IMPROVING THE PREDICTIVE CAPABILITY OF SPACECRAFT COST MODELS

by

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A DISSERTATION

Submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy in The Department of Industrial & Systems Engineering and Engineering Management to The School of Graduate Studies of The University of Alabama in Huntsville

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Submitted by Joseph W. Hamaker in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Industrial and Systems Engineering and accepted on behalf of the Faculty of the School of Graduate Studies by the dissertation committee.

We the undersigned members of the Graduate Faculty of The University of Alabama in Huntsville, certify that we have advised and/or supervised the candidate on the work described in this dissertation. We further certify that we have reviewed the dissertation manuscript and approve it in partial fulfillment of the requirements of the degree of Doctor of Philosophy in Industrial and Systems Engineering.

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ABSTRACT
The School of Graduate Studies
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Title: Improving the Predictive Capability of Space Project Cost Models

Current space project cost models predict costs using regression equations that typically relate the cost of projects to technical variables such as Weight, Power, Thrust, Data Rate, and Pointing Accuracy. While improvements in space project parametric cost modeling have been made since its advent in the 1960s, significant statistical error persists. This remains true even when a rich set of technical independent variables are used. Anecdotal evidence suggests that part of this variability may be due to the current cost models' inability to capture the impacts of the nontechnical considerations required to develop space systems—nontechnical factors that are under the control of project management. This dissertation investigates the feasibility of introducing nontechnical variables into the cost models, then analyzes the improvement in the explanatory power from these additional variables. The study involved researching management influenced nontechnical variables and constructing a database of historical projects containing both technical and nontechnical characteristics. Subsequently, an extensive multivariable regression analysis was performed to develop two new cost models: one with technical variables only, as a control, and one with both technical and nontechnical variables. The two models were compared to assess any improvements in the predictive power of the new model containing both technical and nontechnical variables, as compared to the more classic approach of focusing mainly on technical variables.

Abstract Approval:	Committee Chair	______________________
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Finally, I also want to especially thank my wife, Louise, who never lost confidence that I would someday find the focus to complete what I had started. For our daughter, Alaina, I hope the completion of this task serves as some inspiration for continuing her own studies.

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LIST OF ACRONYMS AND ABBREVIATIONS

ACE	Advanced Composition Explorer
AMPTE	Active Magnetospheric Particle TraceR Explorer
ATP	Authority to Proceed
CAIV	Cost As An Independent Variable
CC&DH	Command, Control, and Data Handling
CER	Cost Estimating Relationship
CMOS	Complementary Metal Oxide Semiconductor
COBE	Cosmic Background Explorer
CPM	Critical Path Method
CRRES	Combined Release and Radiation Effects Satellite
CSAP	Center for Substance Abuse Prevention
DDT&E	Design, Development, Test, and Evaluation
DoD	Department of Defense
DoE	Department of Energy
ET	External Tank
EVM	Earned Value Management
FAST	Fast Auroral Snapshot
G&A	General and Administrative
GaAs	Galium Arsenide
GLAST	Gamma Ray Large Area Array Telescope
GN&C	Guidance, Navigation, and Control
GPS	Global Positioning System
GRO	Gamma Ray Observatory
HST-SSM	Hubble Space Telescope–Spacecraft Support Module
IQ1, IQ3	Interquartile 1, Interquartile 3
ITAR	International Traffic in Arms Regulations
IUS	Inertial Upper Stage
JPL	Jet Propulsion Laboratory
kbps	Thousand Bits Per Second
NAFCOM	NASA Air Force Cost Model

NASA	National Aeronautics and Space Administration
NEAR	Near Earth Asteroid Rendezvous
NOAA	National Oceanic and Atmospheric Administration
NRO	National Reconnaissance Organization
OCFO	Office of the Chief Financial Officer
PERT	Program Evaluation and Review Technique
PRESS	Prediction Error Sum of Squares
RCS	Reaction Control System
RTG	Radioisotope Thermoelectric Generators
SAIC	Science Applications International Corporation
SLOC	Software Lines of Code
SOTA	State of the Art
SRB	Solid Rocket Booster
SRM	Solid Rocket Motor
STEP	Space Test Experiment Platform
TDRSS	Tracking and Data Relay Satellite System
USRA	
VIF	Variance Inflation Test
VLSI	Very Large-Scale Integration
WBS	Work Breakdown Structure

