Journal of Operations Management 18 (2000) 401–425
JOURNAL OF OPERATIONS MANAGEMENT
www.elsevier.com/locate/dsw

# Successful execution of product development projects: Balancing firmness and flexibility in the innovation process [☆]

Mohan V. Tatikonda [a,*], Stephen R. Rosenthal [b,1]

[a] Kenan-Flagler Business School, University of North Carolina at Chapel Hill, McColl Building, Carroll Hall, CB 3490, Chapel Hill, NC 27599-3490, USA
[b] School of Management, Boston University, 595 Commonwealth Avenue, Boston, MA 02215-1609, USA

Received 1 January 1999; accepted 1 October 1999

## Abstract

This paper investigates project management methods used during the execution phase of new product development projects. Based on prior field observations, organizational theory and product development literature, we pose hypotheses regarding the effectiveness of the project execution methods of formality, project management autonomy and resource flexibility. A cross-sectional survey sample of 120 completed new product development projects from a variety of assembled products industries is analyzed via hierarchical moderated regression. We find that the project execution methods are positively associated with project execution success. Further, these methods are effective singly and collectively, suggesting that firms can ''balance firmness and flexibility'' in product development via appropriate execution methods. Surprisingly, the effectiveness of these methods is not contingent on the product or process technology novelty inherent in a given development project. The findings suggest that firms should adopt high levels of these approaches, and that a variety of projects can be managed using broadly similar project execution methods. The findings also suggest limitations on the application of organizational information processing theory to the context of product development projects. Directions for additional theory development are outlined. © 2000 Elsevier Science B.V. All rights reserved.

*Keywords:* Product development; Project management; Technology; Innovation management; Empirical research

## 1. Introduction

New product development has received increasing research attention in response to considerable industrial concern for development effectiveness. In studying product development, researchers have applied different functional perspectives such as a marketing orientation (Wind and Mahajan, 1997), design engineering orientation (Suh, 1990), or manufacturing orientation (Ettlie, 1995). Others adopt cross-func-

[☆] This paper was awarded the Chan K. Hahn prize for best paper in the Operations Management Division, Academy of Management 1999 Conference.

[*] Corresponding author. Tel.: +1-919-962-0050; fax: +1-919-962-6949.

*E-mail addresses:* mohan_tatikonda@unc.edu (M.V. Tatikonda), srrosent@bu.edu (S.R. Rosenthal).

[1] Tel.: +1-617-353-4288; fax: +1-617-353-5454.

0272-6963/00/$ - see front matter 
PII: S0272-6963(00)00028-0

tional perspectives at different organizational levels of analysis such as the firm or business unit (Capon et al., 1992), the product development portfolio (Meyer et al., 1997) or the individual development project. Researchers who adopt a project perspective (Clark, 1989; Rosenthal, 1992; Iansiti, 1995; Tatikonda, 1999) note that development of an individual product can be viewed as the organizational process of managing a project. This paper adopts the perspective of the individual development project, and so focuses on project management aspects.

Product development projects have two important characteristics this paper considers. First, such projects draw on equipment, skills, resources and personnel from diverse functional areas that must work together to achieve the objectives of the project (Dougherty 1992; Adler, 1995). These resource amalgamations are often of a temporary nature, like ad hoc task forces. Second, product development projects face many forms of uncertainty, one of which is technology uncertainty (Henderson and Clark, 1990; Wheelwright and Clark, 1992a; Utterback, 1994; Iansiti, 1995; Barnett and Clark, 1996). Product development is particularly difficult when firms have limited experience with the product and process technologies they intend to employ in or with a product development effort (Gupta and Wilemon, 1990; Wheelwright and Clark, 1992a; Iansiti, 1995; Swink, 1998).

The literature on new product development projects demarcates two major phases: project planning and project execution (Clark, 1989; Moenaert et al., 1995; Griffin, 1997a; Khurana and Rosenthal, 1997; Tatikonda and Rosenthal, 2000). Project planning, also popularly called the ‘‘fuzzy front end’’ (Smith and Reinertsen, 1998) of product development projects, includes choosing the project to work on, setting product and project targets, and putting in place the key resources and mechanisms to accomplish the development effort. The project execution phase involves actually carrying the project through completion.

It has been noted that new product development is not just a series of predictable steps that can be identified and planned in advance (Rosenthal, 1992; Bailetti et al., 1994; Schilling and Hill, 1998). For many product development projects, particularly those with some non-trivial level of technology uncertainty, the resulting capabilities of the product and the exact means to achieve the product are not known with certainty at the start of the development project. This uncertainty, along with the required amalgamation of project resources, calls on project managers to conduct project planning. However, it is exactly these issues that make planning ahead so difficult. Often, before project execution starts, there is no precise understanding of the detailed project tasks, task sequence, task interdependencies and task times. As one project manager at a photo-imaging products company explained to us, ‘‘Of course, we know what the big pieces are, but the problem is that we don’t know what the small tasks are until we get there in the project, and oftentimes, these small tasks turn out to be big tasks!’’ Due to the limitations inherent in project planning for product development projects, product development managers must also focus attention on managing the project *during its execution* to adapt to uncertainties as they arise and to assure a consistent project-oriented focus of the multiple resources. This requires a shift from thinking solely about detailed project planning to also considering the context within which the project work is accomplished, i.e., project execution.

Practitioners naturally emphasize the significance of project execution. The Project Management Institute (PMI), the professional organization of project managers, cites ‘‘project execution as the single most important factor in the success or failure of new products’’ (Project Management Institute, 1998). In the field, we observed a variety of approaches applied by project managers to manage project execution. A recurring, problematic challenge practitioners faced was what we call ‘‘balancing firmness and flexibility’’ in project execution. This involves determining the degree to which to apply a formal process (‘‘firmness’’) to the project, while allowing leeway (‘‘flexibility’’) to conduct project work.

Product development is often characterized as an exercise in information processing (Clark and Fujimoto, 1991; Tatikonda and Rosenthal, 2000). Accordingly, the application of organizational information processing theory is appropriate in characterizing the function of development groups. This theory explains that ‘‘organic’’ organizational approaches are required for successful execution of uncertain tasks and ‘‘mechanistic’’ approaches for relatively certain tasks (Galbraith, 1973). But our field observations conflict with theoretical predictions because we found instances where development process formality, a mechanistic approach, was effective for projects having high uncertainty. And we found that project management's flexibility in managing the project was beneficial for a variety of projects, not just those that should benefit from such organic approaches.

Although there is a substantial operations management literature on the topic of project management, the project execution phase of projects has received relatively little attention in this literature, which has instead focused primarily on detailed network scheduling approaches for project planning. Smith-Daniels (1997) (pp. 11–12) notes that while ‘‘managers with project management skills have become a hot commodity’’, most current literature does not ‘‘reflect the project environment where most of our graduates will work’’ and provides ‘‘little guidance on topics that are now viewed as crucial to project success (such as) structuring the project management process.’’

In all, there are practical, field-based, theoretical and topical motivations to study project execution. We aim to contribute to both the new product development and project management literature by providing a large sample, cross-sectional, confirmatory test of theory- and field-based hypotheses regarding effectiveness of selected project execution methods. We also aim to provide relevant guidance regarding project execution to practicing managers.

We address two research questions. First, ‘‘How do the project execution methods of formality, project management autonomy and resource flexibility influence the execution success of product development projects?’’ Specific hypotheses are posed based on research literature and our field observations. This question is investigated by examining relationships between project execution practices and project execution success for a sample of 120 product development projects from a variety of assembled products industries. Answering this question helps us understand whether these approaches should be adopted in practice, and helps us gain insight into the perplexing ‘‘firmness and flexibility’’ issue.

The second research question asks, ‘‘Does the newness of the technology to be developed during the project influence the strength of the relationship between project execution methods and project execution success?’’ Technology novelty corresponds to organizational information processing theory's concept of task uncertainty. Accordingly, we hypothesize that the effectiveness of formality, project management autonomy and resource flexibility varies for projects having different levels of technology novelty. This question is investigated via examination of hierarchical moderated regressions that contain interaction terms of given project execution methods and technology novelty aspects. Answering this question helps us understand whether these project execution methods are most effective for specific project types or a variety of projects, and so helps project managers choose project execution approaches for a given project type.

Section 2 presents literature on the project execution approaches and presents the hypotheses. Section 3 describes the data collection methods and measures. The analysis approach and hypothesis results are presented Section 4. Section 5 discusses the results, Section 6 addresses implications for practice and future research, and Section 7 concludes this paper.

## 2. Literature review and hypotheses

The conceptual framework (Fig. 1) addresses three project execution methods (formality, project management autonomy and resource flexibility) that project managers may employ, either singly or collectively, to achieve greater project execution effectiveness in new product development projects. These methods, called ‘‘structural mechanisms’’ in the organizational design literature, are controls or parameters over the means by which organizational work gets done (Ouchi 1977; Ettlie et al., 1984; Eisenhardt, 1985). All three methods are integrative and project-oriented rather than oriented to a single function or department. *Formality* refers to existence of an overall process and structure for the project. *Project management autonomy* and *resource flexibility* refer to adaptability during the project to meet emerging circumstances, and represent the discretion available to the project management. We posit that

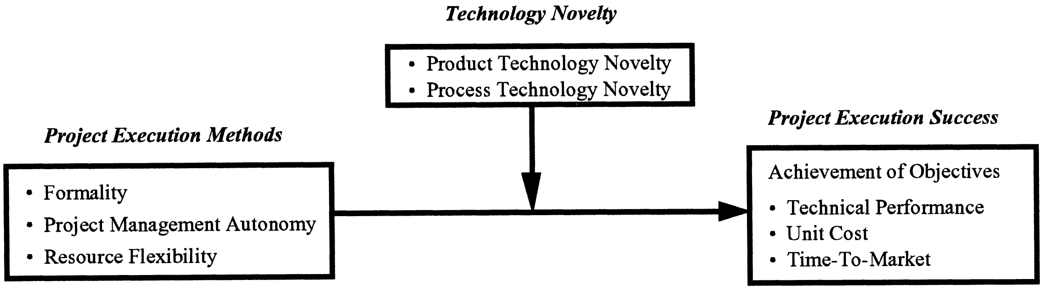


Fig. 1. Conceptual framework of project execution effectiveness in product development projects.

these factors have a positive, direct relationship with *project execution success*. We also posit that the degree of *product and process technology novelty* incurred in the project influences the relationship between project execution methods and project execution success; i.e., technology novelty has a moderating effect.

