Refining the search for project success factors: a multivariate, typological approach

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Although the causes for project success and failure have been the subject of many studies, no conclusive evidence or common agreement has been achieved so far. One criticism involves the universalistic approach used often in project management studies, according to which all projects are assumed to be similar. A second problem is the issue of subjectiveness, and sometimes weakly defined success measures; yet another concern is the limited number of managerial variables examined by previous research. In the present study we use a project-specific typological approach, a multidimensional criteria for assessing project success, and a multivariate statistical analysis method. According to our typology projects were classified according to their technological uncertainty at project initiation and their system scope which is their location on a hierarchical ladder of systems and subsystems. For each of the 127 projects in our study that were executed in Israel, we recorded 360 managerial variables and 13 success measures. The use of a very detailed data and multivariate methods such as canonical correlation and eigenvector analysis enables us to account for all the interactions between managerial and success variables and to address a handful of perspectives, often left unanalyzed by previous research. Assessing the variants of managerial variables and their impact on project success for various types of projects, serves also a step toward the establishment of a typological theory of projects. Although some success factors are common to all projects, our study identified project-specific lists of factors, indicating for example, that high-uncertainty projects must be managed differently than low-uncertainty projects, and high-scope projects differently than low-scope projects.

1. Introduction

The wide deployment of projects in organizations today makes the search for factors that influence project success of great importance to both researchers and practitioners. Yet the conceptual understanding and the theoretical foundation of the project phenomenon are still in their early days, undergoing, critical, but necessary changes. In spite of extensive research in recent years, there has been limited convergence, let alone agreement, on the ingredients and causes of project success (Pinto and Slevin, 1987). One criticism concerns the assumption that a universalistic theory of project management can be applied to all types of projects. The search for a universalistic theory may be inappropriate, given the fundamental differences that either exist across innovation, or across project types (Dewar and Dutton, 1986; Damanpour, 1991; Pinto and Covin, 1989; Shenhar, 1993). Yet as Pinto and Covin noted 'the implicit view of many academics could be represented by the axiom "a project is a project is a project" ' (1989, p. 49); similarly, most project management texts and handbooks tend to assume that all projects constitute of a universal set of functions and activities.

The purpose of this paper is to examine the managerial factors influencing project success across various types of technical projects. Our main proposition is that different factors influence the success of different kinds of projects and that future scholarship of project management must adapt a more project-specific approach to identify the exact causes of project success and failure. Using a previously developed typological framework and a set of project 'ideal types' (Shenhar, 2001; Shenhar and Dvir, 1996), we investigate the dimensions of technological uncertainty and system scope as the main first-order constructs for project distinction. This study is also a further step in the process of developing a typological theory of projects (Doty and Glick, 1994; Shenhar and Dvir, 1996). Specifically, the quantitative modeling and rigorous empirical testing of project effectiveness across various project types provide the falsifiable components that are critical for any typological theory building process (Blalock, 1989; Whetten, 1989; Doty and Glick, 1994).

Here, we develop a multi-dimensional method to assess project success (see Cooper and Kleinschmidt, 1987). Because project outcome is assessed differently by the various stakeholders, success criteria must reflect different interests and viewpoints. Our multi-dimensional success criteria include 13 measures, grouped into three dimensions (Dvir and Shenhar, 1992).

Our primary method employs multivariate analysis (Anderson, 1974; Lipovetsky and Tishler, 1994; Rao, 1973) to account simultaneously for the multi-attribute nature of projects' success and for the multitude of managerial variables that were hypothesized to affect the different dimensions of projects' success. All in all, we recorded 360 managerial variables for each project in our sample. Multivariate methods, such as canonical correlation and eigenvector analysis, enable us to account for all the interactions between the managerial and success variables (Anderson, 1974; Lipovetsky and Tishler, 1994) and to explore several angels not yet subject to scrutiny (Pinto and Slevin, 1987). Multivariate methods have often been used in the systems approach to study the concept of fit in contingency theory. They have been described as the most effective components of configurational theories (Van de Ven and Drazin, 1985). Furthermore, multivariate methods also allow identification of the effects of several key managerial variables on different dimensions of success that the more common univariate and regression methods have failed to reveal.

As we expected, the analysis by multivariate models of very detailed data describing managerial activities and success dimensions did indeed yield some new results. Some of the highlights are as follows.

1. Design considerations such as quality, reliability, and serviceability have a major impact on the success of high-uncertainty projects. Therefore in high-technological-uncertainty projects, the design process should be a major focus of managerial attention.
2. The design-freeze stage is more important for low-uncertainty projects than for high-uncertainty projects. It may be that in high-uncertainty projects, design freeze must be delayed in order to encompass all the changes that are generated during development. The timing of design freeze in projects with lower levels of technological uncertainty is usually at the discretion of the project team; in most cases there is no real need to delay this decision and design can be frozen in the early stages of the project.
3. The use of a detailed WBS (work breakdown structure) is important principally to high-uncertainty projects. These projects are helped significantly by the use of schedule monitoring techniques. For low-uncertainty projects, it is more important to monitor budget expenditures and technical performance goals.
4. Documents and written reports are powerful means of communication in technical projects. As we found, written reports are of great importance to high scope projects, as well as to low- and high-uncertainty projects. For high-uncertainty projects, documents must be structured formally and must systematically address all critical issues.
5. The skill level of the project team can determine the success of high scope projects as well as that of low-uncertainty projects. We found, though, that the skills of the project team have little impact on high-uncertainty projects. This may be because, in such challenging projects, it is usual to recruit only skillful workers. The competence of the project manager is the variable that exercises the greatest influence on the outcome of high-uncertainty projects.

This paper is organized as follows: Section 2 presents the theoretical background; data organization and notation are described in Section 3; the method for choosing the critical variables is described in Section 4, and the application of this method to our data set is given in Section 5; the results are discussed in Section 6; Section 7 concludes.

