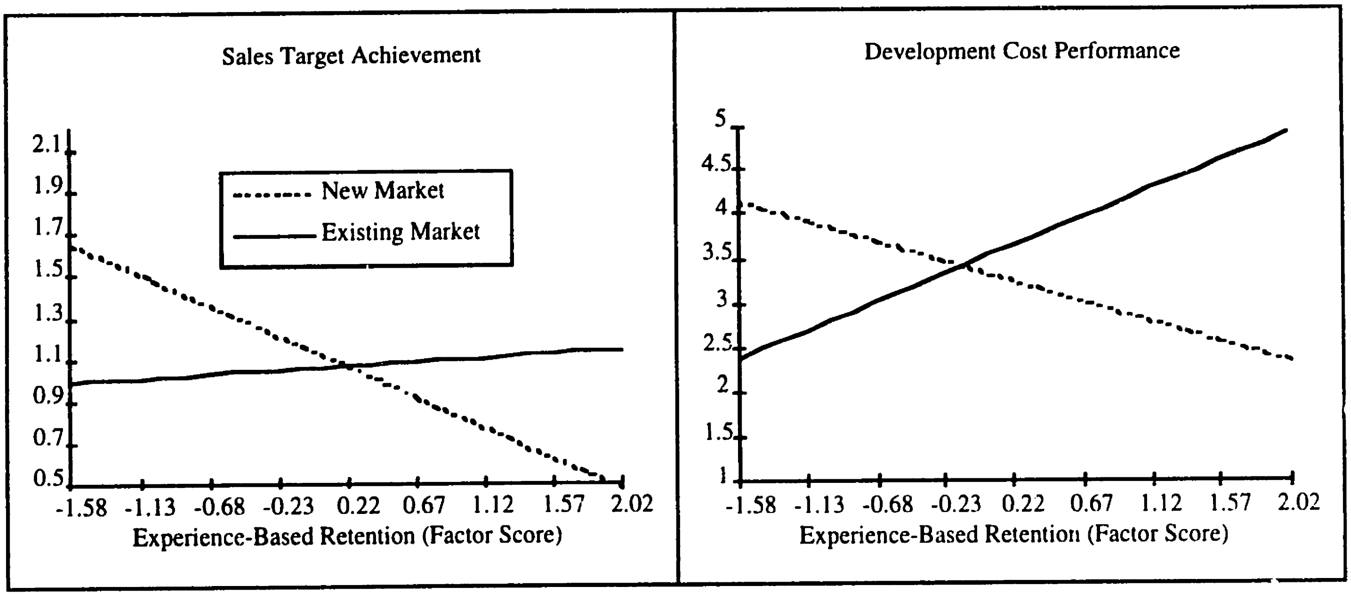
	Experience-based retention X		X-generational communication X	
	Market newness	Technical newness	Market newness	Technical newness
Product cost performance			* (-)	
Development cost performance				
Adherence to schedule				
Manufacturability				
Technical novelty				
Technical performance				
Match to customer needs				

*p < .1, **P < .05, ***p < .01

Asterisks mean that interactions between retention mechanisms and task newness have significant negative impacts on performance indicators.

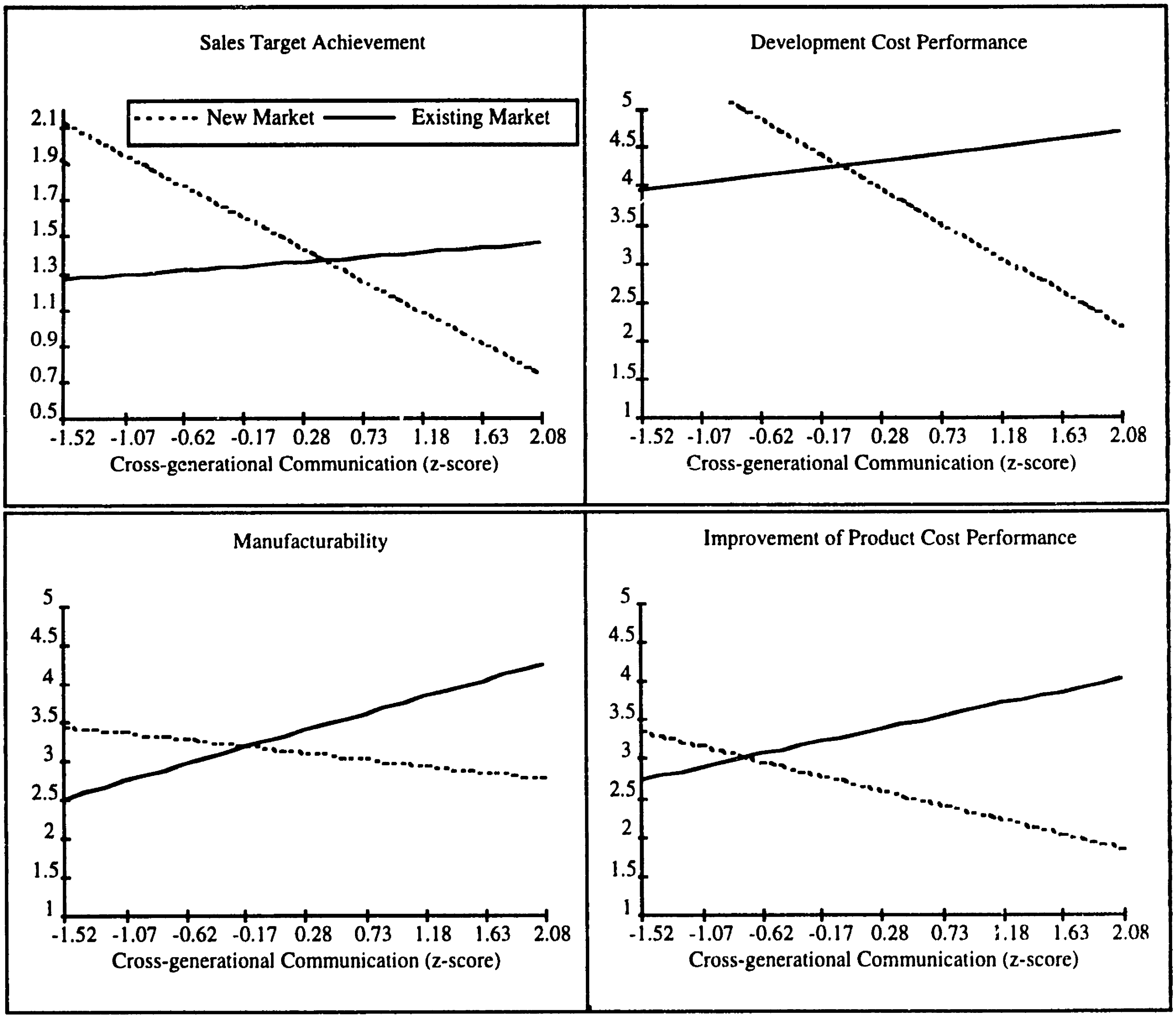
As these tables show, we found expected moderating effects by market newness on relationships between experience-based retention and satisfaction in development cost performance ($p < .05$) and sales achievement ($p < .1$). This implies that, when projects developed new models targeted to new customer bases, retention of prior individual experiences may negatively affect development efficiency and market performance. Figure 5.2 below indicates the fitted regression lines obtained from regression models in Appendix 9 and 10, and graphically show the interaction effects.

Figure 5.2 Fitted regression lines for the relationship between experience-based retention and performance indicators by market newness



We also found that a similar expected moderating effect by market newness on relationships between cross-generational communication and satisfaction in development cost performance ($p < .05$), in manufacturability ($p < .1$), achievement of sales target ($p < .01$), and improvement of product cost performance ($p < .1$). As indicated in Figure 5.3, these results suggest that retention of prior knowledge through face-to-face communication may not be appropriate for projects developing new products with different target markets from the previous models.

Figure 5.3 Fitted regression lines for the relationship between cross-generational communication and performance indicators by market newness


Sales Target Achievement

Development Cost Performance

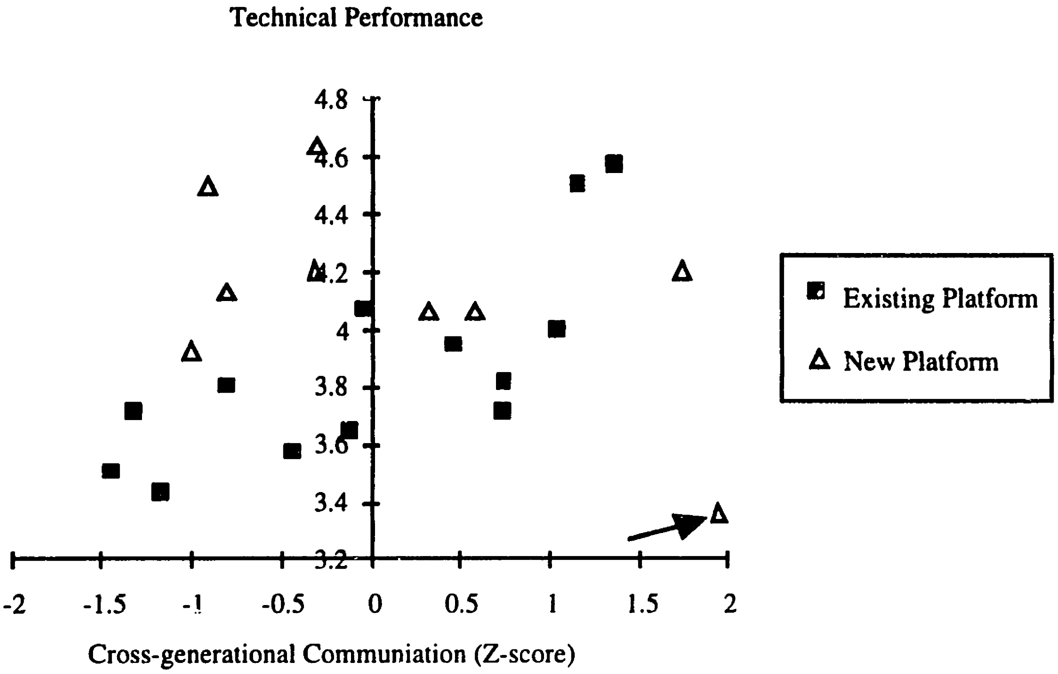
Manufacturability

Improvement of Product Cost Performance

Our variable indicating communication with the previous project members also partially captures transfer of previous members (as we already explained, the more members are transferred from the previous projects, the more current intra-project communication overlaps communication with the previous project members). Therefore, these results may generally indicate that, while retention of embedded knowledge may be particularly important in the case where there is continuity of customer needs, it creates some problems in adapting to new market conditions.

On the other hand, technical newness had a significant moderating effect on the relationship between technical performance and cross-generational communication variables ($p < .01$). This suggests that, when projects developed new platform designs, communication with the previous generations of project members negatively affected technical performance. However, technical newness had no other significant moderating effect. In fact, close examination in the scatter plot shown in Figure 5.4 below indicates that the observed strong moderating effect by technical newness for technical performance was, in fact, strongly influenced by one data point (indicated by an arrow).

Figure 5.4 A Scatter plot between technical performance and cross-generational communication by platform newness



While the scatter plot seemed to clearly show a positive impact of cross-generational communication on technical performance in the case of products using existing platforms, we cannot conclude that it has a negative impact on technical performance when products have new platform designs.

These results may indicate that knowledge about linkages to the customer base is more context-specific than technical integrative knowledge, as some researchers have pointed out (e. g., Christensen and Rosenbloom, 1995; von Hippel, 1994), and thus tend to become obsolete when there is a significant change in the customer base. On the other hand, existing technical knowledge might be more widely applicable in different settings, implying that prior knowledge may be useful even in developing novel technological concepts (Iansiti, 1995b).

Qualitative information obtained from interviews also suggests that, while the retention of market-related knowledge may be particularly important to obtain a sophisticated understanding of the requirements for well-established customer bases, it may sometimes prevent project members from bringing in new market concepts. For example, Mr. Fukai, Project Manager ("Shukan") at Nissan, responsible for the Sentra project, pointed out that Nissan has changed very recently so that a project manager is responsible for two successive generations because of the importance of marketing knowledge:

> "[Since around 1980] project managers have tended to be replaced by each major model development project. However, as our very recent policy, we are shifting back to make project managers responsible longer, say, two generations.... This is related to the fact that marketing [and its relationship with engineering] has become increasingly important. Marketing [knowledge] is not something quickly and easily understood.... Career paths like Mr. Honda at Toyota might be required [he has been responsible for the Corolla project for 16 years as a project coordinator]... However, when we develop a new product that has no prior history, we try to get new [inexperienced] people. "[95]

The description of the history of Toyot's Celica/Carina projects in Chapter 3 also indicated that continuity of a project managers' group has been driven by continuity of the customer base. In the Celica/Carina projects, candidates for the project manager were long trained to understand the technology-market interfaces despite occasional technological discontinuity indicated by, for example, shift from a FR to a FF platform in 1983.

Although we found that technical newness tended not to moderate the impact of experience-based retention on performance, it may not be appropriate to conclude that retention of experience bases is always important regardless of technical discontinuity. This is because, first, our technical newness indicator merely shows the newness of the platform design, not of fundamental technological approaches, and, second, because automobile technology is generally "mature". This implies that what is new in this industry may not be sufficiently new to indicate the degree of technological change that might occur in newer

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[95] Interview with Mr. Fukai, General Manager, Nissan Motor Corp., April 11, 1995.

industries. .

5-3.4 Other Results: Impact of Traditional Performance Predictors and Their Relationships with the Individual-Based Retention Capability

Tables 5.20 and 5.21 show correlations between performance indicators and indicators for cross-functional integration, cross-functional communication, dedicated project teams, and individual retention capabilities.

Table 5.20: Correlations between indicators for cross-functional integration and overall performance satisfaction

	Product Cost Performance	Development Cost Performance	Adherence to Schedule	Manufactura-bility	Match to Customer Needs	Technical Novelty	Technical Performance	Sales Achievement
X-Functional Integration	0.24	0.34	0.43 **	0.33	0.33	0.34	0.33	0.02
X-Functional Communication	-0.05	0.21	0.08	0.07	0.12	0.33	0.51 **	0.34
Project Independence	-0.23	-0.25	-0.25	0.02	0.08	0.20	-0.08	0.41 **

*p < .1, **p < .05, ***p < .01

Table 5.21: Correlations between indicators for cross-functional integration and overall improvement performance

	Product Cost Performance	Development Cost Performance	Adherence to Schedule	Manufactura-bility	Match to Customer Needs	Technical Novelty	Technical Performance
X-Functional Integration	0.19	0.54 **	0.48 **	0.26	0.18	0.28	0.31
X-Functional Communication	-0.06	0.22	0.23	0.18	-0.02	0.37 *	0.46 **
Project Independence	-0.30	-0.39 *	0.02	-0.07	-0.03	0.23	0.10

*p < .10
**p < .05
***p < .01

These tables show that different ways to achieve cross-functional coordination were differentially related to performance dimensions. For example, the cross-functional integration variable, which primarily indicates structural mechanisms for cross-functional integration, tended to be positively related to development process efficiency reflected in satisfaction in and improvement of adherence to schedule ($r = .43$ and $.48$, $p < .05$ and $.05$, respectively), and development cost performance improvement ($r = .54$, $p < .05$).[96] On the other hand, the cross-functional communication that indicates cross-functional integration through on-going processes tended to be related to technical performance indicators, such as satisfaction in technical performance ($r = .51$, $p < .05$) and technical performance improvement ($r = .46$, $p < .05$). This may suggest that, while development efficiency is achieved through disciplined mechanisms, such as heavy-weight project systems and project-types of organizations, group processes are more important for technical performance.

