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One Size Does Not Fit All Projects: Exploring Classical Contingency Domains

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Not many authors have attempted to classify projects according to any specific scheme, and those who have tried rarely offered extensive empirical evidence. From a theoretical perspective, a traditional distinction between radical and incremental innovation has often been used in the literature of innovation, and has created the basis for many classical contingency studies. Similar concepts, however, did not become standard in the literature of projects, and it seems that theory development in project management is still in its early years. As a result, most project management literature still assumes that all projects are fundamentally similar and that "one size fits all." The purpose of this exploratory research is to show how different types of projects are managed in different ways, and to explore the domain of traditional contingency theory in the more modern world of projects. This two-step research is using a combination of qualitative and quantitative methods and two data sets to suggest a conceptual, two-dimensional construct model for the classification of technical projects and for the investigation of project contingencies. Within this framework, projects are classified into four levels of technological uncertainty, and into three levels of system complexity, according to a hierarchy of systems and subsystems. The study provides two types of implications. For project leadership it shows why and how management should adapt a more project-specific style. For theory development, it offers a collection of insights that seem relevant to the world of projects as temporary organizations, but are, at times, different from classical structural contingency theory paradigms in enduring organizations. While still exploratory in nature, this study attempts to suggest new inroads to the future study of modern project domains.
(*Project Management; Contingency Theory; Project Types; Project Classification; Technological Uncertainty; System Complexity*)

Introduction

As an organized activity of mankind, projects could probably be found in all civilizations. However, as a formal managerial discipline, project management is usually traced back to the precedence network diagramming techniques developed for the Polaris Submarine project in the 1950s and early 1960s (Fondahl 1987). Today, however, virtually all construction, product development, and engineering efforts are using some formal project management structure, typically defined as a temporary organization that has been established to complete a specific goal (Cleland and King 1983).

The wide deployment of projects today illuminates, in a rather paradoxical way, that as an organizational concept project management is quite new, probably not well understood, and clearly understudied. Most research literature on the management of projects is relatively young and still suffers from a scanty theoretical basis and lack of concepts. The goal of this

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exploratory research is to contribute to theory building of project management in two ways: first, to show how different types of projects are managed in different ways, and second, to explore the domain of traditional contingency theory in the more modern world of projects. This study was conducted in two steps while using a combination of qualitative and quantitative methods, and a two-dimensional model for the classification of projects. The first step involved a qualitative study of 26 case projects, and was followed by the second, quantitative, part, which involved statistical data on 127 projects.

The paper is structured as follows. Following the theoretical background, the paper suggests a conceptual model for distinction among projects. The methodology section describes, respectively, the cases as well as the statistical data sets for the qualitative and quantitative parts. The qualitative findings then show how project management styles are typically clustered according to the project's technological uncertainty and system complexity. The quantitative second-part findings are then used to support the qualitative results and to test significant emerging trends. Finally, the discussion and implication sections illustrate the theoretical differences between existing and temporary organizations (projects) and suggest implications for management and further research.

Theoretical Background and Basic Proposition

Classical contingency theory asserts that different external conditions might require different organizational characteristics, and that the effectiveness of the organization is contingent upon the amount of congruence or goodness of fit between structural and environmental variables (Lawrence and Lorsch 1967, Drazin and van de Ven 1985, Pennings 1992). The theory was introduced by Burns and Stalker (1961), who were among the first to suggest the traditional distinction between incremental and radical innovation, and between organic and mechanistic organizations. A mechanistic organization was described as formal, centralized, specialized, and bureaucratic; having many authority levels; and maintaining only a minimal level of communication. An organic organization, in contrast, was characterized as being informal, decentralized, having just a few authority levels, having a breadth view (rather than a specialized one), and typically using extensive levels of communication. According to the classical theorists, organic organizations would better cope with uncertain and complex environments while mechanistic organizations predominate in simple, stable, and more certain environments. Mechanistic and organic organizations also differ in their capacity to deal with information, suggesting that organic organizations provide more capacity. Later scholars have similarly hypothesized that organizations that perform more innovative tasks would be different from organizations that develop more routine products (e.g., Perrow 1967, Thompson 1967, Mansfield 1968, Zaltman et al. 1973, Moch and Morse 1977, Blake 1978, Abernathy and Utterback 1978, Freeman 1982, Galbraith 1982, Burgelman 1983, Ettlie et al. 1984, Drazin and van de Ven 1985, Dewar and Dutton 1986, Bart 1988, Pennings 1992).

While correlates of structural and environmental attributes have been well studied when the organization is the unit of analysis, they have been much less investigated in the project context. The project management literature has often ignored the importance of project contingencies, assuming that all projects share a universal set of managerial characteristics (Pinto and Covin 1989, Shenhar 1993, Yap and Souder 1994). Yet, projects can be seen as "temporary organizations *within* organizations," and may exhibit variations in structure when compared to their mother organizations. Indeed, several authors have recently expressed disappointment in the universal "one-size-fits-all" idea, and recommended a more contingent approach to the study of projects (Yap and Souder 1994, Eisenhardt and Tabrizi 1995, Balachandra and Friar 1997, Brown and Eisenhardt 1997, Souder and Song 1997, Song et al. 1997). As argued, by utilizing traditional concepts in a new domain, new insights will most likely emerge in this evolving and dynamic field (Brown and Eisenhardt 1997).

But how would classical contingency arguments hold, and what are the dimensions of structure and variations in the dynamic, temporary, and changing world of projects? As the coming discussion demonstrates, a careful review of the classical, as well as the more recent, literature suggests the emergence of two major dimensions—uncertainty and complexity. Thus, we have made them the focus of this research. In selecting these dimensions, we are not suggesting that these are the only variables that might be found to be different in various projects, but only that they seemed to be relevant dimensions which our own observations and those of earlier researchers have suggested might be important. We start by discussing the role of uncertainty and complexity in the classical, as well as modern, literature of organizations, and then observe their function in the project and product management literature.

Three influential works that were published independently in 1967 have had a significant impact on contingency theory. Lawrence and Lorsch (1967) focused on how different rates of change in technology, science, and markets impact the organization's ability to cope with these changes. Specifically, they asked how such changes might influence the organization's orientation toward differentiation (division of labor and acquiring specific skills and practices) and integration of the complex organization (collaboration and unity of effort). Using one integrated score of uncertainty, they concluded that in a more diverse and dynamic field, effective organizations have to be highly differentiated *and* integrated, while in a more stable and less diverse environment, effective organizations can be less differentiated, but must still achieve a high degree of integration. Thompson (1967) suggested that coping with uncertainty is the central problem for complex organizations, and that technology and environments are major sources of uncertainty. To deal with contingencies, he showed how rational organizations would use different strategies for interaction and organizational design. Finally, Perrow (1967) used an integrated viewpoint on technology and complex organizations, while treating technology as the independent variable and structure as the dependent variable. Using technology to distinguish between analyzable and unanalyzable problems, he identified four types of industries—craft, routine, nonroutine, and engineering.

More recent studies have looked at management of innovation and associated it with change. For example, Tushman and Anderson (1986) discussed the interplay between radical and incremental innovation and the cyclical model of technological change. Henderson and Clark (1990) linked different types of technological change to product class and different organizational consequences. Also, Burkhardt and Brass (1990) have conceptualized technological change as a source of uncertainty, and discussed the relations between social structure and power and the diffusion and adoption of technological change.

Although traditional contingency studies in the management of innovation have had only a limited impact on the literature of project management, some exceptions exist. Most have similarly focused on the impact of uncertainty and change on the way organizations are conducting their project operations. For example, Blake (1978) has suggested a normative distinction between minor change (alpha) projects, and major change (beta) projects, and Wheelwright and Clark (1992) have mapped in-house product development projects according to the degree of change in product portfolio. Some have adapted the radical versus incremental distinction (e.g., Yap and Souder 1994, Eisenhardt and Tabrizi 1995, Brown and Eisenhardt 1997, Souder and Song 1997, Song et al. 1997), while others suggested more refined frameworks (e.g., Steele 1975, Ahituv and Neumann 1984, Cash et al. 1988, Pearson 1990). While almost all of these studies used a distinction based on technical uncertainty, none of their typologies has developed so far into a standard, empirically based theoretical framework that is used to analyze the full range of today's projects.

As for project complexity, the hierarchical nature of systems and their subsystems has long been at the cornerstone of general systems theory (Boulding 1956, Van Gigch 1978, Shenhar 1991). Boulding (1956), for example, suggested a hierarchical classification of systems which includes nine levels, starting with the lowest type of static structures and going up to transcendental systems. This concept has often been mentioned in the design literature to distinguish between a product as a whole and a product in its parts (Marples 1961, Alexander 1964). Obviously, since products are composed of components, and systems of subsystems, hierarchies in products are almost always addressed in practitioners' books and monographs that deal with engineering design problems (e.g. Pahl and Beitz 1984, Lewis and Samuel 1989, Rechtin 1991). However, as has been noted, a great deal of the existing knowledge of the design concept is still anecdotal and diverse; its theoretical basis is quite scant, and applicable design principles are only beginning to appear. Consequently, a clear taxonomy of product levels and their design domains is difficult to construct (Hoover and Jones 1991); thus, no clear classification of project hierarchies and their management styles has so far been suggested.