2. Theoretical background

Success measures

The first step in investigating the interdependence between managerial variables and project success is to establish what success means. Although studies of organizational effectiveness have been at the heart of organization theory for many years (e. g. Seashore and Yuchtman, 1967; Goodman and Pennings, 1977; Pfeffer and Salancik, 1978), project success research has been slow to converge to a standard, or even to an accepted operative framework. 'There are few topics in the field of project management that are so frequently discussed and yet so rarely agreed upon as the notion of project success' (Pinto and Slevin, 1988, p. 67). It is tempting to resort to a formula that is unequivocal and easy to apply. Such simplistic measures have often equated success with meeting the objectives of project budget and schedule, and achieving an acceptable level of performance (Pinto and Slevin, 1988). However, all these measures, even when taken together, are at best partial and misleading. For example, they may count as successful, projects that met budget and schedule constraints, but did not meet customer needs and requirements (Baker *et al.*, 1988), or projects that resulted in a product that was difficult to market.

Project success may also differ according to the assessor. According to Freeman and Beale, 'Success means different things to different people. An architect may consider success in terms of aesthetic appearance, an engineer in terms of technical competence, an accountant in terms of dollars spent under budget, a human resources manager in terms of employee satisfaction. Chief executive officers rate their success in the stock market' (1992, p. 8). Comprehensive success criteria must therefore reflect different interests and views – leading to a multidimensional, multi-criteria approach (Cooper and Kleinschmidt, 1987; Pinto and Mantel, 1990; Freeman and Beale, 1992). Pinto and Mantel (1990) identified three aspects of project performance as benchmarks for measuring the success or failure of a project: the implementation process; the perceived value of the project; and client satisfaction with the delivered project. Client satisfaction and customer welfare were also studied by Paolini and Glaser (1977) and Pinto and Slevin (1988). Cooper and Kleinschmidt (1987) used factor analysis techniques to identify the success dimensions of a new product. They identified three different dimensions as relevant to the success of new products: financial performance, opportunity window, and market impact. A similar approach was taken by Dvir and Shenhar (1992) to assess the success of high tech strategic business units. Reviewing project management literature, Freeman and Beale (1992) identified seven main criteria used to measure projects success. Five criteria are frequently used: technical performance; efficiency of execution; managerial and organizational implications (mainly customer satisfaction); personal growth; and manufacturer's ability and business performance.

To account simultaneously for various viewpoints of different stakeholders, our study employs a multidimensional approach. We use 13 success measures adopted from Dvir and Shenhar (1992), and arranged them into the following three dimensions: (i) meeting design goals, (ii) benefit to the customer, and (iii) benefit to the organization. The derivation of these measures and their structure is discussed in Section 3.

Management factors critical to project success

For more than two decades, researchers have labored to identify managerial variables critical to business success. The focus has been placed either on the product, project, or the business unit level. According to the classical proposition, organizations must develop a set of key strategic strength areas that are suitable to the environment and industry in which they operate (Ansoff, 1965; Andrews, 1971; Porter, 1980). Notable studies at the product level are Project SAPPHO, performed in the UK in the early seventies (Rothwell *et al.*, 1974), Newprod project, executed in Canada in the early eighties (Cooper, 1983), the Stanford innovation study (Maidique and Zirger, 1984), and the studies of Cooper and Kleinschmidt (1987). Success factors at the business unit level were studied by MacMillan *et al.* (1982) and by Dvir *et al.*, (1993). Several attempts have also been made to identify the critical success factors of industrial projects. In their study Murphy *et al.* (1974) analyzed 646 projects and found 31 managerial factors related to project success. The success factors are covering organizational issues like the strategy of the company and the organizational structure of the project, individual issues like the skills of the project manager and the project team and issues of the project coordination like the use of network techniques and controlling methods. Using a path analysis they show that the success factors are influencing each other. Rubinstein *et al.* (1976) found that individuals, rather than organizations, make an R&D project successful. According to their findings, certain individuals, usually called 'product champions', play a major role in the initiation, progress and outcome of projects. Slevin and Pinto (1986) developed a research framework that includes the following major factors that contribute to the success of project implementation: clearly defined goals, top management support, a competent project manager, competent project team members, sufficient resource allocation, adequate control mechanisms, adequate communication channels with feedback capabilities and responsiveness to client's needs. Using this framework to analyze 52 large projects in the USA, they found that the most important factors are those related to satisfying the client's needs (Pinto and Slevin, 1987). Pinto and Slevin also studied success factors across the project life cycle (1988). Pinto and Covin (1989) compared the success factors of construction projects with those of R&D projects; and Pinto and Mantel (1990) studied the major causes of project failure. Finally, Might and Fischer (1985) investigated structural factors assumed to affect project success. These factors include: the organizational structure, the level of authority delegated to the project manager, and the size of the project. They found only a weak relationship between organizational structure and project success, and no connection between project size and success. On the other hand, the level of authority entrusted to the project manager was found to be positively related to all internal measures of success (meeting budget, time-table and technical performance).

The abundance of research and its inconclusive findings suggest at least three areas of concern for additional investigations into the causes of project success. First, although the multidimensional assessment of project success is quite well-developed, it has not usually been linked to the search for project success factors (however, note that Murphy *et al*, (1974), Cooper and Kleinschmidt (1987), Dvir *et al.*, (1993), and Pinto and Mantel (1990) are exceptions at the product, business unit, and project levels).

The second issue involves the range of management variables that were included in previous studies. In fact, a great portion of previous research has been focused on a single major aspect of the project such as: the management of professionals in R&D projects (Katz and Tushman, 1979; Roberts and Fusfield, 1981); communication patterns in technical and R&D projects (Allen *et al.*, 1980; Katz and Tushman, 1979); project organizational structure (Larson and Gobeli, 1985), and group and team performance (Thamhain and Wilemon, 1987). Even studies explicitly investigating project success factors have often concentrated on specific variables. For example Tubig and Abetti (1990) studied variables contributing to the success of defense R&D contractors such as contractor selection, type of contract, and type of R&D effort. And Chan and Kumaraswamy (1996) analyzed factors which caused time overruns.