The project independence variable that indicates the extent of dedicated membership of core-project members tended to show negative relationships with efficiency-related performance indicators while it had a positive association with sales achievement. However, close examination revealed that observed correlations are spurious, caused by a high correlation between the project independence variable, and new platform ratios ($r = .60$, $p < .01$) and an assembler proprietary parts ratio ($r = .50$, $p < .01$). These high correlations imply that highly dedicated core-project teams tend to be formed when projects are aimed at developing new platforms with more in-house new parts. After controlling for these two variables, we did not obtain any significant relationship with performance indicators.

Table 5.22 below shows correlations between these indicators for cross-functional integration and indicators for individual-based retention capabilities.

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[96] Signs of the correlation coefficients among the cross-functional integration variable and performance variables were consistently positive. This is not surprising since both performance indicators and a cross-functional integration indicator were strongly influenced by project managers' responses in the questionnaire survey.

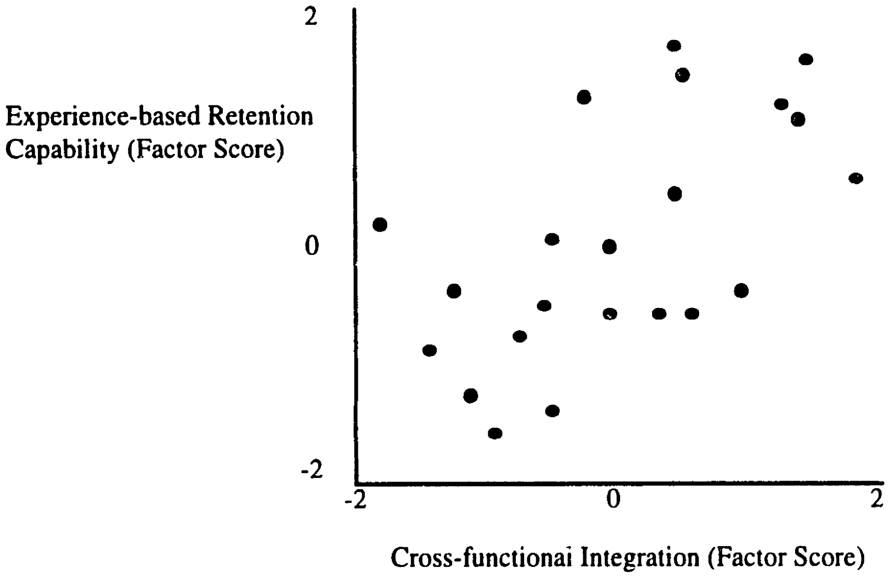
Table 5.22: Correlations between indicators for cross-functional integration and individual-based retention capabilities

	Experience base	X-gen. Com.	X-func. Integ.	X-func. Com.
Experience-based Retention				
Cross-generational Communication	0.51 **			
X-Functional Integration	0.57 ***	0.53 ***		
X-Functional Communication	0.14	0.42 **	0.37 *	
Project Independence	-0.20	-0.19	0.02	0.29

*p < .10
**p < .05
***p < .01

It is significant that the table shows high correlations between the cross-functional integration variable, and experience-bases retention or cross-generational communication variables. Figure 5.5 shows the relationship between experience-based retention and cross-functional integration graphically.

Figure 5.5 Correlations between experience-based retention capability and cross-functional integration



Observed high correlations are not tautological since we measured these variables in completely different ways, as already explained. This finding is important since it suggests that retention of prior cross-functional experiences may be required to achieve high cross-functional integration in the present project. This further implies that the ability to integrate cross-functionally may not be created instantaneously, but, rather, it is an historical outcome.

5-4 Summary

This chapter explored how integrative knowledge retention capabilities, indicated by retention of individual experience bases and face-to-face communication among individuals of successive generations of projects, affect new product development performance at the project level. We found that these capabilities positively affected several performance dimensions in new product development. In particular, they are related to the improvement of new product development performance over previous generations, and to system performance derived from the complex interactions among different engineering domains. The results generally supported our hypothesis that the retention of integrative knowledge by individual-based mechanisms is of fundamental importance to performance derived from the complex interaction among different functional and engineering domains.

These results contrast with the results in the previous chapter. In Chapter 4, we found no significant impact of individual-based retention capabilities on local performance. Instead, local performance was affected by the use of archival-mechanisms for knowledge retention, indicated by reference to documents and reports, and the use of computer-aided design systems. However, the analyses in this chapter showed that archival-based knowledge retention is not a critical contributor to system level performance. This contrast implies that, although knowledge retention is important to improve product development performance, different retention capabilities may be required to achieve system level performance as compared to local performance.

In addition, since the contribution of local performance to overall product development performance depends on several factors, such as product architectures, environmental conditions, and technological maturity, companies may take different approaches to manage knowledge retention processes. In the concluding chapter, we further discuss this strategic aspect of knowledge-retention management.

This chapter also examined whether or not the retention of integrative experiences has a positive impact on performance, even when projects are required to adapt to new technological or market conditions. Our findings suggest that the retention of prior experience tends to cause problems when projects have to introduce new market concepts, rather than new technology. This finding also has important managerial and theoretical implications which we also discuss in the concluding chapter. Finally, our analyses suggest that the retention of integrative knowledge through continuity of project members and cross-generational communication may be a foundation for the cross-functional integration of subsequent projects, which is a traditional performance predictor.

Chapter 6

Conclusion: Implications and Limitations

As long as companies introduce a sequence of new products over time, how to retain knowledge obtained from past development experience should be of concern to management of new product development. Especially, in industries where a fast product cycle is a critical source of competitiveness, capabilities to retain and quickly utilize prior knowledge may have particular importance. However, there have been few broad-based empirical examinations dealing with this issue. Most existing studies of new product development have tended to focus on management of a single project, and ignored linkages across different generations of projects. As a result, we have had little systematic understanding on the role of knowledge retention in a sequence of new product development projects.

This study, by drawing on examples from the Japanese automobile industry, has explored how companies can effectively retain prior knowledge about new product development and how knowledge retention affects new product development performance. We found that knowledge retention across generations of projects *does* affect new product development performance and has profound implications for the management of new product development. We first briefly review our findings below. Then, in the subsequent sections, we discuss managerial implications, theoretical implications, and limitations of this study.

Chapter 3 examined relationships between knowledge types and appropriate knowledge retention mechanisms. There, we specifically focused on knowledge of the interactions among fragmented functional domains, which we defined as integrative knowledge. Based on descriptions of knowledge retention practices at Japanese automobile producers, conceptual discussions suggested that integrative knowledge may tend to be tacit and context-specific, and that its retention may require direct transfer of individual experience and intensive face-to-face interactions. Two simple tests using data for 183 core members of new product development projects at seven Japanese automobile producers partially supported this. In the first test, we found that project members responsible for integration activities tended to continue their positions in successive generations of projects. The second test showed that vehicle layout engineers tended to rely less on documents, reports, and standards to learn from past design practices than do component engineers. We also found that design information stored in these archival facilities seemed to be more important to design individual parts of component systems than whole component systems. This is because it seems that the more knowledge becomes integrative, the less its retention depends on archival media.

In the subsequent two chapters, we examined the impact of knowledge retention capabilities on performance in new product development. In particular, Chapter 4 focused on performance within well-established component system development areas, which we defined as local performance. Chapter 5 examined both overall performance at the entire project level and performance derived from interactions among different functional domains, which we defined as system performance. There are important contrasts in the results between these two chapters.

We found in Chapter 4 that retention of prior knowledge in articulated and generalized forms seems to be of great benefit to well-defined component system development. Test results showed that dependence on documents and reports for knowledge retention had a positive impact on a range of local performance indicators; use of computer-stored design information improved product cost performance; use of computer simulation tools resulted in higher technical performance. However, organization-based and individual-based mechanisms for knowledge retention had either no association or negative associations with performance indicators.

On the contrary, the test results discussed in Chapter 5 showed that retention of individual experience bases and face-to-face communication with previous project members had a positive impact on several performance indicators at the project level. Especially, we found that these individual-based retention capabilities affected improvement of system performance derived from the complex interactions among different engineering and functional domains. Archival mechanisms for knowledge retention, on the other hand, did not seem to be critical to improvement of system level performance.

Other results discussed in Chapter 5 indicate that the impact of experience-based retention capabilities on product development performance was affected by the characteristics of project tasks. Test results showed that the benefit of experience-based retention is greater when projects introduce new products for existing customers, using prior platform designs. Our findings further suggested that retention of prior experience tends to cause problems when projects have to introduce new market concepts. We also found a high association between capabilities for experience-based knowledge retention and those for cross-functional integration, implying that retention of an experience base may be fundamental to project integration.

6-1 Managerial Implications

The above findings have several direct implications for the management of new product development, as described below.

- Explicit management of knowledge retention processes may be important both from the point of view of retaining critical knowledge, as well as disregarding unnecessary knowledge.

While existing literature on management of new product development has identified coordination and communication across specialized activity areas as critical to development speed, productivity, and product quality, our findings suggest that such coordination and communication alone may not be enough to achieve project-level integration for high product development performance. We showed that the success of projects also hinges upon their ability to learn from past integrative experiences. Our results also suggested that a project's ability to retain integrative knowledge may be the foundation for the cross-functional integration of subsequent projects. These findings imply that instantaneous structural solutions such as cross-functional teams and heavy-weight project structures may not be the only answer to improve development performance. Projects may be able to execute their integration activities most effectively when they deeply understand potential interactions across different knowledge domains through past development experiences.

However, our results also implied that knowledge retention may not always be desirable. Especially, we found that prior experience bases seem to prevent projects from successfully introducing products for new markets or unfamiliar customers. This suggests that managers have to explicitly manage knowledge flows from previous projects in accordance with the specific objectives for each new product development project. For example, when projects are trying to introduce a new product line for new customer groups, companies may want to isolate those projects organizationally from other projects, as GM did for its Saturn product line. In such a case, it might also be appropriate to form projects with members who do not have too much experience in developing a particular product line.

- Companies can improve product development performance either by improving local performance or system performance, each of which requires different knowledge retention capabilities.

Our results showed that, while improving local performance may require capabilities to retain knowledge in articulated forms, such as documentation and computerized CAD files, improving system performance at the project level may call for the transfer of individual experience bases. This implies that archival-based and individual-based mechanisms for knowledge retention are not necessarily substitutes, but, rather, they are complementary.

Companies may greatly benefit from formalization of knowledge within well-established engineering domains. Especially, we believe that advanced computer-aided design systems will increasingly capture design know-how once embedded in experts and craftsmen in these specialized domains. However, as long as a new product is the outcome of complex interactions among different knowledge domains, retention of individual experiences may remain important. Besides, once knowledge is fully articulated and standardized, it becomes relatively easy to transfer it across companies, which decreases its competitive value. Therefore, the increasing articulation and standardization of automobile design knowledge do not necessarily devalue individual experience bases, but rather, they may increase their value if they have integrative characteristics.

Although both archival-based and individual-based knowledge retention are important, the relative emphasis between these may differ across industries and different stages of industry evolution. First, the nature of product architecture may affect the relative importance. When a product is completely modularized both in terms of the physical design and the design process, its overall performance may be influenced mostly by the initial architecture or design of how the individual components work separately as well as together, rather than on how the components interact as a system.[97] In this case, investment in archival and computerized mechanisms for knowledge retention may become important. On the other hand, when a product architecture is highly integrated, including complex interdependencies between different components, improvement of product performance may require more subtle knowledge of interactions among individual components. In such a case, the retention of individual experience bases may play a critical role.

Second, the characteristics of user requirements may also influence the relative importance between archival or computer-based and experience-based retention. When the required product functionality is stable and consists of only a few clear dimensions, knowledge about user-design interfaces is relatively simple, thus, a project can concentrate only on technical issues. We conjecture that, in such a circumstance, archival and computerized mechanisms may be important ways to retain knowledge. On the other hand, some products, such as an automobile can satisfy customers in a number of ways, such as in styling, acceleration, space utility, and mileage. An appropriate combination of different performance dimensions is often very subtle, which even customers may not be able to articulate. In such a case, knowledge to integrate customer needs with physical designs may have to be kept as tacit and embedded knowledge by individuals.

Although we assume in this dissertation that automobile development involves substantial complexity and uncertainty both in the product architecture and user interface,

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[97] However, even if the interfaces for each component isolate interactions, the system can be highly integrated when important performance characteristics arise from the physical properties of multiple components. For example, on a computer, a design of the disk drive is totally modularized. However, if it is slow, then the computer as a system exhibits poor performance.

this may change in the future. For example, our interviews revealed that automobile design is increasingly being modularized to enable more efficient sharing of components across different models. This may result in more importance of archival and computerized mechanisms for knowledge retention. On the other hand, some interviewees mentioned that it had become increasingly difficult to understand user needs. This may indicate that roles of persons who manage linkages between user needs and product designs will become more critical than before. In any case, managers may need to consider the required level of integration activities involved in new product development to appropriately invest in different knowledge retention facilities.

- An organization's knowledge accumulation process in new product development partially reflects a pattern of personnel transfer across different projects over time.

Results of this study suggest that companies need to carefully manage and plan the transfer of project members across different generations since personnel transfer is a critical means to retain integrative knowledge and accounts for an important part of organizational-level knowledge accumulation processes. For example, we described in Chapter 3 that Toyota has maintained a systematic flow of people within project manager groups. This systematic flow seemed to contribute to the accumulation of knowledge about complex project integration. However, not all companies that we interviewed had such a systematic process for considering the transfer of project members. Companies often assign people to projects simply because of their availability. Since personnel changes, in most cases, have no formal link to project activities, project managers sometimes leave projects halfway because of their promotion. More explicit attention to the knowledge retention aspect of personnel changes may therefore be of significant benefit to companies.

Companies may also need to take into account project members' past experiences and their common experiences more systematically in forming new product development projects. In addition, since integrative knowledge tends to be embedded in individuals, explicit training of persons who can integrate different functional domains is clearly important. In this respect, some existing studies have identified the importance of strong project coordinators, represented by heavyweight project managers proposed by Clark and Fujimoto (1991). However, this study further suggests that the abilities of such strong coordinators to work effectively does not automatically come with the position, but rather results from an historical process resulting in the accumulation of experience. Thus, just giving strong formal authority to project managers is not enough. Companies probably may need to train and maintain persons who deeply understand past integration activities.

6-2 Theoretical Implications for New Product Development Strategy and Organization

This study has several theoretical implications for studies of new product development. Below, we focus on new product development strategy and organizational design.

Strategic Dimensions for New Product Development

The results of this study suggest that there are, at least, two important strategic dimensions to new product development. The first is related to the decision of whether to adopt an integration or system orientation versus a functional or component orientation. The second is related to whether new product development includes the retention of prior knowledge or whether it limits its use of existing knowledge gained in past projects.