Based on the rich foundations of structural contingency theory for existing organizations, the main proposition of this research is that, in projects too, "one-size-does-not-fit-all" (Balachandra and Friar 1997, Souder and Song 1997). Further, we contend that modern projects exhibit a richer variation than can be captured by a simple dichotomy such as the radical versus incremental distinction, or the traditional organic versus mechanistic model (Burns and Stalker 1961, Eisenhardt and Tabrizi 1995, Brown and Eisenhardt 1997). The conceptual model used in our study is discussed in the next section.

The Conceptual Model

At this exploratory stage, we have decided to focus on the study of technical and engineering-based projects typically resulting in a new product, process or service. This choice was based on two reasons. First, while there are other types of projects, technically based tasks capture a significant portion of today's activity in modern organizations. Second, much of the classical, as well as the later, literature has focused on technology-based (enduring) organizations. Extending the theory to projects (i.e., temporary organizations) seems to be a natural evolutionary step at this time. Based on our observations and earlier research, this paper is using task technological uncertainty and complexity as the main dimensions, and suggests a framework of four levels of uncertainty and three levels of complexity (Dvir et al. 1998).

The Technological Uncertainty Dimension

The classification presented below is based on levels of technological uncertainty at the time of project initiation (Shenhar 1993, Shenhar and Dvir 1996). In general, we associated such uncertainty with the degree of using new (to the company) versus mature technology within the product or process produced. Such association is based on previous studies, equating "high-tech" with extensive use of new technologies, and technological maturity with low uncertainty (Shanklin and Ryans 1984, Roussel et al. 1991, Eisenhardt and Tabrizi 1995). Since most projects employ a mixture of technologies, our classification is related to the share of new technology within the product. The four project types are defined as follows (see Table 1a).

Type A—Low Technological Uncertainty Projects (Low-Tech). This type of project involves implementation of familiar technologies. Such projects rely only on mature technologies to which all industry players have equal access. All technologies are well known, well established, and considered base technologies, namely, they offer little potential for competitive advantage (Little 1981, Roussel et al. 1991). Although the effort may be very large in scale, technology is easily obtained and does not carry any difficulty or uncertainty in execution. Typical projects in this category are construction, road building, bridges, and utility installation. Another example is "build to print" projects in which one contractor is required to build a product previously developed by someone else.

Type B—Medium Technological Uncertainty Projects (Medium-Tech). These are the most common industrial projects. Such projects rest mainly on existing and mature technologies; however, they may involve a limited amount of new technology (often one or two, but never more than 50% of the technologies embodied). In some cases, such projects incorporate a new feature which has not been tried before. The new technology or feature is what usually provides the competitive advantage of the product, and thus serves as its key technology (Little 1981, Roussel et al. 1991). Typical projects in this category may include the development of a new model in a

Table 1 Definition of Different Project Types

(a) Four types of technological uncertainty

Project Type	A	B	C	D
Name	Low-Tech	Medium-Tech	High-Tech	Super High-Tech
Definition	Using existing technologies	Adaptation of familiar technologies; some new technology or a new feature	Integrating many new, but existing, technologies	Integrating key technologies that do not exist at the time of project initiation
Typical Projects and Examples	Construction, road building, utilities, "built to print"	Derivatives or improvements of existing products; new models in a well-established, stable industry e.g., automobiles, consumer electronics	New systems in a fast-moving industry, e.g., computers, new military systems	New nonproven concepts, beyond the current state of the art, e.g., Apollo, moon-landing project

(b) Three levels of system scope

Scope Level	1	2	3
Name	Assembly	System	Array
Definition	Building or developing a collection of components and modules combined into a single unit, either as a subsystem of a larger system, or a stand-alone product performing a single function	Building or developing a collection of subsystems and interactive elements that perform a wide range of functions or activities	Building, developing, or adding to a large widespread collection of systems functioning together to achieve a common purpose
Examples	A power supply, an antenna, household appliances such as, CD players or washing machines	Computers, radar, buildings, aircraft	National air defense system, building a city, a neighborhood, or the city's public transportation system

well-established industry (e.g., automobile or consumer electronics), or improvements, modifications, derivatives, and upgrades of existing products.

Type C—High Technological Uncertainty Projects (High-Tech). These projects constitute the first use of new, but existing, technologies. Specifically, in such projects, more than 50% of the technologies employed are pacing new technologies. As defined, such technologies have the potential to change the basis of competition (Little 1981, Roussel et al. 1991, Eisenhardt and Tabrizi 1995). Although not yet embodied in a product or process, these technologies have been developed prior to the actual project effort. Incorporating existing, but new, technologies for the first time typically leads to products that did not exist in the past, or are even "new to the industry." Many defense development projects that employ recently developed technologies would be included in this category, as well as projects in high-tech or high-velocity industries (Bourgeois and Eisenhardt 1988).

Type D—Super High Technological Uncertainty Projects (Super-High-Tech). Such projects require the development of new technologies that do not exist at the time of project initiation. Some of these technologies are emerging (Little 1981); others are still unknown and have to be developed during the period of project execution. This kind of project is very risky and relatively rare. Although it provides enormous opportunity for competitive advantage, it is usually carried out by few and probably large organizations or government agencies. Typical known examples of this type are the Apollo moon-landing program (Pellegrino and Stoff 1985) or the Hubble Space Telescope (Villard 1989).

The Complexity Dimension—System Scope

The notion that there are different hierarchies within a product or a system with different levels of design and managerial implications is used as the second dimension for distinction among projects (Table 1b). We chose to conceptualize complexity by a hierarchical framework of systems and subsystems (Boulding 1956, Lewis and Samuel 1989, Rechtin 1991). We labeled this dimension system scope. Its three levels are defined as follows:

Scope 1—An Assembly Project. Such a project deals with a single component or with a complete assembly—defined as a collection of components and modules combined into a single unit. An assembly can be a subsystem performing a well-defined function within a larger system, or it can be an independent stand-alone product that performs a *single function* of a limited scale. A radar receiver or a computer's hard drive are common examples of assemblies (subsystems) within larger systems. Compact disk players, television sets, washing machines, and other household appliances are independent assemblies of the second kind. Using dimensions both of uncertainty and scope, the first VCR developed in the mid-1970s (Rosenbloom and Cusumano 1987) would be considered a high-tech assembly project in our framework.

Scope 2—A System Project. A system is defined as a collection of interactive elements functioning together within a single product. However, unlike an assembly, a system consists of many subsystems and is capable of performing a wide range of functions to address an operational need or mission. Projects at this level are dealing with systems such as radar, computers, missiles, or communication; yet they may also involve a higher level of system, which consists of entire platforms, such as aircraft, vessels, automobiles, or buildings. The first Macintosh computer developed by Apple in the 1980s was a typical example of a high-tech system project (Guterl 1984), and building the famous SR-71 "Blackbird" reconnaissance aircraft by Lockheed can be classified as a super-high-tech system project (Johnson and Smith 1985).

Scope 3—An Array Project (or Program). An array is defined as a dispersed collection of systems that function together to achieve a common purpose. Such systems are never placed in a single site; rather, they are spread over a wide geographical area. An array can be considered a "super-system," expressing its nature as a conjunction or conglomeration of systems. A national air defense system with early warning radar, command, and control centers, combat aircraft, and ground-to-air missiles is a good example of such a super-system. Well-known examples of array efforts are New York City's Transit Authority Capital Program of modernizing its subway infrastructure (Manne and Collins 1990), the English Channel Tunnel (Lemley 1992), and the U.S. Strategic Defense Initiative, or, as it is often called, "Stars Wars" (Lawrence 1987). Within the other dimension, uncertainty, these array programs can be classified as low-tech, medium-tech, and super-high-tech respectively.

Research Focus

In the present study we concentrated on an individual project as the fundamental unit of analysis and examined the relationship between project classification and project-specific characteristics. Any project effort involves linking two different, though not disjointed, processes along the project life cycle (Clark and Fujimoto 1989). The first process—the technical process—involves the reduction of technological uncertainty, while assembling external and/or internal pieces of technological knowledge. Essentially, it consists of all technical activities that lead to the creation and shaping of the project's final outcome. The second process—the managerial process—consists of the management activities that are performed to complete the project task within a given time frame and other constraints. This process involves allocating, utilizing, and monitoring resources; coordinating the parties involved; managing the communication and information flow; and supporting the technical process via decision making and data management. In our search for project contingencies, we have asked how these processes would be affected with different levels of technological uncertainty and system scope. However, given the early nature of our research, our main goal was to validate the two-dimensional framework described above and suggest additional contingency insights for future research.

