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In search of project classification: a non-universal approach to project success factors

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Abstract

In this study we attempt to answer two questions: Is there a natural way to classify projects and what are the specific factors that influence the success of various kinds of projects? Perhaps one of the major barriers to understanding the reasons behind the success of a project has been the lack of specificity of constructs applied in project management studies. Many studies of project success factors have used a universalistic approach, assuming a basic similarity among projects. Instead of presenting an initial construct, we have employed a linear discriminant analysis methodology in order to classify projects. Our results suggest that project success factors are not universal for all projects. Different projects exhibit different sets of success factors, suggesting the need for a more contingent approach in project management theory and practice. In the analysis we use multivariate methods which have been proven to be powerful in many ways, for example, enabling the ranking of different managerial factors according to their influence on project success. © 1998 Elsevier Science B.V. All rights reserved.

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1. Introduction

The widespread use of projects in organizations today is the driving force in the search for factors that influence project success. In spite of extensive research in recent years, there has been little agreement on the causal factors of project success (Pinto and Slevin, 1987). A major reason, in our opinion, is the widespread assumption that a universal theory of project management can be applied to all types of projects.

The search for a universal theory may be inappropriate given the fundamental differences that exist across projects and innovations (Dewar and Dutton, 1986; Pinto and Covin, 1989; Damanpour, 1991; Shenhar, 1993; Shenhar and Dvir, 1996). Although several studies have suggested various classification frameworks (e.g., Steele, 1975; Blake, 1978; Ahituv and Neumann, 1984; Cash et al., 1988; Pearson, 1990; Wheelwright and Clark, 1992), none of these constructs has become standard practice and most project management textbooks still focus on a universal set of functions and activities considered common to all projects.

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Another topic of concern is the question of project success factors. What are the major managerial variables that contribute to project success? Are all projects subject to the same set of success factors? In spite of extensive research in recent years and a general agreement that some success factors are common to all projects, there has been limited convergence, let alone agreement, on the full spectrum of ingredients and causes of project success (Pinto and Slevin, 1987; Lechler and Gemunden, 1997).

The purpose of this study is to combine the theory of project success factors with the search for a natural project classification. However, unlike previous research which presented a given construct and then identified specific factors for each type, this research first searches for an appropriate classification scheme using linear discriminant analysis and then uses this classification in order to identify specific project success factors for different classes of projects.

We applied our approach to a sample of 110 projects. For each project, we collected data on more than 400 managerial variables. In assessing project success, we employed a multidimensional approach (Cooper and Kleinschmidt, 1987; Shenhar et al., 1997), using 11 measures which were then grouped into two major dimensions; benefits to the customer and meeting design goals (Lipovetsky et al., 1997). Our primary method of investigation uses multivariate analysis (Rao, 1973; Anderson, 1974; Lipovetsky and Tishler, 1994; Tishler and Lipovetsky, 1996) to account simultaneously for the multi-attribute nature of project success and the multitude of managerial variables. Specific multivariate methods, such as canonical correlation and eigenvector analysis, have enabled us to account for all the interactions between the managerial and success variables and to discover several angles not yet explored.

As we expected, the analysis using multivariate models, with very detailed data on managerial variables and success dimensions, did indeed yield some new findings. First, three major classification constructs emerged: pure software vs. hardware projects, project scope (or complexity) and project outcome (i.e., product improvement, a new generation or a new system concept). In addition, we found that the pre-contract activities, the involvement of the customer follow-up team and project control (schedule and milestones, budget utilization, etc.) are very important factors in the success of all types of projects. Design considerations such as producibility and maintainability proved important in five of the six types of projects that we considered (feasibility study projects were the exception). The managerial variables representing management policy appear to influence all types of projects, with the greatest impact evident in large hardware projects (particularly meeting project goals). In contrast, the number of design cycles prior to design freeze has no impact on customer benefits. Design freeze timing mostly affects hardware projects of low scope and exhibits no impact on high-scope hardware projects that are not feasibility studies. A late design freeze also contributes to the success of feasibility studies and small hardware projects. Software projects are very different from hardware projects. They are particularly sensitive to a priori criteria for operational effectiveness whereas this is less critical for hardware projects. On the other side, the definition of technical and operational specifications is an important factor in hardware projects but it is not so important in software projects. Prototypes are mainly important for satisfying customer's needs in software projects and small hardware projects. The managerial variables managerial style, delegation of authority and organizational learning seem to have little or no impact on customer benefits. However, communication style strongly affects customer benefits in software projects. Flexibility in management affects the success of small projects only, while team charac-teristics and project manager qualifications have considerable impact on achieving design goals for all project types. Managerial qualifications of key personnel proved more important to achieving customer satisfaction than to meeting design goals.

The paper is organized as follows. Section 2 presents the theoretical background by surveying the literature, developing a list of success measures as well as a set of managerial variables critical to project success and describing various classifications of projects. Section 3 describes the research design, the structure of the data and the linear discriminant analysis which produced the best classification scheme. The critical success factors that influenced different types of projects are presented and discussed in Section 4. Section 5 summarizes the paper.

2. Theoretical background

2.1. Classification of projects

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 that develops a more routine product (Burns and Stalker, 1961; Abernathy and Utterback, 1978; Galbraith, 1982; Burgelman, 1983; 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 more recent study on in-house product development projects, classified 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 Steele (1975), Ahituv and Neumann (1984), Cash et al. (1988), and Pearson (1990).

Shenhar (1993) and Shenhar and Dvir (1996) have recently suggested a two-dimensional typological framework for project classification. According to this framework, projects are classified into four levels of technological uncertainty at project initiation and three levels of system scope, which specifies their location on a hierarchical ladder of systems and subsystems. As a typological theory of projects, Shenhar and Dvir's framework provides a set of relationships among constructs and demonstrates variants in the independent variables which are used to describe their ideal types. Furthermore, the same framework has also been found useful in the development of a taxonomy of products and innovations (Shenhar et al., 1995) and in the classification of systems engineering methods (Shenhar and Bonen, 1997). Following their extensive review of the literature, Balachandra and Friar (1997) proposed a contingency framework which is somewhat similar to that of Shenhar and Dvir (1996). Specifically, they suggest classification of new product development and R&D projects according to the nature of the technology (low, high), the innovation (incremental, radical) and the market (new, existing).