Yet project management is more complex; bringing a project to a successful conclusion requires the integration of numerous management functions such as management of technical issues; control of cost, schedule and risk; communication, team-building and conflict resolution; and many other skills (Morris, 1988). In response to this variety of tasks, the 'systems approach' to project management, has evolved, aiming to help managers see the intricate nature of a project, and capturing it as a 'whole' (Cleland and King, 1983). Unfortunately, however, theory building did not develop at the same pace and it essentially did not address the multi-facet, multivariable nature of modern project management. A unique exception is Baker and Green (1984).

The third problem associated with studying project success factors is that, to date, little attention has been given to project's type and its relation to strategic and managerial variables. Furthermore, a major obstacle has been the vagueness of theoretical constructs, and the limited number of types recognized by project management studies. Although innovation studies have often used a traditional distinction between incremental and radical innovation (Mansfield, 1968; Moch and Morse, 1977; Dewar and Dutton, 1986), the project management literature has been slow in adapting a similar approach. In our review of the current research we also found that since the beginning of the nineties only few empirical studies were undertaken to analyze the success factors of project management. This tendency could also be identified in the reviews of empirical studies in the field of technology and innovation management. Most of the success factor studies were undertaken in the eighties (Balachandra and Friar, 1997). In the more recent years we see a clear tendency towards more narrow research questions.

To summarize our discussion, most studies of project success factor have made no distinction between projects, often neglecting the context in which a project is implemented (Murphy *et al.*, (1974) and Pinto and Covin (1989) are exceptions). In the following discussion we address these last two issues, namely, the application of multivariate analysis to the study of projects and the theoretical framework of project typologies.

The multivariate analysis approach

Multivariate analyses are employed when researchers need to represent a very large data set by several, easy-to-interpret, variables, or when it is necessary to relate a set of variables (rather than a single variable) to other sets of variables. Multivariate methods enable us to identify the effects of key variables in one data set on variables in the other data sets. Depending on the particular application and the available data, a multivariate method may be applied in the first stage of the quantitative analysis (serving as a linear approximation for a more complicated nonlinear model), or may itself be an adequate representation of the theoretical model that one needs to estimate.

There are numerous examples of the use of multivariate methods used in the past. In the case of a single data set, principal components analysis (PCA) proved to be very useful in reducing the dimensionality of the variables' space in applications in psychology, sociology, education, economics and operations research (see, for example, Harman (1952), Timm (1975), Heath (1952)). Interpretation of PCA results can be found in Rao (1964) and Guttman (1954). In the case of two or more data sets canonical correlation analysis (CCA) has been used successfully in different applications in the behavioral, social and economic sciences. Numerous examples of the use of CCA in these areas can be found in the studies of Mardia *et al.* (1979), Timm (1975), Fornell (1982) and Green (1978). Methodological aspects of CCA and the interpretation of CCA results in behavioral problems appear in Cliff and Krus (1976), and Cliff (1987).

In this paper, we estimate the effect of 360 managerial variables on the success of projects. The success of a project is represented by 13 variables. Thus, we have to account simultaneously for the multi-attribute nature of a project's success and for the multitude of managerial variables that are hypothesized to affect the different dimensions of project success.

Typological theories of project management

The traditional distinction between incremental and radical innovation (Zaltman *et al.*, 1973; Abernathy and Utterback, 1978; Dewar and Dutton, 1986) has led scholars of innovation to suggest that an organization that performs an innovative task should be different from an organization developing a more routine product (Burns and Stalker, 1961; Abernathy and Utterback, 1978; Burgelman, 1983; Galbraith, 1982; Bart, 1988). In contrast to the innovation literature, the project management literature has not used innovation to distinguish between projects, offering instead various typologies for project classification. For example, Blake (1978) suggested a normative distinction between minor change (alpha) projects, and major change (beta) projects; Wheelwright and Clark (1992), in a study on in-house product development projects, mapped such projects according to the degree to which they changed the company's product portfolio. Their typology included derivative, platform, breakthrough, and R&D projects; Tyre and Hauptman (1992) studied the impact of technical novelty on the effectiveness of organizational problem solving in response to technological change in the production process; and Pinto and Covin (1989) addressed the differences in success factors between R&D and construction projects. Other frameworks have also been proposed by Olson *et al.*, (1995) Cash, *et al.*, (1988), Ahituv and Neumann (1984), Pearson (1990), and Steele (1975).

Our research is based on a two-dimensional typological framework suggested by Shenhar and Dvir (1996) and Shenhar (2001). According to this framework projects are classified into four levels of technological uncertainty at project initiation and three levels of system scope – which is a measure of their complexity on a hierarchical systems and subsystems ladder. According to Doty and Glick (1994) fully developed typologies are complex theories that can be subjected to quantitative modeling and rigorous empirical testing. Such theories involve the derivation of ideal types prescribed in terms of multiple dimensions of organizational and structural variables. Shenhar and Dvir's ideal types represent holistic configurations of multiple unidimensional constructs. The set of project types constitutes a model, so that deviation from extreme or ideal types can be noted and explained (Shenhar and Dvir, 1996). Furthermore, the same framework has also been found useful in developing a taxonomy of products and innovations (Shenhar and Dvir, 1996) and in testing some of the classical propositions of structural contingency theory and their relevance to project organizations (Shenhar, 2001). The next step is to build a typological theory of projects – which is the subject of this article. This involves testing the quantitative deviation of projects from project ideal types and using the correlates of this measure with the dependent variable, namely, project success.