Many existing studies have emphasized the first dimension (Allen, 1986; Clark and Fujimoto, 1991; Marquis and Straight, 1965; Katz and Allen, 1985; Iansiti, 1992). While the development of technologically advanced components typically requires highly specialized functions, the development of an integrated product system usually calls for cross-functional interactions, which may involve a loss of some of the advantages of specialization (Clark and Fujimoto, 1991; Imai, Nonaka, and Takeuchi, 1985; Katz and Allen, 1985). Herein lies the trade-off between, on the one hand, giving priority to the attainment of maximum performance at each component and functional level (local performance), and, on the other hand, focusing on the integration of the product system as a whole (system performance).

However, we have demonstrated in this study that knowledge retention is another critical activity that affects new product development performance. In particular, we found that effectiveness in knowledge retention may depend on task characteristics specified by project strategies. Whereas some projects may depend heavily on technological and market knowledge embedded in previous projects and products, other projects may create entirely new sets of knowledge. Thus, new product development can be characterized according to whether it includes, deliberately or not, knowledge retention, or whether it limits its use of existing knowledge gained in past projects. This dichotomy has a direct link with the distinction between radical and incremental innovation as we discussed in Chapter 1 (Dewar and Dutton, 1986; Ettlie, et al., 1984; Tushman and Anderson 1986).

These two strategic dimensions highlight different objectives for new product development as shown in Figure 6.1 below.

Figure 6.1 Different objectives of new product development

Knowledge Retention	Elements (Local Performance)	System (System Performance)
High	Component-Level Improvement	System-level Improvement
Low	New Component Introduction	New System Introduction

Locus of Product Development

For example, the upper-right cell indicates that projects may incrementally enhance existing products by improving interactions across different engineering and functional domains. This may require substantial efforts to retain integrative experience obtained in prior development activities. On the other hand, the lower-right cell indicates that projects may develop new products from "scratch" and provide entirely new system solutions into unfamiliar customer bases. Retention of prior experiences may be restricted in this case.

The left two cells indicate that companies may focus on specialized technological elements in new product development. For example, in the case of automobile development, companies may place a particular emphasis on development of superior suspension technologies. The development of such technological elements sometimes requires a departure from the existing technological concepts, such as from traditional passive suspension systems to electrically controlled active suspension systems. This is indicated in the lower-left cell. In the other case, development of technological elements may be cumulative and based on existing knowledge. This type of development has been characterized as incremental innovation., and is indicated in the upper-left cell.

This characterization of new product development is important because achievement of each of these four objectives may require different processes for managing knowledge retention. In turn, companies can pursue these objectives with organizational designs, as we discuss in the next section.

A Framework for Organizational Designs in New Product Development

An important task in organizational design is to categorize its various activities into several groups, to break these groups into clusters, and eventually to create an overall structural pattern (Thompson, 1967). The division of labor is a process of allocating various activities into several organizational subunits, and task partitioning (von Hippel, 1990) This refers basically to the same process, as do the concepts of task differentiation and then integration discussed by Lawrence and Lorsch (1967).

Existing studies of product development suggest two ways of dividing labor: either organizing around functions or organizing around products. This corresponds to the first strategic dimension described earlier in this thesis: a system (integration) focus versus an element (specialization) focus. The development of advanced technologies favors functional organizations, and integration among different technological and functional domains require a project-based organizational design. As various scholars have noted, since project organizations can effectively manage cross-functional integration , they are more appropriate to improve system level performance (Fujimoto and Clark, 1991; Imai, Nonaka and Takeuchi, 1985). On the other hand, since functional organizations facilitate communication within functional areas, they may be more effective when a higher standard of local performance is required (Katz and Allen, 1986). Between these two extremes, there are other possible organizational choices. For example, Clark and Fujimoto (1991) proposed a spectrum of four ideal types of organizations. These range from traditional functional structures with a relatively low level of cross-functional integration; to light-weight project structures with a high level of integration within engineering departments; to heavy-weight project structure with high levels of both engineering and customer integration to ; and autonomous project teams with the most integration.

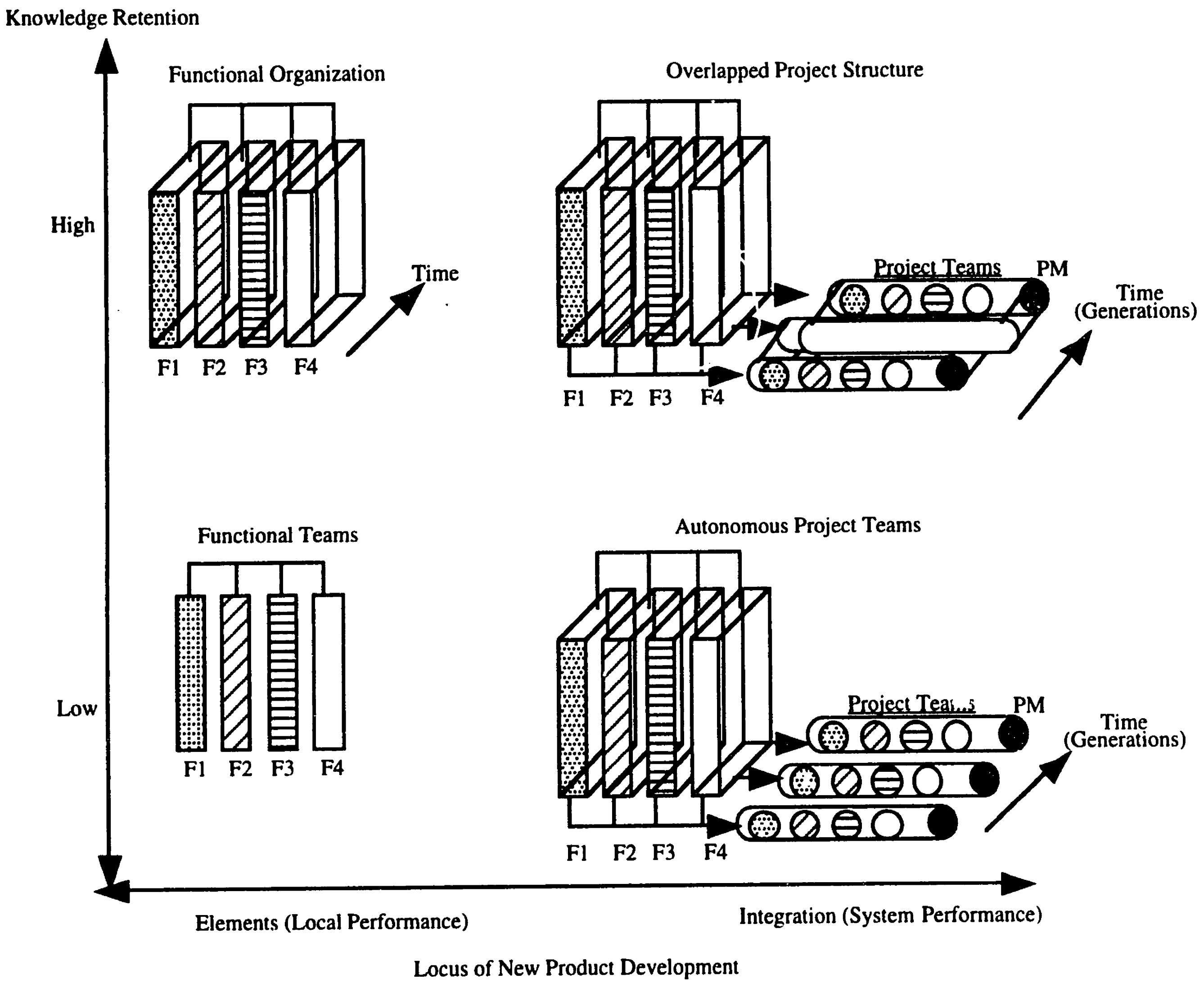
However, explicit consideration of knowledge retention as a strategic dimension may call for some modifications to this spectrum from autonomous project teams to traditional functional organizations. The existing model deals only with organizational structures at a specific point in time. It overlooks the fact that various activities within a product development organization are spread out over time, and erroneously de-emphasizes temporal inter-relationships between product development efforts. It says nothing about how previous development projects are organizationally linked to current projects and how people are assigned across different generations of projects.

The results of this study suggest that structural mechanisms to link different activities *within* individual projects are not enough to properly characterize new product development projects. For example, projects with the same level of heavy-weight project managers may substantially differ in their organizational relationships with previous projects. We found that mechanisms to link different generations of projects organizationally, for example, the continuous assignment of key project members, significantly affect development performance.

New product development is not necessarily a momentary activity, but is often continuous. This requires the inclusion of a time dimension to take into account of this fact. How to divide and categorize development activities spread out along the time dimension is, therefore, an important element of designing new product development organizations, which influences knowledge accumulation processes in organizations.

Figure 6.2 illustrates a framework for designing new product development organizations, and explicitly involves the time dimension in organizational design. This figure classifies product development organizations along two dimensions. The first relates to the distinction between functional-based and project-based organizations. This corresponds to the distinction between the system and element focus shown in Figure 6.1. The second dimension deals with how to link different generations of projects, and corresponds to the level of knowledge retention. These two dimensions identify four organizational design modes: 1) an autonomous project team; 2) an overlapped project structure; 3) a functional organization; and 4) a functional team structure. We describe each of these four modes below. However, since these organizational design modes are stylized, actual designs may show a mixture of characteristics.

Figure 6.2: A framework for the design of new product development organizations



F1, F2, F3, and F4 stand for functional departments

Autonomous project teams

In this type of organization, individuals from different functional and technological areas are formally assigned and dedicated to the project team. Project leaders are influential throughout the entire development process (Wheelwright and Clark, 1992). Project members together concentrate on the development of a single new product. Each project member is more a generalist than a specialist, and pursues high performance of final products instead of component-level functional performance. Since project teams are organizationally independent of other projects, they create their own products from scratch, and do not make significant use of existing practices or knowledge created in other product development activities.

Overlapped project structure

In this form of organization, similar to autonomous project teams, individuals are grouped around products rather than disciplines, and are responsible for the overall performance of final products. However, each project is no longer independent of the others. It does not create its own product from scratch. Instead, it learns from previous projects and utilizes knowledge, especially integrative knowledge, to achieve system level improvement . Since retention of integrative knowledge require retention of individual experience bases, project members responsible for integration activities tend to continue in successive generations. In addition, some key project members may also be responsible for multiple generations. In this sense, projects in successive generations are organizationally overlapped. What is important in this mode is that, even if project members work on multiple generations of projects, they are responsible for the performance of final products, instead of the functional performance of individual components. In this type of organization, project managers might be further directed by super-project managers who supervise multiple generations of product development.

Functional organization

In contrast to the above two structures, in the traditional functional organization, individuals are organized around disciplines instead of products (Allen 1986; Clark and Fujimoto, 1991). Each task is directed by its own functional manager. Individuals are specialists and try to achieve high performance within each functional area (e.g., engine development, suspension development and testing) while being relatively independent of other functional activities. Since each functional activity is continuous over time in this organization, functions or subfunctions can accumulate deep component knowledge. In addition, since domain-specific knowledge may be effectively retained in articulated forms, archival mechanisms for knowledge retention, such as documents, reports, standards, and computerized systems may play a particularly important role.

Functional team structures

Individuals in this structure are also grouped together by discipline and focus on their own functional activities as specialists. The functional organization assumes that each functional activity is continuous over time so that, for example, current component development is dependent on prior accumulated knowledge. Companies may choose, however, to separate current component development activities from previous ones in order to attain uniqueness and newness in current component technologies. In the functional team structure, component development tasks are organizationally partitioned over time. Current functional teams try to develop new components relatively independent of technological knowledge embedded in prior components. Although the pure form of this structure is rarely observed in the field, there exist several organization types between functional organizations and functional team structures, according to the partitioning pattern of component development over time.

Need for Research with a Dynamic View for New Product Development Organization

As we discussed in Chapter 2, most existing studies of new product development have depended upon "Information-processing theories of organizations" (March and Simon, 1959; Thompson, 1967; Galbraith, 1977; Lawrence and Lorsch, 1967). This is a static theory of organization in a sense that it views organizational designs as tools to process information efficiently to achieve pre-defined objectives given inputs, productive resources, and knowledge, which are exogenous to the framework.

However, the framework summarized in the previous section suggests that an organizational design also gives a specific dynamics to knowledge accumulation processes. A product development effort not only develops a new product for current customers, but it also creates technological and market knowledge available for future projects. Design of organizations influences both activities. And, both activities influence new product development performance.

As long as research on new product development has its theoretical foundation in traditional information processing theories, cross-sectional studies may be dominant. On the other hand, our conceptualization of new product development organizations inevitably requires examination of inter-temporal relationships of product development efforts, thus calling for longitudinal studies.. Some recent studies have tried to apply what is called a resource-based view of the firm or a capability theory that emphasizes the dynamic aspect of organizations, to new product development research (e. g., Henderson and Cockburn, 1994; Iansiti and Clark, 1994; Fujimoto, 1994). However, they tend to be based on cross-sectional data and capture an organization's capability only at a specific point in time. Our study also relied on data from a cross-sectional survey. Although the knowledge retention on which we have focused is an activity cutting across generations, we examined it only from the perspective of projects receiving prior knowledge. Future research needs to examine historically inter-related projects both as knowledge receivers and knowledge providers.

6-3 Limitations of This Study

The analyses involved in this study have several limitations. They also suggest several directions for future research, as described below.

Generalizability

First, this study focuses only on Japanese companies. While this focus enabled us to eliminate possible country effects on performance differences, the obvious question is whether results here are generalizable in different countries. For example, Japanese automobile producers typically replace existing models once every four years. On the other hand, some European producers replace their products only once every eight to ten years (Clark and Fujimoto, 1991; Nobeoka, 1993). Retention of prior knowledge may be beneficial only when intervals between introduction of successive generations of products are short enough. In future work, we would like to expand our sample so as to include companies in the other countries where new product introduction is less frequent.

Second, some of our results may be unique to the automobile industry. For example, our finding that integrative knowledge retention is important might be because the development of automobiles involves numerous complex interactions among different component designs, and between product design and user needs. Thus, it would be interesting to compare our results to a similar study in another industry where either product architectures are modularized or user needs are fairly comprehensive and stable. This further confirms the propositions examined in Chapter 5.

Third, this study focused only on projects for development of replacement models that have direct predecessors. While this focus enabled us to relatively easily observe and understand knowledge retention practices and mechanisms, it inevitably reduced the variety of project types that we considered. Particularly, this weakened our results in section 5.3.3 in Chapter 5. There, we found moderating effects by market and technical newness on the relationship between experience-based retention and overall project performance indicators. However, since replacement models, almost by definition, include some commonalties with preceding models both in technological and market concepts, we might look at only marginal differences among relatively homogeneous project groups. Thus, our analysis may not fully capture the impact of market and technical newness on relationships between performance and market newness. As a simple extension, the future study should include other types of projects, for example, those adding completely new product lines or those making merely minor changes for existing models, to fully understand how knowledge retention differentially affects product development performance.

Methodological Issues

This study has several methodological weakness which may be improved in the future study. The first is related to performance measurement. This study heavily depends upon project members' self-ratings to measure product development performance. In particular, local performance indicators in Chapter 4 totally rely on each functional representative's self-ratings. While subjective ratings enabled us to examine a wide range of performance dimensions, they may substantially decrease the reliability of our results.

