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KNOWLEDGE RETENTION AND NEW PRODUCT DEVELOPMENT PERFORMANCE

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Abstract

Drawing on examples from the Japanese automobile industry, this study investigated how differences in the ability to retain product-related knowledge across product generations affect product development performance.

Two sets of analyses were conducted on this issue, based on data obtained from 229 key project members in 25 new product development projects. First, we investigated how knowledge retention influences performance within well-established component development, which we called *local performance*. We found that, in general, dependence on archival-based mechanisms, such as documents, reports and computerized tools, rather than on individual-based mechanisms, tended to be associated with higher local performance.

Next, we analyzed our data set at the project level. Data suggested that retention of individual experience bases and communication with previous project members have positive impact on several performance indicators at the entire project level. In particular, we found that these individual-based retention mechanisms affected improvement of *system performance* derived from the complex interactions among different engineering and functional domains. However, data also suggested that retention of prior experience tended to cause problems when projects have to introduce new market concepts.

1. *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). In addition, due to intensive competitive pressures, a fast product development cycle has also become a critical source of competitiveness in many industries (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. 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). However, 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 paper 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 differences in the ability to retain product-related knowledge across multiple generations of products affect performance in developing 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). By exploring differences within Japanese projects, this paper can extract explanatory factors independent of the country effect.

2. *Conceptual Foundations and Hypotheses*

This section provides conceptual foundations of the hypothetical relationships between knowledge retention and product development performance. Below, we begin by discussing that different performance attributes involved in new product development activities may call for different types of knowledge retention.

We then discuss several mechanisms to retain knowledge across product generations. This is important since an empirical part of this paper focuses projects' dependence on particular retention mechanisms as an indicator for knowledge retention. We close this section by making the specific hypotheses to be tested in the subsequent sections.

2-1. Performance Attributes and Knowledge Types

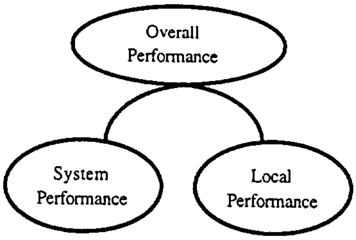
In the conceptual scheme used in this paper, overall performance of new product development consists of two factors, local performance and system performance, as indicated in Figure 1 below.

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.

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

FIGURE 1. LOCAL PERFORMANCE AND SYSTEM PERFORMANCE



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).

This distinction between local and system performance becomes important when examining the impact of knowledge retention on product development performance since projects may have to retain different types of knowledge to improve different performance attributes.

Achieving high local performance may require specialized or domain-specific functional knowledge, often based on fundamental scientific understanding. No chassis engineer in automobile development, 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. 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.

On the other hand, system performance may primarily depend on knowledge that goes beyond functional and technical boundaries, which we call *integrative knowledge*. Development of new "system" products invariably calls for knowledge to integrate potentially fragmented and specialized knowledge to apply specific contexts. 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, 199). 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, which may have a particular impact on the system portion of new product development performance.

The above discussion can be summarized as the following propositions:

Proposition 1: Effective retention of domain specific and functional knowledge across generations of projects is positively associated with the local portion of new product development performance.

Proposition 2: Effective retention of integrative knowledge across generations of projects is positively associated with the system portion of new product development performance.

2-1. Positive or Negative Effects of Knowledge Retention

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). 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.

Organizational learning literature has also somewhat contradictory conclusions on the effect of knowledge retention on organizational performance. On the one 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.

On the other 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).

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.

The above discussion leads to the following proposition:

> Proposition 3: The relationship between knowledge retention and product development performance is moderated by the degree of task newness involved in new product development activities.

However, other 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 and Clark, 1990; 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). We shall take into account these factors in our data analyses.

2-3. Retention Mechanisms and Product Development Performance

One of the critical problems involved in the empirical research dealing with knowledge retention is that it is not an easy task to measure the amount of retained knowledge, especially when considering less observable integrative knowledge. One way to overcome this problem may be to focus on several possible mechanisms for knowledge retention and specify boundary conditions as capabilities to facilitate knowledge retention across generations of projects. They are, for example:

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 domain specific knowledge, we can use a projects' dependence on such mechanisms as an indicator of the retention of integrative knowledge. To do so, however, we need to understand a difference of the nature between integrative knowledge and domain-specific one.