The development of a typological theory of project management is served in three ways by the use of multivariate analysis. First, this approach refines the search for project success factors. Our comprehensive quantitative analysis accounts objectively for the actual effects of managerial variables on project success. Second, the method yields new insights into the particular influence of certain variables on project success. Such influences usually remain unnoticed by common univariate and regression methods and by subjective unidimensional assessments of project success. Finally, the distinction between different project types provides additional support for the introduction of contingency arguments into the theoretical study of projects. If different projects are affected by different sets of success factors then clearly, researchers and authors must adopt a project-specific approach.

The next step in developing a project-specific theory and identifying additional effects of project success factors is to assess the relative importance of various managerial variables, to the different success measures. Also needed in order to predict the dependent variable – project success – is quantitative comparison of actual projects with ideal types. Such analyses will be the subject of our forthcoming studies.

3. Data organization and setup

Information was collected on 127 projects, executed in Israel and completed during recent years, was collected using structure questionnaires. End-products were aimed for military or commercial use. The likelihood of bias in the results is reduced by our sample's diversity in project size (less than $100,000 to over $1 billion), and in core technology (electronics, computers, software, mechanics, aerospace, optics, chemicals, and construction). Nevertheless, since project managers chose which projects to report, there may indeed have been a tendency to report successful projects.

Measures

Success measures. The questionnaires elicited data on 13 measures of success. These measures were developed in previous research (Dvir and Shenhar, 1992) and adjusted to the surveyed industries and to the present study. They were grouped into three dimensions. The first success dimension, denoted as meeting the project's design goals, refers to the contract signed with the customer, or the goals set by management at project initiation. Those goals included technical and operational performance of the final product, and schedule and budget goals. The second dimension refers to the benefit and impact of the project's end-product on the customer. It assesses success in meeting customer needs, customer satisfaction, and customer usage of the end-product. The third dimension measures the benefits that were gained by the developing organization from executing the project. It assesses commercial success, market share, and the extent to which the project created new opportunities and provided new technologies for use in future projects. The measures comprising each dimension are listed in Table 1.

Managerial variables. We examined 360 managerial variables, derived from the theoretical and practical literature, for their influence on the success of the sample projects. Data were classified into five managerial groups, each having a common managerial theme. Groups were further disaggregated into factors. Factors contained several variables, each describing a specific managerial aspect of the project execution process. The five groups are as follows. Group M^1 includes three factors that describe the sources of project initiation, the formal procedures that were instituted during initiation, and the project's milestones; Group M^2 includes four factors relating to the planning and control processes. Variables in this group describe planning methods, work breakdown structure (WBS) and financial management; Group M^3 contains five factors related to engineering design policy and considerations. These included the number of design cycles, and time of design freeze, design techniques, design considerations such as design for manufacturability, serviceability etc., risk management, and quality management. Group M^4 consists of four factors with various measures of organizational aspects such as organizational structure, managerial autonomy, resource-sharing with other parts of the organization, and skill level of the project team. Group M^5 includes five factors with variables describing the documentation generated during the project execution, design review procedures, management policy, formal contracting, and communication procedures with customers and subcontractors.

Initial analysis of the data suggested that answers to many questions were divided into too many categories, and that several variables exhibited very little variance, or were exact linear combinations of other variables. Appropriate aggregation of these variables and the elimination of variables with too many missing observations (25% or more of the 127 observations) reduced the number of the managerial variables to about 170.

Table 2 organizes the remaining managerial variables into the five groups and the 22 factors described above.

Project typology

Projects were classified according to perceived degree of technological uncertainty, and level of system scope.

Degree of technological uncertainty

Our measure of the degree of technological uncertainty is based on the organization's perception of the level of technological uncertainty at the time of project initiation. Because most projects employ a mixture of technologies, we considered only technologies that were new to the firm. Our classification recognizes four distinct types of projects (Shenhar, 1993; Shenhar and Dvir, 1996).

Table 1. Success dimensions and measures.

Success dimension	Notation	Success measures	Notation
Meeting design goals	S^1	Met operational performance	S^{11}
		Met technical performance	S^{12}
		Met project schedule	S^{13}
		Stayed on budget	S^{14}
Benefits to customers	S^2	Addressed a recognized need	S^{21}
		Solved a serious problem	S^{22}
		The product is used by the customer	S^{23}
		The customer is satisfied	S^{24}
Commercial success and future potential	S^3	Achieved commercial success	S^{31}
		Increased market share	S^{32}
		Created a new market	S^{33}
		Created a new product-line	S^{34}
		Developed a new technology	S^{35}

Table 2. Organization of managerial variables.

Managerial groups	Notation	Managerial factors	Notation	Number of Variables
Idea origination and project milestones	M^1	Origin of idea	M^{11}	12
		Formal procedures	M^{12}	8
		Project milestones	M^{13}	17
Planning and control	M^2	WBS (work breakdown structure)	M^{21}	9
		Schedule planning	M^{22}	9
		Planning and control methods	M^{23}	11
		Financial management	M^{24}	3
Policy and design considerations	M^3	Design phases	M^{31}	4
		Design considerations	M^{32}	8
		Risk management	M^{33}	5
		Design techniques	M^{34}	4
		Quality management	M^{35}	4
Organizational factors	M^4	Organizational structure	M^{41}	6
		Management levels	M^{42}	1
		Resource sharing	M^{43}	6
		Project manager autonomy	M^{44}	6
		Project team	M^{45}	8
Documentation, reporting and management policy	M^5	Documentation	M^{51}	27
		Design reviews	M^{52}	5
		Management policy	M^{53}	8
		Formal contracts	M^{54}	4
		Customer participation	M^{55}	7

Low-tech projects rely on well established technologies to which all industry players have equal access. Although low-tech projects may be very large in scale, no new technology is employed, nor is new technology acquired or implemented at any stage. Technological uncertainty is virtually nil. Most projects in the construction and road-building industries are in this category. Other examples are 'build-to-print' projects where a contractor is required to rebuild a product already designed by the client or another contractor.