There are several reason why we had to rely on project member's subjective ratings. First, since many of the sample projects were quite new, not enough time has passed after product introduction to obtain more objective performance measures such as experts evaluations, the number of quality problems, and revenues. We may be able to overcome this problem as more data become available in the near future. Second, some participating companies refused to give us productivity data. We obtained data on engineering hours only from 16 projects, and lead time data from 20 projects. In addition, we found that ways of calculating engineering hours seemed to be substantially different across companies, and that lead time data did not have enough variance because all companies had similar standard schedules from which projects rarely deviate, as we discussed in Chapter 2.

The second methodological problem is related to our way of distinguishing system and local performance. Since performance of automobile development is highly complex and includes numerous dimensions, we could not obtain separate local and system performance directly. Instead, we statistically created system performance indicators. As a result, our system performance indicators might be unreliable because they included all the variances of overall performance variables not explainable by local performance variables. The future research in other industries where performance dimensions of products are not as complex as those of automobiles should use a more direct way to separate system and local distinction[98] (see for example, Iansiti, 1995e).

Third, one of the reasons why there have been few systematic empirical studies examining the impact of learning on performance may lie in the difficulties in measuring learning separately from outcome or performance. We tried to measure the existence of knowledge retention as a part of the learning process, independently of its outcome, by looking at mechanisms for knowledge retention, such as project member's continuous assignments. However, this metric is clearly imperfect. How to measure learning independent of outcome still remains a problem for future research.

Need for Examination of Multiple Generations of Projects

This study used cross-sectional data. However, the real effect of knowledge retention should encompass multiple generations of projects. Therefore, ideally, we would

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[98] In this respect, Iansiti (1995e) demonstrated a sophisticated method to separate performance of products into technical yield and the fundamental potential.

like to study multiple generations of projects as the unit of analysis. The long-term effect of knowledge retention may be identified only when we examine both average performance and performance improvement of multiple generations of projects (Iansiti and Clark, 1994).

Moreover, because of the cross-sectional survey, we did not consider performance of the previous project in our analyses. The utility of knowledge retention should depend upon the content of knowledge retrieved from the past experience. Therefore, while knowledge transfer from well-performing projects benefits current projects. that from unsuccessful projects may have a negative effect on performance. The future research needs to consider performance of multiple generations of projects.

This study is one of the first empirical attempts to systematically address the issue of knowledge retention in the context of new product development. Despite problems mentioned above, we believe that this study has provided several important findings regarding knowledge retention across generations of new product development. We hope that the findings of this study drive further research in various industry contexts to accumulate our knowledge about management of new product development.

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Appendix 1: Successive Project Managers in Selected Product Lines

Toyota

Tercel		Corolla		Corona	
Introduction	Project Manager	Introduction	Project Manager	Introduction	Project Manager
8/78 (1 st.)	Sasaki+	3/79 (3 rd.)	H. Agezuma*	9/78 (6 th.)	Hirai*
5/82	Hirai	5/83	H. Agezuma**	1/82	Wada*, Adachi
5/86	Hirai**	5/87	A. Saito*	1/83	Wada**, Adachi**
9/90	Ishidera*	5/91	A. Saito**	12/87	Konishi*
9/94	Ishidera**	5/95	T. Honda*	12/91	Konishi**

Carina/Celica		Camry		Mark II (Cressida)	
Introduction	Project Manager	Introduction	Project Manager	Introduction	Project Manager
8/1977 (2 nd.)	Nishida**, Wada*	4/1982 (2 nd.)	Matsumoto+	1/77 (3 rd.)	Jinbo*
9/81	Wada**	8/86	Miyakawa*	10/80	Jinbo**
5/84	Wada**	7/90	Miyakawa**	9/84	Jinbo**
5/88	Kuboji*	7/94	Iwata, Miyakawa**	9/88	T. Watanabe*
5/92	Nakagwa*			10/92	T. Watanabe**

Crown		Celsior (Lexus 400)			
Introduction	Project Manager	Introduction	Project Manager		
9/79 (7 th.)	Shindo*, Imaizumi*	9/89 (1 st.)	Suzuki		
10/83	Imaizumi**	9/94	Okamoto*		
9/87	Imaizumi**				
9/91	H. Watanabe				
8/95	H. Watanabe**				

** A former project manager in the same product line
* Promoted from the former sub-project manager in the same product line
+A former project manager for The other projects
Transferred from other departments than engineering departments

Appendix 1: Successive Project Managers in Selected Product Lines (Continued)

Nissan

Sunny (Sentra)		Pulsar		Bluebird (Stanza, Ultima)	
Introduction	Project Manager	Introduction	Project Manager	Introduction	Project Manager
11/77 (4 th.)	Tanaka	5/78 (1 st.)	Ariga	11/79 (6 th.)	Ishikawa
10/81	Tanaka**	6/82	Chino	10/83	Ishikawa**
9/85	Chino+	5/86	Chino**	9/87	Machida+
1/90	Kikuchihara#	5/90	Chino**	9/91	Kawamura+
1/94	Fukai*	5/94	Ito+, Sakurada	10/95	Naka
Fairlady Z (300ZX)		Skyline		Silvia (240SX)	
Introduction	Project Manager	Introduction	Project Manager	Introduction	Project Manager
8/78 (3 rd.)	Sakagami	8/77(5 th.)	Sakurai**	3/79 (3 rd.)	Tanaka
9/83	Takagi	8/81	Sakurai**	8/83	Ishikawa
7/89	Yamada	8/85	S. Ito*	5/88	Kawamura
		5/89	S. Ito**	5/92	
		5/93	Watanabe*, Taguchi		
Cedric/Gloria					
Introduction	Project Manager				
6/79 (5 th.)	Fuiji				
6/83	Fujii**				
6/87	Misaka#				
6/91	Kusumi				
5/95	Endo*				

** A former project manager in the same product line
* Promoted from the former sub-project manager in the same product line
+A former project manager for The other projects
\# Transferred from other departments than engineering departments

Appendix 2: Measurement of Task Newness

To calculate novelty involved in different activities corresponding to 10 different project core-members, we assigned 0.2 to minor modification, 0.5 to major modification, 0.8 to new design, and 1 to new technology. Novelty involved in activities of component engineers was calculated by averaging newness of appropriate component designs as shown:

- Exterior/interior designer: Newness of exterior/upper-body design
- Body Engineers: Newness of floor-panels and exterior/upper-body
- Chassis Engineers: Newness of suspension systems and braking systems
- Engine Engineers: Newness of engine and engine control systems
- Electronics components: Newness of interior/trim, engine control, and instrument panels.

We measured novelty of tasks for project managers, layout engineers, and vehicle test engineers by newness of platform design. For layout engineers, we averaged newness of floor panels and suspension systems to indicate platform newness. Although we would have liked to measure newness of layout design independently of other measures for component design, we decided to use this averaged measure to ensure comparably of measurement across different technical functional areas. To confirm the validity of this indicator for platform newness, we compared our indicator with the platform newness index developed by Nobeoka (1993).

We measured novelty of vehicle test engineering by averaging the newness of suspension systems, engine designs, and under-floor panels since our interviews revealed that testing methods are strongly influenced by these three major component systems that comprise the platforms. We used the same indicator for the novelty of project managers' task.

Novelty in the design activities of production engineers was measured by the percentage of new production equipment. The below table shows summary statistics for these newness indicators.

	N =	Mean	S.D.	Min.	Max.
Project Managers	21	0.49	0.20	0.10	0.80
Layout Engineers	20	0.49	0.23	0.10	0.80
Vehicle Test Engineers	20	0.49	0.22	0.10	0.80
Exterior/Interior Designers	21	0.77	0.16	0.10	1.00
Chassis Engineers	21	0.49	0.28	0.10	1.00
Body Engineers	21	0.60	0.22	0.10	1.00
Engine Design Engineers	22	0.58	0.30	0.10	1.00
Electronics Component Engineers	20	0.64	0.29	0.10	1.00
Production Engineers	17	0.30	0.24	0.05	0.82

Appendix 3: Sales Estimation

Since some of the sample products were introduced after September 1994 (one year before the last month of our sales data) , we could not obtain monthly sales data for these models for the entire first year of product introduction. For such products, we estimated average monthly sales volume by considering both seasonal effects and new model introduction effects.

Seasonal effects were estimated by using sales data for the entire domestic passenger cars during the period between 1988 and 1994. Estimated seasonal indices were as follows:

January = 64.42%
February = 99.74%
March = 164.60%
April = 94.75%
May = 83.65%
June = 108.04%
July = 122.58%
August = 67.22%
September = 101.39%
October = 96.85%
November = 102.34%
December = 94.41%

After adjusting the monthly sales data of our sample models by these seasonal indices, we then estimated new model introduction effects by using the monthly sales data of new products in our sample that have complete 12 months' sales data. The resultant new product introduction effect indices are shown below. Missing monthly sales data were then estimated by using these indices.

1st month = 120.33%
2nd = 137.41%
3rd = 128.47%
4th = 117.80%
5th = 104.89%
6th = 103.31%
7th = 90.65%
8th = 86.51%
9th = 82.99%
10th = 76.20%
11th = 74.94%
12th = 77.44%

Appendix 4: Decomposition of Overall Performance

To separate system performance from overall project performance, indicators for overall performance satisfaction and performance improvement at the entire project level were regressed on corresponding local performance and local performance improvement indicators. The results from this are shown below:

Regression Results between Overall Project Performance and Local Performance

	Development Cost Performance		Product Cost Performance		Adherence to Schedule	
	I	II	I	II	I	II
Body Design	0.63 **	0.68 ***	0.59 **	0.63 ***	0.54 **	0.45 **
Chassis Design	-0.44	-0.05	-0.07	-0.02	0.13	0.20
Exterior/Interior Design	0.44 *	-0.09	-0.04	0.02	-0.02	-0.14
Electronic Component Design	-0.21	-0.29	0.13	0.31 *	-0.21	-0.38 *
Engine Design	-0.37 *	0.07	0.24	0.09	0.18	-0.02
d. f. of residuals	16	16	16	16	16	16
Adjusted R-square	0.27 *	0.28 *	0.38 **	0.64 ***	0.18	0.31 **

	Manufacturability		Technical Novelty		Technical Performance	
	I	II	I	II	I	II
Body Design	0.07	0.13	0.07	0.05	0.53 **	0.25
Chassis Design	0.54 **	0.23	0.40 **	0.20	0.40 *	0.47 *
Exterior/Interior Design	-0.02	-0.51 **	0.61 ***	0.54 ***	-0.36 *	0.36
Electronic Component Design	0.06	-0.33	0.18	0.22	0.04	0.10
Engine Design	-0.27	0.18	0.08	0.28 *	0.19	-0.15
d. f. of residuals	16	16	16	16	16	16
Adjusted R-square	0.27 *	0.05	0.39 **	0.56 ***	0.34 **	0.20

I = Performance Satisfaction
II = Performance Improvement

*p < .1
**p < .05
***p < .01

Appendix 5: Correlations Between Performance Indicators and Individual Variables Forming the Experience-Based Retention Capability Construct

Correlations between individual indicators for experience-based retention capabilities and overall performance indicators

	Product Cost Performance	Development Cost Performance	Adherence to Schedule	Manufacturability	Match to Customer Needs	Technical Novelty	Technical Performance	Sales Achievement
Previous Member	0.12	0.14	0.11	0.16	0.23	0.17	0.05	-0.12
Previous Integrators	0.37**	0.28	0.15	-0.18	0.52**	0.00	-0.28	0.19
Expectation for assignment	0.33	0.33	0.40*	-0.21	0.43*	0.01	-0.15	0.08
Common Experiences	0.04	0.37*	0.51**	0.03	0.25	0.32	0.26	-0.21
Communication with the previous members	-0.04	-0.18	0.05	0.14	0.47**	0.48**	0.21	-0.16
Improvement from the previous model								
Previous Member	-0.11	0.12	0.16	-0.03	-0.01	0.00	0.48**	
Previous Integrators	0.27	0.42*	0.42**	-0.09	0.34*	-0.18	0.34	
Expectation for assignment	0.37*	0.50**	0.60 ***	0.01	0.08	-0.04	0.15	
Common Experiences	0.18	0.35*	0.19	0.21	-0.06	0.27	0.41*	
Communication with the previous members	-0.01	0.01	0.19	0.21	0.22	0.26	0.54***	

Correlations between individual indicators for experience-based retention capabilities and system performance indicators

	Product Cost Performance	Development Cost Performance	Adherence to Schedule	Manufacturability	Match to Customer Needs	Technical Novelty	Technical Performance	Sales Achievement
Previous Member	0.26	0.41*	0.23	0.32	N/A	0.46**	-0.38	N/A
Previous Integrators	0.25	0.52**	-0.03	-0.09	N/A	0.14	-0.22	N/A
Expectation for assignment	0.30	0.47**	0.19	0.07	N/A	0.22	-0.14	N/A
Common Experiences	0.43**	0.43**	0.33*	0.03	N/A	0.48**	0.13	N/A
Communication with the previous members	0.28	-0.05	0.07	0.16	N/A	0.65***	0.21	N/A
Improvement from the previous model								
Previous Member	0.12	0.16	-0.03	-0.01	N/A	0.00	0.48**	N/A
Previous Integrators	0.42*	0.42**	-0.09	0.34*	N/A	-0.22	0.34	N/A
Expectation for assignment	0.50**	0.60***	0.01	0.08	N/A	-0.13	0.15	N/A
Common Experiences	0.35*	0.19	0.21	-0.06	N/A	0.38*	0.41*	N/A
Communication with the previous members	0.01	0.19	0.21	0.22	N/A	0.28	0.54***	N/A

*p < .10
**p < .05
***p < .01

Appendix 6: Results of Regression Analyses for Relationships between Knowledge Retention Capabilities and *Performance Satisfaction*

	Product Cost Performance						Development Cost Performance					
	I	II	III	IV	V	VI	I	II	III	IV	V	VI
New Platform	-0.37	-0.37	-0.36	-0.36	-0.36	-0.36	-0.02	-0.02	-0.08	-0.10	-0.10	-0.02
Assembler Parts							-0.31	-0.22	-0.33	-0.25	-0.27	-0.18
Bubble Economy	-0.34	-0.33	-0.37	-0.31	-0.38	-0.34						
Standard-based Retention		0.07		0.15	0.07	0.05		-0.19		0.07	-0.06	-0.13
Computer Simulation		-0.04		0.22	0.16	0.15		0.07		0.23	0.17	0.28
Documents & Reports		0.15						0.23				
Experience-Based Retention			0.28	0.41	0.24				0.62 •••	0.65 •••	0.37 •	
X-Generational Communication			-0.10	-0.28		0.07			-0.44 •	-0.52 ••		-0.18
d. f. of residuals	19	16	17	15	16	16	19	16	17	15	16	16
Adjusted R-square	0.31 ••	0.21	0.29 ••	0.29 •	0.29 •	0.21	0.01	-0.11	0.26 ••	0.24	0.05	-0.07