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

There are a couple of reasons why integrative knowledge tends to less articulable. First, there is no established languages 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. In particular, since integrative knowledge involves knowledge to translate different languages between different thought worlds, it tends to be difficult to articulate.

Second, integrative knowledge tends to be context-specific: it is knowledge of the particular circumstances of time and place. 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.

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.

Direct face-to-face interactions may also 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.

In accordance with the above discussion, Propositions 1, 2, and 3 can be rewritten to the following hypotheses.

Hypothesis 1: The use of archival-based knowledge retention mechanisms, reflected in documents, reports, standards, and computer-aided design systems, will be associated with high local performance in new product development.

Hypothesis 2: The use of individual-based knowledge retention mechanisms, 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.

Hypothesis 3: The relationship between the degree of projects' dependence on knowledge retention mechanisms and product development performance will be moderated by task newness, reflected on either or both technical and market newness.

3. *Research Methods*

This study used a cross-sectional questionnaire survey to address the research questions. 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.

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.

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.

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.

We also conducted in-depth interviews with project managers and other core-members at 14 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.

3. 1 Research Design

To examine the hypotheses discussed above, we conducted two sets of analyses. First, we focused on development activities within each component development area, such as body design, engine design, and chassis design, to explore the impact of knowledge retention on local performance. We thus empirically regarded local performance as performance of particular component development attributed only to activities within each component design group.

Next, we analyzed data at the project level. As already mentioned, performance of an entire project can be influenced both by each functional or component development activity and interaction between them. Therefore, comparison of the results between component level analyses and project level ones presumably identifies differences between capabilities to improve system performance and those to improve local performance.

The comparison of results obtained from different samples, however, has limitations. Therefore, we also attempted to compare between factors affecting system performance and those affecting local performance within the same project-level sample. Finally, we examined the moderating effects of market and technological newness on the relationships between experience-based retention and project performance as a partial test for Hypothesis 3.

4. *Knowledge Retention and Local Performance*

4. 1 Sample

Out of the 229 entire sample, we focused on only component design engineers to examine local performance. Although our data sets comprises 118 component design engineers, the final sub-sample analyzed included only 83 engineers because of missing values for some explanatory variables. All these 83 members were key project members, representing five different engineering or design areas, exterior/interior design, chassis design, body design, engine design, and electronics component design.

4. 2 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 development cost performance, component cost performance, adherence to schedules, manufacturability of component systems, novelty of component systems, and technical performance of component systems. Table 1 below shows summary statistics for these performance indicators.

TABLE 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	0.09	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. 3 Explanatory Variables

Table 2 below indicates descriptive statistics for explanatory variables considered in the subsequent analyses. Each explanatory variable corresponds to one of the six knowledge retention mechanisms: documents and reports, standards, computer-aided systems, direct transfer of project members, face-to-face communication, and involvement of independent organizational units. Below, we briefly explain how we constructed these measures.

Use of Archival Mechanisms: Documents and Reports, and Standards

Our observation reveals that Japanese automobile companies use two types of documents to store prior knowledge. The first type describes standardized knowhow such as technical standards, standard design procedures, and standard test methods, which engineers must follow. Non-standardized knowhow or lessons obtained from past activities were retained through several other formal and informal reports and memos such as the test reports, the knowhow documents, and the user-claim reports, the problem-handling document, and the communication memos.

Although the boundary between standards and non-standardized knowhow is not clearly

TABLE 2. DESCRIPTIVE STATISTICS FOR EXPLANATORY VARIABLES

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 simulation	3.22	1.25	1.00	5.00
Computer-based design retention	3.63	0.90	2.00	5.00
Direct creation of parts program by CAD/CAM	3.48	1.32	1.00	5.00
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	94.3
Communication with previous project members	21.0	18.4	2.5	67.1
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
% of previous project members	0.18	0.14	0.00	0.75

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 (mean = 3.78, s. d.= 0.91). 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 (mean = 3.78, s. d. = 0.99). Standards here include design standards, standard testing procedures, standard design procedures, and standard design tools.