Generally, previous studies employed various typological frameworks for project classification. Depending on the nature of the projects being studied, researchers proposed an initial set of ideal project types and proceeded to analyze the data according to these project types. Our approach is different in that we do not start with a hypothetical classification or an initial set of ideal project types. Instead, we use the rich data from 110 projects, which include several hundred managerial variables, to search for the best classification scheme. This approach of searching for an optimal classification scheme based on data analysis is suggested as a methodology to identify ideal project types for general classes of projects.

2.2. Success measures

The first step in investigating the interdependence of managerial variables and project success measures is to agree on the definition of success. 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 an operative, framework. According to Pinto and Slevin (1988) (p. 67) ''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.'' An obvious approach would be to look for simplistic formulae, in particular ones that are unequivocal and easy to assess. Such measures have often paralleled success with meeting the objectives of project budget and schedule and achieving an acceptable level of performance (Pinto and Slevin, 1988). However, even when these measures are taken together, they represent at most a partial list of success measures and may be misleading. For example, projects that meet budget and schedule constraints may be considered successful even though they do not meet customer needs and requirements (Baker et al., 1988) or subsequently meet with great difficulty in the commercialization process of the final product.

The assessment of project success may also differ according to the assessor (Freeman and Beale, 1992). Comprehensive success criteria must therefore reflect different interests and views which leads to the necessity for a multidimensional, multicriteria 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 final product. Client satisfaction and customer welfare were 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 discussed three different dimensions as relevant to the success of new products: financial performance, the window of opportunity and market impact. A similar approach was used by Dvir and Shenhar (1992) to assess the success of high-tech strategic business units. Finally, while reviewing the latest project management literature, Freeman and Beale (1992) identified seven main criteria used to measure projects success. Five of these are frequently used: technical performance, efficiency of execution, managerial and organizational implications (mainly customer satisfaction), personal growth and manufacturer's ability and business performance.

With data gathered in a recent study of defense projects performed by Israeli industry, Lipovetsky et al. (1997) used a multidimensional approach to measure the success of various defense projects. Based on previous studies, four dimensions of success were defined: *meeting design goals*, *benefits to the customer*, *benefits to the developing organization* and *benefits to the defense and national infrastructure*. For each project, three different stakeholders (the customer, the developing organization and the coordinating office within the Ministry of Defense) were asked for their views on the relative importance of these dimensions of success. Analysis of the data revealed that *benefits to the customer* is by far the most important success dimension and the second *is meeting design goals*. The other two dimensions proved relatively unimportant. In this paper, we use the results of Lipovetsky et al. (1997) and measure the success of our sample projects using two success dimensions: the perceived *benefits to the customer* and the success in *meeting design goals*.

2.3. Project management critical success factors

The search for critical success factors has been going on for more than two decades, focusing at the product, project or business unit level. According to the classical proposition, organizations must develop a set of strategic strength areas that are key 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), the 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). Critical success factors at the business unit level were studied by MacMillan et al. (1982) and Dvir et al. (1993).

Several attempts have been made to identify the critical success factors of industrial projects. Rubinstein et al. (1976) found that individuals, rather than organizations, ensure the success of an R&D project. According to their findings, 'product champions' play a major role in the initiation, progress and outcome of projects. Slevin and Pinto (1986) developed a research framework that included the following major factors believed to 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 US, they found that the most important factors are those related to satisfying the client's needs (Pinto and Slevin, 1987). Pinto and Slevin (1988) also studied success factors across the project life cycle. 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. Might and Fischer (1985) investigated structural factors assumed to affect project success, which included the organizational structure, the level of authority delegated to the project manager and the size of the project. They found that the level of authority entrusted to the project manager is positively related to all internal measures of success (meeting budget, time-table and technical requirements).

The wealth of research and its inconclusive findings bring to mind at least three reasons for additional investigation into the determinants of project success. The first concerns the minor distinction that has been assumed in previous research between the project type and its strategic and managerial variables. Furthermore, perhaps one of the major barriers to understanding the nature of projects has been the lack of specificity of constructs and the limited number of typologies applied in project management studies.

Second, the multidimensional concept in assessing project success has not been linked to the search for project success factors, despite its strong theoretical background (Cooper and Kleinschmidt, 1987; Pinto and Mantel, 1990; Dvir et al., 1993 are exceptions at the product, project levels, and business unit). In many cases, the issue of assessing success was left to the research respondents, who were permitted to interpret success according to their own past project experiences (e.g., Pinto and Slevin, 1987).

The third reason involves the range of management variables that were included in previous papers. A great deal of previous research has focused on a single aspect of the project such as the management of professionals in R&D projects (Katz and Tushman, 1979; Roberts and Fusfeld, 1981), communication patterns in technical and R&D projects (Katz and Tushman, 1979; Allen et al., 1980), project organizational structure (Larson and Gobeli, 1985) and team performance (Thamhain and Wilemon, 1987). Even studies aimed explicitly at identifying project success factors have often concentrated on a limited number of 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, while Pinto and Slevin (1987) used their research respondents to identify, for each successful project, a single action that would substantially help implementation. However, project management is more complex. Bringing a project to a successful conclusion requires the integration of numerous management functions such as controlling, directing, team building, communicating, cost and schedule management, technical and risk management, conflict and stakeholders management and life-cycle management, among others (Morris, 1988). The large variety of tasks has gradually fostered the ‘systems approach’ to project management, aimed at helping managers to understand the intricate nature of a project and capturing it as a ‘whole’ (Cleland and King, 1983). Unfortunately, the theory did not develop at the same pace as the multi-faceted, multivariable nature of modern project management (Baker and Green, 1984 present one exception). Consequently, the complexity and breadth of project management requires a broader investigative perspective.