## 2.1. Project execution success

The project execution success 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 (Rosenthal, 1992; Rosenthal and Tatikonda, 1993; Smith and Reinertsen, 1998). These objectives are set in place by the start of project execution, and their achievement is evaluated at the end of project execution.

Consistent with the intent to assess the effectiveness of executing the product development project, this performance measure is distinctive in four important ways. First, it is specifically a success measure of the project *execution* phase (rather than project planning success or success for a combination of planning and execution). Second, it is an *internal* measure (Hauptman and Hirji, 1996). Product development success is certainly multidimensional (Griffin and Page, 1996; Zirger and Hartley, 1996); however, market-oriented and other external measures are beyond the internal, execution-oriented scope and intent of the present research. A project that is well executed would result in a high level of project execution success, but could still result in a product that is a market failure. Market failure can occur in spite of high operational success if the product is planned poorly (e.g., the wrong product features had been chosen) or introduced to the market poorly (e.g., inadequate sales promotion). This paper does not study product planning or project planning, and does not study market introduction issues. This paper does study project execution, which is one of the key links in the complex business process of product development. Third, this measure is a *composite* measure because it includes technical performance, time and cost, rather than simply one of these outcomes. Fourth, it is a more extensive measure than utilized in previous studies because it employs multiple continuous scale items, with *weightings* for the relative importance of technical performance, time and cost for a given project.

The six hypotheses below are grounded in our prior field observations and literature on project management, organizational design and new product development.

## 2.2. Formality

Formality is ‘‘the degree to which rules, policies and procedures govern the role behavior and activities of organizations’’ (Van de Ven and Ferry, 1980, p. 303). Formality represents how explicitly the norms of the organization have been formulated (Price and Mueller, 1986), and is often expressed via instructions, guidelines and communications (Oldham and Hackman, 1981; Scott, 1981).

In the product development context, formality occurs via utilization of structured processes for managing the project. Structured processes consist of rules, procedures, and periodic reviews for project control and review. Various structured processes in use have been described (see Cooper and Kleinschmidt, 1990; Rosenthal, 1992; Wheelwright and Clark, 1992b). Of these, the ''phase gate'' system has gained most attention. It involves a review (a ''gate'') at various points in the execution of the project (at the end of each ''phase'') to assess project status and determine necessary project revisions. Project control and review varies from the highly formal (employing numerous rules, procedures, contract books, sign-off forms and structured, periodic project or design reviews) to the quite informal (employing ad hoc project management review and control procedures with few structured progress reviews).

Formality in product development projects has pros and cons (Cooper 1983; Gupta and Wilemon, 1990; Rosenthal, 1992; Eisenhardt and Tabrizi, 1995). Formality may aid product development effectiveness for a number of reasons. A work process with controls and reviews provides a sense of structure and sequence to the work, reducing ambiguity for project personnel regarding what to work on and when. Rules and reviews can provide both motivation and a sense of accomplishment. Rules and reviews require personnel to consider their work activities and assess whether they are on track, and, if necessary, to determine how to get back on track. These procedures allow earlier surfacing and resolution of potential problems in product design, development or manufacturing ramp-up, and so reduce overall elapsed time and work effort.

Formality can cause personnel to adopt a project-focus (a ''collective orientation'') rather than solely a departmental focus. Formality is holistic, promoting cross-functional communication and coordination. Formality brings parties together because project problems are the responsibility of the project group as a whole rather than the ''fault'' of a single functional area, so the team works together to resolve problems before they get aired at a formal review gate.

Formality has other benefits. Periodic reviews can inject a formal senior management role into the process, providing a time and place for senior management intervention and guidance while assuring that they do not ''meddle'' with the project through excessive hands-on control. Rules and reviews may make it easier to see when and where reallocation of resources is necessary. Further, a formal process allows for data capture during the project and sets a base for organizational learning both during and after the project.

One argument against formality is that too much time can be spent preparing for the reviews (Cooper and Kleinschmidt, 1990; Rosenthal, 1992; O'Connor, 1994). Conducting reviews and following rules can be very time-consuming, detracting from accomplishment of ''real'' work such as prototype development or design of product subsystems. An even more problematic concern is that excessive formality can reduce the flexibility required to conduct projects (Rosenthal, 1992). Rules, reviews and structure may force project execution in one pre-determined manner, rather than allowing the adaptability necessary to cope with uncertainties that arise in development projects as new market information becomes available, or as unanticipated technological problems arise. Although formality does not necessary imply or require very detailed pre-planning, it does, at minimum, require following a somewhat codified overall work structure and process with periodic assessments of project progress.

The early, exploratory cross-sectional studies of product innovation — the MIT study by Myers and Marquis (1969), the SAPPHO study by Rothwell et al. (1974), and the NSF study by Rubenstein et al. (1976) — all found that having a specified development process or a logical flow of activities was associated with greater product development success in terms of financial outcomes.

More recent field-study-based investigations point to increased product development effectiveness (for the types of reasons listed above) when some form of a formal process with project controls is employed (Clark and Fujimoto, 1991; Mabert et al., 1992; Rosenthal, 1992). In our earlier field research, we found process formality to be effective in many companies. For example, one firm that develops and manufactures telephone switching systems routinely depends on a formal development process, and has incorporated the process into their organizational culture. In the development of a new switch having very high levels of new digital technology, the firm found that the formal process helped them get back on track after they ''failed'' an early gate review. Interestingly, failure to pass Gate 1 led to greater downstream cooperation among project personnel to resolve problems before subsequent formal review events. It was clear to all parties that lack of thoroughness and discipline would lead to collective failure. A firm that developed a handheld pager, for them a product of moderate technology novelty, found that employing a ''contract book'' (which specified major work procedures and interim project targets) in conjunction with periodic executive reviews was key to successfully achieving project objectives. A Midwest-based maker of industrial conveyor systems, products of relatively low technological sophistication and uncertainty, employed a formal five-phase development process and periodic progress reviews. They found this formality beneficial to timely and cost-effective development. In these three firms, a formal development process with formal reviews helped ensure closure on deliverables to downstream organizations, and established a common understanding that the project as a whole would not proceed until certain interim activities and targets had been achieved.

Large-sample confirmatory studies with findings on formality-related issues have been conducted. Zirger and Maidique (1990), in a study that used senior executives as informants, found that a ''well planned, conducted and executed product development project'' was positively related to product development financial success. Eisenhardt and Tabrizi (1995) found that the greater amount of time between formal milestones was associated with longer product development time. The study by Griffin (1997a) by most closely addressed process formality by employing a dichotomous measure of whether or not a ''formal product development process'' was used in the development project. She found that formality is beneficial in reducing time-to-market for complex products. In all, there is empirical support that process formality, broadly construed, aids in achieving product financial success or timeliness. Still, no large sample confirmatory studies have investigated the composite effectiveness of formality in the project execution phase of product development.

**Hypothesis 1.** *Projects having a greater degree of formality have higher levels of project execution success.*

### *2.3. Project management autonomy and resource flexibility*

Autonomy is described in the organizational design literature as the degree to which an organization has power with respect to its environment (Van de Ven and Ferry, 1980; Price and Mueller, 1986). It captures the extent to which the organization is responsible for and has discretion regarding work activities and job-related decisions (Hackman and Oldham, 1980; Klein, 1991). Autonomy represents decentralization of decision-making power to those who will actually carry through the work, and also represents the ability to deviate from a detailed plan.

There are several organizational levels and types of autonomy. Autonomy can be viewed at the portfolio or firm level (e.g., the autonomy of an entire R&D laboratory vis à vis corporate headquarters) (Cardinal, 2000), or at the level of the individual such as a single scientist (Souder, 1974; Koys and DeCotiis, 1991; Kahn and Kram, 1994). An intermediate organizational level is that of the project. Further, there are strategic and operational types of autonomy (Bailyn, 1985). Strategic autonomy refers to the organizational unit's ability to choose the project to work on, while operational autonomy refers to the unit's ability to choose the manner in which the work will be accomplished. Within operational autonomy, we make the further distinction of project planning vs. project execution autonomy. Project planning autonomy includes resource selection such as choosing who would work on the project and what resources should be put in place, while project execution autonomy addresses resource deployment such as the use of those resources once the project begins. In this paper, we focus on project-level autonomy of an operational nature during project execution.

Investigation of autonomy in product development groups has received little empirical attention (Gerwin and Moffat, 1997a). Here, we review extant field-based and survey studies. Single- and multiple-case study analyses of product development projects generally find that autonomy is associated with project success. Autonomy facilitates creativity in solving problems and enhances team learning in uncertain environments (Imai et al., 1985; Thamhain 1990; Moorman and Miner, 1998). This, in turn, reduces wasteful effort and time delays, helping achieve technical objectives and a speedier development process (Clark and Fujimoto, 1991; Susman and Dean, 1992). Imai et al. (1985) note that certain Japanese firms have successful development projects in large part due to the flexibility with which these companies adapt their development process to environmental uncertainty. This five-case study investigation finds that autonomy granted to project teams by top management gave personnel a strong sense of responsibility and an assurance than they could proceed with project work as they saw fit. Similarly, the ethnographic study by Donnellon (1993) of 12 product development teams found that team autonomy helps in accomplishment of work because teams provide the best control over the task.