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.

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. Along with this conceptual distinction, a principal component analysis enabled us to group these variables into three indicators. The first is the use of computer simulation consisting of CAE simulation for structural analysis and CAE simulation for vehicle performance (alpha = 0.83). The second indicates the computer-based past design retention that consists of the standardized database and the reuse and edit of past design information (alpha = 0.78).[1] Third, we preserved a variable of CAD/CAM with direct creation of parts programs as a separate variable.

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. 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 nine types of individuals indicated by the 3 x 3 matrix in Table 3 below.[2]

Respondents rated the frequency of communication on 6-point scales, with 1 = two to

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[1] The second factor obtained from the principal component analysis consisted of these two variables as well as the design information sharing variable. However, the computer-based past design retention is conceptually different from design information sharing. Therefore, we excluded the information sharing variable, and then averaged scores for the remaining two variables.

[2] 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

TABLE 3. 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

The different functional departments shown in the third row include production, marketing/product planning, sales, quality insurance, purchasing, cost management, long-term planning groups, and suppliers.

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 3 above.

To identify an underling pattern, we subjected these nine indicators to a principal components analysis. Four factors emerged. 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).[3]

Organizational Influence

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

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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).

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

planning group relative to that of a project manager.

Control Variables

In addition to the above explanatory variables, we considered five control variables that presumably have strong influences on component development performance. These control variables are summarized as follows.

Bubble economy:	respondents involved in the projects that introduced new models during 1991 were coded as 1: 0 otherwise
Micromini Car:	respondents who worked on micromini car development were coded as 1; 0 otherwise
Design Newness:	the percentage of change in the component from the existing design
Engineering area:	a dummy variable indicating respondents' engineering areas
Company:	a dummy variable indicating respondents' companies

4. 4 Results and Discussions

Table 4 below shows the correlations among performance variables and explanatory variables.

Results in Table 4 appears to support our proposition that local performance is positively associated with archival-based knowledge retention capability.[4] 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

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[4] 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.

TABLE 4. 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

performance indicator.

Table 5 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.[5] 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.

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.

Contrary to our hypothesis, the full regression models show that the use of standards is negatively related to development cost performance, manufacturability, and technical performance. However, 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 multicollinearity.[6]

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.[7]

Third, the use of computer simulation tools was significantly associated with technology-

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[5] 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.

[6] The signs of regression coefficients were, however, still negative. It might be that there is some real negative influence from the use of standards on performance. 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.

[7] In the additional analysis which excluded exterior/interior designers from the sample, we found that the CAD/CAM variable was significantly associated with manufacturability.

TABLE 5. RESULTS OF THE FITTED REGRESSION ANALYSES FOR LOCAL PERFORMANCE INDICATORS

	Component 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			0.10	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 5. RESULTS OF THE FITTED REGRESSION ANALYSES FOR LOCAL PERFORMANCE INDICATORS (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

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. In this respect, 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, partially because CAE tools tend to make engineers spend too much time for marginal performance improvement.

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.[8]

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

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[8] 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.

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. This result implies that knowledge retention through people may not be critical to improve local performance.

In summary, results in this section partially supported Hypothesis 1. 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.

5. *Knowledge Retention and New Product Development Performance at the Project Level*

5-1 Sample

The project level analyses below include data obtained from 229 respondents at 25 new product development projects. 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 includes 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.

5-2 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. 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 3, which refers to an interaction effect between experience-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.

5-3 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

TABLE 6. 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 need	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*	3.97	0.37	3.78	0.59

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* 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.

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 6 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*.

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. We calculated sales achievement ratios only for the first year of model introduction so as to maintain data comparability across sample projects. The mean score of this indicator across sample projects was 1.01 (s.d. = 0.36).

5-4. 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 the analyses in the section 3. 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.[9]

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[9] Appendix 2 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.