Medium-tech projects mainly use existing technologies but incorporate some new technology or a new feature. Such projects are characterized by a relatively low level of technological uncertainty. The new technology or feature is usually the source of the project's advantage. Examples include industrial projects of incremental innovation, as well as improvements and modifications of existing products.

High-tech projects use technologies that are mostly new, but have already been developed prior to project initiation. Integrating several new technologies for the first time leads to a high level of technological uncertainty. Defense development projects that make use of new, but previously developed technologies are also included in this category.

Super high-tech projects are based primarily on new technologies that may not even exist at the time of project initiation. These technologies are still in their experimental or R&D phase, or must be developed during the period of project execution. Projects of this type entail extreme levels of technological uncertainty; they are therefore relatively uncommon, involve high-risk, and are usually undertaken only by large organizations or government agencies. A well-known example is the Apollo Moon-landing mission.

Degree of system scope

The second dimension along which projects are distinguished is system scope (Shenhar and Dvir, 1996). System scope measures the breadth, complexity, and number of hierarchical levels of a product or a system. Three levels of system scope are described, each of which presents different challenges to the design and management teams:

An assembly is a collection of components and modules combined into a single unit. An assembly may perform a well-defined function as part of a larger system, thus being one of its subsystems; or it may be an independent, self-contained product that performs a single, limited function. A radar receiver, a missile guidance and control unit, and a computer hard disk are examples of assemblies (subsystems) within larger systems; CD players, radios, coffee makers, and other household appliances are independent assemblies.

A system is a complex collection of interactive elements and subsystems within a single product, jointly performing a wide range of independent functions to meet a specific operational mission or need. A system consists of many subsystems (and assemblies), each performing its own function and serving the system's major mission. Radar systems, computer networks, missiles, and, for that matter, complete aircraft are all systems that perform independent tasks.

An array is a large, widely dispersed collection of different systems that function together to achieve a common purpose. An array can also be considered a 'super-system' – a conglomeration of systems. Usually arrays are scattered over wide geographical areas and consist of a variety of systems. A nation's air defense system, consisting of early warning radar, command and control centers, combat aircraft and ground-to-air missiles, are such super-systems. Similarly, the public transportation network of a large city may also be considered as an array.

Shenhar and Dvir (1996) showed that project management styles are typically clustered around the project categories described above. However, classification of the projects in our sample into these four-by-three types proved to be too detailed for the size of our sample, hence precluding operational conclusions. In the present study we therefore aggregated the four types of technological uncertainty into two groups: low technological uncertainty, combining the first two levels described above (72 projects in our sample are in this category); and high technological uncertainty combining the two higher levels (55 projects). Similarly, system scope dimension was aggregated into low scope, which consisted of the first level (assembly), and includes 35 projects in our sample, and high scope, which combined the two higher levels (system and array). There are 92 projects in the high scope category.

4. Identifying the critical variables

As explained, the main goal of this paper is to evaluate the effects of a set of managerial variables on various dimensions of project success, for various levels of technological uncertainty and system scope. Thus, for a particular level of scope, or uncertainty, we want to find the largest possible overall connection (correlation) between the set of managerial variables and the set of success measures. We then identify the managerial variables that contribute most to this connection (correlation) – denoted critical variables. Then, we compare the sets of critical variables across different levels of scope and uncertainty. For this purpose, we shall use a multivariate statistical model (see Appendix A) that can be applied simultaneously to all managerial variables and all measures of success (see Tishler *et al.* (1996) and Tishler and Lipovetsky (1996, 2000)).

Suppose that for a particular level of scope, or uncertainty, data are available on n managerial variables and m success measures for K projects. Organize the n managerial variables and m measures of success for all K projects in the $(K \times n)$ matrix M and the $(K \times m)$ matrix S, respectively. We use canonical correlation analysis (CCA) as our major multivariate method to identify the critical variables in M that affect S.

Table 3. Critical managerial variables according to scope and uncertainty level: idea origination and project milestones.

Factor	Variable	Complexity Low	Complexity High	Uncertainty Low	Uncertainty High
Origin of idea	Operational need	X	X		X
	Initial concept by customer	X			
Formal procedures	Idea screening	X		X	X
	Feasibility studies			X	X
	Proposal preparation		X	X	X
	Bid		X	X	
	Selection of contractor	X	X	X	
	Decision on acquisition	X			
	Entry into production	X			
Project milestones	Requirement definition		X	X	
	Concept selection				X
	Configuration selection		X	X	X
	Configuration specs		X		X
	Subsystems specs		X		X
	Test plan			X	X
	End of integration				X
	Qualification test	X			X
	Final test		X	X	

Note: X denotes critical variable.

Table 4. Critical managerial variables according to scope and uncertainty level: planning and control.

Factor	Variable	Complexity		Uncertainty	
		Low	High	Low	High
WBS	System level	X	X	X	X
	Detailed product tree		X	X	X
	Development	X			
	Testing	X			
	Production preparations				X
	ILS				X
	Management				X
Planning and control methods	Detailed Gantt or PERT		X		X
	Detailed milestones				X
	Monitoring schedule objectives				X
	Monitoring budget objectives			X	
	Monitoring technical performance			X	

Note: X denotes critical variable.

Table 5. Critical managerial variables according to scope and uncertainty level: policy and design considerations.

Factor	Variable	Complexity		Uncertainty	
		Low	High	Low	High
Design cycles	No. of design cycles	X	X	X	X
	Stage of design freeze – system			X	
	Stage of design freeze – subsystems	X		X	
Design considerations	Manufacturability			X	
	Service and support				X
	Quality				X
	Reliability	X	X		X
	Human factors	X			X
	Product cost		X		X
Design techniques	System engineering		X		
	Configuration control	X			X
Quality management	Total quality		X		X
	Quality objectives	X	X	X	
	Reliability objectives	X	X		X
	Statistical quality control			X	

Note: X denotes critical variable.

