Technology Novelty, Project Complexity, and Product Development Project Execution Success: A Deeper Look at Task Uncertainty in Product Innovation

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***Abstract*—This paper applies the construct of task uncertainty to study relationships between product development project characteristics and project outcomes. We characterize product development projects in terms of their technology novelty and project complexity levels. This characterization is based on product development literature and organizational information processing theory. We hypothesize that technology novelty and project complexity characteristics contribute to project task uncertainty and are in turn associated with project execution outcomes. A cross-sectional survey of 120 new product development projects for assembled goods was employed to test relationships between project characteristics and project success. Success measures include achievement of individual project goals, such as technical performance, unit-cost, and time-to-market, and overall achievement of project goals.**

Results suggest that projects with high levels of technology novelty or project complexity are not associated with overall project failure, but are associated with specific project outcome elements. Technology novelty is strongly associated with poor unit-cost and time-to-market results, and project complexity is strongly associated with poor unit-cost outcomes. Looking deeper into the technology novelty and project complexity dimensions, we find that process technology novelty is more problematic than product technology novelty and that the relative newness of a project's objectives to the firm is more problematic than other project complexity characteristics. Results suggest that technology novelty and project complexity do not interact to influence project outcomes and so can be seen as potential managerial tradeoffs.

These findings suggest that future research should investigate detailed project task characteristics and specific project goals rather than solely address aggregate task factors and overall outcomes. In addition, these findings can help firms improve product development effectiveness through better estimates of outcomes for different types of projects, guidance into which projects to undertake, and insight into appropriate structuring of the task content of product development projects.

***Index Terms*—New product development, project execution, project management, task uncertainty, time-to-market.**

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I. Introduction

PREVIOUS research has underscored the substantial and varied challenges firms face in managing product development projects [2], [7], [8], [20], [48], [62]. In particular, the use of new technologies has been observed to be an important and recurring problem in industry [32], [37], [61]. Product development appears to be especially difficult when firms have limited experience with the product and process technologies they intend to employ in or with a product development effort [28], [63]. Some firms choose to employ technologies that are new to them in order to achieve products having high market distinction and to further the firm's technological competencies. However, the use of new, unproven, or "risky" technologies can lead to undesirable project outcomes including late time-to-market, high product unit-cost, and/or low product quality and functionality.

Effective management of product development projects employing new technologies can be studied by characterizing projects in terms of the technological challenges they pose to the development group that must carry the project through. Product development project characteristics are critically important. Clark [11] explains that product content and project scope decisions have strategic significance due to their effects on project performance. Griffin [26] explains that the level of product newness and project complexity define inherent characteristics of the project and represent the overall strategy of the project. Although project characteristics are important, relatively little literature addresses characteristics of the new product development project or associations between specific project characteristics and project success. This is in contrast to the more fully developed empirical literature on organizational processes and techniques to carry effectively through new product development projects (e.g., simultaneous engineering [29], stage/gate systems [13], or development team composition [5]). The view that project characteristics merit study is supported by Gerwin and Susman [25, p. 122], who state in their introduction to this TRANSACTIONS Special Issue on Concurrent Engineering that future research on product development projects should explore "task conditions…such as complexity, interdependence, uncertainty, and technical risk."

This paper employs a survey of 120 "high-tech" new product development projects to study product development project characteristics and project outcomes. Special emphasis is given to the levels of new technology employed. Our conceptual framework (Fig. 1) characterizes projects as varying along

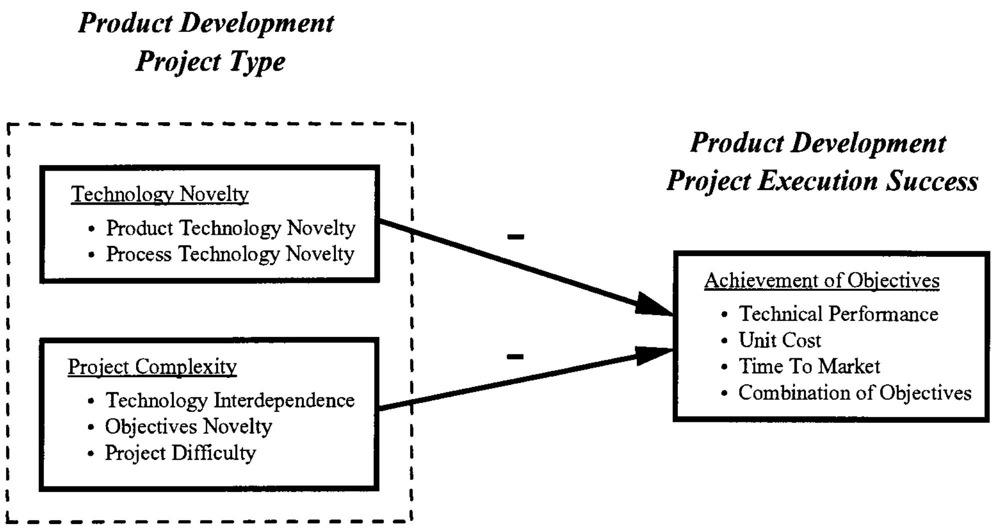

Fig. 1. Conceptual framework of project type characteristics and project success.

two dimensions: technology novelty and project complexity. We postulate that product development projects differ in their execution challenges and therefore their project execution success, based on the extent of their technology novelty and project complexity. Accordingly, we analyze the sample to determine outcomes for different types of product development projects.

This paper contributes to the extant literature on project task characteristics and project outcomes by employing deeper operationalizations of technology novelty and project complexity, by analyzing these operationalizations in conjunction with multiple project success outcomes, and by employing a broad cross-sectional sample of assembled goods. Studies of project tasks and project outcomes typically focus solely on time-related outcomes [26], [37], [38], [40] rather than multiple project execution outcomes (e.g., one or more of technical performance/quality, development or unit-cost, and development time). Clark [11] and Clark and Fujimoto [12] consider multiple project execution outcomes but limit their study to the automobile industry. Most research on technology novelty and project complexity in product development projects is limited to one industry [11], [12], one company [40], or small projects [37], [38]. Griffin [26] employs a cross-company, cross-industry sample but does not consider multiple execution outcomes. Larson and Gobeli [36] present a large sample study that considers multiple outcomes, but employ less extensive independent variable operationalizations (single item scales) than in the present work.