Three larger-sample investigations of autonomy-related concepts in product development projects have been conducted. In a study of 53 international product development project teams, Gerwin and Moffat (1997b) found that the *withdrawal* of autonomy (usually by senior management) during the project is negatively associated with team performance. On the other hand, Kim and Lee (1995), in their study of 80 Korean R&D project teams, found that the ''autonomous climate'' of the project team had a negative association with team performance. However, they did find that under conditions of high ''change orientation'' (such as high task or environmental uncertainty), autonomy proved beneficial in terms of team performance. They speculate that the negative main effect is due to cultural factors. Eisenhardt and Tabrizi (1995) focus on an ''experiential'' product development approach consisting of frequent in-progress reviews, a powerful project leader and a cross-functional team. Their study, limited to computer systems products, finds that this approach is effective because it supports during-project learning and adaptation to problems as they emerge, allowing refocus of resources and energy to the uncertainties. They explain that the inherent flexibility of an experiential approach leads to project effectiveness.

The extant empirical literature, which has taken a broad view of autonomy, generally finds that autonomy is associated with project success. Here, we test the efficacy of two specific aspects of project-level autonomy in a large sample of development projects for assembled goods.

Due to the uncertainty inherent in product development projects, project management needs some flexibility during project execution to adjust to emerging needs of the project and to take advantage of increasing knowledge about the nature of the project. Project managers are closest to the project and are intimate with the team and the project's progress, and so should be able to choose how to implement and adjust the project management approach. We define relative flexibility in the project management approach as ''project management autonomy.'' In the field, we observed benefits that accrue from project management autonomy. For example, one firm that was developing a sophisticated laser printer had the project manager decide — in conjunction with senior technical managers — which project personnel should attend important product development meetings. Such efforts made review and other meetings genuinely helpful, rather than just time-consuming, for particular personnel. At a maker of mini-computers, the project manager could call cross-functional meetings and reviews as necessary separate of formal gate reviews. And at the firm developing telephone switches, it was widely understood that the project manager had an important role in developing consensus and helping redefine work rules and procedures as needed.

**Hypothesis 2.** *Projects having a greater degree of project management autonomy have higher levels of project execution success.*

Project management must also have the discretion to make resource adjustments to cope with emerging and unexpected problem areas, and to reduce the resources allocated to areas that no longer need attention. Such resource flexibility cuts across functional boundaries and is a means of dynamic matching of available resources to necessary work requirements. We define flexibility in reallocation of project resources as ''resource flexibility.'' Specific resource types include financial, personnel and equipment resources (Meredith and Mantel, 1995). In the field, we observed repeatedly that resource sharing and redeployment was not commonly done across the development areas and stages in a given development effort. For example, in development of the laser printer described earlier, upstream technical personnel were ''screaming'' for additional technical personnel to ''come on board'' the project to resolve some early technical problems that had arisen unexpectedly, and to help prepare downstream functions for the coming work. Personnel flexibility was not allowed by upper management in this project. We observed similar behavior at a developer of scientific instrumentation for biomedical research applications. This firm faced a tremendous challenge in technically characterizing the core module for a product that would automate electrophoretic biochemical analysis. Although project personnel with technical skills that could contribute to solving the problem were located just one door from the laboratory, these personnel did not offer to help because, as they explained to us, that was simply not how things were done there. These situations were largely due to bureaucratic controls over resources and political issues in resource control (whose resources were whose). These projects could have benefited from timely reallocation of resources, but did not due to a lack of project-level autonomy in terms of resource controls.

We did observe a few instances of application of resource flexibility. In developing a flat-bed scanner device, mechanical engineers from the design engineering function were loaned to the manufacturing engineering function when unexpected problems arose with development and fabrication of new manufacturing tooling. Here, personnel and equipment resources were flexible, and this project achieved better overall time and cost performance than would otherwise have been possible. At the manufacturer of industrial conveyor systems, development of a new rack conveyor would have been slowed down significantly due to problems in sourcing a key part, the ''rack clip.'' Technical personnel and financial resources were applied to diagnose part quality problems, re-specify the part, and work with the vendor to resolve the problem earlier rather than later. An aerospace firm we studied allocated a ''slush fund'' to a major development project. This fund could be applied in a speedy, flexible manner to needed areas upon the discretion of project management, allowing project management to allocate project resources to solve emergent problems while they were still comparatively small.

**Hypothesis 3.** *Projects having a greater degree of resource flexibility have higher levels of project execution success.*

### 2.4. The moderating effects of technology novelty

The hypotheses above posit that formality, project management autonomy and resource flexibility are beneficial for all projects. In addition, we posit that the degree of effectiveness is, in part, dependent on the given project's *uncertainty*. Organizational information processing theory explains that organizational ''tasks,'' such as product development projects, vary in their level of uncertainty. Uncertainty represents lack of knowledge about the exact means to accomplish the task. Task-related characteristics, such as the degree of technology novelty undertaken, contribute to a task's overall uncertainty level. Tasks having higher uncertainty require greater information processing during the execution of the task than tasks having lower uncertainty. ''Organic'' organizational approaches provide greater information processing capacity to the organization, while ''mechanistic'' approaches provide less (Burns and Stalker, 1961; Tushman and Nadler, 1978). Therefore, in order to be successful, tasks with high uncertainty should be executed using organic organizational approaches, while tasks with low uncertainty are accomplished most efficiently with mechanistic organizational approaches (Galbraith, 1973, 1977; Daft and Lengel, 1984, 1986). Organic approaches are characterized by fluidity and flexibility in the task execution process, rich and frequent communication, decentralized decision-making, high levels of organizational integration, few formal procedures, and higher personnel training and skills. Mechanistic approaches are typified by organizational hierarchies employing rules and regulations to guide actions and make decisions, and are characterized by centralized decision-making, formalized procedures and written communication.

Technology novelty is a major contributor to task uncertainty in product development (Gupta and Wilemon, 1990; Wheelwright and Clark, 1992a; Iansiti, 1995; Barnett and Clark, 1996; Tatikonda and Rosenthal, 2000). The product development literature, as well as the broader technological innovation literature, describes technology novelty in terms of the degree of familiarity with the given technology or degree of change in the technologies relative to products previously developed or manufactured by the company (Abernathy and Clark, 1985; Meyer and Roberts, 1986; Henderson and Clark, 1990; Adler et al., 1995; Tatikonda, 1999). We adopt this perspective in considering two aspects of technology novelty that apply in the assembled products context. *Product technology novelty* includes the newness of the product architecture, product parts and modules, while *process technology novelty* includes the newness of the manufacturing flows and layouts, and manufacturing tools and process stages.

Per organizational information processing theory (Galbraith, 1977; Tushman and Nadler, 1978; Daft and Lengel, 1986), formality is a mechanistic approach, and project management autonomy and resource flexibility are organic approaches. Therefore, projects having lower technology novelty (lower task uncertainty) should benefit more from formality, and projects having higher technology novelty (higher task uncertainty) should benefit more from project management autonomy and resource flexibility. Although there is a considerable empirical literature on task and organization contingencies in a variety of organizational contexts (e.g., Tushman, 1979; Daft and Lengel, 1986; Cohen and Levinthal, 1990; Tyre and Hauptman, 1992), the technology novelty contingencies addressed here have not been investigated in prior large sample studies of product development projects.

**Hypothesis 4.** *The positive relationship between formality and project execution success is weaker in projects having higher technology novelty than in projects having lower technology novelty.*

**Hypothesis 5.** *The positive relationship between project management autonomy and project execution success is stronger in projects having higher technology novelty than in projects having lower technology novelty.*

**Hypothesis 6.** *The positive relationship between resource flexibility and project execution success is stronger in projects having higher technology novelty than in projects having lower technology novelty.*

## 3. Methods

*Overview:* a cross-sectional survey methodology was employed. The unit of analysis is a development project for an assembled product. The sample consists of 120 projects.

### *3.1. Sample*

Solicitation mailings were sent to selected members of two groups: the Product Development and Management Association (PDMA), and past participants of selected executive education programs at Boston University. This study was supported by both groups. We sampled both groups to gather data on more projects. The PDMA membership and executive education program participants have served as samples for previous studies of product development (Zirger and Maidique, 1990; Griffin and Page, 1996; Zirger and Hartley, 1996). The membership lists were scrutinized to filter out consultants and academics. Individuals from non-assembled products industries were also filtered. In some cases, it was not obvious whether an individual belonged to a company that did product development for assembled products. These individuals were retained on the list. Each person on the list was sent a letter describing the research and inviting their participation. In many cases, letters were sent to several different people in the same firm. The solicitation letters did not include a survey. The recipient was to indicate on a fax-back form the number of surveys they desired and who they should go to in the company. The contact correspondence clearly stipulated the respondent qualifications and that the survey applies only to recently completed development projects for assembled products. Firms were asked to provide, when they could, data on different projects where the projects differed in project success and technology risk. The number of product development projects conducted by firms varies greatly — some complete one every few years, others have several underway and introduced each year. Participating firms provided data on one to four projects, with most providing data on two projects.

Two-hundred fifty-one firms were contacted. Twenty-seven firms that requested participation were disallowed because they did not meet study qualifications (e.g., they had no respondent available who had served through the life of the project, had no recently completed projects, were software or process firms, etc.). We received 120 usable surveys (from 57 companies). The number of firms participating with respect to the number of firms contacted is 23%. This rate is consistent with other survey-based research in operations management (e.g., Vickery et al., 1997; Bozarth et al., 1998), and exceeds the 20% benchmark recommended by Malhotra and Grover (1998) in their survey methods paper. In general, we found significant willingness to participate and real disappointment by firms that did not meet study qualifications.