2.4. *The multivariate analysis approach*

Multivariate analyses are often employed when researchers need to represent a very large data set by several, easy-to-interpret variables or when it is necessary to relate one set of variables (rather than a single variable) to other sets of variables. These methods facilitate the identification of the effects of key variables in one data set on all, or several, of the variables in other sets. Depending on the particular application and the available data, a multivariate method is utilized either as the true representation of the theoretical model or as the first stage of a quantitative analysis serving as a linear approximation for a more complicated nonlinear model.

There are many examples of the use of multivariate methods. In the case of one data set, these methods proved to be very useful in reducing the dimensionality of the variables’ space. Applications can be found in psychology, sociology, education, economics and operations research (see, for example, Harman, 1976; Timm, 1975; Heath, 1952). In the case of two or more data sets, Canonical Correlation Analysis (CCA) has been used successfully in many applications in the behavioral, social, managerial and economic sciences. Numerous examples of the use of CCA in these areas can be found in the studies of Timm (1975), Green (1978), Mardia et al. (1979), Fornell (1982), Cliff (1987), Lipovetsky and Tishler

(1994), Tishler et al. (1996) and Tishler and Lipovetsky (1996).

In this paper we use CCA to estimate the effects of over 400 managerial variables on the success of projects, where success is represented by 11 variables grouped into two dimensions. Thus, we simultaneously account for the multi-attribute nature and for the multitude of managerial variables that are hypothesized to affect the different dimensions of a project's success.

3. Data organization

Data on 110 defense projects undertaken in Israel during the last 20 years and completed between 1981 and 1990 were gathered using questionnaires and interviews. The questionnaires were completed by three key personnel related to the projects: one member of the customer team, one member of the contractor team and one representative of the Ministry of Defense. Thus, the different points of view of the major participants were reflected. The data collected from the various stakeholders were combined into one database by the interviewers, who developed a deep understanding of the projects about which they were collecting the data.

The projects in our sample were undertaken in a variety of industries such as electronics, computers, aerospace and munitions. The main customer was the Israeli Ministry of Defense. The project officers representing the Ministry of Defense at the contractors' facilities came from end-user organizations such as the airforce, navy and ground forces, reflecting different lines of thoughts about the ways projects should be managed and performed.

The project population includes many types of defense projects, representing a diverse variety of project sizes (from less than US$1 M to over US$500 M) and development duration (from about 1 year to more than 20 years). The average time of development was 6 years with a standard deviation of 2.9 years. Twenty-five of the projects developed new weapon systems, 44 developed surveillance and electronic warfare systems, while others developed communication, command and control systems and support equipment. Nineteen of the projects were feasibility studies, 28 were improvement projects of existing systems and the others developed entirely new systems. Twenty-seven of the projects were pure hardware projects while the others included software and hardware. Thirty-three of the projects were developing subsystems, 76 were developing full-scale systems and one project was engaged in the development of a platform.

The questionnaires gathered data on 20 different measures of success. These measures were developed through earlier research (see Dvir and Shenhar, 1992; Dvir et al., 1994; Tishler et al., 1996) and were adapted for application to defense projects in the surveyed industries.

The measures were divided into four separate groups (dimensions). The first dimension, designated *meeting design goals*, refers to the contract that was signed with the customer. The second dimension measures the *benefits to the customer* from the project's end-products. It includes measures for assessing the success in meeting acquisition and operational needs, as well as measures of customer satisfaction. The third dimension measures the *benefits to the developing organization* from executing the project, both in the short run (i.e., profit level) and in the long run (i.e., improved reputation and creation of new markets and product lines). The fourth dimension measures the *benefits to the defense and national infrastructure* gained from the project. A recent study by Lipovetsky et al. (1997), based on the data employed here, evaluated the assessments of the three key personnel of each project regarding the relative important of the four success dimensions. Lipovetsky et al. (1997) concluded that for all practical purposes, the success of defense projects, and possibly of all kinds of projects, should be evaluated only, or mostly, by the *benefits to the customer* and by *meeting design goals*, that is, by measuring to what extent the customers are satisfied with the delivered product, and second, by measuring the level of success in meeting schedule and budget, and technical and functional specifications. Following these conclusions, the analysis in this paper classifies projects according to the success dimensions *benefits to the customer* and *meeting design goals*. The measures comprising each dimension are listed in Table 1.

About 400 managerial variables, derived from both the theoretical and the practical literature, were

Table 1
Success dimensions and measures

Success dimensions	Notation	Success measures
Meeting design goals	S^1	Functional specifications
		Technical specifications
		Schedule goals
		Budget goals
Benefits to the customer	S^2	Meeting acquisition goals
		Meeting the operational requirements
		Product entered into service
		Reached the end-user on time
		Product used over a substantial period of time
		Product yields substantial improvement in user's operational level
		User is satisfied with product

examined for their influence on the success of the sample projects. Based on previous work (Dvir et al., 1994), data were classified into four managerial groups. Each group was further disaggregated into several subgroups (factors), each containing variables that affected a specific managerial aspect of the project execution process. The four groups of managerial variables are as follows. Group M^1 includes the managerial variables that describe the initiation phase of the project and the pre-contract activities. M^2 includes managerial variables that describe project preparations, design policy, technological infrastructure and design methods. M^3 includes variables which describe the planning and control processes of the project. M^4 consists of managerial variables that characterize the organizational and managerial environment of the project. Initial analysis of the data suggested that answers were often divided into too many categories and that several variables exhibited very little variance, or were exact linear combinations of other variables. Through appropriate aggregation of these variables and the elimination of variables with missing data (where 25% or more was unavailable), the number of managerial variables was reduced to 106 (see Tishler et al., 1996).

Table 2 presents the remaining managerial variables arranged into four groups and 26 factors. The organization of the data in this paper closely resembles the structure of the questionnaire by which the data were collected.