The conceptual framework we employ is grounded in organizational information processing theory and literature on product development and technological innovation. Sections II and III describe the central relationships and present the hypotheses. Section IV describes the research methods employed to test the hypotheses. Hypothesis results are presented and discussed in Section V. Section VI addresses implications for practice, and Section VII concludes this paper with directions for future research.

II. Product Development as Information Processing: A Task Uncertainty Framework

Product development is frequently described as an exercise in information processing [2], [4], [12], [17], [19], [42], [53]. For example, Burns and Stalker [9, p. 78] characterize product development as having many work elements, where "each is performed in response to information received; each involves altering, rearranging, or recomposing information or things; each ends with the transmission of the altered information or thing to someone else." Since product development projects are organizational tasks that require substantial information processing, it is useful to view them through the lens of organizational information processing theory.

One principle of organizational information processing theory is that organizational tasks pose information processing requirements to the organization. Organizational tasks vary in their degree of *uncertainty*. Task uncertainty is "the difference between the amount of information required to perform the task and the amount of information already possessed by the organization" [24, p. 36]. The more uncertain the task, the greater the quantity and quality of information processing required during the task activity to generate necessary knowledge to complete the task [16], [24]. Higher task uncertainty implies high variability in and unpredictability of exact means to accomplish the task, in turn leading to poorer task outcomes. Therefore, the nature of the task, as represented by its task uncertainty, directly influences the quality of task outcomes [23], [59]. To apply organizational information processing theory to the specific context of product development projects, we must characterize the product development *task* (including its task uncertainty contributors) and determine measures of the *effectiveness* of the execution of the product development task.

Here the *task* is the new product development project. We refer to specific projects as having particular "project type" dimensions and characteristics. In theoretical terms, project type represents the task uncertainty posed by the project. In practical terms, project type captures the overall execution challenge posed by that project to the development organization. Firms need to understand the uncertainty inherent in particular project types so that they may select among, plan for and execute projects appropriately. We posit that "technology novelty" and "project complexity" (described in detail in Section III) are central *contributors* to task uncertainty in the product development project context.

To assess the *effectiveness* of executing the product development project task, one must identify internal, operational measures of product development success. New product development success is multidimensional [14], [27], [36], [49], [65]. It can be viewed in market-oriented terms such as product sales levels, customer satisfaction, and market share; or in strategic terms such as the degree to which the new product helps the firm enter a new market or preempt a competitor's entry. Measures that are market oriented and/or external to the development organization are very relevant for firms and are appropriate for certain research questions, but they are beyond the scope and intent of the present research. This research focuses on internal, execution-oriented outcomes as described in [29].

The execution-oriented outcome measure we employ is the degree to which an individual project achieves its original objectives. Central objectives for a product development project are *technical performance* (the technical functionality and quality of the product), product *unit-cost*, and *time-to-market* for the development effort [48], [51]. These objectives are set in place by the start of project execution,[1] and their achievement can be evaluated at the end of project execution. We measure product development success individually (degree of achievement of *each* objective) and overall (degree of achievement of the *combination* of the three objectives).

Because the variables capture elements that "happen" at different points in the life of the project, the conceptual framework is a process model of product development project execution. Project type is known at the start of project execution and project success is known at the end of project execution. The notion that these constructs occur at different temporal points is important since we aim to assess end-of-project outcomes for the project type, where the project type is the project type as it was understood at the time of initiation of project execution.[2] Ideally, such a conceptual framework is investigated via longitudinal data collection for each project. For feasibility reasons, this study employs a retrospective survey approach. Through careful instrument design, the data collected provide retrospective "snapshots" of a product development project at two points in its execution. This approach has been called the "pseudopanel method"[3] [35] and has been employed in previous studies of product development (e.g., [42]).

[1]A *project planning* phase occurs before the start of the *project execution* phase. The project planning phase, sometimes called the "fuzzy front end" or the "project definition phase," is complex, iterative, and often unstructured [33], [34], [42], [51]. In this phase, market requirements, technology choices, and other project-related decisions are proposed, considered, and traded off. The result of the project planning phase is a formal or informal statement of somewhat firm product requirements, project objectives, and technology choices. The sense that product development projects have these two phases is established in some empirical studies [11], [26], [34], [42]. The present paper does not study the project planning phase; rather, it studies the project execution phase. To assure comparability across the cases we define the start of the project execution as the time by which the major technological approach had been chosen and official project "go ahead" had been given. Conceptually, the start of project execution coincides with the end of project planning.

III. Product Development Project Type: Selected Literature and Hypotheses

Literature which differentiates projects by the technological challenges they pose identifies two bases for characterizing types of product development projects: 1) technology newness, change, or novelty and 2) project size, scope, or complexity.[4] Such characterizations can describe the project in some depth and are based at least in part on the project's intrinsic technological characteristics.

This paper considers both technology novelty and project complexity dimensions to better distinguish among types of projects and to more fully capture the nature of the associated development challenges in project execution. The importance of including both dimensions can be illustrated simply. Design-for-assembly is a technique employed to reduce the number of parts required for a product [55]. Often when this technique is applied a great many relatively simple parts are replaced by one part. For example, an assembly made up of several metal plates, hinges, and screws can be replaced by one custom injection molded part. The case of the plates and screws represents low technology novelty and high project complexity. In contrast, the molded part situation represents high technology novelty (since custom injection molded parts are new to many organizations) and low project complexity.