Methodology

Research Design: Two Databases
Because of the exploratory nature of our research and the complexity of the research problem, we performed a two-stage study that involved a combination of qualitative and quantitative methods. The first stage involved 26 projects on which we applied a multiple case study approach, focusing on the dynamics within single settings (Yin 1984). Specifically, we subscribed to the process of case study research as suggested by Eisenhardt (1989). This process is particularly useful in cases such as ours, when an a priori construct is triangulated by multiple investigators, within-case and cross-case analysis, and combined with the role of literature (Glaser and Strauss 1967, Strauss 1987, Eisenhardt 1989, Kirk and Miller 1986). For this portion we initially approached 29 projects in 16 companies. The final set of projects was selected based on the clarity and detail of the data obtained. The second form of data collection involved the distribution of questionnaires among project managers and the collection of detailed quantitative data on each project. For this portion we obtained information on 127 projects (in 76 companies) out of a total number of 182 managers who were approached (70% response rate).

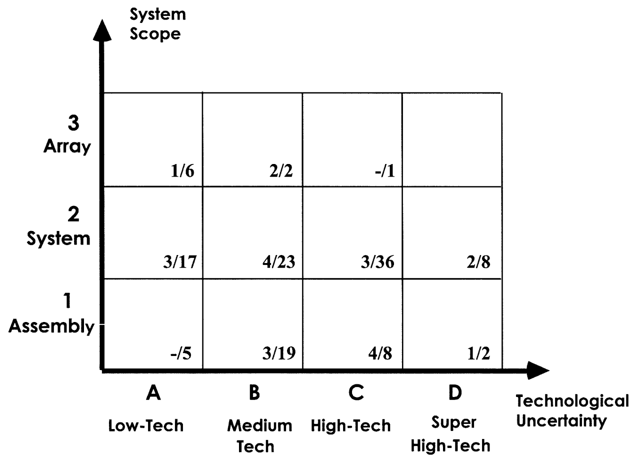
Data collection was performed in Israel, in firms operating in the military or commercial market. Out of these firms, 30 were electronics companies, 18 aerospace, 12 construction, 4 computer, 2 mechanical, and the rest represented a variety of industries such as chemical, pharmaceutical, biochemical, etc. The largest firms in our study included an aerospace company that provided information on 26 projects, two defense development contractors that provided information on 23 and 10 projects respectively, an electronics and communication company (6 projects), a computer company (5 projects), and a construction contractor (5 projects). The rest of the companies were mostly commercial, and each provided information on less than three projects. The projects we studied ranged in budget from $40,000 to $2.5 billion, and in duration from 3 months to 12 years. Out of our sample of 127 projects, 62% were projects of new product development, 15% were product modification projects, and 23% were construction projects; 18% of the projects were for the consumer market, 21% for the industrial market, and 61% for the government.

Caution should be exercised in generalizing the results of this study because the projects studied here were not randomly selected and may not be representative of all projects in general, or in other parts of the world. However, Israeli industry is closely coupled to Western culture, either in Europe or the United States, and many of the organizations involved in our study are subsidiaries or partners of American companies. Projects for this study were mainly chosen because data were available to record characteristics and managerial practices in real, or almost real, time. However, no project was dropped because it did not fit the model, and there is no reason to suspect that the sample is biased in any particular way.

The two-dimensional typology described above was presented to all managers who participated in our study. They were asked to classify their projects on 4-by-3-level scales, according, respectively, to our defined levels of technological uncertainty and system scope. Almost all respondents were comfortable with this classification, and easily placed their task in the appropriate categories. Less than 5% expressed some doubt as to where a specific project should be placed in the uncertainty dimension. Their doubts were promptly resolved, however, after they were asked to do a two-step classification—first into radical versus incremental change, and then into one of the four types. Classifying scope was even easier, since almost all managers immediately acknowledged the hierarchical nature of the defined scope. Our research design resulted in a widespread distribution of the surveyed projects in the two-dimensional space (see Figure 1).

The Case Research
Data collection for the first part was multifaceted (Kirk and Miller 1986), and included in-depth interviews, observations, questionnaires, documents, and archives. Interviews were conducted by teams of two

Figure 1 The Two-Dimensional Model and the Distribution of Data Projects: Case Projects/All Projects Studied



or three, and they interviewed a total of 115 people over a period of more than two years. In addition to the project managers, interviewees included members of the project management team, functional team members who were involved in the project, project managers' supervisors, and customer representatives. At least three people were interviewed from each project. All investigators in this portion of our study were graduate students in Management of Technology who received, prior to its execution, at least 20 hours of training in organizational research. To strengthen our research validity, and as is often required by qualitative studies (Kirk and Miller 1986), we insisted that investigators interact with their subjects on their own turf, namely, at the project site. Notes were taken during all encounters and they were promptly summarized in writing after each interview.

Following an initial phase of data collection, a draft report was prepared for each project according to a common set of guidelines. After an intrateam reliability test, based on thoroughness and detail, and an initial integration stage of these drafts, teams were usually asked to obtain additional data to discover new facts before a final report was prepared (Kirk and Miller 1986). The lengths of these reports were between 40 and 120 typewritten pages. In some cases the author and several of the field investigators returned to a project to clarify additional questions and cross-check relevant data.

Most data for this portion were obtained through interviews in the form of open questions listed in a structured document that was used by all investigators. Questions were asked about the project mission and objectives, and the motivation of the various parties involved: the contractor, customer, and user. Data were also obtained on the managerial procedures and tools used, such as organization, planning and control methods, engineering design practices, computer-aided and software packages, and documentation. Finally, data were also obtained on decision-making processes, information flow, and communication patterns.

The qualitative case data of this study were processed through a method of cross-case comparative analysis (Glaser and Strauss 1967, Miles and Huberman 1984). Multiple tables were created to cluster typical project characteristics for various variables tested. As this strategy requires, the process was highly iterative, with continuous comparison of data and theory, until patterns clearly emerged and additional data no longer added to the refinement of the concepts (Eisenhardt 1989, Kirk and Miller 1986). Clusters of behavior were clearly converging and they were summarized in a set of typical characteristics (Eisenhardt 1989) according to the underlying twofold typology.

The Quantitative Research

During the case data collection of our study, we prepared a preliminary draft of the questionnaire for our second research stage. This draft was distributed to a convenience sample of 17 projects before it was refined to form the final questionnaire version. Data obtained included information about the kind of work that was done. It identified the project as involving a new product development, a product modification, or a construction or production effort. It also identified the type of user (consumer, industrial, or government), and the type of industry. In addition, the questionnaire included several theoretical constructs using seven-point multi-item scales, ranging from "To no extent" to "A great extent" or from "Very low" to "Very high." These constructs related to the engineering and design practices that were used in the project and to various managerial and administrative variables such as extent of planning, control, modifications, replanning, and computer utilization. Finally, we collected data on the project's budget and duration, number of personnel occupied, percentage of workers holding academic degrees, number of design cycles, and the design freeze quartile.

Analysis of the quantitative data included testing the consistency of all multiscale items using Cronbach's alpha values. We then calculated descriptive statistics of all scale variables for each level of technological uncertainty and system scope. ANOVA tests and correlation calculations were performed for all single- and multiscale representative variables with our two dimensions of uncertainty and scope. Finally, we performed regression analyses to determine the linear trends of variables and the interaction effects between our two main dimensions.

Qualitative Findings

The comparative analysis of the 26 case projects allowed the identification of distinct patterns of project management strategies, clustered according to our grounded classification model. At the tactical level, the study identified the various management tools and practices used in different projects and at different levels of uncertainty and scope. As we looked along the uncertainty dimension we found typical activities for reducing technical uncertainty. Distinctions along the second dimension, system scope, related to typical organizational and administrative practices that were employed for different levels of scopes. We present these patterns separately for each dimension, followed by additional observations relating to a joint advancement along the two axes. Later we will use our quantitative data analysis to support our qualitative findings and suggest additional insights.

Reducing Uncertainty Though Design Cycles and Design Freeze

Shaping the product's configuration and setting its specifications involves the execution of many technical activities such as engineering design, building, assembling, testing, and approving. In some of the cases, the completion of the design required additional iterations of design, building, and testing. These iterations were part of the development activities (Hoover and Jones 1991, Eisenhardt and Tabrizi 1995), and they were defined in our study as *design cycles*. A technical project can therefore be seen as a multistage logical process of design cycles, performed to reduce uncertainty (Weick 1979). This process tended to be greatly influenced by the initial level of technological uncertainty.

The data in our study indicate also that the completion of the sequence of design cycles was marked by an important event called *design freeze*. This event did not mean that no further changes were made; it did indicate, however, that the product had reached its final projected form and that additional changes would be made only if essential. The transition from pre- to post-design freeze was characterized by an abrupt change in the project managers' attitude towards change. A high level of flexibility and tolerance for change characterized the project during the initial stage, followed by low or almost no flexibility once the design was frozen. The specific differences between the various types of projects will be demonstrated by the following discussion.