We tested for significant differences between the PDMA and executive program participants sub-samples. A chi-square test shows no significant difference (at $p < 0.1$) between the two sub-samples in terms of firm size. Further, one-way ANOVA of the project execution success measure shows no significant difference (at $p < 0.1$) between the two groups. These tests supported our a priori expectations. The two groups were pooled because the tests showed no significant differences. We contacted 30 randomly selected non-respondent firms to find their firm size. A Chi-square test shows no significant difference (at $p < 0.1$) between respondents and non-respondents in terms of firm size.

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, process controls and manufacturing equipment. Most (92%) of the products are electro-mechanical goods, while 8% is primarily mechanical assemblies. Most (82%) are industrial products, while 18% is consumer goods. The typical product was expected to sell over 10,000 units in its lifetime, and sold for \$100–10,000 per unit. Most projects (81%) were completed within a 36-month period. 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.

### 3.2. Respondent

The self-administered questionnaire was completed by the project manager. The actual respondent title varied greatly among firms since firms use diverse terminology regarding management of product innovation. It was required that the respondent be one who was with the project from beginning to end, had interacted with both upper management and project personnel, and had a significant technical understanding of the product. These restrictions assured that the respondent had a broad view of the project that crossed functional boundaries and organizational levels. These qualifications also assured that the respondent could provide the detailed organizational (management) and technical information required, and could provide data on elements at different points in time in the project effort. Identifying qualified respondents is a significant challenge for research like this. New product development projects are often multi-year projects, and today's business environment is such that project management personnel are moved to other projects/divisions, promoted, downsized, leave the company, etc. The essential qualifications of the respondent were explicit in the survey instrument and survey distribution methods. The strict respondent qualifications were required to assure reliability. The average respondent had 15 years of product development experience.

### 3.3. Instrument development

Assembled products are studied because a large sample analysis within this industrial context supports generalization within this context. Focusing on this industrial context controls for factors that may vary across other contexts such as development of process goods, software or new services. The instrument development focused on assembled products because study of other industrial contexts may require different survey questions and operationalizations (e.g., the survey questions on ''technology novelty'' may not make sense in a services development context).

We adapted existing organizational survey scales to the product development project context and also developed some new scales due to a lack of existing scales for the phenomena of interest. Scale development is often necessary in new research areas (Spector, 1992). Prior exploratory field research we conducted provided contextual knowledge that contributed to our ability to devise appropriate scales. This prior research consisted of compilation and analysis of in-depth, descriptive case studies of seven product development projects for assembled goods (see Rosenthal, 1992; Rosenthal and Tatikonda, 1993 for summaries of the cases). This involved over 100 hours of interviews with project leaders and development team personnel. The concepts of interest in this paper emerged from this prior field work.

The new scales were developed hand-in-hand with experienced product development managers. Resulting scales underwent several waves of pilot tests before full-scale survey administration to assure scale content and construct reliability and validity. Here, we describe the instrument development process. Draft survey item operationalizations were compiled for close review and discussion with senior project managers who had at least 8 years of experience in product development. A complete prototype instrument was prepared based on comments from the project managers. The resulting instrument was reviewed in conjunction with the research hypotheses by six faculty experienced in survey research. This instrument was, in turn, revised based on the faculty comments, and the new version of the instrument was then used for the field pilot test. The pilot test was conducted with respondents representative of the types of people that would complete the final survey, and for projects representative of the types of projects in the full survey administration. Some of the pilot surveys were administered in person, others by mail. In all cases, a post-survey discussion was held with the respondent. Data were collected on 11 projects, five of which had two or three respondents. Pilot respondents told us that they had no difficulty understanding the survey questions, and that the survey as a whole was interesting and of reasonable length. The respondent comments and close comparative review of the surveys gave us confidence that the instrument was reliable and valid, and that a single qualified respondent was sufficient. The detailed comments and observations were compiled, leading to an incremental revision of the instrument that was tested with several other respondents. This final instrument was used for full-scale administration.

The single-respondent retrospective approach is traditional in large-scale survey research on product development projects (Henderson and Clark, 1990; Zirger and Maidique, 1990; Zirger and Hartley, 1996; Eisenhardt and Tabrizi, 1995; Meyer and Utterback, 1995; Hauptman and Hirji, 1996; Griffin, 1997a; Ulrich and Ellison, 1999) primarily due to research feasibility reasons. Obtaining multiple informants for each case for data this detailed and a sample size this large is virtually impossible to achieve. Although we follow the single-respondent tradition, we did conduct limited multiple-respondent analyses in both the survey instrument pretest (described above) and full administration of the survey. In the full survey administration, a second qualified respondent was obtained (for 22 projects) who provided information on the project execution success items. Correlations between first and second rater responses were significant (at $p < 0.1$), providing additional confidence that a single, highly qualified respondent does provide valid and reliable data. In addition, concerns about retrospective bias and common methods variance were, in part, ameliorated via the instrument development process (which involved careful instrument development in terms of question wording and sequence).

### 3.4. Measures

The survey scales are presented in Appendix A and are discussed below. All scales employ Likert-type scale items. A simple average of the scale items was used as the scale measure (with the exception of the project execution success measure, as described below).

### 3.4.1. Project execution methods

The *formality* scale measured the degree to which the project had and followed formal project management rules and procedures, and the degree to which formal project reviews were held. This scale is an adaptation of the formality measure of Oldham and Hackman (1981). We adapt their scale to the product development context and add a specific item on progress reviews.

*Project management autonomy* was measured by the discretion project the management had in determining the overall project management approach, format of progress reviews, and interim schedule targets. This scale is an adaptation of the measure of work group discretion of Van de Ven and Ferry (1980). Our adaptation specifically captures project management autonomy in the new product development context. An issue in operationalizing the concept of autonomy is determining the boundary between the organization and its environment (Price and Mueller, 1986). Here, the organization is the new product development team (as represented by project management) and the environment is the rest of the organization (as represented by senior management).

*Resource flexibility* during the project was measured by the discretion project management had in reallocating personnel, financial and equipment resources during the project. These are the three traditional key resource categories for a project (see Meredith and Mantel, 1995, p. 510). We found no scale in the extant literature that captures the concept of resource flexibility, and so developed this scale.

### 3.4.2. Technology novelty

Technology novelty was measured as perceived newness of the technologies to the firm at the start of project execution. *Product technology novelty* was measured by the degree to which product modules, the product architecture, and product technologies overall were new. Similarly, *process technology novelty* was measured by the degree to which manufacturing stages, the process layout, and manufacturing technologies overall were new. We developed new scales for these variables because there were no extant scales that captured technology novelty in the depth desired. These scales are based heavily on our field experience.

### 3.4.3. Project execution success

The *project execution success* measure is a weighted sum of the degree of achievement of each of the three central project objectives (technical performance, product unit-cost, and time-to-market), where the weights are based on the relative importance of each objective for the given project. This measure is explained in detail in Appendix A. We created this new measure because no extant measure captured, in a composite fashion, the three dimensions of project execution success with embedded weighting. We believe that the use of importance weights in conjunction with end-of-project outcomes is critically important to realistically capture the

Table 1
Factor loadings of project execution methods items on project execution factors

| | Project execution factors | | |
|---|---|---|---|
| | Factor 1: Formality | Factor 2: project management autonomy | Factor 3: resource flexibility |
| Degree of project management formalization | *0.843* | −0.121 | 0.155 |
| Degree project management rules actually followed | *0.897* | 0.084 | 0.179 |
| Degree formal progress reviews held | *0.834* | −0.018 | 0.009 |
| Determine interim schedule targets | 0.061 | *0.701* | 0.130 |
| Determine the project management approach | −0.039 | *0.810* | 0.218 |
| Choose format of progress reviews | −0.087 | *0.790* | 0.014 |
| Reallocate financial resources during project | 0.091 | 0.289 | *0.804* |
| Reallocate personnel during project | 0.129 | 0.131 | *0.906* |
| Reallocate equipment during project | 0.124 | 0.021 | *0.889* |

Table 2
Factor loadings of technology novelty items on technology novelty factors

| | Technology novelty factors | |
|---|---|---|
| | Factor 1: product technology novelty | Factor 2: process technology novelty |
| Product modules novelty | *0.837* | 0.165 |
| Product configuration novelty | *0.726* | 0.136 |
| Product technology novelty | *0.740* | 0.225 |
| Manufacturing stages novelty | 0.174 | *0.854* |
| Process layout novelty | 0.108 | *0.855* |
| Manufacturing technology novelty | 0.338 | *0.775* |

overall execution performance of each project. Such a measure better captures project-to-project subtleties since different projects have different priorities. This weighted, composite measure is an important methodological feature that distinguishes this work from prior research on project management and product development because this measure explicitly recognizes that each project is different, and that the emphasis on each objective in a given project may vary.

As Appendix A shows, the four success items are nine-point Likert-type instead of seven-point Likert-type (which is the case for all other items in the survey instrument). This wider range was provided because survey pretest respondents requested a wider response range for these items, and to capture finer granularity in the variation of the dependent variable. Table 3 shows that there is substantial variation on this measure. Scale-level responses show that the sample consists of projects ranging from quite unsuccessful to quite successful.

#### 3.4.4. Control variable

Project priority is employed as a control variable. This variable serves as a proxy for the level of resources and senior management attention applied to the project. The measure was a single-item (seven-point Likert-type) scale asking, ‘‘To what extent did this project have priority relative to other projects in the company?’’