A. Technology Novelty

The broader technological innovation literature often describes technology novelty on the basis of degree of familiarity with the given technology. This perspective typically dichotomizes technological innovations as "radical" or "incremental" [18], [21], [43], [54], [58]. In the specific area of product development, some literature also differentiates development projects on the basis of technological familiarity [1], [3], [38], [40], [64]. Other product development literature [30], [39] classifies development projects in terms of change in

[2]Shenhar [50] also uses the term "project type" to differentiate projects based on relevant task characteristics recognized at the time of project execution initiation. His analysis of 26 projects ranging from small research efforts to multibillion dollar systems development and construction programs found that "technology uncertainty" and "system scope" are useful project type descriptors. The present work differs by focusing only on product development projects.

[3]Kidder and Judd [35, p. 135] explain the purpose of a pseudopanel research design:

> Sometimes survey researchers are unable to gather data by using a panel design, but they nonetheless have a definite idea about which variables precede which others in temporal sequence. They then may gather all their data at the same time, or cross-sectionally, but act as if those data had been gathered longitudinally.

[4]New product development efforts have also been differentiated based on newness of the product to the customer [6] or newness of the product market to the firm [1], [46]. These newness elements address characteristics *external* to the actual technical development of a new product and are relevant from market selection and other strategic decision-making perspectives. However, these differentiations do not address newness characteristics *internal* to technical development because they give little sense of a project's technological challenges or project execution concerns.

their technologies relative to products previously developed or manufactured by the company.

A small empirical literature identifies project outcomes for projects having different technology newness characteristics. Griffin's [26] study of new product and new service development projects at 11 companies finds that greater levels of product newness, operationalized as the percentage of change in the new product relative to its predecessor product, is associated with greater absolute amount of time to develop that product. Clark and Fujimoto's [12] study of the automobile industry finds that the "introduction of pioneering components" (new product technologies) had no relationship with engineering lead time,[5] engineering hours, or product quality. However, they found that "major changes in body process technology" (new manufacturing technologies) was positively associated with engineering lead time but had no relationship with engineering hours or product quality.

Meyer and Utterback's [40] results contradict those of Clark and Fujimoto. Their one company study of 24 projects finds that newness of product technologies as a whole has significant positive association with absolute development time, but it also finds that manufacturing process newness has no relationship with development time. Larson and Gobeli's study [36] of 546 product development projects found that technology novelty had no association with the project outcomes of technical performance, cost, schedule, and overall results. McDonough and Barczak's [38, p. 48] study of 32 small product development projects in the United Kingdom finds that "familiarity of technology does not impact how quickly development is accomplished." In contrast, McDonough [37], analyzing the same sample, finds that categorization of projects by the "type of work" conducted (this ranged from "applications engineering" to "development or application of new technology") is significant because the technological type of work is negatively associated with achievement of time goals. That is, more radical (versus routine) projects had lower achievement of time goals.

In all, these previous empirical results are not conclusive regarding whether technology novelty is associated with project outcomes. In addition, these results are not conclusive about which technological elements, if any, strongly influence project outcomes.

We define *technology novelty* as the newness, to the development organization, of the technologies employed in the product development effort. Our operationalization of this definition integrates and extends existing measures of technology newness by incorporating multiple elements of technology and by considering these elements in greater depth. The composite measure gives an aggregate sense of the project's technology newness and is called the technology novelty dimension. The dimension has two major characteristics: product technology novelty and process technology novelty. The operationalization of product technology novelty includes new product architectures in addition to new product parts and modules, and the operationalization of process technology novelty includes new manufacturing flows and layouts in addition to specific new manufacturing tools and process stages.

Although practitioners do not commonly use the words "technology novelty," they do refer to this notion via the words "technology risk." Practitioners describe a product development project as having a high level of technology risk when, at the beginning of the development effort, they do not fully understand the technology, know the exact means to accomplish the project, or are unsure about eventual project outcomes. This practical view of technology risk as lack of knowledge is consistent with the theoretical definition of "task uncertainty." Organizational information processing theorists explain that the novelty of task elements and the lack of knowledge about the general process to accomplish a task contribute to task uncertainty [16], [24], [45], [59]. Daft and Lengel [15, p. 220] state "technology is a source of uncertainty" for R&D groups, and Robey [47, p. 306] explains that "factors that influence the amount of uncertainty include nonroutine technology." Hence, we expect that projects with higher levels of technology novelty will have lower levels of project success since they have greater task uncertainty. Accordingly, we have the following hypothesis.

Hypothesis 1: Technology novelty is negatively correlated with project success.

B. Project Complexity

Several studies have empirically investigated relationships between aspects of project complexity and project outcomes in product development projects. Clark's [11] study of automobile product development projects finds that project scope, defined as the percentage of development effort conducted in-house versus by suppliers, is associated with greater engineering hours and development time. Griffin [26] finds that product complexity (she uses the terms "product complexity" and "project complexity" interchangeably) as measured by the number of product functions embodied in the product (e.g., a shampoo with conditioner has *two* functions) is associated with greater absolute development time. Meyer and Utterback [40] find that technology integration, which represents the number of technologies in the development effort, is positively associated with absolute development time. In contrast to the others' findings, Larson and Gobeli [36] find that project complexity has no association with the technical performance, cost, schedule, or overall results for a project. In all, these previous empirical findings accumulate to suggest that project size as represented by the number of components, number of functions, number of parts, or percentage of work done in-house is associated with longer development times.

We believe that project size captures only part of the complexity of a project. For example, a project may be quite large in size but have a highly modular product design and lax unit-cost and time-to-market objectives. This project has low technology interdependence and low difficulty of objectives. Another project may be relatively small in size but have a highly integrated product design and aggressive unit-cost and time-to-market objectives. This project has high technology

[5] Clark and Fujimoto's operationalization of engineering lead time consists of the time to complete these development activities: advanced engineering; product engineering; process engineering; and pilot run. This operationalization does not include concept generation and product planning. They clearly differentiate project planning versus project execution activities.

interdependence and high difficulty of objectives. In terms of technological challenge to the organization, the second project is more complex, although it is smaller.