Linear Discriminant Analysis (LDA) was applied separately for each group of managerial variables ($M^1,\ldots,M^4$) in order to classify the 110 observations (projects). The LDA was based on specific predictors (see Anderson, 1974; Morrison, 1976). Each of the following variables was used:

-Scope (low, high)—reflecting the level of complexity of a hierarchy of systems and subsystems.
-Technological Uncertainty (low, medium, high, super high)—reflecting the level of technological uncertainty at the project initiation.
-Software–Hardware (software (SW), hardware (HW))—pure SW projects vs. HW projects consisting of hardware components and, sometimes, operational SW.
-Type of Usage (weapon systems, detection systems, C^3I, other)–C^3I is shorthand for command, control, communication and intelligence systems.
-Level of Operation (single operator, small team, large group).
-Project Output (feasibility study, improving an existing system (improvement), new generation of an existing system (new generation), completely new system (new system)).
-Type of Basic Technology (electronics, mechanics, optics, other).

The most accurate classification was achieved with the predictors 'Software–Hardware', 'Scope' and 'Output', which produced the correct classification in about 80% of the 110 projects. This classification produced 12 cells (two levels of 'Software–Hardware' by three levels of 'Scope' by two types of Output).

The number of cells was then reduced through aggregation of those with common characteristics regarding scope (small or large), final output (a

Table 2
Organization of managerial variables

Managerial groups	Notation	Managerial factors	Number of variables
Project initiation and pre-contract activities	M^1	Definition of operational need	5
		Urgency of need	2
		Alternative solutions	4
		Definition of technical and operational specs.	6
		Pre-contract activities	5
		Customer follow-up team	5
Project preparations and design policy, technological infrastructure and design methods	M^2	Pre-project preparation	7
		Management policy	10
		Technological infrastructure	4
		Prototypes	2
		Number of design cycles	2
		Design freeze timing	1
		Design considerations	5
Planning and control processes	M^3	Project milestones	10
		Project control	4
		Effectiveness of project control	2
		Budget management	3
		Discussions and reports	2
Organizational and managerial environment	M^4	Organizational environment	5
		Manager style	5
		Communication style	3
		Flexibility in management	2
		Delegation of authority	2
		Organizational learning	3
		Team characteristics	4
		Manager qualifications	3

feasibility study, the improvement of an existing product or system or a new type of system) and software–hardware mix. The classification of projects into six cells is as follows.

Classification of projects into six cells

Cell number	No. of projects	Software–Hardware	Scope	Project output
1	7	SW	low	feasibility study
2	12	SW	low, high	improvement, new generation, new system
3	19	HW	low, high	feasibility study
4	18	HW	low	improvement, new generation, new system
5	22	HW	high	improvement, new generation
6	32	HW	high	new system

Using these six groups, the LDA correctly classified approximately 90% of all projects.

The identification of critical managerial variables, using Canonical Correlation Analysis, was carried out on the success dimension S^1 and each of the sets of managerial variables M^i, $i = 1, \ldots, 4$. The analysis was then repeated for S^2.

4. Results—critical success factors (csf) in different types of defense projects

Tables 3–10 present lists of managerial variables (and managerial factors) related to the project execution process and its relationship to the success of different types of defense projects.

The level of importance of each variable with respect to the success of a given project is denoted by an asterisk ($*$), a plus sign ($+$) or a wave sign ($\sim$), whereby an asterisk denotes a variable which is

Table 3
Group M[1] critical managerial variables—the initiation phase of the project and pre-contract activity—relative to success dimension S[1]

Factor	Variable	No.	All projects	Cell no. 1	2	3	4	5	6
Definition of operational need	Detailed operational requirements	1		~	~		*		
	Product concept	2		~		+			
	Detailed operational specifications	3							
	Criteria for operational effectiveness	4	~	*	*				+
	Method for use in battle	5		+	+		+		
Urgency of need	Recognition of need by end-user	6			~		+	+	
	Project acknowledged as being urgent	7	~	*				*	
Alternative solutions	Higher operational value than other systems	8		+					
	Check for existence of alternatives	9		~	+				
	Technical feasibility checked	10	*		*				*
	Alternative technical solution checked	11	~				*		
Definition of technical and operational specs	Operational specs	12	~						*
	Technical specs	13	+	*			~		*
	Criteria for acceptance	14	+					+	+
	ILS requirements	15	~					*	
	Reliability specs	16		*	+				
	Human engineering specs	17							
Pre-contract activities	Project plan	18		~	~	*	*	~	
	Cost estimation for the entire project	19				+	*	+	
	Negotiations with alternative contractors	20			*	+	~	*	
	Detailed contract documents	21			*		*		*
	Detailed payment milestones	22		*					
Customer follow-up team	Team includes end-user representatives	23		*	*			~	*
	Active participation in development activities	24	+			*	~	~	~
	Key personnel stayed throughout the project	25	*			*	*	+	
	Overall responsibility for project success	26	*		~	*	+	*	~
	High professional qualifications	27	*	+		*	+	*	~
	Canonical correlation between success measures and:	All managerial variables	0.38	0.98	0.91	0.82	0.78	0.47	0.47
		Critical managerial variables	0.41	0.98	0.92	0.81	0.81	0.50	0.48

Critical managerial variables are denoted by *. Moderately critical managerial variables are denoted by +. Less important, but somewhat critical, managerial variables are denoted by ~.