### 3.5. Factor analysis

Factor analysis of the project execution methods 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 1). The three project execution methods factors explain 73% of the variation inherent in their items. A similar factor analysis of the technology novelty items also grouped the scale items as predicted (see Table 2). The two technology novelty factors explain 68% of the variation inherent

Table 3
Scale descriptives

| (A) Measure | (B) Mean | (C) Standard deviation | (D) Number of items | (E) Scale reliability |
|---|---|---|---|---|
| *Project execution methods* | | | | |
| Formality | 3.8 | 1.6 | 3 | 0.83 |
| Project management autonomy | 5.2 | 1.2 | 3 | 0.68 |
| Resource flexibility | 4.2 | 1.6 | 3 | 0.87 |
| *Technology novelty* | | | | |
| Product technology novelty | 4.9 | 1.2 | 3 | 0.70 |
| Process technology novelty | 3.8 | 1.4 | 3 | 0.81 |
| *Project execution success* | | | | |
| Project execution success | 4.5 | 1.4 | 4 | 0.80 |
| *Control variable* | | | | |
| Project priority | 4.5 | 1.8 | 1 | n.a. |

Table 4
Pearson product moment correlations
$n = 120$.

| Variable | (1) Formality | (2) Project management | (3) Resource flexibility | (4) Product technology novelty | (5) Process technology novelty | (6) Project execution success | (7) Project priority |
|---|---|---|---|---|---|---|---|
| (1) Formality | 1.000 | | | | | | |
| (2) Project management autonomy | −0.036 | 1.000 | | | | | |
| (3) Resource flexibility | 0.253*** | 0.312*** | 1.000 | | | | |
| (4) Product technology novelty | 0.189** | 0.100 | 0.276*** | 1.000 | | | |
| (5) Process technology novelty | 0.106 | 0.114 | 0.186** | 0.445*** | 1.000 | | |
| (6) Project execution success | 0.250*** | 0.208*** | 0.225*** | 0.014 | −0.091 | 1.000 | |
| (7) Project priority | 0.139* | 0.151** | 0.366*** | 0.376*** | 0.269*** | −0.077 | 1.000 |

*$p \le 0.1$.
**$p \le 0.05$.
***$p \le 0.01$.

in their items. All multi-item scales are internally reliable per the Cronbach's alpha statistic (Nunnally, 1978). See Table 3 for summary statistics and internal reliabilities (standardized Cronbach's alphas) of each scale. See Table 4 for the correlation matrix.

## 4. Results

Hypotheses 1, 2 and 3 posit a direct, positive relationship between project execution methods and project execution success. The bivariate correlations (see Table 4) of formality, project management autonomy and resource flexibility with project execution success are all statistically significant and positive. Further, multivariate regression analysis (see the step 2 regression in Tables 5–7) show these project execution methods terms to be statistically significant and positively associated with project execution success when project priority is controlled for. These three hypotheses are strongly supported.

Hypotheses 4, 5 and 6 posit that technology novelty moderates the relationship between project execution methods and project execution success. Hier-

Table 5
Hierarchical regression with formality/technology interactions
(1) Dependent variable is project execution success.
(2) $n = 120$.
(3) Main table contains standardized coefficient betas.

| Variables entered | Step 1 | Step 2 | Step 3 | Step 4 |
|---|---|---|---|---|
| Project priority | −0.077 | −0.114 | −0.103 | −0.101 |
| Formality | | 0.266*** | 0.266*** | 0.269*** |
| Product technology novelty | | | 0.054 | 0.050 |
| Process technology novelty | | | −0.115 | −0.117 |
| Formality × Product technology novelty | | | | −0.020 |
| Formality × Process technology novelty | | | | 0.034 |
| Intercept | 4.759**** | 4.889**** | 4.852**** | 4.844**** |
| $F$ for the step | 0.702 | 8.758*** | 0.664 | 0.052 |
| $F$ for the regression | 0.702 | 4.753*** | 2.695** | 1.785 |
| $R^2$ | 0.01 | 0.08 | 0.09 | 0.09 |

**$p \le 0.05$.
***$p \le 0.01$.
****$p \le 0.001$.

Table 6
Hierarchical regression with autonomy/technology interactions
(1) Dependent variable is project Execution success.
(2) $n = 120$.
(3) Main table contains standardized coefficient betas.

| Variables entered | Step 1 | Step 2 | Step 3 | Step 4 |
|---|---|---|---|---|
| Project priority | −0.077 | −0.111 | −0.111 | −0.113 |
| Project management autonomy | | 0.225** | 0.231** | 0.236** |
| Product technology novelty | | | 0.090 | 0.078 |
| Process technology novelty | | | −0.127 | −0.121 |
| Project management autonomy × Product technology novelty | | | | 0.070 |
| Project management autonomy × Process technology novelty | | | | 0.034 |
| Intercept | 4.759**** | 4.878**** | 4.880**** | 4.870**** |
| $F$ for the step | 0.702 | 6.123** | 0.864 | 0.471 |
| $F$ for the regression | 0.702 | 3.428** | 2.142* | 1.572 |
| $R^2$ | 0.01 | 0.06 | 0.07 | 0.08 |

*$p \leq 0.1$.
**$p \leq 0.05$.
****$p \leq 0.001$.

archical moderated regression analysis is used to test these hypotheses. We follow variance partitioning procedures outlined by methodologists (Cohen and Cohen, 1983; Jaccard et al., 1990) and employed in prior empirical operations management research (e.g., Boyer et al., 1997). The analysis is conducted in steps (e.g., see Table 5). First, the control variable (project priority) is entered into the regression. Second, the project execution method variable of interest is entered into the regression. Third, the technology novelty variables are entered as a block. Finally, the interaction terms of the project execution method and technology novelty variables are entered as a block. If the interaction accounts for a significant

Table 7
Hierarchical regression with resource flexibility/technology interactions
(1) Dependent variable is project execution success.
(2) $n = 120$.
(3) Main table contains standardized coefficient betas.

| Variables entered | Step 1 | Step 2 | Step 3 | Step 4 |
|---|---|---|---|---|
| Project priority | −0.077 | −0.184* | −0.172* | −0.170* |
| Resource flexibility | | 0.292*** | 0.296*** | 0.297*** |
| Product technology novelty | | | 0.052 | 0.051 |
| Process technology novelty | | | −0.123 | −0.122 |
| Resource flexibility × Product technology novelty | | | | 0.020 |
| Resource flexibility × Process technology novelty | | | | −0.013 |
| Intercept | 4.759**** | 5.135**** | 5.092**** | 5.085**** |
| $F$ for the step | 0.702 | 9.380*** | 0.752 | 0.022 |
| $F$ for the regression | 0.702 | 5.066*** | 2.898** | 1.906* |
| $R^2$ | 0.01 | 0.08 | 0.09 | 0.09 |

*$p \leq 0.1$.
**$p \leq 0.05$.
***$p \leq 0.01$.
****$p \leq 0.001$.

amount of incremental variance in the dependent variable, then there is evidence to support the hypothesis that there is a significant moderating effect of technology novelty on the given project execution method. A significant incremental variance is determined by the *t*-test for an interaction term, or by the significance test for the incremental *F*-statistic that results from addition of the block of interaction terms (Dean and Snell, 1991; Boyer et al., 1997).

Multicollinearity is a serious problem in moderated regression analysis. Cross-product terms tend to have high correlations with their component terms, leading to inflated standard errors and misinterpretation of the statistical significance of the regression terms (Jaccard et al., 1990). As Neter et al. (1985) (p. 394) explain, ''expression of the independent variables in the form of deviations from the mean serves to reduce substantially the multicollinearity.'' Accordingly, to mitigate any potential multicollinearity, we employed ''centering,'' which involves use of deviation scores for each predictor variable and for calculation of cross-products (the value of the moderator variable is the product of the centered component variables) (Cronbach, 1987; Jaccard et al., 1990). Acceptable variance inflation factors (those close to 1.00) were found in all of the regressions.

Table 5 presents the results for the effects of the interaction of technology novelty and formality. This table shows that the formality main effect is highly significant. However, the two interaction terms have non-significant betas and the incremental *F* for the block of interaction terms is also not significant. There is no evidence of moderation, and Hypothesis 4 is not supported. Table 6 presents the results for the effects of the interaction of technology novelty and project management autonomy. Again, the main effect is highly significant, but the two interaction terms show no significant incremental explanation of variance in project execution success. Hypothesis 5 is not supported. Table 7 presents the results for the effects of the interaction of technology novelty and resource flexibility. The resource flexibility main effect is highly significant. However, Hypothesis 6 is not supported because the two interaction terms show no significant incremental explanation of variance. In

Table 8
Hierarchical regression with all project execution methods and technology interactions
(1) Dependent variable is project execution success.
(2) $n = 120$.
(3) Main table contains standardized coefficient betas.

| Variables entered | Step 1 | Step 2 | Step 3 | Step 4 |
|---|---|---|---|---|
| Project priority | −0.077 | −0.205** | −0.182* | −0.185* |
| Formality | | 0.240*** | 0.245*** | 0.250*** |
| Project management autonomy | | 0.192** | 0.200** | 0.214** |
| Resource flexibility | | 0.179* | 0.185* | 0.179* |
| Product technology novelty | | | 0.026 | 0.008 |
| Process technology novelty | | | −0.137 | −0.124 |
| Formality × Product technology novelty | | | | −0.046 |
| Formality × Process technology novelty | | | | 0.052 |
| Project management autonomy × Product technology novelty | | | | 0.044 |
| Project management autonomy × Process technology novelty | | | | 0.048 |
| Resource flexibility × Product technology novelty | | | | −0.006 |
| Resource flexibility × Process technology novelty | | | | −0.014 |
| Intercept | 4.759**** | 5.209**** | 5.129**** | 5.135**** |
| $F$ for the step | 0.702 | 6.809**** | 1.043 | 0.177 |
| $F$ for the regression | 0.702 | 5.308**** | 3.889**** | 1.948** |
| $R^2$ | 0.01 | 0.16 | 0.17 | 0.18 |

*$p \leq 0.1$.
**$p \leq 0.05$.
***$p \leq 0.01$.
****$p \leq 0.001$.

all, contrary to expectations, the results of the tests of Hypotheses 4, 5 and 6 suggest that technology novelty does not influence the strength of the relationship between project execution methods and project execution success.