Type A Projects

All Type A case projects in our study employed well-known and existing technologies, and almost all involved some type of construction. Product architecture, engineering design, and resources planning were carried out during the conceptual and planning phases and were usually performed by engineering consulting firms. Those served as a basis for price quotation and contract negotiation with potential contractors who were responsible for project execution. In each one of these projects, the product was entirely shaped and the design completely frozen prior to the execution phase.

Projects were executed after a formal contract was signed, and from there on, they were managed in a very formal and rigid style. Managers' main concern was to finish the project on time and within the expected budget, and in general, no changes were introduced.[1] None of these projects entailed any

[1] As one manager put it: "We are in this business to make money when finishing our projects on time. To do so, I must be firm and

development, testing, or redesign. Communication between management teams and subcontractors was typically conducted through formal channels, documents, existing forms, and regular meetings on a low-rate basis, usually once every month or two weeks.

Type B Projects

Substantial differences were found between this group and the previous, Type A projects. The projects observed in our study included building a new product in a well-established industry, developing a derivative or modification of a previous design to achieve better performance, increased reliability, or extended operational life. In contrast to the Type A projects, the contractors undertaking these projects were responsible for the entire range of activities, from engineering design, to resources planning, to execution. Although the technologies employed were not entirely new, almost all projects in this category involved some development and testing. However, only limited changes were added to the initial design. Management's policy in these cases was usually to resist change, and managers were highly aware of the need to avoid excessive costs.[2] Design was usually frozen early, no later than the first or second quarter of the project's execution period, after one or at most two design cycles, and none of these projects had utilized a formal risk-management procedure.

The communication pattern in our Type B projects was more intense than in those categorized as Type A. There were regular weekly or biweekly meetings of the management team, as well as biweekly or monthly meetings with major subcontractors. Additional in-between communications were conducted through ad hoc meetings, telephone discussions, and e-mail correspondence to resolve occasional problems.

Type C Projects

Most high-tech projects in our study produced completely new products or systems that did not exist in the past. Some of these products were even "new to the industry" and constituted a new product line for the company. The companies involved in these projects were all in the aerospace, electronics, and computer industries. In half of the cases, projects were based on technical feasibility rather than market need (Marquis 1969), and were initiated by the contractor.[3]

Type C projects were characterized by long periods of development, testing, and redesign. Design freeze was scheduled, in most cases, to be in the second or even the third quarter of the project's duration, and it was not concluded until two or even three design cycles were performed. During this period many changes were made before the product's specifications were finalized. In comparison to Types A and B projects, managers of Type C projects had to employ a much more flexible attitude, and they had to make extensive trade-offs. In at least two of the cases, the initial requirements could not be met without a substantial addition of time and budget. In these cases customers were asked and agreed to waive some of their requirements.[4]

Formal and informal communication among project teams, as well as with the customer, was usually intensive. It included written information in the form of status reports, computer printouts, minutes, messages, and memos.[5] However, the major flow of information was oral, and was conducted during meetings for problem solving and information sharing. These

inflexible. I resist any changes or new ideas. If the customer wants a change he must pay for it."

[2] One project manager expressed his strategy by saying: "Our policy is to add value to the product without adding cost. We will therefore use the previous product as much as we can; we are not trying to be perfect and we do not need too many improvements."

[3] One project manager described this process: "We had this idea for years. We knew it could be done; the problem was to sell it to the customer (in this case the military). We were able to get a contract only after four years and numerous technological demonstrations that proved the validity of our new concept to various management levels within the customer's organization."

[4] In one project all specifications could be achieved except one high-end requirement. It became clear to all parties that this requirement would involve enormous additional resources. The project manager recalls: "Our customer understood our problem. To him this requirement was really marginal compared to the additional time needed. However, he required that we make sure two other specifications would be met completely."

[5] Since some of these projects were in aerospace and electronics industries and had early access to electronic mail systems, they have used this medium as an additional form of project communication, thus increasing their "richness of media" (Daft and Lengel 1986).

consisted of internal meetings of the project team, meetings with all subcontactors (both together and separately) and meetings with the customers. In general, the atmosphere in these projects was one of open communication and continuous discussion. In some cases, managers have initiated social events, like parties, barbecues, and field trips, to increase interaction among team members and to reinforce group cohesiveness and spirit.

Type D Projects

The three Type D case projects in our data were defense projects, envisioned to respond to some far-reaching needs. As defined, no adequate technology was available at project initiation. The major concern was the extremely high level of uncertainty as to what technology should be used, and how to resolve it. Customers' decision to commit themselves to the project was typically marked by a great deal of hesitation because of the unknown technologies and the risk involved.

All projects in this category used a similar technique to resolve the issue of unknown technologies. They involved an intermediate program in which an experimental, scaled-down prototype model was developed and built. These intermediate programs were instituted to prove the validity of the system's concept and to test unknown technologies.[6] The decision to freeze product design and to set its specifications was therefore scheduled for a late moment, often during the third quarter of the project life cycle, and the typical number of design cycles was two or three, with one exception of five.

Management styles required high levels of flexibility and tolerance for change, and high awareness of potential problems. The atmosphere can be characterized as: "Look for trouble—it must be there; if you don't see it, you have a problem." The high level of uncertainty and the continuous flow of changes required enormous amounts of information exchange and extensive communication. All team members were expected to share immediate information, and no one waited for the formal meetings and documents to report problems and difficulties.[7]

Addressing System Scope: Managing Resources and Project Administration

Project planning typically starts by breaking the work into a "Work Breakdown Structure" (WBS) in a tree-like form and identifying all product subunits and support activities (Lavold 1988). Each activity is then budgeted and its projected length is estimated. This process results in a project schedule and budget, which are often set as constraints for project management. As we observed, when system scope increased, this process became more intense, more detailed, and more formal. Another major difference that was found, however, was the project organizational structure. The following discussion summarizes the main distinctions that were observed among projects for different scope levels.

Scope 1 Projects

Several of the projects in our study were set up to build a unit or a module that would become part of a larger system. Others involved stand-alone products designed to be used as is. Most of the project was done in-house, and the responsibility for the project completion was usually within one functional group, engaging, at times, additional disciplines from other functions. Team members knew each other very well and the atmosphere, in general, was casual and informal.

Resources planning and scheduling was relatively simple, done either manually, or with a personal computer software package designed to handle no more than a few hundred activities. Control was also simple, consisting mainly of budget and milestone monitoring. Most of the documents were technical, with some supplemental managerial documents, including a general milestone and work plan, financial

[6] One project manager described the intermediate program: "Like in the moon-landing program, this served as our less ambitious 'Gemini' program before the full-scale launch of 'Apollo.' Through this model we learned a lot about the new concept. We could test our algorithms for solution, simulate the behavior of various parameters and decide which of the possible technologies should be integrated into the system."

[7] As one project manager explained: "I require that any major problem in the project be brought to my attention within half an hour from its emergence. If I am not available, everyone in the chain of command must know about the problem."

and man-hour reports, and purchasing documents. Finally, communication and decision making within the project team were informal too. Although the general informal attitude usually contributed to technical success, it sometimes impaired managerial aspects, resulting in less order, which led to excessive costs.[8]

Scope 2 Projects

Our fifteen case projects in this category included development or construction of complex systems that were designed either to function independently or to be installed on another, larger system, such as an aircraft or vessel. Managerial styles and related practices were the same, however, for both kinds. Each of the system projects we studied had a main contractor who was responsible for the final product. The entire effort was divided among several subcontractors, either in-house or external. The main contractor was in charge, though, of the final integration of the product, and was responsible for meeting performance, quality, time, and budget goals. Work within the leading organization was usually done in a matrix form, and was led by a project management office interacting with various functional departments and dealing with outside organizations through separate contracts.

Dividing the work among separate subcontractors, and performing the coordination among them, required considerable managerial efforts: defining and analyzing customer needs, planning the program resources, negotiating with all subcontractors, and instituting a complicated system of coordination, control, decision, and information gathering. Management, in general, tended to 'bureaucratize' the project by installing a system of procedures, documents, management tools, meetings, reviews, and organizational structure. Project control was just as complex, and required extensive reports, meetings, and reviews.[9] In most cases there were at least ten formal documents relating to various technical and managerial aspects of the project. Some projects had to develop their own format to fit their specific needs and organizations.[10]

Scope 3 Projects

All the array projects we studied consisted of sizable programs that simultaneously managed many other projects. However, unlike the previous Scope 2 projects, they posed much less of an integration problem. They were not required to build a single integrated product that had to be delivered to the customer at one time. Arrays were built in an evolutionary manner, and their various components were finalized and supplied at different times and even in different places. Typically, the program structure involved a large "umbrella" organization whose primary mission was to set goals, direct, and coordinate the efforts of many subprojects. In two cases the array organization was even established as an ongoing program to which more projects could be continuously added.