Table 4
Group M^2 critical managerial variables—project preparations, design policy, technological infrastructure and design methods—relative to success dimension S^1

Factor	Variable	No.	All projects	Cell no. 1	2	3	4	5	6
Pre-project preparations	Main contractor involved in system definition	1		*			~		
	Proposal based on existing technological infrastructure	2		*	~	*		*	
	Proposal based on a feasibility study	3							
	Organizational and logistic preparations	4	~	~		*	+	~	~
	Definition of organizational structure	5	*	*	+		*	*	+
	Type of organizational structure	6	+	+	~	*	*		
	Fit of organizational structure	7	*		*			~	~
Management policy	Risk management	8				*			*
	Resources and schedule control	9	*	*				*	+
	Budget management	10		+					~
	Quality and reliability assurance	11	~	*			*		~
	Test management	12	+		~		*	*	+
	Communication with customer	13		~					*
	Configuration control	14							
	Personnel management	15			~	~	~	+	*
	Decision-making procedures	16	~				~	*	
	Communication and reports	17	+				+	*	+
Technological infrastructure	From earlier projects	18		+		*			
	Acquired from external sources	19							
	Developed as a basic technology	20					~		
	Developed during the project's execution	21			*	~	~		
Prototypes	Conceptual prototype	22							
	Prototype for field tests	23		~			*		~
Number of design cycles	For critical subsystems	24							
	For the whole system	25							
Design freeze timing	For the whole system	26		+		*	+		
Design considerations	Producibility	27	*	+	*			+	+
	Maintainability	28	~	*	+		*		*
	Quality and reliability	29	*	*	*		*	+	*
	Design to cost	30	*		*	+	*	~	*
	Human engineering	31			*				
	Canonical correlation between success measures and:	All managerial variables	0.52	0.92	0.88	0.79	0.73	0.68	0.70
		Indicated managerial variables	0.53	0.97	0.89	0.79	0.72	0.70	0.69

Critical managerial variables are denoted by *. Moderately critical variables are denoted by +. Less important, but somewhat critical, managerial variables are denoted by ~.

critical to success, a plus sign denotes a moderately critical variable and a wave sign denotes a less critical yet important variable. At the bottom of each table, the canonical correlations between success and the values of all managerial variables, or only those found to be important for the success of a project, are indicated.

The analysis of the results is three-fold. First we attempt to isolate, in each group of managerial variables, the critical factors that are highly correlated to

Table 5
Group M^3 critical managerial variables—planning and control processes—relative to success dimension S^1

Factor	Variable	No.	All projects	Cell no. 1	2	3	4	5	6
Project milestones	Final system requirements	1		*			~		+
	System concept	2		*		~	~		
	System configuration	3		*			+		
	Subsystem specs	4				+	*		
	System integration	5	+		+	*		*	
	Presentation of prototype	6			+	*			
	Design freeze	7	*				*		+
	Qualification tests	8	~	*	+			*	
	Final test and delivery	9	~	~				*	
	Planning of activities with WBS	10							~
Project control	Schedule and milestones	11	*		*	+	*	+	+
	Budget utilization	12	*		*	*	*		*
	Specifications	13	*	~	*	*		~	
	Configuration control	14	~	~	*	~		+	
Effectiveness of project control	Assisted in early trouble-shooting	15	*	+				*	*
	Used as a tool for senior management	16	~					+	~
Budget management	Day-to-day follow-up	17		*		+	*		
	Profit and loss report	18					~		
	Cash-flow report	19							*
Discussion and reports	With all subcontractors	20						+	
	To higher management	21					*		
	Canonical correlation between success and:	All managerial variables	0.41	0.96	0.76	0.74	0.79	0.74	0.60
		Indicated managerial variables	0.41	0.97	0.75	0.75	0.78	0.76	0.55

Critical variables are denoted by *. Moderately critical variables are denoted by +. Less important, but somewhat critical, managerial variables are denoted by ~.

both success dimensions or at least to one success dimension for all classes (cells) of projects. Second, we attempt to identify the most important factors in a specific class. Finally, we isolate the most important variables in each class of projects.

Note that applying the CCA method to two data sets (M^1 and S^1, say) amounts to estimating the weights which maximize the correlation between linear aggregators (weighted averages) of the two data sets. The CCA is applied to standardized variables (variables are standardized by subtracting their mean and dividing them by their standard deviations). Thus, a variable with a large estimated weight affects the correlation between the two data sets *more* than a variable with a small weight. Managerial variables are defined as critical relative to a success dimension when their weights in the CCA between a data set of managerial variables and the data set of success measures were large (see Dvir et al., 1994; Tishler et al., 1996; Lipovetsky et al., 1997 for algorithms which select critical variables from large data sets). Managerial variables that are not designated as critical relative to a success dimension may still affect project success. However, their influence on project success may not be as pronounced as the influence of critical variables. Moreover, they may become critical in situations where some managerial variables which were declared critical in our sample are not employed in the management of projects (or omitted from the analysis). Alternatively, variables may be declared non-critical because they exhibit very little variability in the sample. For example, the managerial variable *budget management* (see factor Management policy in M^2)

Table 6
Group M^4 critical managerial variables—organizational and managerial environment—relative to the success dimension S^1

Factor	Variable	No.	All projects	Cell no. 1	2	3	4	5	6
Organizational environment	Existence of unit spirit	1	*		*				+
	Managers as role models	2	*		*		*	~	*
	Social activities out of working hours	3				*		*	
	Room for professional growth	4		~			+		
	Possibilities for consulting with experienced professionals	5		*	*		*	*	
Manager's style	Exact specification of tasks	6	+			*	*		*
	Personal supervision of performance	7							~
	Involvement with workers	8					*		+
	Acts to increase workers' motivation	9							*
	Involving workers in decision-making	10							*
Communication style	Open communication	11	+	~		*		*	*
	Frequent updating of status	12		+		~			+
	Involvement of manager in day-to-day problem solving	13	~			~	+		~
Flexibility in management	Encouraging new ideas	14	+	*		~	*		
	Willingness to consider changes and new approaches	15		*			~		
Delegation of authority	Setting general policy and goals	16		*				*	
	Technical issues managed by the professionals	17		+					
Organizational learning	Participation in professional seminars	18			~		+		
	Constant follow-up of technological development	19				~			
	Application of lessons learned during project execution	20		*				*	
Team characteristics	Key personnel in the project for its entire duration	21	*		*	*	*	*	~
	High technical level	22	*		*	+		*	*
	Key personnel with strong managerial qualifications	23				~			*
	Some team members with operational experience	24		*					
Manager's qualifications	Professionally experienced	25	*		*		+		*
	A technical leader	26		+			~		
	Extensive managerial experience	27	*		+	+	*		+
	Canonical correlation between success measures and:	All managerial variables	0.47	0.94	0.91	0.78	0.61	0.67	0.64
		Indicated managerial variables	0.53	0.95	0.89	0.76	0.63	0.68	0.64

Critical variables are denoted by *. Moderately critical managerial variables are denoted by +. Less important, but somewhat critical, managerial variables are denoted by ~.

was well developed in almost all projects and thus exhibited little variability across projects. Hence, it is possible that *budget management* is important to project success even though it is not a critical managerial variable (see Tables 4 and 8) in our sample.