*p < .1, **p < .05, ***p < .01

	Adherence to Schedule						Manufacturability					
	I	II	III	IV	V	VI	I	II	III	IV	V	VI
New Platform	-0.16	-0.13	-0.25	-0.26	-0.26	-0.18	-0.06	-0.08	-0.06	-0.14	-0.15	-0.15
Assembler Parts	-0.53 •••	-0.45 ••	-0.57 •••	-0.50 •••	-0.51 •••	-0.44 •	-0.37	-0.30	-0.38 •	-0.27	-0.26	-0.29
Bubble Economy												
Standard-based Retention		-0.20		0.09	0.02	-0.11		0.20		0.25	0.32	0.29
Computer Simulation		0.18		0.19	0.16	0.25		0.35		0.37	0.42 •	0.36
Documents & Reports		0.22						0.24				
Experience-Based Retention			0.62 •••	0.65 •••	0.50 •••				-0.21	-0.15	-0.02	
X-Generational Communication			-0.21	-0.28		0.05			0.47 •	0.28		0.20
d. f. of residuals	19	16	17	15	16	16	19	16	17	15	15	16
Adjusted R-square	0.26 ••	0.22	0.53 •••	0.53 •••	0.49 •••	0.20	0.05	0.30 •	0.14	0.27 •	0.25 •	0.30 •

*p < .1, **p < .05, ***p < .01

Appendix 6 (continued) : Results of Regression Analyses for Relationships between Knowledge Retention Capabilities and *Performance Satisfaction*

	Technical Novelty						Technical Performance					
	I	II	III	IV	V	VI	I	II	III	IV	V	VI
New Platform	0.56 ***	0.57 ***	0.56 ***	0.55 ***	0.54 ***	0.54 ***	0.43 **	0.34 *	0.44 *	0.39 **	0.41 **	0.33 *
Assembler Parts	0.06	0.11	0.04	0.08	0.10	0.07						
Bubble Economy												
Standard-based Retention		0.34		0.30 *	0.40 **	0.33 **		-0.19		-0.28	-0.24	-0.21
Computer Simulation		0.23		0.17	0.22	0.17		0.60 ***		0.60 ***	0.61 ***	0.59 ***
Documents & Reports		0.07						-0.13				
Experience-Based Retention			-0.22	-0.10	0.12				-0.18	-0.25	-0.16	
X-Generational Communication			0.54 ***	0.39 **		0.34 **			0.19	0.18		0.05
d. f. of residuals	19	16	17	15	16	16	20	17	18	16	17	17
Adjusted R-square	0.25 **	0.42 **	0.43 ***	0.54 ***	0.43 **	0.56 ***	0.14 **	0.40 ***	0.08	0.42 **	0.43 ***	0.41 ***

	Match to Customer Needs						Achievement of Sales Target					
	I	II	III	IV	V	VI	I	II	III	IV	V	VI
New Platform							0.25	0.25	0.28	0.27	0.27	0.27
Assembler Parts	0.43 **	0.56 **	0.39 **	0.47 *	0.53 **	0.39	0.29	0.35	0.32	0.39	0.37	0.39 *
Bubble Economy												
Standard-based Retention		-0.19		-0.14	-0.12	-0.19		-0.15		-0.13	-0.16	-0.10
Computer Simulation		0.22		0.12	0.02	0.03		0.06		0.16	0.13	0.13
Documents & Reports		0.01						0.01				
Experience-Based Retention			0.34	0.34	0.44 **				-0.11	-0.16	-0.24	
X-Generational Communication			0.21	0.18		0.43 *			-0.17	-0.17		-0.23
d. f. of residuals	19	16	17	15	16	16	18	16	16	14	15	15
Adjusted R-square	0.14 **	0.05	0.32 **	0.26 *	0.29 **	0.23 *	0.06	-0.01	0.02	-0.08	-0.04	0.05

*p < .1, **p < .05, ***p < .01

Appendix 7: Results of Regression Analyses for Relationships between Knowledge Retention Capabilities and *Improvement Performance*

	Product Cost Performance						Development Cost Performance					
	I	II	III	IV	V	VI	I	II	III	IV	V	VI
New Platform	-0.43 *	-0.37	-0.42 *	-0.36	-0.36	-0.36	-0.25	-0.25	-0.32	-0.33	-0.33	-0.25
Assembler Parts												
Bubble Economy	-0.22	-0.29	-0.27	-0.31	-0.35	-0.33						
Standard-based Retention		-0.14		-0.10	-0.14	-0.19		-0.06		0.12	0.04	-0.05
Computer Simulation		0.25		0.28	0.25	0.22		0.39 *		0.37 *	0.34 *	0.39 *
Documents & Reports		-0.05						0.01				
Experience-Based Retention			0.30	0.36	0.28				0.53 **	0.60 **	0.41 **	
X-Generational Communication			-0.05	-0.14		0.12			-0.22	-0.34		-0.02
d. f. of residuals	19	16	17	15	16	16	20	17	18	16	17	17
Adjusted R-square	0.25 **	0.18	0.25 *	0.24	0.28 *	0.19	0.02	0.02	0.15	0.26 *	0.21 *	0.02

	Adherence to Schedule						Manufacturability					
	I	II	III	IV	V	VI	I	II	III	IV	V	VI
New Platform	-0.37 *	-0.35	-0.46 **	-0.47 **	-0.47 **	-0.41 *	-0.39 *	-0.39 *	-0.42 *	-0.41 *	-0.40 *	-0.42 *
Assembler Parts	0.31	0.40	0.27	0.34	0.33	0.39 *						
Bubble Economy												
Standard-based Retention		-0.23		-0.03	-0.03	-0.18		-0.26		-0.32	-0.25	-0.29
Computer Simulation		0.21		0.15	0.15	0.19		0.36 *		0.34	0.36 *	0.33
Documents & Reports		0.14						0.00				
Experience-Based Retention			0.51 **	0.51 **	0.49 **				0.00	-0.11	0.05	
X-Generational Communication			-0.01	-0.03		0.23			0.24	0.29		0.23
d. f. of residuals	19	16	17	15	16	16	20	17	17	15	16	16
Adjusted R-square	0.12	0.04	0.32 **	0.26 *	0.31 **	0.09	0.11 *	0.14	0.08	0.16	0.14	0.20 *

*p < .1, **p < .05, ***p < .01

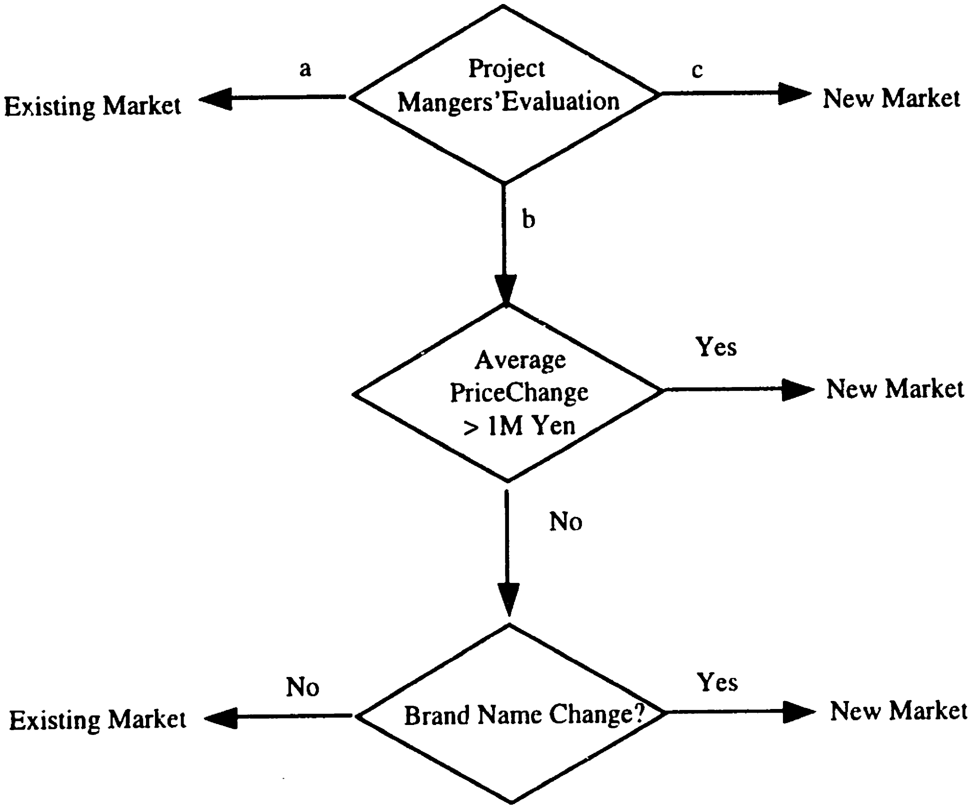
Appendix 7 (continued) : Results of Regression Analyses for Relationships between Knowledge Retention Capabilities and *Improvement Performance*

	Technical Novelty						Technical Performance					
	I	II	III	IV	V	VI	I	II	III	IV	V	VI
New Platform	0.36	0.32	0.42 *	0.34	0.31	0.30	0.49 **	0.50 **	0.42 **	0.42 **	0.41 **	0.45 **
Assembler Parts												
Bubble Economy	0.33	0.44 **	0.28	0.42 *	0.46 **	0.44 *						
Standard-based Retention		0.33		0.33	0.36 *	0.38 *		0.10		0.13	0.23	0.07
Computer Simulation		0.14		0.15	0.16	0.15		0.18		0.10	0.14	0.11
Documents & Reports		0.09						0.06				
Experience-Based Retention			-0.28	-0.16	-0.10				0.17	0.22	0.43 **	
X-Generational Communication			0.28 ***	0.10		0.01			0.45 **	0.38 *		0.50 ***
d. f. of residuals	19	16	17	15	16	16	20	17	18	16	17	17
Adjusted R-square	0.31 ***	0.42 **	0.32 **	0.40 **	0.43 **	0.42 **	0.20 **	0.14	0.46 ***	0.43 **	0.35 **	0.43 ***

	Match to Customer Needs					
	I	II	III	IV	V	VI
New Platform	-0.41 **	-0.37 *	-0.41 **	-0.38 *	-0.40 **	-0.35 *
Assembler Parts	0.47 **	0.36	0.45 **	0.30	0.31	0.33
Bubble Economy						
Standard-based Retention		0.36		0.34	0.38 *	0.29
Computer Simulation		-0.11		-0.28	-0.27	-0.26
Documents & Reports		-0.19				
Experience-Based Retention			0.08	0.21	0.28	
X-Generational Communication			0.20	0.14		0.25
d. f. of residuals	20	16	17	15	16	16
Adjusted R-square	0.28 **	0.28 *	0.28 **	0.35 **	0.37 **	0.35 **

*p < .1, **p < .05, ***p < .01

Appendix 8: Classification of Market Newness



Project Managers' Evaluation:

"(a) mainly targeted to the existing customer base"
"(b) targeted both to the existing customer and the new customer base"
"(c) mainly targeted to the new customer base"

Appendix 9: Results of Regression Analyses for Performance Satisfaction, Including Interaction Terms between Individual-Based Retention Capabilities and Task Newness

Dependent variables: performance satisfaction
Including interactions with platform newness

	Product Cost Performance		Development Cost Performance		Adherence to Schedule		Manufacturability		Technical Novelty		Technical Performance		Match to Customer Needs		Achievement of Sales Target	
	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II
New Platform	-0.36	-0.37	-0.13	0.22	-0.27	-0.17	-0.05	-0.05	0.54 ••	0.53 •••	0.37 •	0.39 ••	0.03	0.04	0.29	0.31
Assembler Parts			-0.49 ••	-0.40 •	-0.64 •••	-0.53 ••	-0.28	-0.44 ••	0.07	0.03			0.42 ••	0.36 •	0.30	0.35 •
Bubble Economy	-0.39	-0.34														
Experience-Based Retention	0.22		0.39 •		0.51 •••		0.01		0.06		-0.01		0.44 ••		-0.19	
X-generational Communication		0.05		-0.16		0.09		0.37 •		0.44 ••		0.14		0.45 ••		-0.26
Experience*New Platform	-0.12		-0.34		-0.16		0.21		0.19		-0.26		0.13		-0.09	
Communication*New Platform		-0.07		-0.33		0.03		-0.20		0.05		-0.60 •••		0.27		-0.28
d. f. of residuals	17	17	17	17	17	17	17	17	17	17	18	18	16	16	16	16
Adjusted R-square	0.29 ••	0.24 •	0.19	0.04	0.51 •••	0.19	-0.02	0.14	0.21 •	0.40 ••	0.05	0.43 •••	0.27 ••	0.28 ••	0.00	0.17

*p < .1, **p < .05, ***p < .01

Dependent variables: performance satisfaction
Including interactions with market newness

	Product Cost Performance		Development Cost Performance		Adherence to Schedule		Manufacturability		Technical Novelty		Technical Performance		Match to Customer Needs		Achievement of Sales Target	
	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II
New Platform	-0.18	-0.19	0.06	0.13	-0.19	-0.11	0.01	0.06	0.58 ••	0.60 •••	0.36	0.32			0.34	0.16
Assembler Parts			-0.62 ••	-0.50 ••	-0.69 •••	-0.64 •••	-0.43	-0.53 ••	0.08	0.05			0.41 •	0 28	0.10	0.18
Bubble Economy	-0.41 ••	-0.37														
New Market	-0.24	-0.23	-0.06	-0.03	-0.01	0.00	-0.07	-0.08	-0.10	-0.14	0.12	0.18	-0.16	-0.18	0.12	0.23
Experience-Based Retention	0.15		0.10		0.39 ••		-0.04		0.09		0.04		0.47 ••		-0.42	
X-generational Communication		-0.05		-0.39		-0.04		0.20		0.48 ••		0.04		0.37 •		-0.48 ••
Experience*New Market	-0.15		-0.60 ••		-0.25		-0.12		0.06		0.22		0.00		-0.47 •	
Communication*New Market		-0.26		-0.60 ••		-0.31		-0.44 •		0.10		-0.19		-0.17		-0.61 •••
d. f. of residuals	16	16	16	16	16	16	16	16	16	16	17	17	16	16	15	17
Adjusted R-square	0.31 ••	0.30 •	0.26 •	0.17	0.50 •••	0.22 •	-0.13	0.23	0.13	0.38 ••	0.06	0.06	0.28 ••	0.26 •	0.09	0 37 ••

*p < .1, **p < .05, ***p < .01

Appendix 10: Results of Regression Analyses for Improvement Performance, Including Interaction Terms between Individual-Based Retention Capabilities and Task Newness

Dependent variables: performance improvement
Including interactions with platform newness

	Product Cost Performance		Development Cost Performance		Adherence to Schedule		Manufacturability		Technical Novelty		Technical Performance		Match to Customer Needs	
	I	II	I	II	I	II	I	II	I	II	I	II	I	II
New Platform	-0.42 *	-0.45 *	-0.32	-0.25	-0.48 **	-0.39 *	-0.40 *	-0.41 *	0.37	0.38	0.41 **	0.45 **	-0.16	-0.15
Assembler Parts			-0.09	-0.33	0.16	0.28							0.41 **	0.35 *
Bubble Economy	-0.28	-0.22							0.37	0.29				
Experience-Based Retention	0.28		0.43 *		0.50 ***		0.13		-0.16		0.40 **		0.12	
X-generational Communication		0.12		0.05		0.23		0.24		0.14		0.53 ***		0.25
Experience*New Platform	0.00		-0.02		-0.27		0.11		-0.05		0.08		0.42 **	
Communication*New Platform		-0.14		0.04		-0.07		-0.13		-0.03		-0.03		0.36 *
d. f. of residuals	17	17	17	17	17	17	18	18	17	17	18	18	17	17
Adjusted R-square	0.25 *	0.20	0.06	-0.15	0.39 **	0.09	0.04	0.10	0.25 *	0.25 *	0.29 **	0.44 ***	0.19 *	0.16