We define *project complexity* as the nature, quantity, and magnitude of organizational subtasks and subtask interactions posed by the project. The operationalization of this definition extends existing measures of complexity by considering multiple project elements other than size to address the nature of the work effort. Three project complexity characteristics are considered: the degree of interdependence between and among the product and process technologies to be developed[6]; the newness of the project's objectives to the development organization[7]; and the difficulty of the project objectives. A composite measure called the project complexity dimension includes all three characteristics and gives an aggregate sense of the project's complexity. The three characteristics are consistent with complexity-related contributors to task uncertainty identified by information processing theorists [24], [45], [47], [59]: the interdependence of task units (e.g., technology interdependence)[8]; novelty of task objectives (e.g., objectives novelty)[9]; and the level of task performance required (e.g., project difficulty).[10] Hence, we expect that projects with higher levels of project complexity will have lower levels of project success since they have greater task uncertainty. Thus we have the following hypothesis.

Hypothesis 2: Project complexity is negatively correlated with project success.

IV. Methods

A. Sample

A cross-sectional, survey-based methodology was employed. The unit of analysis is a recently completed development project for an assembled product. The conceptual framework adopts generic information theoretic concepts and therefore applies to projects from diverse companies and industries. Much previous research on product development and product innovation has also taken a cross-industry view [20], [29], [31], [42], [66]. To maximize variation on key dimensions, companies were asked to provide data for projects of high and low technology risk and projects of high and low success. Since the unit of analysis is a single project, multiple projects from one company or division were included in this study (whenever the firm had, and was able to provide data on, more than one recently completed project). Sampling efforts consisted of a solicitation mailing to selected members of the Product Development Management Association (PDMA) and the Center for Enterprise Leadership (CEL).[11] The resulting sample consists of surveys for 120 projects (from 57 firms) meeting the qualifications of this study, and exhibits substantial variation along the key dimensions (see Table I).

The resulting sample has greatest representation from the medical/scientific instruments and imaging products categories (cameras, printing systems, scanners, photocopiers). Other large categories include: computers; chip sets; video and audio systems; communication transmission equipment; radar devices; process controls; and manufacturing equipment. The typical product was expected to sell over 10 000 units in its lifetime, and sold for $100 to $10 000 per unit. Most projects (81%) were completed within a 36-month period. The sample generally represents larger, established companies. The average company reported that its past product development performance was somewhat better than that of its competitors. Still, the average company also reported that it had achieved the objectives for past development projects only to a low or moderate extent.

TABLE I
MEASURES OF PROJECT TYPE AND PROJECT OUTCOMES

Project Type	Mean	Standard Deviation	# of Items	Scale Reliability
Technology Novelty				
Technology Novelty Dimension	26.1	6.6	6	.79
Product Technology Novelty	14.7	3.6	3	.70
Process Technology Novelty	11.5	4.2	3	.81
Project Complexity				
Project Complexity Dimension	41.8	7.6	10	.73
Technology Interdependence	12.5	3.8	3	.77
Objectives Novelty	10.6	3.3	3	.60
Project Difficulty	18.9	4.1	4	.75
Project Outcomes				
Achievement of Technical Performance Objective	5.5	1.9	1	n/a
Achievement of Unit Cost Objective	3.9	1.7	1	n/a
Achievement of Time-to-Market Objective	3.7	2.1	1	n/a
Achievement of Combination of Objectives	4.5	1.6	1	n/a

B. Data Collection

Data were collected via a self-administered questionnaire which was completed by a project, program, or engineering manager for the development effort. This individual had significant technical understanding of the product, had been involved in the project from start to end, and had interacted with both upper management and project personnel. These essential qualifications of the respondent were explicit in the survey instrument and survey distribution methods. We chose a single informant per project because these individuals could fully and reliably answer the survey questions. The average respondent had 15 years of product development experience.

[6]Challenges associated with product modularity, module interactions, technology interdependence, and task interdependence have been addressed by [19], [40], [51], and [60].

[7]Firms vary in their experience in achieving the various project objectives. Firms have *low* objectives novelty when they are accustomed to facing similar project objectives across a series of product development projects. A case of *high* objectives novelty can be simply illustrated. Some defense firms have great experience in developing high technical performance, high unit-cost products. As these firms shift to different (e.g., consumer) markets, they must now aim to achieve lower unit-cost objectives for their products. Hence, the low unit-cost objective is highly novel to the firm.

[8]Tushman and Nadler [59, p. 616] explain that "task interdependence is…[an] important source of work-related uncertainty."

[9]Perrow [45] explains that tasks vary in the degree to which the organization has experience with the task objectives and knows how to address them, in turn decreasing task uncertainty.

[10]Galbraith [24, p. 37] explains "the level of goal performance needed" is a determinant of task information requirements, and so is a determinant of task uncertainty.

[11]The Center for Enterprise Leadership is a university–industry research consortium housed at the Boston University School of Management.

TABLE II
FACTOR LOADINGS OF PROJECT TYPE ITEMS ON PROJECT TYPE FACTORS

	Project Type Factors				
	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Project type items	Product Technology Novelty	Process Technology Novelty	Technology Interdependence	Objectives Novelty	Project Difficulty
Product modules novelty	**.830**				
Product configuration novelty	**.687**				
Product technology novelty	**.738**				
Manufacturing stages novelty		**.799**			
Process layout novelty		**.800**			
Manufacturing technology novelty		**.743**			
Product technology interdependence			**.827**		
Manufacturing technology interdependence			**.802**		
Product and mfg. technology interdependence			**.705**		
Technical performance objective novelty				**.780**	
Unit-cost objective novelty				**.724**	
Time-to-market objective novelty				**.612**	
Technical performance objective difficulty					**.634**
Unit-cost objective difficulty					**.772**
Time-to-market objective difficulty					**.868**
Project as a whole difficulty					**.827**

* only loadings > .450 are shown

The survey contained composite, Likert-type scales. New survey scales were developed (and fully pretested) due to a lack of existing detailed scales for the phenomena of interest. Scale development is often a necessary step in conducting investigations in a new area of research [52]. The new scales were developed hand in hand with experienced product development managers. Resulting scales underwent three waves of field pilot test before full-scale survey administration to assure scale content and construct reliability and validity. Exploratory field research we conducted prior to the current research also contributed to our ability to devise appropriate scales.[12] Studies of product development commonly employ retrospective methods [29]–[31], [40], [42], [57], [65]. The survey instrument was carefully designed [22], [35] with respect to question wording and question sequence to minimize recall bias and common methods variance.