4.1. Group M^1: the initiation phase of the project and pre-contract activities

Considering first the relations between managerial factors of this group and the first dimension of success (S^1), it is obvious that the customer follow-up

Table 7
Group M^1 critical managerial variables—the initiation phase of the project and pre-contract activity—relative to success dimension S^2

Factor	Variable	No.	All projects	Cell no. 1	2	3	4	5	6
Definition of operational need	Detailed operational requirements	1					~		
	Product concept	2		~		+	+		
	Detailed operational specifications	3		~	+			*	
	Criteria for operational effectiveness	4		*		+		~	*
	Method for use in battle	5		*					~
Urgency of need	Recognition of need by end-user	6	*		*	~	~	*	*
	Project acknowledged as being urgent	7	*	*	*		*		
Alternative solutions	Higher operational value than other systems	8	~	*	*	*			~
	Check for existence of alternatives	9							*
	Technical feasibility checked	10		~					
	Alternative technical solution checked	11		+	*	~	*		
Definition of technical and operational specs	Operational specs	12	~	~				~	*
	Technical specs	13	+	*			+		*
	Criteria for acceptance	14	*		~	*		*	*
	ILS requirements	15	*			*	+	*	
	Reliability specs	16	+	+		*	*		
	Human engineering specs	17				~			
Pre-contract activities	Project plan	18		+					
	Cost estimation for the entire project	19							
	Negotiations with alternative contractors	20				~			
	Detailed contract documents	21	+		~		~	~	+
	Detailed payment milestones	22	*	*					
Customer follow-up team	Team includes end-user representatives	23		*	+				~
	Active participation in development activities	24	~		+	*	~		+
	Key personnel stayed throughout the project	25	+			*	*		~
	Overall responsibility for project success	26	*			~	*	*	+
	High professional qualifications	27	~	~	*	*	*	+	~
	Canonical correlation between success measures and:	All managerial variables	0.41	0.84	0.86	0.77	0.64	0.42	0.53
		Indicated managerial variables	0.44	0.87	0.82	0.76	0.68	0.47	0.57

Critical managerial variables are denoted by *. Moderately critical managerial variables are denoted by +. Less important, but somewhat critical, managerial variables are denoted by ~.

team is the most important factor in the success of all types of projects and the pre-contract activities are almost at the same level of importance (see Table 3). When investigating the relationship with the second dimension of success (S^2), the customer follow-up team remains the most important factor but the factor pre-contract activities is no longer as important (see Table 7). It is replaced by two factors: the definition of operational and technical specifications and the urgency of need. The data provide further insight. For example, the definition of technical and operational specifications is an important factor in hardware (HW) projects but not in SW projects. The criteria of acceptance proved to be an important variable for HW projects, particularly with respect to S^2. Furthermore, the urgency of need factor proved important, in general, to customer satisfaction but was less important with regard to S^1.

An interesting phenomenon can be tracked through observation of the relationship between pre-contract activities and S^2. While almost all variables in this factor proved to be of no importance in satisfying customer needs, preparation of detailed contract documents proved vital to satisfying customer's needs regardless of the project type.

Table 8
Group M^2 critical managerial variables—project preparations, design policy, technological infrastructure and design methods—relative to the success dimension S^2

Factor	Variable	No.	All projects	Cell no. 1	2	3	4	5	6
Pre-project preparations	Main contractor involved in system definition	1		*	+	~	*		*
	Proposal based on existing technological infrastructure	2	*	*		*	~	*	
	Proposal based on a feasibility study	3	~	+			~	+	
	Organizational and logistic preparations	4		+	*			~	
	Definition of organizational structure	5	*		~				*
	Type of organizational structure	6			*	*	~		~
	Fit of organizational structure	7			~				+
Management policy	Risk management	8		+	+	*	~		
	Resources and schedule control	9		+		~			~
	Budget management	10							
	Quality and reliability assurance	11	+				~		~
	Test management	12							
	Communication with customer	13		~				*	
	Configuration control	14							~
	Personnel management	15				~			+
	Decision-making procedures	16	~		*	*		*	+
	Communication and reports	17	*		*			*	*
Technological infrastructure	From earlier projects	18	*	*		~	*	~	
	Acquired from external sources	19				*	+		
	Developed as a basic technology	20		~	+				
	Developed during the project's execution	21	~	~			*		
Prototypes	Conceptual prototype	22			*		+		
	Prototype for field test	23			*		*		
Number of design cycles	For critical subsystems	24			*				
	For the whole system	25			+			+	
Design freeze timing	For the whole system	26		*		+			
Design considerations	Producibility	27	*					+	+
	Maintainability	28	+	*					*
	Quality and reliability	29	*	*	~		*	+	*
	Design to cost	30	*	+			*	*	~
	Human engineering	31					*		~
	Canonical correlation between success measures and:	All managerial variables	0.37	0.90	0.85	0.89	0.84	0.62	0.58
		Indicated managerial variables	0.38	0.92	0.83	0.87	0.85	0.57	0.60

Critical managerial variables are denoted by *. Moderately critical managerial variables are denoted by +. Less important, but somewhat critical, managerial variables are denoted by ~.

4.2. Group M^2: project preparations, design policy, technological infrastructure and design methods

Seven managerial factors, dealing mainly with design policies, methods and design considerations are included in this group. Of these seven factors, the design considerations factor seems to have the greatest impact on almost all types (or classes) of projects, except for HW feasibility studies. Design considerations, while vital to meeting design goals, irrespective of project type, proved unimportant in achieving customer satisfaction in SW projects.