*p < .1, **p < .05, ***p < .01

Dependent variables: performance improvement
Including interactions with market newness

	Product Cost Performance		Development Cost Performance		Adherence to Schedule		Manufacturability		Technical Novelty		Technical Performance		Match to Customer Needs	
	I	II	I	II	I	II	I	II	I	II	I	II	I	II
New Platform	-0.19	-0.21	-0.29	-0.21	-0.32	-0.27	-0.34	-0.27	0.52 **	0.54 **	0.49 **	0.47 **		
Assembler Parts					0.09	0.18							0.30	0.29
Bubble Economy	-0.37	-0.26							0.38	0.23				
New Market	-0.32	-0.28	0.00	0.00	-0.10	-0.09	-0.19	-0.16	-0.29	-0.33	-0.10	-0.09	-0.11	-0.12
Experience-Based Retention	0.32		0.30		0.32		0.28		-0.25		0.29		0.03	
X-generational Communication		-0.03		-0.09		0.11		0.11		0.18		0.47 **		0.11
Experience*New Market	0.06		-0.23		-0.38		0.29		-0.19		-0.20		-0.15	
Communication*New Market		-0.37 *		-0.31		-0.32		-0.31		0.01		-0.17		-0.17
d. f. of residuals	16	16	17	17	16	16	17	17	16	16	17	17	18	18
Adjusted R-square	0.28 *	0.35 **	0.11	-0.06	0.38 *	0.13	0.06	0.14	0.34 **	0.32 **	0.29 **	0.44 ***	0.03	0.03

*p < .1, **p < .05, ***p < .01

Appendix 11: Questionnaire (For Project Managers)

車両担当プロジェクトリーダー

マサチューセッツ工科大学（ＭＩＴ）
スローン経営大学院

自動車の新製品開発に関する調査

(内容秘密厳守)

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青島矢一
延岡健太郎
Greg Scott

今回の調査にご協力いただき誠にありがとうございます。この質問票は、マサチューセッツ工科大学の国際自動車プログラムが世界の自動車メーカーを対象に行っている調査の一環として位置付けられるもので、自動車の新製品の開発過程をよりよく理解することをその目的としています。特に今回の調査では、過去の開発プロジェクトと現在もしくは将来の開発プロジェクトとの相互関係を含めた異なるプロジェクト間での技術や情報の移転といった問題に私たちの関心があります。

質問票にお答えになられるにしたがって、いくつかの質問項目が過去に実施されたものと重複していることにお気づきになられることかと思います。今回の調査は過去の調査とは基本的に異なった目的をもっていますが、過去の調査との最低限の比較可能性を確保するためにはそうした質問項目を削除することが出来なかったという事情をどうぞご理解ください。

ご記入にあたってご質問等がございましたら以下のところまでご連絡ください。お忙しい中、貴重なお時間をさいていただきまして、誠に感謝致しております。

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I. プロジェクトの概要

初めに、プロジェクトの概要についてご質問致します。また、以下では貴方が担当された車種プロジェクトのことを一貫して当該プロジェクトと呼ぶことにします。

I-1.　以下の表に当該プロジェクトの開発車種名、開発期間、貴方の担当された期間、開発車種のボディタイプ数をご記入ください。開発期間はコンセプトスタディから市場導入までの期間を想定してください。

開発車種名	
開発期間	年　月　から　年　月まで
担当期間	年　月　から　年　月まで
ボディタイプ数	

I-2.　当該開発車種の基本コンセプトと開発ゴールについて簡単に記述してください（オプショナル）。

II. 開発組織

以下では、当該プロジェクトのプロジェクト・リーダーとプロジェクト・チームに関してご質問致します。

II-1　プロジェクト・リーダー個人に関する情報

II-1.1　次にあげる項目について貴方自身の情報をご記入ください。a～eについてはプロジェクト終了時点での情報をご記入ください。

a. プロジェクト終了時の年齢　a.＿＿＿＿＿才

b. 自動車産業での経験年数　b.＿＿＿＿＿年

c. 入社年度　c.＿19＿＿＿年

d. プロジェクト・リーダーとしての経験年数　d.＿＿＿＿＿年

e. 企画・統合担当者としての経験年数
(プロジェクト・リーダーとしての経験年数を含む)　e.＿＿＿＿＿年

f. 大学時代の専攻分野　f.＿＿＿＿＿

g. 現在の所属部門と役職　g.＿＿＿＿＿部門
＿＿＿＿＿役職

II-1.2.　当該車種の担当はいつ正式に決定されましたか。

19＿＿＿年＿＿＿月

II-1.3.　当該車種開発のプロジェクト・リーダーを担当することを貴方は、当該プロジェクトの担当が決定する以前に（つまり当該プロジェクトの前に担当していたプロジェクトで活動されている時に）どの程度予測できていましたか。以下の中から当てはまるものを選んで○印で囲んでください。

a　全く予想していなかった(0%)
b　ほとんど予想していなかった(25%)
c　いくらか予想していた(50%)
d　だいたい予想していた(75%)
e　ほとんど確信していた(100%)

II-1.4.　貴方は、当該車種と同時に他の車種のプロジェクト・リーダーも兼任していましたか。兼任していた場合、それはどの車種開発プロジェクトでしたか。

はい　　いいえ　　プロジェクト名（複数可）＿＿＿＿＿＿＿＿＿＿

II-1.5.　II-4で「はい」とお答えになった場合、当該プロジェクトには平均して何%程度の時間を費やしましたか。

＿＿＿＿＿%

II-1.6.　当該車種の先代（旧）モデルの開発を担当したプロジェクト・リーダーと貴方との関係に関する以下の記述の中から、当てはまるもの全てを選んで数字を○印で囲んでください。ここで、先代モデルとは、通常ブランド名の同じ前世代のモデルを指しますが、モデルのブランド名が異なった場合でも、事実上当該開発モデルが代替したと考えられる旧モデルがある場合には、そうしたモデルを念頭にお答えください。（以下の質問でも、先代モデルという場合にはここでの定義に従うものと考えてください。）

1　先代モデルでも私がプロジェクト・リーダーを担当していた。

2　先代モデルの開発で私はプロジェクト・リーダーの補佐的役割を勤めていた。

3　先代モデルのプロジェクト・リーダーとはかつて特定の車種開発で一緒に仕事をしたことがある。

4　先代モデルのプロジェクト・リーダーとは、かつて特定の車種開発で一緒に仕事をしたことはないが、以前に(または今も)同じ部門に所属していたので良く知っていた。

5　先代モデルのプロジェクト・リーダーとは同じ部門に所属したこともないし、一緒に車種開発を行ったこともないが、個人的には知っていた。

6　先代モデルのプロジェクト・リーダーとは仕事でも一緒になったことはないし、個人的にもほとんど知らなかった。

II-1.7.　今回の車種開発以前の貴方の担当について新しいものから順に可能な限り遡って以下の欄にご記入ください。回答にあたっては、少なくとも6カ月以上の期間にわたり30%以上の時間を費やした開発プロジェクトでの活動に限ってご記入ください。また、時間的にオーバーラップして複数の車種を担当していた場合には担当開始がより最近のものから順にご記入ください。

	担当車種名	所属部門	当時の役割	担当期間
1(前回)				19　年　月 ～ 19　年　月
2(前々回)				19　年　月 ～ 19　年　月
3				19　年　月 ～ 19　年　月
4				19　年　月 ～ 19　年　月
5				19　年　月 ～ 19　年　月
6				19　年　月 ～ 19　年　月
7				19　年　月 ～ 19　年　月

II·2　プロジェクト・リーダーの役割と権限範囲

以下では当該車種のプロジェクト・リーダーとしての貴方の役割と権限範囲についてご質問致します。

II·2.1.　**貴方は、以下にあげる当該車種開発の各段階に対して責任を持っていましたか。**

	はい	いいえ	
a.　製品コンセプトの作成／製品計画	□	□	a
b.　製品設計	□	□	b
c.　車両実験	□	□	C
d.　工程エンジニアリング	□	□	d
e.　生産準備	□	□	e
f.　生産の立ちあげ	□	□	f
g.　市場導入後の改良・改善	□	□	g

II·2.2.　以下にあげる意思決定もしくは開発活動について、貴方は実際にどの程度の役割を果たしましたか。
以下の中から当てはまる数字を選んで○印で囲んでください。

		全く関与しなかった				極めて大きな役割を果たした
a.	商品コンセプトの作成	1	2	3	4	5
b.	先行開発・新技術の先行開発	1	2	3	4	5
c.	車両レイアウトの決定	1	2	3	4	5
d.	主要コンポーネントの選択	1	2	3	4	5
e.	流用コンポーネントの選択	1	2	3	4	5
f.	サプライヤーの選択	1	2	3	4	5
g.	詳細設計活動	1	2	3	4	5
h.	開発試作車の開発	1	2	3	4	5
i.	実験活動・実験結果の分析とフィードバック	1	2	3	4	5
j.	生産試作車の開発	1	2	3	4	5
k.	開発コスト・開発工数の管理	1	2	3	4	5
l.	生産コストの管理	1	2	3	4	5
m.	マーケティング計画の決定	1	2	3	4	5
n.	開発スケジュールの管理	1	2	3	4	5
o.	開発目標の管理	1	2	3	4	5
p.	設計・実験部門の技術者間のコーディネーション	1	2	3	4	5
q.	設計技術部門、生産部門、マーケティング部門間のコーディネーション	1	2	3	4	5

II-2.3.　当該プロジェクトの製品開発に関する、次にあげる各部門における活動や意志決定について、貴方はどの程度の影響力をもっていたと思いますか。それぞれの部門の部長のもつ影響力と比較して、プロジェクト・リーダーとしての貴方の影響力を評価してください。回答にあたっては、以下の記述の中から最も当てはまるものを選んで対応する数字を○印で囲んでください。また、部長でなくても（例えば課長でも）各部門の意見を代表し当該プロジェクトに強い影響を与えた人がいた場合にはその人の影響力も考慮して貴方の影響力と比較してください。

1　プロジェクト・リーダーである私が極めて大きな影響力をもっていた。
2　プロジェクト・リーダーである私が比較的大きな影響力をもっていた
3　各部門の部長とプロジェクトリーダーである私がほぼ同等の影響力をもっていた。
4　各部門の部長が比較的大きな影響力をもっていた
5　各部門の部長が極めて大きな影響力をもっていた。

		プロジェクト・リーダーの影響大				各部の部長の影響大
a.	エクステリア/インテリアデザイン	1	2	3	4	5
b.	ボディ設計	1	2	3	4	5
c.	シャシー設計	1	2	3	4	5
d.	電子部品設計	1	2	3	4	5
e.	車両実験	1	2	3	4	5
f.	エンジン設計	1	2	3	4	5
g.	生産エンジニアリング	1	2	3	4	5
h.	生産部門・工場	1	2	3	4	5
i.	マーケティング/商品企画（営業サイド）	1	2	3	4	5
j.	国内海外営業	1	2	3	4	5
k.	品質管理	1	2	3	4	5
l.	購買	1	2	3	4	5
m.	コスト管理	1	2	3	4	5
n.	スケジュール管理	1	2	3	4	5
o.	先行技術研究	1	2	3	4	5

II-3. 開発プロジェクトの主要メンバーについて

以下では、当該開発プロジェクト全体を通じて中心的な役割をはたしたと考えられる、中心メンバーに関してご質問致します。ここで中心メンバーとは、プロジェクト・リーダーを中心に、プロジェクト・リーダーの補佐的役割を勤める企画統括部門の人々(サブ・リーダー)、ボディ設計部門、エンジン設計部門、シャシー設計部門、実験テスト部門、エクステリア/インテリアデザイン部門などの各技術部門からの代表者の人々、それに商品企画・マーケティング部門、営業部門、生産部門からの代表者などからなる考えられますが、それ以外にも、当該プロジェクトで中心的な役割を果たしたと貴方が考える人がいましたらそれらの人々も念頭において以下の質問にお答えください。

II-3.1. 以下の各部門を代表する当該プロジェクトの中心メンバーの人々は、担当期間中このプロジェクトの専任でしたか、それとも他の車種開発も同時に兼任していましたか。以下の記述の中からあてはまるものを選んで該当する数字を○印で囲んでください。２と３についてどちらにも該当する場合には、両方とも○印で囲んでください。

1. この部門からの中心メンバーは、当該プロジェクトに専念していた。
2. この部門からの中心メンバーは、技術的に強く関連する他の車種開発の担当も同時に兼任していた。
3. この部門からの中心メンバーは、技術的関連性の薄い他の車種開発の担当も同時に兼任していた。

		このプロジェクトに専任	技術的に強く関連したものを兼任	技術的に関連の薄いものを兼任
a.	製品企画統括部門（開発サイド、貴方以外）	1	2	3
b.	エクステリア/インテリアデザイン部門	1	2	3
c.	ボディ設計部門	1	2	3
d.	シャシー設計部門	1	2	3
e.	電子部品設計部門	1	2	3
f.	車両実験部門	1	2	3
g.	生産エンジニアリング	1	2	3
h.	生産部門・工場	1	2	3
i.	マーケティング・商品企画（営業サイド）部門	1	2	3
j.	購買部門	1	2	3
k.	品質管理部門	1	2	3
l.	コスト管理部門	1	2	3
m.	技術研究所	1	2	3
n.	サプライヤー・部品協力会社	1	2	3
o.	その他（特定してください　　　）	1	2	3

II-3.2.　当該プロジェクトの中心メンバーと貴方が考える人はだいたい何人くらいでしたか。

＿＿＿＿＿＿＿人

II-3.3.　これら中心メンバーの中で、プロジェクト・リーダーである貴方自身が当該開発プロジェクトに強く推薦した人は何人いましたか。

＿＿＿＿＿＿＿人

II-3.4.　これら中心メンバーの中で、当該開発車種の先代モデルの開発に携わった経験のあった人は何人いましたか。今回の開発を期にモデルのブランド名がかわった場合でも、事実上当該開発モデルが代替したと考えられる旧モデルがある場合には、その旧型モデルの開発での経験を想定してお答えください。

＿＿＿＿＿＿＿人

II-3.5.　これら中心メンバーの中で、当該プロジェクト以前に特定の車種開発プロジェクトで、貴方が一緒に仕事をしたことのある人は何人いましたか。当該車種の過去のモデル開発だけでなく、マイナーチェンジやボディタイプの追加を除く、あらゆる車種開発プロジェクトでの過去の共通経験を念頭に置いてお答えください。

＿＿＿＿＿＿＿人

II-4. プロジェクトをまたがる長期的な部門の関与について

以下では個々の車種開発プロジェクトや世代を越えて開発活動の長期的な計画やコーディネーションにかかわる部門やグループの当該開発活動に対する役割についてご質問いたします。