The dispersed nature of the end product and the extent of subcontracting made it necessary to manage these programs in a very formal way and to put a lot of effort into the legal aspects of numerous contracts. In addition, program managers were mainly occupied with the direction and mission of the program as a whole and with financial and budgetary controls, while they were less concerned with technical aspects, which were usually left to the managers of subprojects.

[8] One of the team members explained: "The only problem with this form of communication was that the contents of these discussions and even the decisions reached were not always recorded. We finally overcame this question by creating a 'master document' that contained all the technical decisions that were reached and was continuously maintained and updated by one of the team members."

[9] In three of the case projects in this category we found, in addition to the usual status and cost reports, a "Cost Performance Index" report or an "Earned Value" report that expressed the project's combined status of money spent and the actual work achieved in terms of financial figures.

[10] For example, in one of the projects we found a "Termination Price Report" to continuously assess the cost in case the customer decides to terminate the project. Another project has used a "Level of Effort" (LoE) document that classified all activities into those that have a direct impact on the program and those that do not. This enabled management to concentrate its efforts on activities that directly affect the probability of success, rather than waste time on non-LoE activities.

Managing the Combination of High Uncertainty and High Scope

Managing the execution of high-scope, high-uncertainty projects required more than just detailed planning and technical skills. These projects were designed to produce large multidisciplinary systems, which involved numerous new technologies and many subsystems and components. The case data indicate that most of these projects found it necessary to incorporate the tools of system engineering to optimally harmonize an ensemble of subsystems and components (Booton and Ramo 1984).

Because many of the components of large system projects were developed by external subcontractors, the main contractor faced a difficult problem of system integration. Problems of interfaces, energy dissipation, and even lack of space, required a long and tedious process of assembly, testing, and necessary trade-off,[11] and resulted, in some cases, in more than one design cycle of the entire system. Finally, there were problems of configuration and risk management. Special software was used in high-uncertainty, high-scope projects to keep track of all the decisions and changes and to identify potential interactions that would occur with each change. As for risks, higher-scope, higher-tech projects were more receptive to the need for systematic risk analysis and management. The objective of the risk-management program was not to eliminate risk, but to balance it across the project, so as to avoid investing excessive resources in the resolution of a given risk while neglecting another.

Quantitative Analysis

In the qualitative part of our research we found consistent patterns of behavior for different categories of technological uncertainty and system scope. As mentioned, the goal of the quantitative portion of our study was to strengthen the validity of the two-dimensional model by testing the statistical differences in managerial variables among different project types and identifying various contingency trends. To do so, we used all scale assessment variables as they appeared in the questionnaire and have quantified all other variables as described hereafter.

Table 2 contains information about the resources consumed by different project types. It includes the descriptive statistics for various levels of uncertainty and scope. The scale value associated with budget was coded into: 1—less than \$100,000; 2—\$100,000 to \$1M; 3—\$1 to \$10M; 4—\$10 to \$100M; 5—\$100M to \$1B; and 6—more than \$1B. The project's duration scale value was coded into: 1—less than 6 months; 2—between 6 months and two years; 3—two to four years; 4—four to eight years; and 6—more than eight years. The other two variables were the average number of employees during execution and the percentage of people holding academic degrees. Table 2 also contains the results of ANOVA tests for each variable. It also contains Pearson correlation coefficients between these variables and the two dimensions of uncertainty and scope, where uncertainty was quantified into 1—Type A, 2—Type B, 3—Type C, and 4—Type D, and scope into 1—1, 2—2, and 3—3.

As we found, there seems to be an association between scope and size. Both budget and duration were significantly increased with scope. Yet, a similar trend was also observed for uncertainty; namely, higher uncertainty required increased budgets and longer projects. Still, while the average number of workers employed on the project was found to be positively associated with scope, this number did not increase with technological uncertainty. The increase in budget and time of higher-tech projects can be attributed to the project's complexity and not to the need to employ more people. However, higher-tech projects employ more academicians than lower-tech projects. This trend was positively correlated and significant. In contrast, we found that this percentage tends to decrease with scope, probably because building high-scope projects requires a large number of builders and craft workers and a smaller portion

[11] One of the project managers of a high-tech system in our research admitted that no integration problems were anticipated when the project was initiated. All key members of the project management team were relatively young, with previous experience only in smaller-scale, though high-tech, projects. Once all subsystems were ready, they expected a very short integration period. It resulted, however, in numerous problems of combining units of various disciplines and poor functioning of the system as a whole. External experts had to be called in, and it took another year before all the integration problems were resolved.

Table 2 Project Resources for Various Levels of Uncertainty and Scope

	Technological Uncertainty							System Scope					
	A	B	C	D	ANOVA		Corr.	1	2	3	ANOVA		Corr.
Variables	Mean (S.D.)	Mean (S.D.)	Mean (S.D.)	Mean (S.D.)	*df*	*F*		Mean (S.D.)	Mean (S.D.)	Mean (S.D.)	*df*	*F*	
1. Project budget	3.03	3.11	3.51	3.70	3, 123	2.04	.218	2.47	3.47	4.55	2, 124	31.45	.548
- scale level	(1.17)	(1.16)	(0.78)	(0.67)			*	(0.99)	(0.81)	(0.88)		***	***
2. Project duration	2.39	2.88	3.15	3.40	3, 123	6.12	.318	2.50	3.00	3.66	2, 124	8.12	.308
- scale level	(1.10)	(0.78)	(0.95)	(0.96)		***	***	(0.96)	(0.90)	(1.11)		**	***
3. Average labor	142	45	38	80	3,123	1.99	−.142	11	54	393	2, 124	18.26	.359
employed	(382)	(90)	(36)	(126)				(17)	(79)	(623)		***	***
4. Percentage of	20.2	55.1	59.3	66.6	3, 123	15.2	.452	57.2	49.6	23.3	2, 124	4.52	−.229
acad. degrees	(29.9)	(27.2)	(25.5)	(17)		***	***	(28.0)	(31.3)	(23.1)		*	**

*$p < 0.05$
**$p < 0.01$
***$p < 0.001$

Table 3 Descriptive Statistics and ANOVA Results for Various Levels of Technological Uncertainties and System Scope: Engineering- and Design-Related Variables

	Technological Uncertainty							System Scope					
	A	B	C	D	ANOVA		Corr	1	2	3	ANOVA		Corr
Variables (Alpha)	Mean (S.D.)	Mean (S.D.)	Mean (S.D.)	Mean (S.D.)	*df*	*F*		Mean (S.D.)	Mean (S.D.)	Mean (S.D.)	*df*	*F*	
Design Cycles	1.03	2.07	2.60	2.70	3, 121	28.7	.608	1.97	2.20	1.44	2, 122	3.1	−.022
	(0.33)	(0.60)	(0.95)	(1.2)		***	***	(0.77)	(1.1)	(0.53)		*	
Design Freeze	.25	1.95	2.3	2.6	3, 121	37.65	.581	1.75	1.83	0.77	2, 122	3.39	−.125
	(0.52)	(1.0)	(0.83)	(0.96)		***	***	(1.1)	(1.1)	(1.2)		*	
Design Considerations	4.65	5.20	5.26	5.26	3, 114	1.09	.134	4.75	5.27	5.26	2, 115	1.74	.150
(0.91)	(2.1)	(1.0)	(1.20)	(1.1)				(1.7)	(1.1)	(1.5)			
Design Reviews	3.13	5.29	5.97	5.6	3, 117	12.66	.416	4.63	5.57	3.65	2, 118	5.12	.050
(0.78)	(2.3)	(1.9)	(1.3)	(1.8)		***	***	(2.2)	(1.8)	(2.0)		**	
Risk Management	1.87	2.38	2.8	3.25	3, 89	2.07	.255	2.22	2.81	2.2	2, 90	1.80	.107
(0.83)	(1.7)	(1.5)	(1.4)	(0.94)			*	(1.4)	(1.5)	(1.3)			
Systems Engineering	2.74	3.95	4.99	4.58	3, 92	6.31	.364	3.20	4.84	3.81	2, 93	8.55	.264
(0.86)	(2.2)	(1.8)	(1.5)	(1.8)		**	***	(1.9)	(1.6)	(2.5)		***	***
Quality Management	3.59	3.87	4.72	4.85	3, 96	2.35	.247	3.52	4.63	4.28	2, 97	3.71	.214
(0.87)	(2.3)	(1.8)	(1.7)	(1.5)			*	(1.9)	(1.8)	(1.6)		*	*

*$p < 0.05$
**$p < 0.01$
***$p < 0.001$

Table 4 Descriptive Statistics and ANOVA Results for Various Levels of Technological Uncertainty and System Scope Managerial and Administrative Variables