Our data includes five groups of managerial variables and three dimensions of success. Technically, it is possible to identify the managerial variables that are critical to project success by analyzing the entire set of managerial variables as a whole. In practice, however, each group of managerial variables contains different amounts of information, depending on the importance of the group relative to other groups, on our ability to represent the required data in the questionnaire, and on the available data. Furthermore, the groups of managerial variables are not equally relevant to the different success measures. Thus, in the following analysis, we identify the critical managerial variables separately for each of the five managerial groups. The critical managerial variables, organized in the original five groups and 22 factors (see Table 2), are listed in Tables 3–7.

6. Critical managerial factors and their relation to project success

Tables 3–7 present the managerial factors critical to projects' success with a low or a high level of scope, and with a low or a high level of uncertainty. The data in Tables 3–7 present the critical managerial variables separately for the two levels of uncertainty and the two levels of scope. We started our analysis (after appropriate aggregation of variables and the elimination of variables with too many missing observations) by

Table 6. Critical managerial variables according to scope and uncertainty level: organizational factors.

Factor	Variable	Complexity		Uncertainty	
		Low	High	Low	High
Organizational structure	Functional structure			X	
	Level of fitness				X
Resource sharing	Direct labor				X
	Logistic support	X		X	
	Equipment and facilities	X	X		X
	Design and manufacturing services				X
	No sharing			X	
PM autonomy	Manpower	X		X	
	Budget		X		X
	Time overruns		X		
	Schedule changes		X	X	
	Spec. changes	X	X		
Project team	Technical level	X			
	Manager's technical level		X	X	
	Manager's managerial level		X	X	X
	Personnel enrichment		X	X	
	Team spirit			X	

Note: X denotes critical variable.

Table 7. Critical managerial variables according to scope and uncertainty level: documentation, reporting and management policy.

Factor	Variable	Complexity		Uncertainty	
		Low	High	Low	High
Documentation	Existence of requirement document	X			
	Requirement document in formal form		X		X
	Systems specs in formal form		X		
	Existence of contract	X		X	
	Contract in a formal form		X	X	X
	Existence of SOW		X	X	
	SOW in formal form			X	X
	Existence of WBS		X	X	
	WBS in formal form		X	X	
	Existence of project plan	X		X	
	Project plan in formal form		X		X
	Existence of configuration management document		X	X	
	Configuration management document in formal form		X	X	
	Acquisition management document in formal form	X			
	Existence of testing plan		X		X
Design reviews	At the end of each main phase		X	X	
	Formal documents prepared		X		
	Customer participation			X	
Management policy	Organizational policy			X	
	Engineering design		X		
	Testing and approval	X		X	
	Specifications		X	X	
	Quality and reliability	X			X
	Redundancy				X
	Acquisition		X		
Formal contracts	With customer		X		
	With subcontractors Within the organization				X
Customer participation	Requirement definition		X	X	
	Concept definition	X	X		X
	Setting specs		X		
	Problem solution			X	X

Note: X denotes critical variable.

observing the impact of 170 managerial variables on project success. In total 96 of these variables are relevant for a successful project implementation. The main objective of this study was to prove the contextual influence of project characteristics on the impact of the success factors or projects. The X signs in the four columns of the tables denote the managerial variables that were found to have a major impact on the projects success relative to the other variables.

The results show three different types of success factors. Factors which are independent of the project characteristics, factors which are solely influenced by uncertainty and factors which are solely influenced by scope. Only 20 of the managerial variables are critical for the project success independent of the project's characteristics. Variables of this group have a significant influence on the success of projects along both classification dimensions or at least along one dimension. These 20 variables cover nearly all factor categories except Planning and Control, Design Techniques, Organizational Structure, Design Reviews, Management Policy and Formal Contracts.

The second question we address is the hypothesis that success factors are dependent on contextual influences. Generally, 76 variables influence the success of different types of projects (i.e. higher scope projects versus lower scope projects or projects with low uncertainty versus projects with high uncertainty).

The table shows the number of success factors dependent on the project characteristics. The factors were grouped by the four project classes created by the two classification dimensions. The results in the table strongly support the hypothesis of contextual influences on the project characteristics. Most of the 76 factors which depend on the scope or the uncertainty would not show up in an aggregate analysis!

Several specific observations are as follows. First, consider the initiation and definition phase of projects (Table 3). Most of the general success factors (4) belong to the group of the formal procedures. While the initial stages of the project idea screening and feasibility studies are critical to the success of all types of projects, a formal bid selection process is critical only to high-scope and low-uncertainty projects. Using formal procedures for the final stages of projects (e.g. acquisition and entry into production) is more important for low-scope projects. Extremely important to the success of high uncertainty projects (and of some importance to the success of high-scope projects) is careful identification of milestones (particularly those concerning configuration selection, systems specs setting, and subsystems specifications) prior to entry into development.

Table 8. Number of critical managerial variables in scope/uncertainty cells.

		Uncertainty	
		Low	High
Scope	Low	23	25
	High	30	28

Table 4 addresses the issues of project planning and control; it reveals two main phenomena. First, it seems that the use of a detailed WBS (work breakdown structure) is particularly important in high-uncertainty projects. Second, schedule-monitoring techniques are more important to high-uncertainty projects. For low-uncertainty projects, however, it is more important to monitor budget expenditures and technical performance goals, because when there is little uncertainty both budget and performance goals can be predefined and are less prone to change.

Table 5 deals with the design-related activities in projects. The most important conclusion here is the need to account for design considerations such as quality, reliability and serviceability during the design and development stages of high-uncertainty projects. These considerations are less important for low-uncertainty projects. This result has not been found by earlier studies. Appropriate planning of design cycles is important to all projects. Another finding is that early design freeze is more important for low-uncertainty projects than for high-uncertainty projects. This is because the design cannot be frozen in high-uncertainty projects until all technological gaps are closed. However, when there is little uncertainty design freeze must not be delayed. The decision to freeze design is usually at the discretion of the project manager and his team, and for better project success, design should be frozen as early as possible in less uncertain projects.