II-4.1　以下にあげる意志決定もしくは開発活動について、個別のプロジェクトからは独立した長期技術計画グループはどの程度の役割を果たしたと貴方は考えますか。ここで、長期技術計画グループとは、主として、車種や世代を越えてプラットフォームや主要コンポーネントの搭載計画を全社的な技術戦略の観点から担当するグループを指しているとお考えください。該当するグループが存在しない場合には次の「0」の数字を○印で囲んでください。

0.　該当するグループは存在しない

		全く関与しなかった		ある程度関与した		極めて大きな役割を果たした
a.	商品コンセプトの作成	1	2	3	4	5
b.	先行開発車の開発	1	2	3	4	5
c.	車両レイアウトの決定	1	2	3	4	5
d.	性能目標の決定	1	2	3	4	5
e.	プラットフォーム・主要コンポーネントの選択	1	2	3	4	5
f.	流用コンポーネント・共通部品の選択	1	2	3	4	5

II-4.2　以下にあげる意志決定もしくは開発活動について、個別のプロジェクトからは独立した長期商品計画グループはどの程度の役割を果たしたと貴方は考えますか。ここで、長期商品計画グループとは、主として、長期的な商品展開計画を全社的な商品戦略の観点から担当するグループを指しているとお考えください。該当するグループが存在しない場合には次の「0」の数字を○印で囲んでください。

0.　該当するグループは存在しない

		全く関与しなかった		ある程度関与した		極めて大きな役割を果たした
a.	商品コンセプトの作成	1	2	3	4	5
b.	商品バリエーションの決定	1	2	3	4	5
c.	マーケティング計画の策定	1	2	3	4	5
d.	車両レイアウトの決定	1	2	3	4	5
e.	性能目標の決定	1	2	3	4	5
f.	プラットフォーム・主要コンポーネントの選択	1	2	3	4	5

II-4.3　生産しやすい設計デザイン(Design for Manufacturing)の開発をしたり、そうした設計デザインに関する情報を収集・蓄積して個々のプロジェクト活動へ展開する独立したグループ（例えば、生産設計課や生産企画室、デザイン・フォー・マニュファクチュアリング・センターといったもの）は、当該プロジェクトにおいて、どの程度重要な役割を果たしたと考えますか。以下の項目についてあてはまる数字を○印で囲んでください。該当するグループが存在しない場合には次の「０」の数字を○印で囲んでください。

0.　該当するグループは存在しない

		全く関与しなかった		ある程度関与した		極めて大きな役割を果たした
a.	車両レイアウトの設計	1	2	3	4	5
b.	エンジンルームレイアウトの設計	1	2	3	4	5
c.	個々のコンポーネントの設計	1	2	3	4	5
d.	コンポーネント間にまたがる設計活動 （コンポーネント間での設計上の調整）	1	2	3	4	5
e.	プラットフォーム・主要コンポーネントの選択	1	2	3	4	5

II-4.4　個々のプロジェクトから独立して、車両レイアウトに関する情報を収集して長期的な観点から最適な車両レイアウトの開発を行い、個別の車種開発プロジェクトへの展開を行うグループは、当該プロジェクトの車両レイアウトの設計においてどの程度の役割を果たしたと考えますか。該当するグループが存在しない場合には次の「０」の数字を○印で囲んでください。

0.　該当するグループは存在しない

全く関与なかった		ある程度関与した		極めて大きな役割を果たした
1	2	3	4	5

II-4.5　車両開発の企画・統括に関して、異なる車種や世代を越えて個別のプロジェクトリーダーの活動をコーディネートする人は、当該プロジェクトのプロジェクトリーダーとしての貴方の活動にどの程度の影響力をもっていたと考えますか。そうした人は、例えば、企画統括部門内での個々のプロジェクトリーダーの上司にあたる場合が多いかと思いますが、それ以外でも、個別のプロジェクトリーダー間の調整を企画統括の立場から担当した人（もしくはグループ）がいた場合には、そうした人も念頭においてください。該当する人が存在しない場合には次の「０」の数字を○印で囲んでください。

0.　該当するグループは存在しない

全く関与しなかった		ある程度影響力をもっていた		極めて大きな影響力をもっていた
1	2	3	4	5

II-5. コミュニケーション

以下では、当該車種開発における他の人々とのコミュニケーションの頻度についてご質問いたします。コミュニケーションの頻度はそれぞれの期間を通じての平均的な数値をお答えください。ご回答にあたっては、次の示される基準を参考にしてください。また公式のミーティングだけでなく非公式のやりとりも含めてお考えください。

1. 年に2回から3回かそれ以下
2. 月に1回程度
3. 月に2回から3回程度
4. 週に1回程度
5. 週に2回から3回程度
6. ほぼ毎日

II-5.1. 以下にあげる当該プロジェクトのメンバーの人達とのコミュニケーションの頻度について当てはまる数字を選んで○印で囲んでください。

		年に2,3回 それ以下	月に1回	月に2,3回	週に1回	週に2,3回	ほぼ毎日
a.	貴方以外の企画統括担当者	1	2	3	4	5	6
b.	エクステリア/インテリアデザイナー	1	2	3	4	5	6
c.	ボディ・シャシー設計者	1	2	3	4	5	6
d.	エンジン・パワートレイン設計者	1	2	3	4	5	6
e.	車両実験担当者	1	2	3	4	5	6
f.	生産エンジニア	1	2	3	4	5	6
g.	工場部門の人々	1	2	3	4	5	6
h.	マーケティング /商品企画（営業サイド）担当者	1	2	3	4	5	6
i.	品質管理担当者	1	2	3	4	5	6
j.	購買担当者	1	2	3	4	5	6
k.	コスト管理担当者	1	2	3	4	5	6
l.	長期技術計画部門の人	1	2	3	4	5	6
m.	サプライヤー	1	2	3	4	5	6

II-5.2. 当該プロジェクトと同時期に平行して行われていた、関連する社内の他車種のプロジェクトメンバーの人達とのコミュニケーションの頻度について当てはまる数字を選んで○印で囲んでください。当該プロジェクトに同時に参加している人も含めてお考えください。

		年に2,3回それ以下	月に1回	月に2,3回	週に1回	週に2,3回	ほぼ毎日
a.	他車種の企画統括担当者	1	2	3	4	5	6
b.	他車種のエクステリア/インテリアデザイナー	1	2	3	4	5	6
c.	他車種のボディ・シャシー設計者	1	2	3	4	5	6
d.	他車種のエンジン・パワートレイン設計者	1	2	3	4	5	6
e.	他車種の車両実験担当者	1	2	3	4	5	6
f.	他車種の生産エンジニア	1	2	3	4	5	6
g.	他車種の工場部門の人々	1	2	3	4	5	6
h.	他車種のマーケティング/商品企画（営業サイド）担当者	1	2	3	4	5	6
i.	他車種の品質管理担当者	1	2	3	4	5	6
j.	他車種の購買担当者	1	2	3	4	5	6
k.	他車種のコスト管理担当者	1	2	3	4	5	6
l.	他車種のサプライヤー	1	2	3	4	5	6

II-5.3. 以下にあげる先代モデルの開発担当者とのコミュニケーションの頻度について当てはまる数字を○印で囲んでください。上記の質問II-5.1～II-5.2.の場合と想定する人が重なる場合があるかと思いますが構わず重複してお答えください。

		年に2,3回それ以下	月に1回	月に2,3回	週に1回	週に2,3回	ほぼ毎日
a.	先代モデルの企画統括担当者	1	2	3	4	5	6
b.	先代モデルの内装・外装デザイナー	1	2	3	4	5	6
c.	先代モデルのボディ・シャシー設計者	1	2	3	4	5	6
d.	先代モデルのエンジン・パワートレイン設計者	1	2	3	4	5	6
e.	先代モデルの車両実験担当者	1	2	3	4	5	6
f.	先代モデルの生産エンジニア	1	2	3	4	5	6
g.	先代モデルの工場部門の人々	1	2	3	4	5	6
h.	先代モデルのマーケティング/商品企画（営業サイド）担当者	1	2	3	4	5	6
i.	先代モデルの品質管理担当者	1	2	3	4	5	6
j.	先代モデルの購買担当者	1	2	3	4	5	6
k.	先代モデルのコスト管理担当者	1	2	3	4	5	6
l.	先代モデルのサプライヤー	1	2	3	4	5	6

III.　プロジェクトの内容

以下では当該プロジェクトによって開発された新製品の内容を中心にご質問致します。

III-1.　製品の技術的性格

III-1.1.　以下にあげる、当該製品の各技術システムの新規性について、次の1～4までの説明の中でもっとも適切なものを選んで、表中の対応する数字を○印で囲んでください。また、これらの技術システムが従来のシステムの修正・変更を含む場合（つまり、1もしくは2とお答えになった場合）には、それらがa：当該車種の先代モデルのものをベースにしたのか、それとも、b：他の車種から移転されたのかを重ねてお答えください。

1. 以前に他のモデルで利用されたシステムの移転、もしくは比較的小さな変更（20%以下）
2. 以前に他のモデルで利用されたシステムの比較的大きな変更（20%～80%）
3. 当該車種用に新しく設計されたシステム(80%以上)。しかし、技術的には社内で既に開発されていたもの。
4. 社内にかつてなかった完全に新しい技術。

a. 当該モデルの先代モデルで利用されたものをベースにした。
b. 当該車種とは異なった社内の別モデルで利用されたものをベースにした。

		小さな変更	大きな変更	新設計	完全な新技術	先代モデルをベース	他モデルをベース
a.	エクステリア/ボディ	1	2	3	4	a	b
b.	インテリア/トリム	1	2	3	4	a	b
c.	ステアリング	1	2	3	4	a	b
d.	フロアパン	1	2	3	4	a	b
e.	ブレーキ	1	2	3	4	a	b
f.	サスペンション	1	2	3	4	a	b
g.	トランスミッション	1	2	3	4	a	b
h.	エンジン	1	2	3	4	a	b
i.	エンジンコントロール	1	2	3	4	a	b
j.	インスツルメントパネル	1	2	3	4	a	b

III-1.2　上記質問III-1.1で「1」（小さな変更）もしくは「2」（大きな変更）とお答えになった技術システムそれぞれについて、他車種や先代モデルからの移転は当該プロジェクトが開始する以前に決まっていましたか、それともプロジェクト開始後に決定されましたか。１：プロジェクトスタート以前、２：プロジェクトスタート後、のどちらか当てはまる方を選んで○印で囲んでください。

		プロジェクト開始以前	プロジェクト開始後
a.	エクステリア/ボディ	1	2
b.	インテリア/トリム	1	2
c.	ステアリング	1	2
d.	フロアパン	1	2
e.	ブレーキ	1	2
f.	サスペンション	1	2
g.	トランスミッション	1	2
h.	エンジン	1	2
i.	エンジンコントロール	1	2
j.	インスツルメントパネル	1	2

III-1-3.　上記質問III-1.1で「1」（小さな変更）もしくは「2」（大きな変更）とお答えになった技術システムそれぞれについて、移転のベースとなった技術システムは当該車種への搭載をどの程度考慮して開発・設計されていたと思いますか。次の中から当てはまるものを選んで○印で囲んでください。

1.　当該車種への共用・キャリーオーバーを前提に開発されていた。
2.　将来モデルで共用・キャリーオーバーしやすいようにある程度工夫されていた。
3.　共用・キャリーオーバーは全く考慮せず開発されていた。

		キャリーオーバーを前提	キャリーオーバーしやすいようにある程度工夫	キャリーオーバーは全く考慮せず開発
a.	エクステリア/ボディ	1	2	3
b.	インテリア/トリム	1	2	3
c.	ステアリング	1	2	3
d.	フロアパン	1	2	3
e.	ブレーキ	1	2	3
f.	サスペンション	1	2	3
g.	トランスミッション	1	2	3
h.	エンジン	1	2	3
i.	エンジンコントロール	1	2	3
j.	インスツルメントパネル	1	2	3

III-1.4.　上記質問III-1.1.で「1」もしくは「2」とお答えになった技術システムについて、他車種や前モデルからの技術システムの移転はどのような方法で行われましたか。以下にあげる方法が、それぞれの技術システムの移転において実際に当該プロジェクトでどの程度重要な役割を果たしたのか、を1：全く重要でない～3：非常に重要、まで評価してください。

i).　紙に書かれた図面の検討
ii).　コンピュータによる設計情報データベース（CAD/CAE）に蓄積されたデザイン情報を利用、編集。
iii).　移転元の車種開発でその技術システムの開発を担当した人との頻繁なやりとりをした。
iv).　移転元の車種開発でその技術システムの開発を担当した人が当該車種開発でも引き続き担当した。
v).　その他(特定してください)

		図面の検討	CAD/CAE	頻繁なやりとり	引き続き担当	その他 (　　　)
		重要でない　非常に重要	重要でない　非常に重要	重要でない　非常に重要	重要でない　非常に重要	重要でない　非常に重要
a.	エクステリア/ボディ	1　2　3	1　2　3	1　2　3	1　2　3	1　2　3
b.	インテリア/トリム	1　2　3	1　2　3	1　2　3	1　2　3	1　2　3
c.	ステアリング	1　2　3	1　2　3	1　2　3	1　2　3	1　2　3
d.	フロアパン	1　2　3	1　2　3	1　2　3	1　2　3	1　2　3
e.	ブレーキ	1　2　3	1　2　3	1　2　3	1　2　3	1　2　3
f.	サスペンション	1　2　3	1　2　3	1　2　3	1　2　3	1　2　3
g.	トランスミッション	1　2　3	1　2　3	1　2　3	1　2　3	1　2　3
h.	エンジン	1　2　3	1　2　3	1　2　3	1　2　3	1　2　3
i.	エンジンコントロール	1　2　3	1　2　3	1　2　3	1　2　3	1　2　3
j.	インスツルメントパネル	1　2　3	1　2　3	1　2　3	1　2　3	1　2　3

III-1.5.　当該製品の性格を最も適切に表現していると思われるものを以下の中から選んで○印で囲んでください。

1　既存モデルのユーザーの吸収（買い換え需要）を最大限に意識したフルモデルチェンジ
2.　既存モデルのフルモデルチェンジであるが、新しいユーザー層の獲得をも念頭においている。
3.　既存モデルのフルモデルチェンジであるが、特に新しいユーザーの獲得を目的としている。
4.　その他　（特定してください　　　　　　　　　　　　　　　）

III-2. サプライヤーによる部品の設計

以下では、部品の設計におけるサプライヤーの関与に関してご質問致します。

III-2.1.　当該車種で利用された部品の内、部品点数で何%が新規に設計されましたか。

_______________%

III-2.2.　部品の新規設計に当たってサプライヤーはどの程度貢献しましたか。以下にあげるそれぞれのカテゴリーに当てはまる新規部品点数の割合をご記入ください。内製部品は除いてお考えください。

a.　100%サプライヤーによって設計された部品。　_______________%

b.　おおまかな部品の仕様書もしくは設計図をもとに、サプライヤーが詳細設計、プロトタイプ、テストを行った部品(先行開発もサプライヤーによって行われた)。　_______________%

c.　自動車メーカーが詳細設計を含む全ての設計をおこなって、サプライヤーに発注した部品。　_______________%

合計　１００%

IV. 開発プロセスについて

以下では、開発日程や実際の開発活動などの開発プロセスに関するご質問を致します。

IV-1. 開発日程

IV-1.1. 開発プロセスにおける重要イベントが実際にいつスタートしていつ終了したのかを以下の表中にご記入ください。

IV-1.2. また、それぞれのイベントが当初の日程通りで起きたかそれとも日程をオーバーしたのか、表中の対応する数字を○印で囲んでください(日程どおり：1、日程オーバー：2)。