CHAPTER 1

INTRODUCTION

The project cost estimate is a key piece of information that decision makers rely on to gauge the worth of any new project. The cost estimates are required early in the project life cycle, thus achieving an acceptable level of accuracy has proven difficult to accomplish for all types of major projects. For technologically challenging projects, such as a typical space mission, the cost estimating approaches are plagued by high variability. Current cost estimation approaches for new space projects are often based on statistical models that relate the cost of projects to a number of technical variables. Any improvements in these models would be welcome.

Context

All projects need a project plan to be developed very early in the project life cycle. One of the key elements of any project plan is the cost estimate. Space projects are no different than other projects in this regard, but because space projects are among the most costly of human endeavors, decision makers typically consider the project cost as one of the major pieces of information they need to make evaluations about commitment to the project and how it should be technically and programmatically structured. Accurately predicting the cost, or at least being correct within acceptable tolerances, is of paramount importance according to Aldridge (2004), the General Accounting Office (2004), Gross (2001), Moorman and Anderson (2002), Shawcross (2003), and Young (2003).

Most space projects today continue to be government funded. Once approval is sought for a government-funded space project, serious commitments are made to the project stakeholders who include the sponsoring government organization (i.e., NASA, the Air Force, and the Intelligence Community), the White House and the Office of Management and Budget, the Congress and the Congressional Budget Office, the Government Accounting Office, and other involved parties. Perhaps the most important stakeholder is the taxpayer. They all deserve a project cost estimate that is credible, reasonable, and accurate.

A general issue in space project cost estimating is predicting the cost of projects early in their formulation phase so that accurate commitments can be made on what the project is likely to cost before serious and irrevocable investments are made. Parametric cost models are used because, in the early stages of project definition, not enough detailed information is known to perform other types of estimates, such as a detailed engineering estimate, which is based on a labor and material buildup of cost (Russo, Garvey, and Hulkower 1998). The trade space for decisions regarding projects, particularly space projects, obviously includes many technical considerations (e.g., the mass budget for the spacecraft, the available onboard electrical power, the required data rate, the choice of stabilization method, the selection of structural materials, the level of redundancy, the level of autonomy that the spacecraft should possess, the type of reaction control, the type of propulsion system, the type of communication system, and many,

many other technical decisions). Managers and engineers are generally aware that their choices on these matters have large implications for the cost, schedule, and risk of their missions.

Still, the statistical variability that remains in today's best space project cost models remains distressingly high (Mackenzie and Addison 1999). Even when a large number of space project cost drivers are considered in the set of independent variables used by the best models, significant residual error is "left on the table." Most of the work conducted over the years to improve the models has been focused on adding technical cost drivers to try to explain the cost behavior of space projects (Bearden 1999). It seems the thinking has been that if enough engineering nuances are reflected by the cost models, the costs will line up on a regression line (so to speak).

All the while, many knowledgeable observers of the space project landscape have often been heard to wonder if "it's not the way they are managed" that has a lot to do with the cost outcome of space projects. There is much anecdotal belief that such is the case (Mandell 2005). It is an interesting theory.

Problem Statement

This study investigated whether the introduction of nontechnical variables into space project cost models shows promise for improving the accuracy and usefulness of the models. A positive result would point out the importance of the nontechnical decisions that space project managers make in comparison to the technical decisions on which they have traditionally focused. These nontechnical factors include in part:

- the extent to which management insists upon sufficient up front formulation of the project prior to full-scale development;

- the degree to which management ensures that requirements are solidified and maintained after project start;
- the amount of management attention necessary to advocate the availability of timely funding;
- the amount of experience of the development team chosen by management;
- management's choice of the number of science partners;
- management's strategy for using new technology versus off-the-shelf designs.