The effect of organizational factors on project success is demonstrated in Table 6. First, organizational structure seems to have little effect on the success of projects, except for those of low-uncertainty. This result concurs with previous studies (e.g. Might and Fischer, 1985). Sharing project resources seems to affect more the success of high-uncertainty projects. High-scope projects require the project manager to have a high level of autonomy over budget, schedule, and specifications. Project manager autonomy is less important for low-scope projects. A similar result was found by Dvir and Shenhar (1992) in their study at the business-unit level of high-tech industries.

The characteristics of the project team (level of competence of the project manager and team, and the team spirit) can determine the success of high-scope projects and low-uncertainty projects. A surprising finding, not reported before, is that project team characteristics have little impact on high-uncertainty projects. It may be that in such challenging projects, only highly skilled workers are recruited to the team. The only variable exhibiting some variability, and thus apparently affecting the outcome of high-uncertainty projects, is the competence of the project manager.

Table 7, which deals mainly with written and verbal communication with the customers, shows that the most powerful means of communication is written documents. Documents are important to the success of high-scope projects, as well as to low- and high-uncertainty projects. For high-uncertainty projects to succeed, documents must be prepared formally. Various aspects of management policy are important to all types of projects, but all are probably more important to high-scope projects. Quality, reliability and redundancy policies are important to high-uncertainty projects, whereas organizational policy, engineering design policy and testing policy are of more importance to low-uncertainty projects.

Finally, customer participation seems to be important to all projects. It is particularly important during the definition phase and product requirement setting of high-scope and high-uncertainty projects, and during the concept definition phase for high uncertainty projects. Customer participation in problem-solving during the development effort seems to be important for both levels of technological uncertainty.

7. Summary and conclusions

The main purpose of this paper has been to refine the search for project success factors and to identify project-specific managerial variables that are critical to the success of industrial projects. The study employs multivariate analysis and a multidimensional measure of success to assess a battery of managerial variables within a new typological framework.

First, the findings strongly suggest that successful project management is influenced by a rather wide spectrum of variables. Unlike previous studies which addressed only major variables (as they were perceived and indicated by managers), the multivariate statistical approach of the present study reveals a multitude of additional factors which account for project effectiveness, and which, if neglected, may be detrimental to the project's outcome. This paper also demonstrates that multivariate methods are powerful tools for analyzing very large data sets. By using the multivariate method described, we were able to rank managerial factors according to their influence on project success. This ranking produced several new and sometimes surprising results.

Second, multivariate analysis (in contrast to univariate and regression analyses), together with a multidimensional view of project success, enables us to account for the mutual interactions of all managerial variables and success measures. It facilitates the identification of several key managerial factors whose importance has not been recognized by other methods. Indeed, as we demonstrated, some new findings emerge from our analysis that will be extremely useful to professional project managers.

The third major insight yielded by this study is that project success factors are indeed contingent upon the specific type of project – that is, the list of project success factors is far from universal. As demonstrated by Shenhar (2001) and by Shenhar and Dvir (1996), project management is a broad field, and fewer features are common to all projects than previously thought. Further, the analysis indicates that the list of project success factors varies with project type, and that project managers must carefully identify those factors that are critical to their particular project. The distinction between high and low levels of technological uncertainty and system scope serves as a useful classification scheme to assess the different effects of managerial variables on various types of projects. As before (Shenhar, 2001), technological uncertainty is the dominant dimension, which influences managerial variables, suggesting, as expected, that high-uncertainty projects must be managed differently than low-uncertainty projects. For example, high-uncertainty projects demand that special attention be devoted to project definition, project milestones, design considerations, documentation, policy and customer participation. On the other hand, low uncertainty projects require the focus to be on the formal and structured selection of contractor, budget monitoring, early design freeze, design for manufacturability, quality objectives, statistical quality control, and project manager autonomy. Similarly, projects that are broad in scope are more sensitive to formal proposal and bid preparations, identification of project milestones at initiation, project manager autonomy, formal contracts, and formalization of various other documents.

Finally, this study provides a framework upon to build a typological theory of projects. Typologies are complex theoretical statements that must be subjected to quantitative modeling and empirical testing (Doty and Glick, 1994). Furthermore, unlike simple classification systems, typologies include multiple ideal types, each of which represents a unique combination of the organizational attributes that are believed to determine the outcome of the variable under scrutiny (Doty and Glick, 1994). Shenhar (2001) and Shenhar and Dvir (1996) laid the basis of such a typology. They identified first- and second-order constructs of project typologies; a set of ideal project types and a hierarchy of relationships among constructs and proposed a tentative categorization of managerial variables of ideal project types. The present study quantifies the effect of variations in managerial variables on project outcome. In fact, the canonical correlation between managerial variables and success measures illuminates a wide range of relationships among constructs. It is able to demonstrate which variables are the most potent predictors of projects success – and in which settings they are most relevant.

On a final note, this study demonstrates that the use of multivariate – even those whose solution requires nonlinear optimization methods – is simple and effective. This fact is particularly important when using data sets with a large number of variables with a widely varying number of observations (very small, intermediate or very large), as is common when evaluating management performance in large-scale projects.