TABLE 7. DESCRIPTIVE STATISTICS FOR EXPLANATORY VARIABLES

N = 22	Mean	S.D.	Min.	Max.
Experience-based retention	0.00	1.00	−1.59	1.78
Cross-generational communication	15.7	7.02	5.06	29.31
Reference to documents and reports	3.73	0.22	3.43	4.28
Use of standards and computer-stored information	3.76	0.31	3.20	4.37
Use of computer simulation	3.53	0.41	2.65	4.21
Involvement of long-term planning groups	2.06	0.79	1.00	3.46
Involvement of super-project managers	3.05	1.40	1.00	5.00

5-5. Explanatory Variables

Table 7 below indicates descriptive statistics for a set of explanatory variables examined in the subsequent analyses. Below, we briefly explain each of these variables.

Experience-Based Knowledge Retention

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

First, we took a percentage of integrators transferred from the previous generation of projects to indicate experience-based knowledge retention capability (mean = 0.59. s.d. = 0.29).[10] We regarded project managers, vehicle layout engineers, and vehicle test engineers as such integrators in automobile development. 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.

Second, we considered a percentage of project core-members responsible for the previous generations of a project to be the second indicator (mean = 0.34, s.d. = 0.19),. Integrative knowledge may be stored in these people as collective memories (Badaracco, 1991; March, 1988; Huber, 1991; Spender, 1994; Walsh and Ungson, 1991).

Third, degree of common past experiences at the project level was considered. To measure it, we asked respondents whether or not they had worked with the other project core-members in *any past* 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 (mean = 0.61, s.d. = 0.14)

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 useful prior

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[10] As explained in the previous section, 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.

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 (mean = 0.51, s.d. $\doteq$ 0.17).

We subjected the above indicators to a principal component analysis to identify an underlying pattern. One factor emerged (eigenvalue = 2.38).[11] We thus used the first factor as a composite measure for experience-based knowledge retention capability.

Communication-Based Retention

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. Then, we converted each point to an estimate of the number of days, as explained in the previous section. Scores obtained from these project members were averaged to form project level measures.

Archival and Computer-Aided Mechanisms for Knowledge Retention

We examined five indicators for archival-based knowledge retention capability: (1) the reference to documents and reports to learn from the past; (2) the use of standards; (3) the reuse or editing of computer-stored information (including parts database); (4) the use of computerized simulation tools (CAE); and (6) the creation of direct parts programs by CAD/CAM.

Component engineers, vehicle test engineers, vehicle layout engineers, and production engineers rated these five indicators on a 5-point Likert 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.

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 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.

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[11] 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.

TABLE 8. 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

Involvement of Independent Organizational Units

There are 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 call this super-project manager.). Project managers rated the degree of influence of these groups or individuals across a range of development activities and decision making, on a 5-point Likert scale.

A principal component analysis yielded two factors. The 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.

Technical Content, Supplier Involvement, and Other Possible Control Variables

Finally, Table 8 shows the other variables we considered in the analyses, which include technical content, the degree of supplier involvement, and economic conditions.

5-4. Results and Discussions

Correlation Analyses

Tables 9 to 12 below show results of correlation analyses between sets of explanatory variables and indicators for overall performance satisfaction and performance improvement. Table 11 and 12 specifically show results for system performance that we statistically separated

TABLE 9. 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 Achievemen
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

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

TABLE 10. 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 11. 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

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

Table 12. 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

from local performance to indicate performance characteristics derived from interactions among individual engineering domains.

Results here indicate that both experience-based retention capability and cross-generational communication are positively related to several performance variables at the project level. 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 11 and 12 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 *improvement* of system performance. 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 ($r = .37$, $p < .1$), 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, results here show that the reference to documents and reports 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. 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[12]

The use of computer simulation was positively associated with several overall perform-

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[12] 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

TABLE 13. SUMMARY RESULTS OF THE CORRELATION ANALYSES FOR OVERALL AND SYSTEM PERFORMANCE SATISFACTION AND SALES ACHIEVEMENT

	Experience-Based Retention		X-Genetional Communication		Long-Team Planning Group		Standards & Computer-Ttored 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 14. SUMMARY RESULTS OF THE CORRELATION ANALYSES FOR OVERALL AND SYSTEM PERFORMANCE IMPROVEMENT

	Experience-Based Retention		X-Genetional Communication		Long-Team Planning Group		Standards & Computer-Ttored 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

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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.

ance indicators, especially those for technical-related performance. 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 12 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.