For comparison, we analyzed a composite hierarchical moderated regression (see Table 8). This regression procedure first entered the control variable, then entered formality, project management autonomy and resource flexibility as a block, then entered the two technology novelty variables as a block, and then the six interaction terms as a block. Results of the composite regression are fully consistent with the earlier results. The composite regression strongly supports Hypotheses 1, 2 and 3, and also shows that these project execution methods are effective as a group. The composite regression shows no significant interaction terms or significant incremental $F$, providing further evidence that Hypotheses 4, 5 and 6 are not supported — technology novelty is not a moderator.

### *4.1. Interactions among methods*

Tests of two-way interactions of the three project execution methods were conducted using the hierarchical moderated regression approach described earlier. We had no a priori reason to believe that these methods would interact. We conducted the interaction tests in the spirit of exploratory analysis. The results presented above suggest that the methods are singly *and* collectively effective in terms of project execution success. Additional interaction tests would show whether these methods are synergistic, which is a step beyond collective effectiveness. The interaction analyses showed no statistically significant cross-products of the methods variables. We conclude that while the three project execution methods are singly and collectively beneficial to project execution success, they are not synergistically beneficial; i.e., the effectiveness of one method is not, in part, modified by, or incumbent on, the level of usage of one of the other methods.

### *4.2. Summary of results*

In all, the statistical results strongly support Hypotheses 1, 2 and 3 that the use of the project execution methods of formality, project management autonomy and resource flexibility is associated with greater project execution success. Hypotheses 4, 5 and 6 are not supported, suggesting that technology novelty does not influence the strength of the relationship between given project execution methods and project execution success.

## 5. Discussion

### *5.1. Firmness and flexibility*

Firms have a practical concern about ''balancing firmness and flexibility'' in product development. Our findings clarify how this may be done. Based on the results, we believe that firmness and flexibility are different roles that are compatible together. Firmness is achieved through project management *formality,* which provides an overall control and review structure for the project. Flexibility is achieved by *project management autonomy* and *resource flexibility*, which allow somewhat unfettered means to get work done and respond to emerging project problems. Effective product development execution requires organizational *flexibility within a structure*; i.e., firmness in the sense of having a predetermined structure, and flexibility in the nature of work within that structure.

From a theoretical perspective, high formality and high autonomy represent different directions on the organic/mechanistic spectrum, and so seemingly conflict. Our findings suggest that high formality and high autonomy are effective together. After all, product innovation requires flexibility but ''at the same time, it is also important to create structure and motivate pace'' (Eisenhardt and Tabrizi, 1995, p. 91). Or as Imai et al. (1985) (p. 357) note, ''checks are needed to prevent looseness, ambiguity, tension or conflict from getting out of control.'' Both firmness and flexibility are needed.

### *5.2. No interactions?*

What might explain our unexpected finding that the project execution effectiveness of formality, project management autonomy and resource flexibility is not significantly influenced by technology novelty? One typical methodological reason for lack of statistically significant interaction terms is sample size and statistical power. Interaction effects of moderate strength should appear for a regression sample of 120 (Cohen and Cohen, 1983). Therefore, from the point of view of statistical power, interaction effects (if they exist at all) must be weak. Non-significant interaction results can also arise due to poor measures (Jaccard et al., 1990). The survey measures employed in this study were rigorously tested in the survey instrument development and field pilots to assure scale validity. The factor analysis results and standardized Cronbach's alpha measures of internal reliability support that these scales are distinct and reliable. And hypothesized main effects were supported, further supporting scale validity. Accordingly, we rule out methodological explanations for lack of significance and now consider theoretical explanations.

The existence of contingent relationships between organizational factors and innovative tasks has been shown empirically in other studies (Tushman, 1978; Katz, 1982), but these studies considered a wide range of innovative activity from maintenance tasks and engineering-change-orders (highly certain tasks) to pure ''breakthrough'' scientific research projects (highly uncertain tasks). In contrast, the present study conducts contingent tests of project execution methods *specifically* for product development projects. We now see that product development projects take up a narrower range in the center of that full innovative spectrum, and have limited variation in task uncertainty relative to the variation inherent in the broad spectrum of innovative tasks. Organizational information processing theory requires broad variation in the task uncertainty dimension for contingent effects to be shown. We speculate there is a ''mismatch'' between the task uncertainty range assumed by theory and the task uncertainty range observed in this sample; i.e., different product development projects are ''not different enough'' in their task uncertainty to gain benefits from different project execution methods. This would explain why we found that the effectiveness of the project execution methods studied is not contingent on the technology novelty of the product development project. Practically, this suggests that firms can manage many product development projects in a broadly similar fashion: project execution could be straightforward, using similar project execution methods in all projects. This also suggests that the application of organizational information processing theory in the product development project context has limited explanatory value.

Our findings still might be consistent with the notion that there are contingent relationships in the project execution phase, but at a very localized (e.g., sub-task or single-function task) level rather than at the project level. Indeed, we would expect this if variation in task uncertainty was greater at the sub-task level than at the full project level. Our measures were cross-project in nature rather than measures of local phenomena, and so would not capture sub-task effects.

We also wonder whether many potential contingencies in project execution get resolved in the earlier project planning phase, and are thus invisible in the subsequent project execution phase. For example, firms could put in place slightly more lax project objectives for projects having higher technology novelty. This organizational action (putting in place ''lax'' objectives) is taken contingent on the perceived level of task uncertainty (represented by higher technology novelty). Implementing the contingent action during the project planning phase obviates the need for contingent methods during the project execution phase. What this means is that broad actions may be taken in project planning to mitigate broad contingencies that might otherwise occur in project execution. This suggests again that in order to achieve project execution success, the project execution phase should be straightforward, with similar execution methods used across a variety of projects.

## 6. Implications for practice and future research

In responding to the uncertainty posed by new product development projects, one key issue project managers face is that of ''balancing firmness and flexibility'' in the execution of product development projects. The results suggest clear implications for practice. Firms should put in place both firmness and flexibility. Firms should create firmness (structure) at a project level, and flexibility at a working level within the project. Balancing firmness and flexibility, by having flexibility within a structure, is both achievable and desirable.

While our findings suggest that firms should put in place relatively high levels of formality, project management autonomy or resource flexibility, we find that these project-oriented, integrative methods are not widely used. For example, although the phase gate system is considered the most widely used product development management approach, a recent study found that 38.5% of firms uses no formal process for managing development projects (Griffin, 1997b). Ninety-three percent of the projects in our sample did not use a very high level of project management formality. Table 9 displays the number of projects that used the project execution methods at a very high level (''very high level'' is defined as a value of 6.0 or above on the scale measure for formality, project management autonomy or resource flexibility). Usage of very high levels is generally the exception in practice, and represents a significant, untapped opportunity for improvement of new product development effectiveness.

The three methods are *decision* variables, but ''who decides'' may vary greatly across firms. In some cases, project managers may decide the levels of the various execution methods, while in other cases, it may be portfolio level managers (e.g., Director of R&D) or corporate level executives. In some cases, no one in the firm (be they project-level management or senior executives) may be able to directly influence the choice of level of these decision variables. Instead, the level of formality, project management autonomy and resource flexibility may be mandated by external players. For example, a developer may be constrained by government contract requirements that specify the project management approach. This is a practical constraint that calls for pre-project negotiation, to the degree possible, with the external, constraining party to allow the developing firm discretion in setting the variable levels.

Table 9
Rate of usage of project execution methods at a very high level

| Project execution method | Percentage of projects using this method at a very high level |
|---|---|
| Formality | 7 |
| Project management autonomy | 22 |
| Resource flexibility | 6 |

Determining how to implement and maintain high levels of these project execution methods can be difficult. For example, 5 years is the norm for achieving nearly full implementation of phase gate processes in firms, and negative results accrue at first (O'Connor, 1994). Implementing autonomy is also difficult (Gerwin and Moffat, 1997b). Future research should determine how firms can efficiently adopt, utilize, evaluate, and continuously improve these project execution methods. Future research should also look more deeply within each execution method to elucidate and evaluate sub-dimensions of formality and autonomy. And future research should study the efficacy of other project execution methods that are integrative and project-oriented, but also not widely applied, such as project-based performance evaluation of project personnel (vs. traditional department-based evaluation and rewards) (Susman and Dean, 1992).

The findings suggest that the project execution methods are equally effective for product development projects of high or low technology novelty. This lack of contingent results calls for future investigation, both practical and theoretical. Replication tests to confirm the lack of interaction would provide greater guidance to practice. In terms of theory, we believe that the range of task uncertainty posed by a variety of product development projects is much smaller than the range conceptualized by organizational information processing theory. This speculation merits further empirical study to determine whether, from the perspective of information processing theory, product development projects are in fact largely similar. Future research should employ both sub-task level and project level measures to determine whether sub-tasks within product development projects exhibit high task uncertainty variation, and so benefit from contingent execution approaches. Future research should also study whether relevant contingencies are resolved in the project planning phase.

Future research on product development project execution could overcome the methodological and scope limitations of this study by applying longitudinal data collection methods with multiple informants. Studies of the hypothesized relationships in non-assembled products contexts such as development of process goods, software and new services would aid in determining the generalizability of the findings across development contexts.