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Appendix

A. Identifying the critical variables: a methodology

Suppose that for a particular level of scope, or uncertainty, data are available on n managerial variables and m success measures for K projects. Organize the n managerial variables and m measures of success for all K projects in the $(K \times n)$ matrix M and the $(K \times m)$ matrix S, respectively. We use canonical correlation analysis (CCA) as our major multivariate method to identify the critical variables in M that affect S. We first standardize all variables in M and S by subtracting their means and dividing them by their standard deviations. Hence, $M'M$, $M'S$ and $S'S$ are matrices of pair-wise correlations between the corresponding variables. We define the following linear combinations:

$$\xi = Ma, \tag{1a}$$

$$\eta = \mathrm{S}b, \tag{1b}$$

Where a and b are $(n \times 1)$ and $(m \times 1)$ vectors of constant coefficients, and ξ and η are $(K \times 1)$ vectors of scores. The terms ξ and η can be interpreted as the aggregators of M and S, respectively. The vectors a and b are the weights (signifying importance) of the variables in the columns of M and S. Generally, a large absolute value to the ith component in the vector a implies that the ith managerial variable (ith column in M) contributes a great deal to the correlation between M and S; that is, the ith managerial variable is critical to the prediction of the set of success measures S. Conversely, if the ith component of the vector a is small in absolute value, then the ith managerial variable exhibits little influence on S, and is declared non critical.

The canonical correlation, ρ, between M and S is the maximal pair-wise correlation between ξ and η. The optimal weights (the importance of the variables in M and S) are found in this maximization problem; that is

$$\max_{a,b} \ \rho = \frac{\xi'\eta}{(\xi'\xi)^{1/2}(\eta'\eta)^{1/2}} = \frac{a'M'Sb}{(a'M'Ma)^{1/2}(b'S'Sb)^{1/2}}. \tag{2}$$

Clearly, a high value for ρ implies that the variables in M are highly correlated (as a group, not individually) with those in S.

The solution of (2), subject to the normalizing conditions $\xi'\xi = 1$ and $\eta'\eta = 1$, is described in Anderson (1974), Rao (1973), Tishler and Lipovetsky (1996, 2000), Tishler *et al.* (1996).

To circumvent multicollinearity problems and obtain a reliable initial subset of critical variables (from the CCA starts), we use restricted eigenvector analysis for two data sets (denoted REA). This technique does not require the inversion of matrices and, therefore, can be used with singular matrices and is less prone to the multicollinearity problems that arise with near-singular matrices. Formally, we present the REA method as follows. Suppose that the data generation process of M and S is

$$M_{k\tau} = \lambda \xi_k a_\tau + e_{k\tau}, \tag{3a}$$

$$S_{k\theta} = \mu \eta_k b_\theta + u_{k\theta}, \tag{3b}$$

Where λ and μ are normalizing constants, $k = 1, \ldots, K$; $\tau = 1, \ldots, n$; and $\theta = 1, \ldots, m$. The terms $e_{k\tau}$ and $u_{k\theta}$ are random errors. Here, we impose the constraint $\xi = \eta \equiv \gamma$ and use the model

$$M_{k\tau} = \lambda \gamma_k a_\tau + e_{k\tau}, \tag{4a}$$

$$S_{k\theta} = \mu \gamma_k b_\theta + u_{k\theta} \tag{4b}$$

Thus, both matrices feature the same scores (up to a proportionality factor) but different weights. Equations (4) imply that all the measurements $M_{k\tau}$ and $S_{k\theta}$ of a given project $k (k = 1, \ldots, K)$ are a product of two effects: the first, γ_k, is the project effect, which is identical for all $M_{k\tau}$ and $S_{k\theta}$. The second differs across variables and measures. It is the effect of either of the τth variable in M (a_τ in 4a) or of the θth measure in S (b_θ in 4b).

Estimation of a, b and γ in (4) is obtained by the following least squares problem:

$$\min_{\lambda,\mu,a,b,\gamma} \{||e||^2 + ||u||^2\} = \min_{\lambda,\mu,a,b,\gamma} \left\{ \sum_{k,\tau} (M_{k\tau} - \lambda a_\tau \gamma_k)^2 + \sum_{k,\theta} (S_{k\theta} - \mu b_\theta \gamma_k)^2 \right\}, \tag{5}$$

Subject to the normalizing conditions,

$$\sum_\tau a_\tau^2 = \sum_\theta b_\theta^2 = \sum_k \gamma_k^2 = 1.$$

The choice of critical managerial variables is similar to that by CCA; that is, variables in M that correspond to a large absolute value in the estimated vector a are declared critical for S.

B. The choice of critical variables: an algorithm

The algorithm for the choice of the variables in the five managerial groups $M^1, \ldots, M^5$ critical to S is as follows. Let n_i be the number of variables in the ith group of managerial variables, and m be the number of success measures in all three success dimensions.

Step 1. We use REA to obtain the initial set of critical managerial variables. That is, for each pair (M^i, S) we formulate the model as in (4) and solve it via expression (5). We then select all the variables in M^i which obey

$$|a_\tau| > |\bar{a}|, \qquad \tau = 1, \Lambda, n_i$$

Where $\bar{a}$ is the average of a_τ across all τ. Denote the set of variables that was selected from each M^i by m^i.

Step 2. We compute the canonical correlation between M^i and S (denoted by CC^i_M), and the canonical correlation between m^i and S (denoted by CC^i_m).

Clearly, $CC^i_m \leqslant CC^i_M$. However, in all cases, we obtained $CC^i_m \geqslant 0.9CC^i_M$.

Step 3. We delete from m^i, by a series of trials, all the variables that can be deleted without reducing CC^i_m by a combined total of at most 3%. Variables were selected for deletion according to their relative weights in canonical correlation with S. Denote by q^i the group of variables not deleted from m^i. Denote by CC^i_q the canonical correlation between q^i and S. We then proceed as follows.

If $CC^i_q \geqslant 0.9CC^i_M$, then q^i is chosen to be the final group of critical variables in M^i.

If $CC^i_q < 0.9CC^i_M$, then we add to q^i variables from M^i (variables that are not included in m^i), according to their respective weights in a series of canonical correlations. We continue to add variables until $CC^i_q \geqslant 0.9CC^i_M$. In practice, we used this procedure only once, and two variables were added to m^i to form the final q^i.

The critical managerial variables (the final sets $q^i, i = 1, \ldots, 5$), organized in the original five groups and 22 factors (see Table 2), are listed in Tables 3–7.