C. Measures

Project type variables were measured by seven-point Likert-type scale items. Several items were used to measure each construct, and for multi-item scales a simple average of the items was used as the scale measure. Nine-point single-item scales were employed for the project execution success variables. Note that the fourth project execution success variable, the combined achievement of project objectives (an overall measure), is also a single-item rather than a summed scale. All scales are presented in Appendix I. Factor analysis of the project type items showed that the predicted factors (variables) emerged from the scale items. Principal components extraction with varimax rotation was employed. The Kaiser criterion (eigenvalues > 1) was employed in conjunction with evaluation of scree plots. This factor analysis empirically grouped the scale items as predicted (see Table II). The five project type factors explain 68% of the variation inherent in their items. Summary statistics and internal reliabilities (Cronbach's alphas) of each scale are provided in Table I. All multi-item scales are reliable [44]. The measure of objectives novelty is “reverse scaled.” All item, scale and correlation information in the tables for objectives novelty is presented in reverse direction of the operationalization shown in Appendix I.

D. Analysis Approach

Pearson product-moment correlations are employed to test the hypotheses. Table III presents correlations between the two project type dimensions and execution outcomes. Table IV presents correlations between the five project characteristic elements and execution outcomes.

[12] Two sequential investigations were conducted prior to the present research. Both were in-depth, descriptive, multiple case study analyses of technological aspects of product development projects (see [48], [49], and [56]). In each investigation, we worked within companies, compiling case study descriptions of individual product development project efforts. This exploratory fieldwork provided us a deeper contextual understanding of the product development phenomenon and aided in variable selection, definition, and operationalization.

TABLE III
PEARSON PRODUCT-MOMENT CORRELATIONS OF PROJECT TYPE DIMENSIONS AND PROJECT OUTCOMES

	Project Outcomes			
	Achievement of the...			
Project Type Dimensions	Technical Performance Objective	Unit-Cost Objective	Time-To-Market Objective	Combination of Objectives
Technology Novelty Dimension	.12*	-.18**	-.15**	-.05
Project Complexity Dimension	.08	-.16**	.04	.03

n = 120.
***p <= .01; **p <= .05; *p <= .1

TABLE IV
PEARSON PRODUCT-MOMENT CORRELATIONS OF PROJECT TYPE CHARACTERISTICS AND PROJECT OUTCOMES

	Project Outcomes			
	Achievement of the...			
Project Type Characteristics	Technical Performance Objective	Unit-Cost Objective	Time-To-Market Objective	Combination of Objectives
Technology Novelty Characteristics				
Product Technology Novelty	.13*	-.16**	-.03	.02
Process Technology Novelty	.08	-.14*	-.21***	-.10
Project Complexity Characteristics				
Technology Interdependence	.11	-.10	-.04	.01
Objectives Novelty	-.02	-.17**	-.10	-.11
Project Difficulty	.03	-.06	.20**	.10

n = 120.
***p <= .01; **p <= .05; *p <= .1

Tests conducted to determine whether the two project type dimensions interact to influence outcomes show no statistically significant interactions. Regressions containing the two dimensions were compared with regressions containing the two dimensions and their interaction term (four pairs of regressions due to four outcome measures).[13] Similarly, tests of two-way interactions among the five project characteristic elements show no strong interactions (40 pairs of regressions due to ten two-way combinations of project characteristics and four outcome measures). The lack of significant interactions suggests these dimensions and pairs of elements do not interact to influence project execution outcomes.

[13]We employed hierarchical moderated regression analysis with centered variables, focusing on the significance of the incremental F for the three term regression versus the two-term regression.

V. RESULTS AND DISCUSSION

A. Technology Novelty

The technology novelty dimension is not associated with overall project execution success (see Table III) but is associated with individual success outcomes. The technology novelty dimension is strongly and negatively associated with the cost and time outcomes and is somewhat positively associated with the technical performance outcome. When considering characteristics within the technology novelty dimension (see Table IV), we find important differences in outcomes associated with product technology novelty and process technology novelty. Process technology novelty appears more problematic than product technology novelty because it has a strong negative association with time-to-market. Both product and process technology novelty have negative association with cost.

The positive association between the product technology novelty characteristic and achievement of the technical performance outcome in Table IV is contrary to expectations (as was the positive association between the aggregate technology novelty dimension and technical performance). Practitioners have long complained that new technologies are often mysterious "black boxes," that efforts to implement them in new products are often disruptive, and that technology risk is often underestimated. The practical guidance has been that technological advances for a given product development project should be of a limited amount, and that "ready" (established) technologies should be employed whenever possible [48], [62]. Further, the theoretical basis is that projects with novel technologies have high uncertainty [24] and so high possibility for poor technical performance outcomes. However, the results here suggest that use of higher levels of new technology actually results in greater achievement of the technical performance objectives, not technical performance failure. Three speculations regarding this surprising result are now provided. Although our data do not allow tests of these speculations, we offer these as possible explanations for the observed results and as avenues for future research and practical attention.

First, firms may routinely underestimate their ability to achieve technical goals (resulting in overachievement of technical performance objectives) and may routinely overestimate their abilities to achieve cost and time goals (resulting in underachievement of these objectives). A simple explanation for this is that *during* the process of developing the new product and its new technologies, firms may often unearth even greater actual technical performance capabilities than they could have reasonably foreseen at the start of project execution. That is, firms may often underanticipate the technical performance capabilities of the new product modules and product architectures they intend to employ in a new product.