Table 9
Group M^3 critical managerial variables—planning and control processes—relative to the success dimension S^2

Factor	Variable	No.	All projects	Cell no.					
				1	2	3	4	5	6
Project milestones	Final system requirement	1		+	*				~
	System concept	2		*	*				
	System configuration	3		*	*				
	Subsystem specs	4			~	*	*	+	*
	Subsystem integration	5					*	*	
	Presentation of prototype	6							
	Design freeze	7	*			~	+	+	+
	Qualification tests	8		*	+	+		*	
	Final test and delivery	9	*			~	+	*	*
	Planning of activities with WBS	10				*			
Project control	Schedule and milestones	11	+						~
	Budget utilization	12	+	*			*		
	Specifications	13	*			*			*
	Configuration control	14	*						+
Effectiveness of project control	Assisted in early trouble-shooting	15	+					*	~
	Used as a tool for senior management	16				*		*	
Budget management	Day-to-day follow-up	17		*	*		*		
	Profit and loss report	18	*			~	~		*
	Cash-flow report	19				+			*
Discussion and reports	With all subcontractors	20		*	+	+	~		
	To higher management	21		+	*			~	
	Canonical correlation between success measures and:	All managerial variables	0.40	0.94	0.80	0.73	0.73	0.55	0.65
		Indicated managerial variables	0.38	0.87	0.79	0.68	0.69	0.49	0.69

Critical managerial variables are denoted by *. Moderately critical managerial variables are denoted by +. Less important, but somewhat critical, managerial variables are denoted by ~.

Pre-project preparations and management policy are also important factors for all types of projects. Management policy seems to have its greatest impact on large, new HW projects, particularly with respect to meeting the project's goals.

Unlikely as it may seem, the technological infrastructure factor seems to influence only small projects. This result may be explained by the low variance of this factor with respect to large HW projects, since a large HW project is unlikely to be undertaken without first establishing the necessary infrastructure.

Prototypes are mainly important for satisfying customer's needs in SW projects and small HW projects. Their impact on meeting the project design goals is minimal.

The number of design cycles undertaken prior to design freeze has no impact on S^1 and this is true for all types of projects. Several design iterations, at the system and subsystem level, are critical to the achievement of customer satisfaction in SW projects. A late design freeze also contributes to the success of feasibility studies and small HW projects, probably because it guarantees that all technical specifications are met.

4.3. Group M^3: planning and control processes

Project control techniques are the basic tools for monitoring progress and assessing the successful meeting of specifications. Consequently, the use of these techniques has a considerable impact on S^1 and a lesser impact on S^2. On the other hand, discussions and reports are the tools that convey the customer's requirements and needs to the project team. Hence,

Table 10
Group M^4 critical managerial variables—organizational and managerial environment—relative to success dimension S^2

Factor	Variable	No.	All projects	Cell no. 1	2	3	4	5	6
Organizational environment	Existence of unit spirit	1	*		∼				*
	Managers as role models	2	*	+		+			*
	Social activities out of working hours	3	*		*	+	*	*	
	Room for professional growth	4	∼	*				*	
	Possibilities for consulting with experienced professionals	5		*					
Manager's style	Exact specification of tasks	6	*		+	*	*	+	
	Personal supervision of performance	7				*		∼	+
	Involvement with workers	8	∼		*	*		+	+
	Acts to increase workers' motivation	9		+	+			*	*
	Involving workers in decision-making	10			*	*		*	+
Communication style	Open communication	11		+	*				∼
	Frequent updating of status	12			*		+	+	
	Involvement of manager in day-to-day problem solving	13	+		*	*	*		∼
Flexibility in management	Encouraging new ideas	14			∼	*			
	Willingness to consider changes and new approaches	15	∼		+	∼			
Delegation of authority	Setting general policy and goals	16			∼	+		+	
	Technical issues managed by the professionals	17	∼				+	*	
Organizational learning	Participation in professional seminars	18	∼					+	
	Constant follow-up of technological developments	19	*				*		
	Application of lessons learned during project execution	20		*	∼		∼	∼	∼
Team characteristics	Key personnel in the project for its entire duration	21	+						*
	High technical level	22							
	Key personnel with strong managerial qualifications	23		*			*		*
	Some team members with operational experience	24		*					
Manager's qualifications	Professionally experienced	25					∼		
	A technical leader	26			*				
	Extensive managerial experience	27					+		
	Canonical correlation between success measures and:	All managerial variables	0.40	0.93	0.70	0.62	0.79	0.68	0.43
		Indicated managerial variables	0.37	0.92	0.68	0.61	0.77	0.61	0.45

Critical managerial variables are denoted by *. Moderately critical managerial variables are denoted by +. Less important, but somewhat critical, managerial variables are denoted by ∼.

extensive use of these tools enhances customer satisfaction but does not assist in meeting project goals. Budget management is probably a common practice in large rather than small projects; therefore it has a greater impact on the success of larger projects. Nevertheless, day-to-day budget control proved to be important to all SW and small HW projects. Profit-and-loss and cash-flow reports are used less frequently, even in larger projects, though when prepared they benefit both the customer and the project itself. Effectiveness of project control, which is usually assumed to be critical to all types of projects, was found to be non-critical to SW and small HW projects in this study.

A final point to be noted is that, according to our results and contrary to common-sense, large, new HW projects do not benefit from discussions and report preparation. This is probably due to a low variance between the variables in this specific class of projects.

4.4. Group M^4: organizational and managerial environment

Tables 6 and 10 include a list of eight managerial factors reflecting mainly the manager's qualifications and attitudes, with an emphasis on managerial style. Only the first factor, which describes the prevailing organizational environment, seems to have a positive impact on all types of projects. The other factors have different impacts on different types of projects with regard to the two success dimensions. For example, managerial style has a positive impact on all types of projects with respect to customer satisfaction (excluding small HW projects) but almost no impact on S^1 (except for projects in cell 6 which were highly influenced by management style). Style of communication has a positive impact on all types of projects, excluding SW projects in S^1. However, SW projects are highly influenced by communication style in S^2. Flexibility in management is important for relatively small projects but is not important at all for large projects. Delegation of authority seems to have a low impact on all types of projects with the exception of SW feasibility studies in S^1 and HW improvement projects in S^2. The learning capability of the organization seems to be a weak predictor of project success. Nevertheless, the ability to apply lessons learned during previous phases of the project execution is important to all types of projects. The remaining factors, team characteristics and project manager qualifications, have a considerable impact on the achievement of design goals for all types of projects but their impact on customer satisfaction is negligible. One interesting observation is that the managerial qualifications of key personnel proved more important to achieving customer satisfaction than to meeting design goals.