	Technological Uncertainty							System Scope					
	A	B	C	D	ANOVA		Corr	1	2	3	ANOVA		Corr
Variables (Alpha)	Mean (S.D.)	Mean (S.D.)	Mean (S.D.)	Mean (S.D.)	*df*	*F*		Mean (S.D.)	Mean (S.D.)	Mean (S.D.)	*df*	*F*	
Activities	1.50 (0.83)	1.66 (0.72)	1.93 (0.69)	2.30 (0.48)	3, 121	12.16 ***	0.301 ***	1.18 (0.47)	1.89 (0.68)	2.66 (0.86)	2, 122	46.2 ***	0.524 ***
Work Breakdown Structure (.94)	4.45 (2.1)	4.62 (2.1)	5.06 (1.6)	4.83 (1.8)	3, 104	0.51	0.097	3.75 (2.2)	5.09 (1.6)	5.91 (0.91)	2, 105	7.07 **	0.340 ***
Planning (0.72)	3.92 (1.9)	4.83 (1.4)	5.20 (1.4)	6.06 (1.1)	3, 120	5.95 ***	0.351 ***	3.99 (1.7)	5.26 (1.4)	4.66 (1.5)	2, 121	7.95 **	0.247 **
Control (0.82)	4.12 (1.8)	4.48 (1.5)	4.89 (1.1)	5.12 (1.5)	3, 123	2.15	0.170	3.90 (1.5)	4.82 (1.3)	5.14 (1.2)	2, 124	5.88 **	0.282 **
Documentation (0.83)	4.95 (1.5)	5.21 (1.3)	5.47 (1.2)	5.73 (0.97)	3, 122	1.30	0.081	4.75 (1.6)	5.45 (1.1)	5.91 (0.96)	2, 123	4.49 *	0.168
Contracting (0.71)	4.90 (1.9)	5.43 (1.6)	5.59 (1.5)	5.50 (1.5)	3, 122	1.19	0.147	4.49 (1.9)	5.66 (1.3)	6.00 (1.2)	2, 123	8.24 ***	0.236 **
Consultation (0.81)	4.01 (2.3)	5.10 (1.6)	5.49 (1.5)	4.90 (1.5)	3, 117	3.85 *	0.227 *	4.60 (1.9)	5.27 (1.7)	3.62 (1.9)	2, 118	4.07 *	0.011

*$p < 0.05$
**$p < 0.01$
***$p < 0.001$

of academic personnel who are usually engaged in design, planning, analysis, and testing.

A major distinction between projects was observed, however, for several managerial and technical variables (Tables 3 and 4). Table 3 includes the descriptive statistics, analysis of variance, and correlation coefficients obtained for variables which relate to engineering design and activities performed to reduce uncertainty. The first two variables describe the number of design cycles performed before the design was frozen and the quarter in which the design freeze took place (zero means the design was frozen prior to the project's initiation). Both measures were significantly associated with technological uncertainty. The rest of Table 3 describes several combined variables of the project management process, together with their alpha reliability measures. For example, the design consideration measure represents eight seven-scale variables assessing the extent to which managers were concerned with issues such as design for manufacturability, design for maintainability, design for serviceability, etc. Together, these variables did not demonstrate significant association with technological uncertainty. The risk management measure represents five scale variables assessing issues such as initial identification of project risks, probabilistic assessment of risks, and a detailed plan for risk mitigation. The systems engineering measure included four variables such as usage of structured systems engineering procedures, configuration management, and usage of various types of software. Also, quality management represents four variables measuring the extent to which a total quality plan was prepared, quality goals were selected, and statistical control was performed in the project. All three variables increased with technological uncertainty, but only systems engineering showed significant association.

As observed in the case research part, the quantitative results show a clear (and often significant) increase in almost all variables with the level of technological uncertainty. Higher-technology projects required more design cycles, later design freeze, and increased attention to design considerations, risk management, systems engineering, and quality management (Eisenhardt and Tabrizi 1995). Fewer of these trends, however, were seen to characterize an increase in system scope. In fact, increase in scope demonstrated in almost all cases a curvilinear pattern in engineering and design-related variables. While many values increased from assembly to system projects, they then declined at the array level. To explain this trend, one needs to look at the nature of system and array projects. Compared to assembly projects, system efforts are typically associated with extensive engineering tasks which require careful technical design, numerous testing and reviews, detailed risk and quality management, and extensive systems engineering activities (Rechtin 1991, Iansiti 1997). Array projects, however, are much less technical in nature, and thus, these tasks will get less emphasis on the entire array effort. These projects would typically employ fewer quality and systems engineers, and would be less concerned with design reviews or design cycles of the entire program. Together, this difference may explain the curvilinear change of variables.

Table 4 includes the results obtained for various managerial and administrative variables. The first variable, the number of activities included in the project's planning network, was coded into: 1—less than 100; 2—between 100 and 1,000; 3—between 1,000 and 10,000; and 4—more than 10,000. The rest of the variables in Table 4 were seven-point scale combined measures representing the extent to which formal methods were utilized in each of these groups of variables. For example, work breakdown structure represents nine variables, measuring the extent to which such structure was built for the system, product, development, testing, logistics, and management. Planning includes three variables, assessing computerized planning methods, detailed milestones, and integrative planning of budget and schedule. Consultation represents three variables, measuring the extent of customer involvement and consultation for articulating customer need, concept selection, specifications, and ongoing problems.

Unlike the previous group, here system scope was the dominating dimension. This clearly indicates the need to resort to more formal procedures when project scope increases. Our results seem to support the trends observed in the qualitative part. As can be seen, all variables in Table 4 are significantly associated with system scope. Similarly, some of these variables were positively associated with technological uncertainty, indicating, for example, the need for better planning and control in high- and super high-tech projects.

Interactive Effects

Tables 5 and 6 include the results of a two-step hierarchical regression analysis. A regression equation was obtained for our two dimensions of uncertainty and scope for each one of our quantitative variables. The R square levels obtained for this phase were between 0.043 and 0.375. The multiplication effect of uncertainty and scope was added during the second step. Several variables exhibit an interactive effect demonstrated by the additional variance, thus supporting our qualitative observations. The main interaction appeared in project resources such as budget, duration, and labor, with some additional interaction in project control, documentation, contracting, risk management, and design considerations.

As mentioned in the qualitative part, high levels of technological uncertainty and system scope characterize projects that are designed to produce large, multidisciplinary systems. Managing such significant efforts requires a delicate balance between two challenges—technical *and* managerial. Managers must pay attention to numerous design considerations, work carefully to reduce project uncertainty and risk, and make technical trade-off decisions at the interface between scientific disciplines. At the same time, they must be aware of multiple managerial and administrative issues, such as planning and controlling the large effort, formalizing the process through detailed documentation, and carefully preparing and monitoring contracting engagements. The interaction effects demonstrate clearly that a combined increase in scope and uncertainty amplifies project complexity and requires additional resources and more detailed managerial attention.

Table 5 Results of Two-Step Regression Analysis[a]: Resources and Design-Related Variables

	Uncertainty	Scope	Uncertainty x Scope					
Variable	*b*	*b*	R^2	*b*	ΔR^2	*F*	*df*	$F(\Delta R^2)$
Budget	0.298**	1.060***	0.368	−0.429**	0.035	27.70***	3, 123	7.21***
Duration	0.371***	0.593***	0.212	−0.423**	0.039	13.70***	3, 123	6.40***
Average Number of Workers	−24.900	123.400***	0.142	−109.500**	0.065	10.73***	3, 123	10.08***
Percentage of Academic Degrees	14.970***	−11.020**	0.242	14.940**	0.048	16.77***	3, 123	8.31***
Design Cycles	0.660***	0.046	0.370	0.084	0.002	23.86***	3, 121	0.38
Design Freeze	0.785***	−0.150	0.375	0.021	0.000	24.22***	3, 121	0
Design Considerations	0.222	0.383	0.043	−0.439†	0.023	2.69*	3, 114	2.80*
Risk Management	0.441*	0.240	0.073	−0.352	0.015	2.81*	3, 89	1.46
Systems Engineering	0.803***	0.883**	0.202	−0.025	0.000	7.78***	3, 92	0
Quality Management	0.518**	0.693**	0.104	−0.113	0.001	3.75**	3, 96	0.11

[a]Unstandardized coefficients are shown; *F* is for the final regression equation.
†$p < 0.10$
*$p < 0.05$
**$p < 0.01$
***$p < 0.001$

Table 6 Results of Two-Step Regression Analysis[a]: Managerial and Administrative Variables