A more complex rationale has to do with who sets the individual project targets and who works to see that these targets are achieved. It can be argued that the technical performance of an assembled product is largely determined by the design engineering function, whereas the product's unit-cost and the project's time duration are determined by the many functions in the whole project. So, assessment of technical performance is an activity "local" to one organizational function, while assessment of cost and time is a "global" activity because it involves multiple organizational functions, not simply design engineering. Organizationally, estimation and perhaps even achievement of "local" objectives such as technical performance may be easier than for "global" objectives such as cost and time. This would explain the positive association of technology novelty with achievement of technical performance targets and the negative association with achievement of cost and time targets.

Finally, the sample consists of "high-tech" firms who presumably place a heavy importance on achieving technical performance objectives, potentially to the detriment of achieving other objectives. Firms may in some cases implicitly prioritize achievement of technical performance objectives over achievement of cost and time objectives. If they do so, they may dynamically reallocate constrained resources (particularly technical personnel and management attention) to technical performance problems in favor of cost and time issues. In some cases projects may not be allowed to conclude until the technical performance targets are achieved (and possibly even exceeded), even if this requires purposeful underachievement of cost and time objectives. This is consistent with our case study observations of the development of several high-tech products [48], [49], [56].

The process technology novelty results are notable because this variable appears to be a major contributor to task uncertainty. This task uncertainty is not resolved during the project as evidenced by the poor cost outcome and very poor time-to-market outcome. Firms need to be particularly aware of this and should consider conducting more of the manufacturing technology development and shake-out offline (before project execution starts) or adding resources to process technology development activities during project execution if process technology novelty cannot be reduced before project execution begins. These findings provide support for contemporary practitioner concerns about effective manufacturing ramp-up and the role of manufacturing engineering in the product development process.

Section III noted that prior empirical literature is not conclusive whether technology novelty, in aggregate, is associated with project outcomes. Nor is the literature conclusive regarding which technological elements strongly influence project outcomes. In terms of overall results, the present findings confirm results of Griffin [26] and McDonough [37] but do not support Larson and Gobeli [36] and McDonough and Barczak [38] by showing that aggregate technology novelty is associated with longer development times. The findings on technology novelty characteristics support the previous results of Clark and Fujimoto [12] but do not support those of Meyer and Utterback [40] by showing that new manufacturing process technologies, but not new product technologies, are associated with longer development times.

B. Project Complexity

The project complexity dimension, like the technology novelty dimension, is not associated with overall project execution success (see Table III). The project complexity dimension is strongly and negatively associated with one specific outcome dimension: unit-cost. When considering the three characteristics making up the aggregate project complexity dimension (see Table IV), we find that objectives novelty is the only project complexity characteristic having a negative association with a project success element. It has strong negative association with achievement of the cost objective.

The nonsignificance of the technology interdependence correlations was unexpected, and it suggests that this element of project complexity—the interaction of various product and process technologies—does not materially influence task uncertainty or project execution outcomes. Firms could then prioritize their attention toward the novelty of the individual technologies rather than interactions among the technologies.

The positive association between project difficulty and achievement of the time objective in Table IV is surprising. We speculate that firms, when they perceive that the project they will undertake is a difficult one, set in place less optimistic (more achievable) time targets and/or put in place additional or better quality resources (than for a typical project) to accomplish the project on time. It is also possible that such projects receive closer management attention.

In contrast to prior studies, we find that the aggregate project complexity dimension is not associated with poor achievement of the time-to-market objective. Instead, we find that the project complexity dimension is associated with poor achievement of the unit-cost objective. This is roughly consistent with Clark's [11] finding in the automobile industry that greater project scope is positively associated with greater engineering work hours (a proxy for development cost). Further, looking more deeply within the aggregate dimension to consider specific project complexity characteristics shows that the three characteristics do not "behave" the same with respect to the cost outcome: objectives novelty has strong negative association, but technology interdependence and project difficulty have no association. Meyer and Utterback [40] found that "technology integration" is associated with absolute development times. Our findings suggest that "technology interdependence," a different but related construct, has no association with achievement of the time objective. Except for the cost outcome, our findings regarding the project complexity dimension are consistent with Larsen and Gobeli [36].

C. Task Uncertainty Theory

With respect to theory presented in Sections II and III, task uncertainty does appear to manifest itself, but at the level of specific project execution outcomes rather than the overall end-of-project outcome. Further, project complexity generally seems to be a weaker contributor to task uncertainty than technology novelty. Therefore, Hypothesis 1 regarding technology novelty is more strongly supported than Hypothesis 2 regarding project complexity.

Task uncertainty may not fully manifest itself in end-of-project outcomes because it might be mitigated during project execution through various organizational approaches applied during the project execution. Indeed one interpretation of the results is that technology novelty is more difficult to mitigate during the project than project complexity. That is, both technology novelty and project complexity are task uncertainty contributors, but the task uncertainty accruing from project complexity is somehow more fully resolved during the project.

VI. Implications for Practice

Significant negative associations between the technology novelty and project complexity dimensions with project outcomes are not at the level of the *overall* outcome of the project, but rather at the level of achievement of *specific* project objectives. Thus it appears necessary to look one level deeper than overall success to determine the task uncertainty manifestations of technology novelty and project complexity. For example, while product and process technology novelty do not appear to negatively influence technical performance, they do appear to negatively influence the achievement of unit-cost objectives. In terms of looking deeper into project type, process technology novelty is more problematic in terms of outcomes than product technology novelty (particularly in terms of time achievement). In sum, the primary challenge for practice regarding technology novelty appears to be in the area of process technology and the achievement of time-to-market objectives.

The findings on project complexity characteristics suggest that firms should assess the novelty of their project's objectives and adjust accordingly, particularly if unit-cost is important. To the best of our knowledge firms rarely explicitly assess objectives novelty. This issue needs to be explicitly considered in the "front-end" of the product development process, where such objectives are set [33], [34], [49]. On the positive side, difficult projects do not necessarily fare badly (perhaps because such projects are planned and resourced more carefully), and technology interdependence does not appear problematic.