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. 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, 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. As a result, they may have tended to ascribe low project performance to the long-term planing groups.

Tables 13 and 14 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.

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.

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 3 and 4 shows results of regression analyses.[13]

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[13] 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 with performance indicators. 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

Table 15. A Summary Table for the Results of Regression Analyses for Relationships Between Knowledge Retention Capabilities and *performance satisfaction*

	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 3 for the standard-based retention and computer simulation.

Results from Models 5s in Appendix 3 for the experience-based retention; Model 6s for the crossgenerational communication

Table 16. A Summary Table for the Results of Regression Analyses for Relationships Between Knowledge Retention Capabilities and *performance improvement*

	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 4 for the standard-based retention and computer simulation.

Results from Models 5s in Appendix 4 for the experience-based retention; Model 6s for the crossgenerational communication

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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 15 and 16 below summarize the results shown in Appendix 3 and 4. 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.

These results 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, the full regression models show 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.

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.

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.[14] 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 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 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 hypotheses, at least, for some performance dimensions. Contrary to the results in the previous section 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. Particularly, we find that their impact is stronger, or broader, on system and improvement performance rather than on static and local performance. 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.

Moderating Effects by Task Characteristics on Relationships Between Project Performance and Individual-Based Retention Capability

Hypothesis 3 suggests that task newness may have moderating effect on the relationship between experience-based retention capability and product development performance. To examine this possibility, we fitted regression models including interaction terms between

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[14] 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.

individual-based retention capability indicators and either technical or market newness involved in new product development.

New platform ratios 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 in Appendix 5.

Appendix 6 shows results of regression analyses that examine the moderating effects either of technical or market newness on performance satisfaction, while Appendix 7 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.

Hypothesis 3 implies that we should expect negative signs on the regression coefficients for interaction terms. Indeed, we found significant negative coefficients for the interaction terms

TABLE 17. 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 18. 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.

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 retention capabilities and product development performance than technical newness*. Tables 17 and 18 below summarize the results.

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.

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 ($p < .1$). 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.

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.[15]

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).[16]

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[15] In fact, close examination in the scatter plot indicates that the observed strong moderating effect by technical newness for technical performance was, in fact, strongly influenced by one data point as a outlier.

[16] 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 industries.

6. *Implications and Conclusions*

6-1. Importance of Explicit Management of Knowledge Retention

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. 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. 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.

6-2. Different retention mechanisms for performance improvement

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.[17] 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 paper that automobile development involves substantial complexity and uncertainty both in the product architecture and user interface, 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.

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[17] 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.

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Appendix 1. 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 2. 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	16	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 2. 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												
Standeard-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 3. 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	−0.38	−0.33						
Standeard-based Retention		−0.14		−0.10	0.07	−0.19		−0.06		0.12	0.04	−0.05
Computer Simulation		0.25		0.28	0.16	0.22		0.39 *		0.37 *	0.34 *	0.39 *
Documents & Reports		−0.05						0.01				
Experience-Based Retention			0.30	0.36	0.24				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	0.29 *	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 3. 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 *						
Standeard-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 4: Market Newness

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. Finally, we classified one product as "new market" since this new model was clearly positioned in a different market class from the previous model. As a result, seven projects were classified as "new market," and 15 projects as "existing market"

APPENDIX 5. 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		Manufactura-bility		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 platform newness

	Product Cost Performance		Development Cost Performance		Adherence to Schedule		Manufactura-bility		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 Platform	−0.15		−0.60**		−0.25		−0.12		0.06		0.22		0.00		−0.47*	
Communication*New Platform		−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 6. 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		Manufactura-bility		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		0.24		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 platform newness

	Product Cost Performance		Development Cost Performance		Adherence to Schedule		Manufactura-bility		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 Platform	0.06		−0.23		−0.38		0.29		−0.19		−0.20		−0.15	
Communication*New Platform		−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