While this paper studied methods that apply to a single project, it would be interesting to explore the notion of ''balance'' in the broader context of all the works being done in a firm. There needs to be balance between project and ongoing functional work activities (Gerwin and Susman, 1996), and balance between a single project and a portfolio of projects (Adler et al., 1995). For example, some forms of autonomy are not always beneficial in the context of multiple projects or a hierarchy of projects because the given project may infringe on the resources, power and work process of other projects (Gerwin and Moffat, 1997a). This is analogous to the classic manufacturing issue of ''local vs. global optimization.'' It is possible to locally optimize a single product development project at the cost of global benefits such as an effective overall product development portfolio or firm level success. Balancing execution methods and success at the project-level with execution methods and success at the portfolio-level or firm-level is a complicated and sometimes contradictory management challenge worthy of further study.

## 7. Research on project execution

We hope this study of project management and product development contributes to a renewed research emphasis on project execution. Operations management literature on project management has primarily addressed network scheduling techniques (e.g., PERT). These are valuable tools; however, ''scheduling is only one of several serious problems that the project manager must solve'' (Meredith and Mantel, 1995, p. vii). The management of project execution has an ambiguity that is uncomfortable for researchers accustomed to precision in the statement of project tasks. And yet, it is exactly this ambiguity that is common in product development practice (Smith-Daniels, 1997).

The need for new theory and investigation of work execution at the project level is now receiving attention in other disciplines. In the marketing field, Moorman and Miner (1998) have advocated an ''improvisational'' approach to project work that includes substantial during-project adaptation. In the strategy field, Eisenhardt and Tabrizi (1995) (p. 93) propose the use of an ''experiential strategy'' that provides an overall ''order and routine that serves as a counterpoint to the more freewheeling'' day-to-day activities of R&D work. We noted earlier that organizational information processing theory may be inadequate in its explanatory power for the specific context of development projects. A different theory, with associated new instrumentation and research methods, may be necessary for a deeper explanatory basis regarding project execution in product development projects.

Product development projects are ad hoc task forces. For the most part, extant organizational theory addresses either workgroups or company division-level activities rather than task forces or projects, which make up an organizational form at a level in between workgroups and divisions. Further, there is a tremendous need to understand how to manage transitional organizational structures — temporary or ad hoc organizations — that draw on resources from many functions and where the leadership of the temporary organization (e.g., the project manager) rarely has primary control over project resources. As such, the concerns noted in this paper regarding product development project execution also apply to other contemporary operations contexts. After all, the ad hoc task force is simply one form of the ''virtual organization'' central to today's operations.

## 8. Conclusions

This paper aimed to contribute to both the new product development and project management literatures by providing a large-sample, cross-sectional, confirmatory test of the effectiveness of selected project execution approaches in achieving product development project execution success. Specific hypotheses were posed based on theory and field observation. This paper differs from the vast majority of operations management literature on project management through its focus on mechanisms employed during the project, rather than on detailed network scheduling techniques for project planning.

The first research question asked, ''How do the project execution methods of formality, project management autonomy and resource flexibility influence the execution success of product development projects?'' We found that these methods are all positively associated with project execution success, and that firms should adopt these approaches. Further, these methods are effective together, suggesting that firms can indeed ''balance firmness and flexibility'' in product development. The second research question asked, ''Does the newness of the technology to be developed during the project influence the strength of the relationship between project execution practices and project execution success?'' Surprisingly, the results suggest that the effectiveness of these methods is not contingent on the technology novelty inherent in a given development project. Therefore, firms can manage a variety of projects using broadly similar project execution methods.

A deeper understanding of project execution provides relevant guidance to practicing managers. We found that there are ways to better manage product development projects. In addition, we hope that this study contributes, in general, to the dialogue on managing projects, and, in particular, to motivating a renewed research emphasis, including theory development, on project execution.

## Acknowledgements

We are grateful to our colleagues who aided in the development of this paper: Barry Bayus, Cecil Bozarth, J. Robb Dixon, Anne Ilinitch, Lawrence Menor, Jeffrey Miller, Christine Pearson, and Pieter VanderWerf. We acknowledge the constructive comments of the associate editor and anonymous reviewers. The Product Development Management Association and the Boston University Center for Enterprise Leadership (CEL) provided access to member companies. The CEL and the Marketing Science Institute provided financial support.

## Appendix A. Variable operationalizations

### A.1. Project execution methods

The *formality* scale is made up of the three items below.

The scale is seven-point Likert type, with: 7 = Completely; 4 = Somewhat; 1 = Not At All.

To what degree were project management rules and procedures *formalized* via documents such as contract book, sign-off forms, and such?

To what degree were formal project management rules and procedures *actually followed* for this project?

To what degree were formal progress reviews held (sometimes also called design, gate, phase or stage reviews)?

The *project management autonomy* scale is made up of the first three items below. The *resource flexibility* scale is made up of the second three items.

The scale is seven-point Likert type, with: 7 = Completely Free; 4 = Somewhat Free; 1 = Not Free At All.

With respect to upper management, how *free* was project management to:

Determine interim schedule targets;
Determine the project management approach;
Choose the format of progress reviews;
Reallocate financial resources during the project;
Reallocate personnel resources during the project; and
Reallocate equipment resources during the project.

### A.2. 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 scale is seven-point Likert type, with: 7 = Completely New; 4 = Somewhat New; 1 = 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*.

### *A.3. Project execution success*

The overall success of the *execution* of the product development project is a composite of the achievement of the individual project objectives. Achievement of an individual project objective is measured with a single item (each of the first three items below).

The 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** (i.e., 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?

The composite project execution success measure is a weighted sum of the individual achievement measures (the first three items) and the overall achievement measure (the fourth item). The fourth item was weighted 25%, while the first three items were collectively weighted 75%. This 75% weight was in turn allocated among the three items based on the relative importance of achieving that project objective. The items regarding importance of each objective are below.

The scale is seven-point Likert type, with: 7 = Great Importance; 4 = Some Importance; 1 = No Importance.

Project objectives also vary in their importance. At the beginning of the project, how *important* was achieving each objective thought to be for project success:

product performance;
unit-cost; and
time-to-market.

This definitional material had been provided earlier in the survey:

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.

## References


Abernathy, W.J., Clark, K.B., 1985. Innovation: mapping the winds of creative destruction. Research Policy (14), 3–22.

Adler, P.S., 1995. Interdepartmental interdependence and coordination: the case of the design/manufacturing interface. Organization Science 6 (2), 147–167.

Adler, P.S., Mandelbaum, A., Nguyen, V., Schwerer, E., 1995. From project to process management: an empirically based framework for analyzing product development time. Management Science 41 (3), 458–484.

Bailetti, A.J., Callahan, R., DiPietro, P., 1994. A coordination structure approach to the management of projects. IEEE Transactions on Engineering Management 41 (4), 394–403.

Bailyn, L., 1985. Autonomy in the industrial R&D lab. Human Resource Management 24, 129–146.

Barnett, B.D., Clark, K.B., 1996. Technological newness: an empirical study in the process industries. Journal of Engineering and Technology Management 13, 263–282.

Boyer, K.K., Leong, G.K., Ward, P.T., Krajewski, L.J., 1997. Unlocking the potential of advanced manufacturing technologies. Journal of Operations Management 15, 331–347.

Bozarth, C., Handfield, R., Das, A., 1998. Stages of global sourcing strategy evolution: an exploratory study. Journal of Operations Management 16, 241–255.

Burns, T., Stalker, G.M., 1961. The Management of Innovation. Tavistock Publishers, London.

Capon, N., Farley, J.U., Lehmann, D.R., Hulbert, J.M., 1992. Profiles of product innovators among large U.S. manufacturers. Management Science 38 (2), 157–169.

Cardinal, L.B., 2000. Technological innovation in the R&D laboratory: the use of input, behavior, and output controls in the pharmaceutical industry. In: Organization Science. forthcoming.

Clark, K.B., 1989. Project scope and project performance: the effect of parts strategy and supplier involvement on product development. Management Science 35 (10), 1247–1263.

Clark, K.B., Fujimoto, T., 1991. Product Development Performance. Harvard Business School Press, Boston.

Cohen, J., Cohen, P., 1983. Applied Multiple Regression/Correlation Analysis for the Behavioral Sciences. Erlbaum, Hillsdale, NJ.

Cohen, W.M., Levinthal, D.A., 1990. Absorptive capacity: a new perspective on learning and innovation. Administrative Science Quarterly 35, 128–152.

Cooper, G., 1983. A process model for industrial new product development. IEEE Transactions on Engineering Management 30 (1), 2–11.

Cooper, R.G., Kleinschmidt, E., 1990. Stage gate systems for new product success. Marketing Management 1 (4), 20–24.

Cronbach, L., 1987. Statistical tests for moderator variables. Psychological Bulletin 102, 414–417.

Daft, R.L., Lengel, H., 1984. Information richness: a new approach to managerial behavior and organization design. In: Staw, Cummings (Eds.), Research in Organizational Behavior 6pp. 191–233.

Daft, R.L., Lengel, R.H., 1986. Organizational information requirements, media richness and structural design. Management Science 32 (5), 554–571.

Dean, J.W., Snell, S.A., 1991. Integrated manufacturing and job design: moderating effects of organizational inertia. Academy of Management Journal 34 (4), 776–804.

Donnellon, A., 1993. Cross-functional teams in product development: accommodating the structure to the process. Journal of Product Innovation Management 10, 377–392.

Dougherty, D., 1992. Interpretive barriers to successful product innovation in large firms. Organization Science 3, 179–202.

Eisenhardt, K.M., 1985. Control: organizational and economic approaches. Management Science 31, 134–149.