	Uncertainty	Scope	Uncertainty × Scope					
Variable	*b*	*b*	R^2	*b*	$\triangle R^2$	*F*	*df*	$F(\triangle R^2)$
Activities	0.290***	0.766***	0.396	−0.100	0.004	26.62***	3, 120	0.80
Work Breakdown Structure	0.265	1.230***	0.129	−0.421	0.009	5.53**	3, 104	1.08
Planning	0.679***	0.815***	0.198	0.003	0.000	9.86***	3, 120	0
Control	0.398**	0.801***	0.139	−0.595	0.34	8.56***	3, 123	5.05**
Documentation	0.281**	0.659**	0.103	−0.461†	0.24	5.89**	3, 122	3.35*
Design Reviews	0.976**	0.232	0.177	−0.195	0.002	8.49***	3, 117	0.28
Contracting	0.296**	0.971**	0.135	−0.514	0.27	7.84***	3, 122	3.93*
Consultation	1.681**	0.409	0.062	−1.233	0.008	3.01**	3, 120	1.03

[a]Unstandardized coefficients are shown; *F* is for the final regression equation.
†$p < 0.10$
*$p < 0.05$
**$p < 0.01$
***$p < 0.001$

Discussion and Insights

Given the scanty theoretical basis of project management, this research may be seen as an early step toward building a theory of project management. It proves that projects indeed have a wide range of variations, and that "one size does not fit all." The two dimensions, technological uncertainty and system scope, seem to be dominant factors which affect project characteristics and managerial styles, and they provide several important insights for the study of projects. First, this study demonstrates that the traditional low-high (or incremental-radical) dichotomy seems inadequate in describing the wide spectrum of today's projects. Both Type A and B projects on the uncertainty scale can be considered incremental innovations. However, Type A projects are mostly construction or installation efforts, while Type B are development projects, which involve building new models within a well-established product line, or improvement of existing products. A similar distinction can be made between C and D types, which both represent a radical innovation in the traditional view. Type C projects are based on *existing*, state-of-the-art technologies symbolizing the existing frontiers of technological advancement, while the more risky (and thus rare) Type D projects are set up to achieve an even higher goal—one which is beyond existing state-of-the-art.

As we have seen, moving along the uncertainty dimension is mainly associated with the way technical problems are resolved. It affects number of design cycles, time committed to design changes, the need for prototype building, the extent of testing, and the frequency and complexity of trade-off decisions. It seems that the second dimension, system scope, is mainly associated with extent of administrative issues and degree of formality of mangerial processes. As scope increases, projects are managed with additional attention to planning, control, and coordination; they usually resort to a larger number of external subcontractors, often use additional legal help, and are generally characterized by increased bureaucracy and documentation. Assembly projects are typically conducted within one internal group, in a rather informal way. System projects use a central office to coordinate the close integration of numerous subcontractors, and array projects deal mainly with administrative and legal issues and leave the technical details to their subunits.

The two-dimensional model and the distinction between four levels of technological uncertainty and three levels of system scope provides, to some extent, an orthogonal framework for looking at engineering projects. Furthermore, the distinction between four levels of technological uncertainty and three levels of system scope provides more than just a classification system of technical projects. Rather, this classification seems to meet the criteria for a typological theory of organizations (Doty and Glick 1994), and the distinct levels of uncertainty and scope can be seen as theoretical "ideal types" (Shenhar and Dvir 1996). Finally, there also seems to be a notable interaction between the two dimensions, and many variables such as project resources, project documentation and control, project contracting, and various design considerations are impacted by a simultaneous increase in uncertainty and scope.

New insights may also be gained from this study on some of the classical domains of structural contingency theory. From an organization theory perspective, our findings seem to challenge the classical distinction between mechanistic and organic organizations, and the traditional link between organic processes and uncertain situations. As we learned, while project organizations may manifest numerous forms, none is simply identified with the traditional modes, nor do they vary in accordance with the classical distinctions. It seems that while management of highly uncertain projects is indeed more flexible and less formal, a central portion of the organic organization is still missing—the breadth aspect. High-tech and super high-tech projects must rely on the knowledge and depth of highly educated and experienced people in specific narrow fields. Breadth and integration are only added with the second dimension—system scope, namely, when highly uncertain projects are also becoming large and complex.

Our qualitative and quantitative observations seem also to be challenging the classical trade-off between rich and less rich media of communication (Daft and Lengel 1986). It seems that in most projects, the choice is not between rich and nonrich media;

namely, they do not use one form *or* the other. To some extent, all projects use the lower end of the richness spectrum. They employ written reports and quantitative data for purposes of monitoring and status reporting. However, more rich media forms are typically being added with increased technological uncertainty, in most cases by additional team meetings and fostering an informal climate within the project. When increasing the second dimension—system scope—additional, more formal, and less rich media are also employed. However, high-uncertainty, high-complexity projects use both formal and informal means of communication.

Finally, perhaps the most important insight is the extent and speed with which decisions are made on project sites. Projects, particularly those in the higher-tech categories, can be seen as "decision intense environments." When strategic decisions made by top management reach the project floor, they typically perpetuate a constant stream of subsequent decisions with much higher velocity and density (Bourgeois and Eisenhardt 1988). As we observed, project managers are required to maintain a balance between inward and outward attention, planning and action, differentiation and integration (Lawrence and Lorsch 1967, Iansiti 1997), and formal and informal conduct (Brown and Eisenhardt 1998).

Implications and Conclusions

In addition to its theoretical insights, our study offers a handful of implications for management. First, it demonstrates that management and organizations at large should deliberately adopt a more project-specific approach to project management. Although, as we learned, most organizations are implicitly using different strategies for different projects, there is usually no clear identification of project type prior to project initiation and no conscious adaptation of management styles. Organizations should add a formal step of project classification to the traditional planning phase, and follow it by a myriad of organizational implications. The specific project type should affect the selection of project leaders, project team members, and skill development needs. For example, leaders of high-tech or super high-tech projects must possess exceptional technical skills, as well as the capability to assess potential value and risk in new, or not yet developed, technology. Similarly, while assembly projects do not require extensive managerial skills, managers of system efforts need a wealth of administrative and organizational capabilities. They should be mature and experienced, able to see the system as a whole and to understand the collective effect of its separate components. When dealing with arrays, managers must be ready to back off from technical matters, developing instead a broader view of the industry, legal, environmental, and political issues.

The second area for adapting project management practices to project type is project organization and processes. Assembly projects will use a small, usually functional, organization with simple processes and tools. In contrast, system projects must establish a project office that will handle the subcontracting and integration efforts and use a more formal process; and array projects will have to build an umbrella organization for coordination and for handling legal and external connections, and use a much more "hands-off" approach. Project communication, in turn, will also be determined by technological uncertainty. At the low and medium levels, communication will be less intense and frequent than at the high and super high levels. At these levels, managers of projects must establish numerous formal and informal communication channels for interaction among team members.

Finally, since different projects are associated with various outcomes on the one hand, and with various levels of risk on the other hand, organizations may use the framework of this research for a more rigorous process of weighing risk and opportunities and for selecting a balanced portfolio of projects. Typically, an organization would concentrate on one (or at most two) type of projects, while engaging at times in more risky and complex ones. For example, a defense contractor would typically execute Type C, high-tech projects, but might attempt, at times, a super high-tech project with an objective of leapfrogging competition. And a consumer electronics firm might commonly launch medium-tech assembly projects, but would sometimes move into a system, and even one or two high-tech projects.

As an exploratory step in the evolving process of theory building, more research seems appropriate to establish additional validity of contingencies in projects and to further explore the "one size does not fit all" paradigm. For example, further studies may use this scheme to build a theory that explains how uncertainty is related to project success and addresses the issue of fit between project classification, project management style, and project effectiveness (Drazin and van de Ven 1985). And if our levels of uncertainty and scope are seen as "ideal types" (Doty and Glick 1994), then how will a deviation of actual management styles from these types affect the project success and its effectiveness? Finally, more research is clearly needed to explore additional dimensions of project contingency. The next candidates, in our view, would be market uncertainty (Wheelwright and Clark 1992) and project pace (Brown and Eisenhardt 1998). Additional studies of traditional contingency theories in new domains may evolve into new organizational paradigms that are more applicable to today's dynamic and continuously changing organizations.

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References
Abernathy, W. J., J. M. Utterback. 1978. Patterns of industrial innovation. *Tech. Rev.* (June–July) 40–47.

Ahituv, N., S. Neumann. 1984. A flexible approach to information system development. *MIS Quart.* (June) 69–78.

Alexander, C. 1964. *Notes on the Synthesis of Form*. Harvard University Press, Cambridge, MA.

Balachandra, R., J. H. Friar. 1997. Factors for success in R&D project and new product innovation: A contextual framework. *IEEE Trans. on Engrg. Management* **44** 276–287.

Bart, C. 1998. Organizing for new product development. *J. Bus. Strategy* **9** (July/Aug.) 34–39.

Blake, S. B. 1978. *Managing for Responsive Research and Development*. Freeman and Co., San Francisco, CA.

Booton, R. C., S. Ramo. 1984. The development of systems engineering. *IEEE Trans. on Aerospace and Electr. Systems* **AES-20**(4) 306–309.

Boulding, K. 1956. General systems theory: The skeleton of science. *Management Sci.* **2** (April) 197–208.