5. Summary and conclusions

The main purpose of this paper was to search for an empirically-driven classification of projects types and to identify project-specific managerial variables that are critical to the success of industrial projects. Indeed, the use of a combination of several characteristics of projects instead of one, or at most two variables, yielded a meaningful classification in the sense that a specific set of managerial variables having a large impact on success can be identified for each project class. Such a classification is different and possibly more useful than classifications employed till now. By employing multivariate analysis and a multidimensional success measure, this study provides several insights, as summarized by the following discussion.

First, the findings strongly suggest that a wide spectrum of variables can affect the success of a project. Unlike previous studies, which analyzed major variables chosen subjectively by managers, the multivariate statistical approach of this study reveals that many variables affect project effectiveness. Neglecting some of these variables may be detrimental to the success of a project. This paper also demonstrates that multivariate methods constitute a powerful tool for the analysis of very large data sets. Multivariate analysis (in contrast to univariate and regression analysis), together with the multidimensional definition of project success, enabled us to analyze the mutual interactions of all managerial variables and success measures. It facilitated the identification of several key managerial factors that were not recognized by other methods. Indeed, as we demonstrated, new results have emerged from our analysis that may be extremely useful to practitioners engaged in industrial project management.

The second major insight gained by this study is the realization that project success factors are indeed contingent upon the specific type of project and that the list of project success factors is far from universal. Project management has a wide range of variations and projects have less characteristics in common than previously considered. In addition, the analysis in this paper emphasizes that the list of project success factors is dependent upon the project type. Consequently, project managers must identify those factors that are critical to their specific project. Examples of managerial variables with considerable impact on specific types of projects are as follows. Pure SW projects are very different from HW projects (that may involve some operational software). SW projects are particularly sensitive to a priori criteria for operational effectiveness, whereas this is less critical for HW projects. On the other side, the definition of technical and operational specifications is an important factor in HW projects but it is not so important in SW projects. Design considerations seem to have a great impact on almost all classes of projects, except for HW feasibility studies. Prototypes are mainly important for satisfying customer's needs in SW projects and small HW projects. Their impact on meeting the project design goals is minimal. Several design iterations, at the system and subsystem level, are critical to the achievement of customer satisfaction in SW projects. The effectiveness of project control is especially important for large HW improvement projects. Risk management and budget control are less critical for low scope (small) projects but extremely important for high scope projects. Obviously, large projects are more sensitive to formal, structured techniques of planning and control. Flexibility in management is important for relatively small projects but is not important at all for large projects. The management style of the project manager is highly important for HW feasibility studies and large HW improvement projects while style of communication is mostly important in SW projects. These types of findings suggest that some variables are more potent than others in predicting project success and that the distribution of project success factors is anything but uniform.

This research provides additional insights into the process of building a typological theory of projects (Shenhar and Dvir, 1996). 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 relevant outcome (Doty and Glick, 1994). The framework of Shenhar (1993) and Shenhar and Dvir (1996) was based on two dimensions: technological uncertainty and system scope. The present study demonstrates that scope is indeed one of the major variables in project classification, together with project output (the type of end-use) and the (somewhat different) classification of software and hardware. On the other hand, technological uncertainty did not emerge as a discriminating element in this study. The fact that we analyzed defense development projects may explain this result since they are often found at the higher end of the technological uncertainty dimension, resulting in lower variance than found in commercial projects generally.

Finally, the results and conclusions of the paper are derived from the particular data set that is analyzed here. However, we believe that they have a wider applicability. First, most of the results in this paper make good sense and are fairly easy to explain. Second, most of our findings are not in conflict with previous studies. For example, we find that pre-contract activities, the involvement of the customer follow-up team, project control (schedule and milestones, budget utilization, etc.), and management policy are highly influential in all types of projects. Third, a previous paper (Lipovetsky et al. (1997)) that utilized the data that we use here found that all stakeholders, including representatives of the developing organizations, either from government-owned firms or private firms, rank the relative importance of project success dimensions in the same way. Fourth, Dvir et al. (1994), who analyzed 127 projects (many of which were civilian projects and other defense projects) did not distinguish between the defense and civilian markets when analyzing critical success factors in project management. Furthermore, there are many similarities in the results of the two studies. For example, project milestones were found to be important to almost all types of projects (excluding feasibility studies), design considerations have a considerable impact on the results of most types of projects especially in relation to meeting budget and schedule goals and the same holds for systematic control of projects.

Clearly, some of the finding in this paper are rather surprising or may run counter to intuition and conventional wisdom. For example, technological uncertainty is not a major factor in project success, and 'learning capability' is only a weak predictor of success. However, these findings should be interpreted as the outcome of using multivariate analysis as the primary method of investigation. This method, which accounts simultaneously for the multi-attribute nature of project success and the multitude of managerial variables, allows the identification of marginal effects of specific success factors, particularly when the projects are a priori classified into homogeneous groups.

In conclusion, this study demonstrates that the use of multivariate methods is both simple and effective when using the large data sets typical of large-scale projects. The use of specific multivariate methods such as Canonical Correlation Analysis, together with an identified classification framework and multidimensional success measures, yielded two results in the analysis of project management. First, it refined the search for project success factors by accounting objectively for the actual effects of managerial variables on project success. Thus we have attained new insights into the particular influence of certain, more refined, variables on project success. Second, the distinction between different project types supports the introduction of contingency arguments into the theoretical study of projects. Different projects are affected by different sets of success factors. Hence, a project-specific approach is appropriate for subsequent research into the practice and theory of project management.

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