Eisenhardt, K.M., Tabrizi, B.N., 1995. Accelerating adaptive processes: product innovation in the global computer industry. Administrative Science Quarterly 40, 84–110.

Ettlie, J.E., 1995. Product process development integration in manufacturing. Management Science 41 (7), 1224–1237.

Ettlie, J.E., Bridges, W.P., O'Keefe, R.D., 1984. Organization strategy and structural differences for radical versus incremental innovation. Management Science 30 (6), 682–695.

Galbraith, J.R., 1973. Designing Complex Organizations. Addison-Wesley, Reading, MA.

Galbraith, J.R., 1977. Organization Design. Addison-Wesley, Reading, MA.

Gerwin, D., Moffat, L., 1997a. Authorizing processes changing team autonomy during new product development. Journal of Engineering and Technology Management 14, 291–313.

Gerwin, D., Moffat, L., 1997b. Withdrawal of team autonomy during concurrent engineering. Management Science 43 (9), 1275–1287.

Gerwin, D., Susman, G., 1996. Guest editorial: special issue on concurrent engineering. IEEE Transactions on Engineering Management 43 (2), 118–123.

Griffin, A., 1997a. The effect of project and process characteristics on product development cycle time. Journal of Marketing Research 34, 24–35.

Griffin, A., 1997b. PDMA research on new product development practices. Journal of Product Innovation Management 14, 429–458.

Griffin, A., Page, A.L., 1996. PDMA success measurement project. Journal of Product Innovation Management 13, 478–496.

Gupta, A.K., Wilemon, D.L., 1990. Accelerating the development of technology-based new products. California Management Review, 24–44, Winter.

Hackman, J.R., Oldham, G.R., 1980. Work Redesign. Addison-Wesley, Reading, MA.

Hauptman, O., Hirji, K.K., 1996. The influence of process concurrency and project outcomes in product development: an empirical study of cross-functional teams. IEEE Transactions on Engineering Management 43 (2), 153–164.

Henderson, R.M., Clark, K.B., 1990. Architectural innovation: the reconfiguration of existing product technologies and the failure of established firms. Administrative Science Quarterly 35 (1), 9–30.

Iansiti, M., 1995. Science-based product development: an empirical study of the mainframe computer industry. Production and Operations Management 4 (4), 335–359.

Imai, K., Ikujiro, N., Takeuchi, H., 1985. Managing the new product development process: how Japanese companies learn and unlearn. In: Hayes, Clark, Lorenz (Eds.), The Uneasy Alliance. Harvard Business School Press, Boston, pp. 337–375.

Jaccard, J., Wan, C.K., Turrisi, R., 1990. The detection and interpretation of interaction effects between continuous variables in multiple regression. Multivariate Behavioral Research 25, 467–478.

Kahn, W., Kram, K., 1994. Authority at work: internal models and their organizational consequences. Academy of Management Review 19, 17–50.

Katz, R., 1982. The effects of group longevity on project communication and performance. Administrative Science Quarterly 27, 81–104.

Khurana, A., Rosenthal, S.R., 1997. Integrating the fuzzy front end of new product development. Sloan Management Review 38 (2), 103–120.

Kim, Y., Lee, B., 1995. R&D project team climate and team performance in Korea. R&D Management 25 (2), 179–197.

Klein, J., 1991. A re-examination of autonomy in light of new manufacturing policies. Human Relations 44 (1), 21–38.

Koys, D.J., DeCotiis, T.A., 1991. Inductive measures of psychological climate. Human Relations, 282–318.

Mabert, V.A., Muth, J.F., Schmenner, R.W., 1992. Collapsing new product development times: six case studies. Journal of Product Innovation Management 9, 200–212.

Malhotra, M.J., Grover, V., 1998. An assessment of survey research in POM: from constructs to theory. Journal of Operations Management 16, 407–425.

Meredith, J.R., Mantel, S.J., 1995. Project Management: A Managerial Approach. Wiley, New York.

Meyer, M.H., Roberts, E.B., 1986. New product strategy in small technology-based firms: a pilot study. Management Science 32 (7), 806–821.

Meyer, M.H., Tertzakian, P., Utterback, J.M., 1997. Metrics for managing research and development in the context of the product family. Management Science 43 (1), 88–111.

Meyer, M.H., Utterback, J.M., 1995. Product development cycle time and commercial success. IEEE Transactions on Engineering Management 42 (4), 297–304.

Moenaert, R.K., DeMeyer, A., Souder, W.E., Deschoolmeester, D., 1995. R&D/marketing communication during the fuzzy front-end. IEEE Transactions on Engineering Management 42 (3), 243–258.

Moorman, C., Miner, A.S., 1998. The convergence of planning and execution: improvisation in new product development. Journal of Marketing 62, 1–20, July.

Myers, S., Marquis, D.C., 1969. Successful industrial innovations. National Science Foundation Report 69-17, Washington, DC.

Neter, J., Wasserman, W., Kutner, M.H., 1985. Applied Linear Statistical Models. Irwin, Homewood, IL.

Nunnally, J.C., 1978. Psychometric Theory. McGraw-Hill, New York.

O'Connor, D., 1994. Implementing a stage gate process: a multi-company perspective. Journal of Product Innovation Management 11, 183–200.

Oldham, G.R., Hackman, J.R., 1981. Relationships between organizational structure and employee reactions: comparing alternative frameworks. Administrative Science Quarterly 26, 66–83.

Ouchi, W.G., 1977. The relationship between organization structure and organizational control. Administrative Science Quarterly 22, 95–113.

Price, J.L., Mueller, C.W., 1986. Handbook of Organizational Measurement. Pitman Publishing, Marshfield, MA.

Project Management Institute, 1998. Membership Literature, Upper Darby, PA.

Rosenthal, S.R., 1992. Effective Product Design and Development. Irwin, Homewood, IL.

Rosenthal, S.R., Tatikonda, M.V., 1993. Time management in new product development: case study findings. IEEE Engineering Management Review 21 (3), 13–20.

Rothwell, R., Freeman, C., Horlsey, A., Jervis, V.T.P., Robertson, A.B., Townsend, J., 1974. SAPPHO updated — project SAPPHO phase II. Research Policy 3, 258–291.

Rubenstein, A.H., Chakrabarti, A.K., O'Keefe, R.D., Souder, W.E., Young, H.C., 1976. Factors influencing innovation success at the project level. Research Management, 15–20, May.

Schilling, M.A., Hill, C.W.L., 1998. Managing the new product development process: strategic imperatives. Academy of Management Executive 12 (30), 67–81.

Scott, W.R., 1981. Organizations. Prentice-Hall, Englewood Cliffs, NJ.

Smith, P.G., Reinertsen, D.G., 1998. Developing Products in Half the Time. Van Nostrand-Reinhold, New York.

Smith-Daniels, D., 1997. Teaching project management to MBAs. Decision Line, 11–13, May.

Souder, W.J., 1974. Autonomy, gratification and R&D outputs: a small sample field study. Management Science 20 (8), 1147–1156.

Spector, P.E., 1992. Summated Rating Scale Construction. Sage Publications, Newbury Park, CA.

Suh, N., 1990. The Principles of Design. Oxford Univ. Press, New York.

Susman, G.I., Dean, J.W., 1992. Development of a model for predicting design for manufacturability effectiveness. In: Susman, G.I. (Ed.), Integrating Design and Manufacturing for Competitive Advantage. Oxford Univ. Press, New York, pp. 207–227.

Swink, M., 1998. A tutorial on implementing concurrent engineering in new product development programs. Journal of Operations Management 16 (1), 103–116.

Tatikonda, M.V., 1999. An empirical study of platform and derivative product development projects. Journal of Product Innovation Management 16 (1), 3–26.

Tatikonda, M.V., Rosenthal, S.R., 2000. Technology novelty, project complexity and product development project execution success. IEEE Transactions on Engineering Management 47 (1), 74–87.

Thamhain, H.J., 1990. Managing technologically innovative team efforts toward new product success. Journal of Product Innovation Management 7, 5–18.

Tushman, M.L., 1978. Technical communication in R&D laboratories: the impact of project work characteristics. Academy of Management Journal 21 (4), 624–645.

Tushman, M.L., 1979. Work characteristics and sub-unit communication structure. Administrative Science Quarterly 24, 82–98.

Tushman, M.L., Nadler, D.A., 1978. Information processing as an integrating concept in organizational design. Academy of Management Review 3, 613–624.

Tyre, M.J., Hauptman, O., 1992. Effectiveness of organizational response mechanisms to technological change in the production process. Organization Science 3 (3), 301–320.

Ulrich, K.T., Ellison, D.J., 1999. Holistic customer requirements and the design-select decision. Management Science 45 (5), 641–658.

Utterback, J.M., 1994. Mastering the Dynamics of Innovation. Harvard Business School Press, Boston.

Van de Ven, A.H., Ferry, D.L., 1980. Measuring and Assessing Organizations. Wiley-Interscience, New York.

Vickery, S.K, Droge, C., Markland, R.E., 1997. Dimensions of manufacturing strength in the furniture industry. Journal of Operations Management 15, 317–330.

Wheelwright, S.C., Clark, K.B., 1992a. Creating project plans to focus product development. In: Harvard Business Review. pp. 70–82, March/April.

Wheelwright, S.C., Clark, K.B., 1992b. Revolutionizing Product Development. Free Press, New York.

Wind, J., Mahajan, V., 1997. Issues and opportunities in new product development. Journal of Marketing Research 34, 1–11, February.

Zirger, B.J., Hartley, J.L., 1996. The effect of acceleration techniques on product development time. IEEE Transactions on Engineering Management 43 (2), 143–152.

Zirger, B.J., Maidique, M.A., 1990. A model of new product development: an empirical test. Management Science 36 (7), 867–883.