Bourgeois, III, L. J., K. M. Eisenhardt. 1988. Strategic decision processes in high velocity environments: Four cases in the microcomputer industry. *Management Sci.* **34**(7) 816–835.

Brown, S. L., K. M. Eisenhardt. 1997. The art of continuous change: Linking complexity theory and time-paced evolution in relentlessly shifting organizations. *Admin. Sci. Quart.* **42** 1–34.

———. , ———. 1998. *Competing on the Edge: Strategy as Structured Chaos.* Harvard Business School Press, Boston, MA.

Burgelman, R. A. 1983. A process model of internal corporate venturing in the diversified major firm. *Admin. Sci. Quart.* **28** 223–244.

Burkhardt, M. E., D. J. Brass. 1990. Changing patterns or patterns of change: The effect of a change in technology on social network structure and power. *Admin. Sci. Quart.* **35** 104–127.

Burns, T., G. Stalker. 1961. *The Management of Innovation.* Tavistock, London, U.K.

Cash, J. I. Jr., W. F. McFarlan, J. L. McKenney. 1988. *Corporate Information Systems Management.* Irwin, Homewood, IL.

Clark, K. B., T. Fujimoto. 1989. Lead time in automobile product development: Explaining the Japanese advantage. *J. Engrg. and Tech. Management* **6** 25–58.

Cleland, D. I., W. R. King. 1983. *Systems Analysis and Project Management.* McGraw-Hill, New York.

Daft, R. L., R. H. Lengel. 1986. Organizational information requirements, media richness and structural design. *Management Sci.* **32** 554–571.

Dewar, R. D., J. E. Dutton. 1986. The adoption of radical and incremental innovations: An empirical analysis. *Management Sci.* **32** 1422–1433.

Doty, H. D., W. H. Glick. 1994. Typologies as a unique form of theory building: Toward improved understanding and modeling. *Acad. Management Rev.* **19**(2) 230–251.

Drazin, R., A. H. van de Ven. 1985. Alternative forms of fit in contingency theory. *Admin. Sci. Quart.* **30** 514–539.

Dvir, D., S. Lipovetsky, A. Shenhar, A. Tishler. 1998. In search of project classification: A non-universal approach to project success factors. *Res. Policy* **27** 915–935.

Eisenhardt, K. M. 1989. Building theories from case study research. *Acad. Management Rev.* **14** 532–550.

———. , B. N. Tabrizi. 1995. Accelerating adaptive processes: Product innovation in the global computer industry. *Admin. Sci. Quart.* **40** 84–110.

Ettlie, J. E., W. P. Bridges, R. D. O'Keffe. 1984. Organizational strategy and structural differences for radical vs. incremental innovation. *Management Sci.* **30** 682–695.

Fondahl, J. W. 1987. The history of modern project management. *Project Management J.* **28**(2) 33–36.

Freeman, C. 1982. *The Economics of Industrial Innovaiton*, 2nd ed. MIT Press, Cambridge, MA.

Galbraith, J. R. 1982. Designing the innovating organization. *Organ. Dynam.* **10** (Winter) 5–25.

Glaser, B. G., A. L. Strauss. 1967. *The Discovery of Grounded Theory: Strategies for Qualitative Research.* Aldine, Chicago, IL.

Guterl, F. 1984. Design case history: Apple's Macintosh. *IEEE Spectrum* **21** (December) 34–43.

Henderson, R. M., K. B. Clark. 1990. Architectural innovation: The reconfiguration of existing product technologies and the failure of established firms. *Admin. Sci. Quart.* **35** 9–30.

Hoover, C. W., J. B. Jones. 1991. Report of the Committee on Engineering Design Theory and Methodology. *Improving Engineering Design.* National Research Council, New York.

Iansiti, M. 1997. *Technology Integration: Making Critical Choices in a Dynamic World.* Harvard Business Review Press, Boston, MA.

Johnson, C. L. "Kelly", M. Smith. 1985. *Kelly: More Than My Share of It All.* Smithsonian, Washington, D.C.

Kirk, J., M. L. Miller. 1986. *Reliability and Validity in Qualitative Research.* Sage University Series on Qualitative Research Methods, Vol. 1. Sage, Beverly Hills, CA.

Lavold, G. D. 1988. Developing and using the work breakdown structure. D. I. Cleland, W. R. King, eds. *Project Management Handbook,* 2nd ed. Van Nostrand, New York. 302–323.

Lawrence, P. R., J. W. Lorsch. 1967. *Organization and Environment: Managing Differentiation and Integration.* Harvard University, Boston, MA.

Lawrence, R. M. 1987. *Strategic Defense Initiative.* Westview Press, Boulder, CO.

Lemley, J. K. 1992. The channel tunnel: Creating a modern wonder of the world. *PmNetwork* **6** (July) 14–22.

Lewis, W., A. Samuel. 1989. *Fundamentals of Engineering Design.* Prentice Hall, New York.

Little, A. D. 1981. *The Strategic Management of Technology.* European Management Forum, London, U.K.

Manne, S. J., L. Collins. 1990. Reconstructuring an aging infrastructure. *Project Management J.* (April) 9–24.

Mansfield, E. 1968. *Industrial Research and Technical Innovation.* Norton, New York.

Marples, D. L. 1961. The decisions of engineering design. IEEE Trans. on Engrg. Management **EM-8** (June) 55–71.

Marquis, D. G. 1969. The anatomy of successful innovations. National Science Foundation, Washington, D.C.

Miles, M. B., M. A. Huberman. 1984. *Qualitative Data Analysis.* Sage Publishing, Beverly Hills, CA.

Moch, M., E. V. Morse. 1977. Size, centralization and organizational adoptation of innovations. *Amer. Soc. Rev.* **42** 716–725.

Pahl, G., W. Beitz. 1984. *Engineering Design.* Springer-Verlag, New York.

Pearson, A. W. 1990. Innovation strategy. *Technovation* **10**(3) 185–192.

Pellegrino, C. R., J. Stoff. 1985. *Chariots for Apollo.* Athenaeum, New York.

Pennings, J. M. 1992. Structural contingency theory: A reappraisal. *Res. in Organ. Behavior* **14** 267–309.

Perrow, C. C. 1967. A framework for the comparative analysis of organizations. *Amer. Soc. Rev.* **32** 194–208.

Pinto, J. K., J. G. Covin. 1989. Critical factors in project implementation: A comparison of construction and R&D projects. *Technovation* **9** 49–62.

Rechtin, E. 1991. *Systems Architecting.* Prentice Hall, Englewood Cliffs, NJ.

Rosenbloom, R. S., M. Cusumano. 1987. Technological pioneering and competitive advantage: The birth of the VCR Industry. *California Management Rev.* **24**(4) 51–73.

Roussel, P. A., K. N. Saad, T.J. Erickson. 1991. *Third Generation R&D.* Harvard Business School Press, Boston, MA.

Shanklin, W. L., J. K. Ryans, Jr. 1984. *Marketing High Technology.* Lexington Books, New York.

Shenhar, A. J. 1991. On system properties and systemhood. *Internat. J. General Systems* **18**(2) 167–174.

———. 1993. From low to high-tech project management. *R&D Management* **23**(3) 199–214.

———. , D. Dvir. 1996. Toward a typological theory of project management. *Res. Policy* **25** 607–632.

Song, X. M., W. E. Souder, B. Dyer. 1997. A casual model of the impact of skills, synergy, and design sensitivity on new product performance. *J. Innovation Management* **14** 88–101.

Souder, W. E., X. M. Song. 1997. Contingent product design and marketing strategies influencing new product success and failure in U.S. and Japanese electronics firms. *J. Product Innovation Management* **14** 21–34.

Steele, L. W. 1975. *Innovation in Big Business.* Elsevier Publishing Company, New York.

Strauss, A. L. 1987. *Qualitative Analysis for Social Scientists.* Cambridge University Press, Cambridge, U.K.

Thompson, J. D. 1967. *Organizations in Action.* McGraw-Hill, New York.

Tushman, M. L., P. Anderson. 1986. Technological discontinuities and organizational environments. *Admin. Sci. Quart.* **31** 439–465.

Van Gigch, J. P. 1978. *Applied General Systems Theory,* 2nd ed. Harper and Row, New York.

Villard, R. 1989. From idea to observation: The space telescope at work. *Astronomy* (June) 38–44.

Weick, K. E. 1979. *The Social Psychology of Organizing,* 2nd ed. Addison-Wesley Publishing, Reading, MA.

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

Yap, C. M., W. E. Souder. 1994. Factors influencing new product success and failure in small enterpreneurial high-technology electronics firms. *J. Product Innovation Management* **11** 418–432.

Yin, R. K. 1984. *Case Study Research: Design and Methods.* Sage Publishing, Beverly Hills, CA.

Zaltman, G., R. L. Duncan, J. Holbek. 1973. *Innovations and Organizations.* Wiley, New York.

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