The lack of interaction effects between the technology novelty and project complexity dimensions and characteristics suggests that these dimensions act independently on outcomes. Therefore, these dimensions and characteristics may be seen as separate elements or decision variables for the purposes of planning and selection early in the project. Due to their lack of interactions, these dimensions and characteristics can be seen as managerial tradeoffs. For example, when the time objective is particularly important, a firm might choose to trade off technology novelty for project complexity (because the technology novelty dimension is highly associated with poor achievement of time outcomes while the project complexity dimension is not).

In planning and selecting projects to add to the product development portfolio, managers may consider our finding that certain product development project characteristics (particularly process-technology novelty, product-technology novelty, and objectives novelty) are associated with poor project execution outcomes. Below we offer some options for consideration. The appropriateness of these options must be assessed in light of competitive requirements and feasibility.

First, firms can reduce the levels of problematic project characteristics through actions taken well before project execution commences. For example, the technology research and evaluation period before project execution starts could be lengthened to allow more time to resolve uncertainties, in turn reducing the levels of novelty (e.g., process technology novelty) and complexity (e.g., objectives novelty) characteristics encountered at the start of project execution. The evaluation period may identify product elements that are particularly novel or complex that should be "slipped" to the next project in a series, allowing more time to explore this element. This reduces uncertainty for both the present project and the next in the series.

Second, firms could simply avoid projects with challenging characteristics (admittedly a myopic choice in many industries) or reduce specific problematic task characteristics (e.g., choose projects with less novel objectives or minimize use of novel process technologies). Firms could simply expect less of challenging projects; that is, make them less challenging by putting in place lax objectives for such projects or simply accept lower absolute project success levels. A creative solution is to restructure a given project based on the relative importance of individual project objectives. For example, technology novelty may be traded off for project complexity or process technology novelty may be traded off for product technology novelty.

Third, a portfolio approach may be employed where a limited number of the "poor outcomes" types of projects are undertaken at once. A portfolio approach allows planned distribution of novelty and complexity challenges across a stream of projects. A particularly novel or complex project may be "broken up" into two less challenging projects to be completed in sequence or in parallel. Through explicit planning, product modules may be devised to maximize sharing across products, in turn reducing technology novelty for at least some of the products in a family. Such a portfolio approach benefits from a clear understanding of product platforms, product families, product variety, and modularity strategies and approaches [41], [54], [60].

Fourth, firms could address the process of target setting and estimation of project characteristics and outcomes. Clearly they should be wary of optimistic estimations of project outcomes (particularly for novel process technology and novel project objectives). Development and implementation of better processes and tools for prediction of project outcomes are necessary. Product development practitioners explain that such tools are especially needed for estimation of time and cost aspects. Indeed, the findings suggest that the technology novelty and project complexity dimensions strongly and negatively influence timeliness and/or unit-cost but do not negatively influence achievement of the technical performance objective. Collection and analysis of historical data on project characteristics and outcomes would help project planners "calibrate" their estimations and predict better. Firms could actively seek to learn from their development efforts through use of postproject audits [10], [62] whose findings can be fed into project planning processes for downstream projects.

Fifth, organizations can plan before the project execution starts to take certain actions during the execution phase to help cope with uncertainty. This includes planning for dynamic reallocation of personnel and equipment resources (from either other pieces of the given project or from other projects) to problem areas as they arise in the given project. More "organic" project organizational structures and leadership approaches [16], [24] may enable this. Further, certain portfolio-level aggregate project planning and monitoring processes provide a continuous means for anticipating and accommodating emerging resource requirements [63].

VII. Conclusion

This study aimed to provide insight on technological innovation in the product development context by integrating and extending extant characterizations of product development projects and by empirically determining project outcomes for different types of projects. We characterized product development projects as varying in their levels of technology novelty and project complexity. Technology novelty and project complexity were described as contributors to greater task uncertainty and so represent greater project execution challenges. Accordingly, higher levels of technology novelty and project complexity were hypothesized to be associated with poorer project outcomes. Both hypotheses were partially supported.

In all, the results suggest that technology novelty and project complexity do influence project outcomes. A key finding is that *it is necessary to look below overall project outcomes and the aggregate levels of project type dimensions*. The technology novelty and project complexity dimensions are not associated with overall project success but are associated with individual success outcomes (both are strongly and negatively associated with unit-cost, and in addition the technology novelty dimension is strongly and negatively associated with time-to-market). In general, *technology novelty is more problematic than project complexity*. Further, looking within the technology novelty and project complexity dimensions, certain detailed characteristics appear much more problematic than others. For example, *manufacturing process technology novelty is most problematic for achieving time-to-market*. Of the three specific project outcomes studied, unit-cost is the hardest to achieve. All these areas merit closer management attention.

We also found that the technology novelty and project complexity dimensions (and their respective characteristics) do not interact with one another. Accordingly, technology novelty and project complexity may be seen as elements suitable for managerial tradeoffs and individual planning. Firms may consider trading off some technology novelty for greater project complexity, particularly if time-to-market is important to them.

It is particularly interesting that projects with high technology novelty are not associated with overall project failure. This is contrary to "conventional wisdom." Instead we find that projects with high technology novelty are associated with failure of specific project objectives. Accordingly, firms need to focus attention on the specific multidimensional objectives they set for their product development projects—in addition to deciding on the project's technologies—to appreciate the risk in achieving desired outcomes.

Knowledge of the typical outcomes associated with different project characteristics can help a firm: select which projects (and sets of projects) to pursue out of all the projects it could pursue; plan the overall task content of different types of projects; and focus on which types of projects might most benefit from improved preproject planning and postproject learning processes. Firms have a number of options (described in Section VI) when they know that certain project characteristics have typical associations with success or failure in achievement of specific project objectives.

A. Limitations and Directions for Future Research

The results of this study must be considered in light of the nature of the sample and the type of data collected. First, the sample represents "good companies"—firms that are at least as good as their competitors in conducting product development. Second, this study addressed assembled products. Development and testing of characterizations of "project type" in other contexts such as the development of software, products manufactured by continuous processes, and new services is necessary. Such studies would determine whether task uncertainty implications of technology novelty and project complexity challenges are generalizable and whether other factors are important in different contexts.