	ー始まりー	ー終わりー	日程どおり	日程オーバー
a. コンセプトスタディ	19　　年　　月	19　　年　　月 (公式の承認)	1	2
b. 車両基本計画	19　　年　　月	19　　年　　月 (公式の承認)	1	2
c. 先行開発	19　　年　　月	19　　年　　月	1	2
d. 詳細設計	19　　年　　月	19　　年　　月 (最終図面の出図)	1	2
e. 工程エンジニアリング	19　　年　　月	19　　年　　月	1	2
f. 量産試作	19　　年　　月	19　　年　　月	1	2
g. 生産の立ちあげ	19　　年　　月		1	2
h. 製品の市場導入	19　　年　　月		1	2

IV-2. 自社内既存モデルの検討

以下では当該車種の企画・基本計画段階で製品コンセプトの策定や基本諸元、基本レイアウトの決定などにおいて特に参考にした既存の自社内モデルについてご質問いたします。

IV-2.1. 当該車種の企画・基本計画段階で（コンセプトの策定、基本諸元／基本レイアウトの決定など）、特に参考にした既存の自社内モデルの車種名とそのモデル導入年次を3つまで重要なものから順に下欄にご記入ください。当該車種の先代モデルも含めてお考えください。またここでは競合他社の製品考慮から除外してください。

IV-2.2 それら過去のモデルについて特にどのような点が検討されましたか。以下にあげる検討項目それぞれについて、他の項目と比較してどの程度重点的に検討したのかを、１：ほとんど検討しなかった～３：特に重点的に検討した、まで当てはまる数字を選んで○印で囲んでください。

	1	2	3
車種名			
モデル導入年次	１９	１９	１９

↓　↓　↓

		ほとんど検討しなかった		重点的に検討	ほとんど検討しなかった		重点的に検討	ほとんど検討しなかった		重点的に検討
a.	市場でのユーザーの評価	1	2	3	1	2	3	1	2	3
b.	製品コンセプト	1	2	3	1	2	3	1	2	3
c	スタイリング.	1	2	3	1	2	3	1	2	3
d	エンジンやブレーキなど個々の技術要素の性能.	1	2	3	1	2	3	1	2	3
e.	静粛性や走行安定性などの製品全体としての性能	1	2	3	1	2	3	1	2	3
f	流用コンポーネントの可能性.	1	2	3	1	2	3	1	2	3
g.	開発の進め方・開発プロセス	1	2	3	1	2	3	1	2	3
h.	設計と実験の協同のしかた	1	2	3	1	2	3	1	2	3
i.	設計と生産技術の協同のしかた	1	2	3	1	2	3	1	2	3
j.	開発コスト	1	2	3	1	2	3	1	2	3
k.	生産コスト	1	2	3	1	2	3	1	2	3
l.	開発工数	1	2	3	1	2	3	1	2	3
m.	設計上の品質	1	2	3	1	2	3	1	2	3
n.	製造上の品質	1	2	3	1	2	3	1	2	3
o.	その他（特定してください　　　　　　）	1	2	3	1	2	3	1	2	3

IV-2.2.　既存の車種を検討するにあたって、以下にあげる方法はそれぞれどの程度重要であったと考えますか。対応する数字を○印で囲んでください。

		全く重要でない		ある程度重要		非常に重要
a.	実際にその車種に試乗した	1	2	3	4	5
b.	雑誌での専門家の評価を参考にした	1	2	3	4	5
c.	その車種の設計図面を検討した	1	2	3	4	5
d.	その車種の開発担当者と話し合った	1	2	3	4	5
e.	その車種の開発担当者を当該プロジェクトに巻き込んだ	1	2	3	4	5
f.	その車種の開発企画書を参考にした	1	2	3	4	5
g.	その車種の開発過程で生じた問題等を記述したドキュメントを参考にした	1	2	3	4	5
h.	品質部門をとおした市場からのフィードバックを参考にした。	1	2	3	4	5
i.	顧客情報に関するデータベースを参照した	1	2	3	4	5
j.	設計情報のデータベースに残されたデザイン情報を利用した	1	2	3	4	5

IV-3　過去の開発活動からの学習

IV-3.1　当該開発活動における次にあげる意志決定や問題解決活動において自社内での過去の開発活動（先代モデルに限らず）から得られた情報や知識がどの程度重要であったと思いますか。当てはまる数字を選んで○印で囲んでください。

		全く重要でない		ある程度重要		非常に重要
a.	製品コンセプトの作成	1	2	3	4	5
b.	ユーザーニーズの把握	1	2	3	4	5
c.	基本レイアウトの決定	1	2	3	4	5
d.	採用コンポーネントの決定	1	2	3	4	5
e.	新技術の開発や採用の決定	1	2	3	4	5
f.	流用コンポーネントの決定	1	2	3	4	5
g.	性能目標の設定	1	2	3	4	5
h.	開発コスト目標の決定	1	2	3	4	5
i.	エンジンやサスペンションなどの各技術コンポーネント設計上の問題解決	1	2	3	4	5
j.	異なるコンポーネント間（例えばボディとサスペンション）にまたがる技術的問題解決	1	2	3	4	5
k.	異なる性能間でのコンフリクトの解決	1	2	3	4	5
l.	設計試作車の評価	1	2	3	4	5
m.	生産試作車の評価	1	2	3	4	5
n.	量産立ち上げに関する問題解決	1	2	3	4	5

IV-3.2　当該車種開発における以下の活動において、過去の開発活動において明らかになった問題解決方法やその他残された問題点などを書き記したドキュメント（例えば、不具合書や技術報告書といったもの）はどの程度参照されましたか。

		ほとんど利用されなかった		ある程度利用した		非常に利用した
a.	製品コンセプトの作成	1	2	3	4	5
b.	基本車両レイアウトの設計	1	2	3	4	5
c.	性能目標の決定・評価	1	2	3	4	5
d.	エンジンルームレイアウトの設計	1	2	3	4	5
e.	エクステリア・インテリアのデザイン・評価	1	2	3	4	5
f.	シャシー設計・評価	1	2	3	4	5
g.	エンジン・パワートレイン設計・評価	1	2	3	4	5
h.	ボディ設計・評価	1	2	3	4	5
i.	異なる技術コンポーネント間（例えばボディとサスペンション）にまたがる問題解決	1	2	3	4	5
j.	異なる性能間でのコンフリクトの解決	1	2	3	4	5
k.	設計試作車の車両評価	1	2	3	4	5
l.	生産試作車の車両評価	1	2	3	4	5

IV-3.3　当該車種開発の以下にあげる設計・評価活動において、構造要件や性能要件などの設計標準や標準化された設計・評価手順、標準ツールはどの程度重要であったと思いますか。

		全く重要でない		ある程度重要		非常に重要
a.	基本車両レイアウトの設計	1	2	3	4	5
b.	性能目標の決定・評価	1	2	3	4	5
c.	エンジンルームレイアウトの設計	1	2	3	4	5
d.	エクステリア・インテリアのデザイン・評価	1	2	3	4	5
e.	シャシー設計・評価	1	2	3	4	5
f.	エンジン・パワートレイン設計・評価	1	2	3	4	5
g.	ボディ設計・評価	1	2	3	4	5
h.	異なる技術コンポーネント間（例えばボディとサスペンション）にまたがる問題解決	1	2	3	4	5
i.	異なる性能間でのコンフリクトの解決	1	2	3	4	5
l.	設計試作車の車両評価	1	2	3	4	5
m.	生産試作車の車両評価	1	2	3	4	5

IV-3.4.　以下にあげるコンピューター情報システムの利用は当該車種開発にとって重要な役割を果たしましたか。

		全く重要でない		ある程度重要		非常に重要
a	CAEによる車両性能のシミュレーション	1	2	3	4	5
b.	CAEによる部品性能のシミュレーション	1	2	3	4	5
c	CAEによる各部品の構造解析	1	2	3	4	5
d	CAD/CAM システムによる部品設計と金型設計の同時進行	1	2	3	4	5
e	利用可能な標準化部品のデータベースの利用	1	2	3	4	5
f	CADなどに保存された過去の設計情報データベースの利用と編集	1	2	3	4	5
g.	CAD/CAEによる技術者間での設計情報の共有	1	2	3	4	5
h	設計担当者の顧客情報データベースへのアクセス	1	2	3	4	5
i	電子メールによる部門内部でのやりとり	1	2	3	4	5
j	電子メールによる部門を越えたやりとり	1	2	3	4	5
k	ビデオコンファレンスの利用	1	2	3	4	5
l	エキスパートシステムの利用	1	2	3	4	5

IV-3.5　以下に、過去の開発活動で得られた技術や知識、情報の世代を越えた移転・伝承に関わるいくつかのメカニズムを列挙します。これらのメカニズムの内、当該プロジェクトにおいて、過去の開発活動での開発成果（技術や知識、情報）を学習・移転するのに、特にどれが有効であったと思われますか。以下にあげる開発の様々な領域について特に有効であったと思われるメカニズムを全て選んで対応する数字を○印で囲んでください。

1. 担当者の移転（過去のプロジェクトでの経験をもつ人が当該プロジェクトに参加）
2. 過去のプロジェクトでの経験を持つ人との話し合い（各部門内での話し合いや部門を越えた話し合い）
3. プロジェクトとは独立した組織（例えば長期技術計画グループや長期商品計画グループなど）が技術や知識、情報を蓄積して各プロジェクトに展開。
4. 過去の開発活動でおきた問題点や問題解決方法を記述したドキュメントやレポートによる移転・伝承。
5. 設計標準、テスト標準、標準設計手順、標準化部品など標準化による移転・伝承。
6. コンピュータデータベースやその他コンピュータに蓄積された情報の利用。

		担当者の移転	担当者の話し合い	独立組織による展開	ドキュメントやレポート	標準化	コンピュータ
a.	製品コンセプト作成に関する情報・知識	1	2	3	4	5	6
b.	ユーザーニーズに関する情報	1	2	3	4	5	6
c.	基本レイアウト設計に関わる技術的情報・知識	1	2	3	4	5	6
d.	性能目標の決定に関わる情報・知識	1	2	3	4	5	6
e.	採用可能な社内の新技術に関する情報	1	2	3	4	5	6
f.	流用可能な部品システムに関する情報	1	2	3	4	5	6
g.	再利用可能なパーツ（ボルトやナット類）に関する情報	1	2	3	4	5	6
h.	エンジンやサスペンションなどの各部品システムの詳細設計上の技術的知識	1	2	3	4	5	6
i.	異なる部品システム間（例えばボディとサスペンション）にまたがる技術的問題解決に関する知識	1	2	3	4	5	6
j.	異なる性能間でのコンフリクト解決に関する知識	1	2	3	4	5	6
k.	開発の進め方・開発プロセスのマネジメントに関する知識	1	2	3	4	5	6
l..	設計試作車の評価に関する情報・知識	1	2	3	4	5	6
m..	生産試作車の評価に関する情報・知識	1	2	3	4	5	6
n.	量産立ち上げに関する問題解決の情報・知識	1	2	3	4	5	6

V. 開発成果について

V-1. 開発目標の達成

V-1.1　以下にあげる当該開発車種の各パフォーマンスについて貴方はどの程度満足していますか。当てはまる数字を○印で囲んでください。

		不満足である		まあまあ満足している		たいへん満足している
a.	居住性	1	2	3	4	5
b.	快適性	1	2	3	4	5
c.	NVH	1	2	3	4	5
d.	走行安定性	1	2	3	4	5
e.	加速性能	1	2	3	4	5
f.	ブレーキ性能	1	2	3	4	5
g.	エンジン性能	1	2	3	4	5
h.	操舵レスポンス	1	2	3	4	5
i.	安全性	1	2	3	4	5
j.	公害・環境対策	1	2	3	4	5
k.	塗装品質	1	2	3	4	5
l.	ボディ剛性	1	2	3	4	5
m.	内外装スタイリング	1	2	3	4	5
n.	空力特性	1	2	3	4	5
o.	車両重量	1	2	3	4	5
p.	製品コスト	1	2	3	4	5
q.	開発コスト（開発工数、試作コスト）	1	2	3	4	5
r.	開発スケジュール	1	2	3	4	5
s.	生産の容易さ	1	2	3	4	5
t.	技術的な新規性	1	2	3	4	5
u.	ユーザーニーズへの対応	1	2	3	4	5

V-1.2　当初の販売計画と比較して、当該開発車種のこれまでの販売実績はどのように評価できますか。国内販売、海外販売、国内・海外を含めた全体の販売のそれぞれについてあてはまる数字を○印で囲んでください。

		計画よりずっと悪い		計画通り		計画よりずっと良い
a.	国内販売	1	2	3	4	5
b.	海外販売	1	2	3	4	5
c.	全体	1	2	3	4	5

V-1.3　以下にあげる当該開発車種の各パフォーマンスを先代モデルの場合と比較して評価してください。

		先代モデルと同レベルもしくはそれ以下		先代より向上した		先代より格段に向上した
a.	居住性	1	2	3	4	5
b.	快適性	1	2	3	4	5
c.	NVH	1	2	3	4	5
d.	走行安定性	1	2	3	4	5
e.	加速性能	1	2	3	4	5
f.	ブレーキ性能	1	2	3	4	5
g.	エンジン性能	1	2	3	4	5
h.	操舵レスポンス	1	2	3	4	5
i.	安全性	1	2	3	4	5
j.	公害対策	1	2	3	4	5
k.	塗装品質	1	2	3	4	5
l.	ボディ剛性	1	2	3	4	5
m.	内外装スタイリング	1	2	3	4	5
n.	空力特性	1	2	3	4	5
o.	車両重量	1	2	3	4	5
p.	製品コスト	1	2	3	4	5
q.	開発コスト（開発工数、試作コスト）	1	2	3	4	5
r.	開発スケジュール	1	2	3	4	5
s.	生産の容易さ	1	2	3	4	5
t.	技術的な新規性	1	2	3	4	5
u.	ユーザーニーズへの対応	1	2	3	4	5

V-2　開発工数

V-2.1.　最も多いとき、当該開発プロジェクトには全体で何名の人が参加していましたか。また、それらの人々のうちだいたい何%が専任のメンバーでしたか。エンジニア、テクニシャン、スタッフの全てを含んでお考えください。

______________人　　　　専任______________%

V-2.2.　当該プロジェクト全体に費やされた開発工数はどの程度でしたか。エンジニア、テクニシャン、スタッフの全てを含んでお考えください。

____________時間

ご回答の終わりました質問票は各社の担当の方までご返送ください。

ご協力誠にありがとうございました。

・もし差し支えございませんでしたら、以下の欄に貴方のお名前、現在所属されている部門、それにお電話番号をご記入ください。

お名前	
現在所属されている部門	
お電話番号	