Third, the data-collection approach employed relied on one knowledgeable respondent per project who assessed, after project completion, issues regarding the project at its initiation and at its conclusion. Future research can overcome the limitations of the single respondent retrospective approach by capturing information from multiple sources internal and external to the project, and by employing a longitudinal data collection approach to better test causality between project task characteristics and project outcomes. Fourth, it is clear that technological phenomena in product development projects are quite complicated. While the present research employed survey operationalizations that are deeper than found in most prior research, future research could investigate in even greater depth factors (such as process technology newness) which appear to be quite influential in terms of project outcomes. Detailed case-study type analyses may be appropriate.

Future research should address how to better plan for and cope with problematic task characteristics (e.g., new process technologies or novel project objectives). Research on planning is important because it is during the project planning process before project execution that the level of task uncertainty is set. Such research could address: the development of improved estimation tools and processes; how project characteristics are estimated, traded off, and set; and how new technologies are best transferred into the development group. Research on coping should identify which organizational approaches in project execution are most effective, specifically in mitigating task uncertainty associated with specific project characteristics and generally in responding to unexpected execution challenges. Research should investigate how firms can learn from projects and most effectively integrate during-project and postproject findings into preproject planning processes to best assess task uncertainty.

Future research could build on this study of individual projects by investigating specific ties between product family streams and the technology novelty/project complexity of individual projects in those streams. Such research might lead to prescriptions of competitively optimal, time-phased product development portfolios while reducing task uncertainty for individual projects in the portfolio.

Finally, a key implication of this study is that future investigations of new product development projects should assess success in terms of multiple specific project objectives rather than overall outcomes, and they should assess project type in terms of multiple detailed project characteristics rather than simply aggregate task factors. Not doing so can lead to misleading interpretation of overall results and lost opportunities to provide practical recommendations regarding technical achievement, cost containment, and time management in product innovation.

APPENDIX I
VARIABLE OPERATIONALIZATIONS

Project Type Characteristics

Technology Novelty: The *product technology novelty* scale is made up of the first three items below. The *process technology novelty* scale is made up of the second three items. The aggregate *technology novelty dimension* is made up of all six items below.

Scale is seven-point Likert type, with

$$7 = \text{Completely New}$$
$$4 = \text{Somewhat New}$$
$$1 = \text{Not New At All.}$$

"The following questions ask about the newness of the technologies to your company, as perceived by the project group, at the beginning of the project. The beginning of the project is the time by which the major technological approach had been chosen and project go-ahead was given.

How new, on average, were the product modules?[1]
How new was the product configuration?[1]
Overall, how new were the product technologies to be employed in this project?
How new, on average, were the individual manufacturing stages?[2]
How new was the process layout?[2]
Overall, how new were the manufacturing technologies to be employed with this project?

These definitional footnotes were provided.

[1]A product is made up of major subsections called modules. Modules may be subassemblies, subsystems, major components, etc. The way the modules are linked together is the product configuration, also called product architecture or systems design.

[2]The manufacturing process is made up of major individual manufacturing stages. A manufacturing stage can be a fabrication, machining, assembly or packaging process. The order of the stages, and linkages among the stages, constitutes the process layout.

Project Complexity: The *technology interdependence*, *objectives novelty*, and *project difficulty* scales are made up of specific items listed below. The aggregate *project complexity dimension* is made up of all ten items below.

Technology interdependence: Scale is seven-point Likert type, with

$$7 = \text{Great Impact}$$
$$4 = \text{Some Impact}$$
$$1 = \text{No Impact At All.}$$

"The following questions address how various technologies interact with each other. For example, a design change in one product module can impact the design effort for other product modules. Answer these questions with respect to what was perceived at the beginning of the project:

On average, a design change in one product module was expected to impact the design effort for other product modules this much…
On average, a design change in one manufacturing stage was expected to impact the design effort for other manufacturing stages this much…
A design change in the product technologies was expected to impact the design effort for the manufacturing technologies this much…"

Project Objectives: The following two scales, both elements of project complexity, address project objectives. Respondents were given the following definition of specific project objectives.

"Project objectives, also called project targets or requirements, are: (1) product performance, (2) product unit-cost, and (3) product time-to-market. Product performance includes the technical functionality, quality, and reliability of the product. Time-to-market means the approximate date for which first customer shipment was planned.

Answer these questions with respect to what the project group perceived at the beginning of the project. The "beginning of the project" is defined as the time by which the major technological approach had been chosen and project go-ahead was given."

Objectives novelty: Scale is seven-point Likert type, with

$7 =$ Great Experience
$4 =$ Some Experience
$1 =$ No Experience.

"A company may have high or low experience in achieving a particular project objective. For example, some firms have great experience in producing low-cost products. In this case, if a firm had low unit-cost as a project objective, this firm has great experience with the unit-cost objective for this project.

At the beginning of the project, how much experience did your company have with:

the product performance objective
the unit-cost objective
the time-to-market objective."

Project difficulty: Scale is seven-point Likert type, with

$7 =$ Great Difficulty
$4 =$ Some Difficulty
$1 =$ No Difficulty

"Project objectives vary in the difficulty they pose. At the beginning of the project, how difficult did the project group believe this would be to achieve:

the product performance objective
the unit-cost objective
the time-to-market objective
the project as a whole."

Project Execution Success

Achievement of Project Objectives: The success of the product development project effort is determined by the degree of achievement of the project's objectives. Achievement of each objective is a single dimension (each of the first three items below). The overall outcome measure is the fourth item.

Scale is nine-point Likert type, with

$9 =$ Significantly Better Than Expectations
$7 =$ Achieved Our Optimistic Estimates
$5 =$ Exactly On Target
$3 =$ Achieved Our Pessimistic Estimates
$1 =$ Significantly Worse Than Expectations

"The questions below address the achievement of the original project objectives. Answer these questions with respect to how your project group perceived these aspects at the end of the project (that is, at the time of first customer shipment). To what degree was the:

Original product performance objective met?
Original product unit-cost objective met?
Original product time-to-market objective met?
Original combination of project objectives met?"

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