These nontechnical variables are not now extensively considered nor modeled in existing space project cost models according to Bearden (1999) and the Space Systems Cost Analysis Group (2005). If the nontechnical factors are important cost drivers, then managers need to be able to assess the impact of decisions in these areas every bit as much as the technical decisions that now dominate the trade space. This dissertation intends to investigate the often heard premise that "the way the project is managed" is a significant cost determinant.

Approach

Existing space project cost models have concentrated on mainly technical variables to explain cost. When nontechnical variables have been included, they have been limited in number, and/or the basis for them has tended to be based on engineering judgment, or at the very least, the basis has not been explicit (SAIC 2002). There are no examples of space project cost models that have been developed with an extensive focus on the contribution of nontechnical variables that are within the control of managers (Space Systems Cost Analysis Group 2005).

This study addressed this gap by performing an extensive body of research on a number of historical space projects to tabulate both technical and nontechnical variables. The set of technical variables was based on those already widely used in space project cost models. The set of nontechnical variables was based on those factors that have been suggested in the literature as having significant influence on project cost and factors that were mentioned as being substantially controlled by management decisions. These variables were researched and tabulated for a large database of past projects. The technical variables were mostly quantitative in nature. The nontechnical variables were mostly categorical and were quantified for regression analysis using indicator variables. A thorough regression analysis was conducted to first develop the best possible model using only technical variables. This served as a control. Then management variables were introduced and checked for significance. The best model using both technical and nontechnical variables was compared to the control model, which used only the more common technical variable approach to determine if the introduction of the additional nontechnical variables improved the model.

In addition to examining whether there were management controlled nontechnical variables that could be used to improve space project cost estimating, this work produced a new regression model, which should be useful in its own right for estimating the cost of proposed space projects. While there are existing models—both commercial proprietary models and government developed models—it was a necessary part of this study to develop a new model for several reasons. First, access to the underlying database was necessary to gauge the effect of adding new variables to the model. This precluded the use of the commercial proprietary models that do not provide the user with access to the data. Secondly, the government models, which do provide access to their databases, could not be used because their databases do not contain characterizations of most of the nontechnical variables that were of interest to this study. Third, the existing models operated at lower levels of the work breakdown structure (WBS) than was necessary or even desirable for this study, which considered cost at the total project level. Fourth, the existing government models did not contain the very latest spacecraft missions that have flown in the last few years for which this study was be able to harvest top-level data and use much earlier than the lower level government models were able to incorporate.

CHAPTER 2

BACKGROUND

The literature review was performed in two steps. First, the broader literature of project management was reviewed for insight into what potential nontechnical variables influenced by engineering managers might be investigated for inclusion into a new space project cost model. Second, the literature survey was concerned with canvassing the more narrow body of literature on existing space project cost models to document the extent to which they addressed any of the nontechnical variables found.

Literature Review of Nontechnical Variables

There is an incredibly rich vein of books, journal articles, studies, briefings, Internet sources, and the like on suggested improvements in project management. In preparation for this study, an extensive review of these sources was conducted and reported in a paper in the June 2005 Engineering Management Journal (Hamaker and Componation 2005). That literature review focused on two major tasks. First, the paper tabulated nontechnical aspects of projects that are both under the control of managers and were mentioned as having an effect on the cost efficiency of the project. Second, because the semantics of project management is not standardized, a concern of the work reported in the June 2005 paper was developing a systematic way to name and record potential nontechnical variables. The 2005 paper "binned" the literature occurrences of the mention of potential variables into a list. For convenience, the list was divided into four categories (Organization, Project Manager and Team, Tools and Processes, and Environment). The result of that research is the taxonomy of management practices shown in Tables 2.1 through 2.5. Across the top of each table are listed a number of nontechnical variables suggested by various authors in the literature—the authors being listed down the left side of the table. The body of the table tallies which authors suggested which nontechnical variables. These tables actually include only a subset of the works reviewed, those which most clearly and convincingly articulated that the particular variable was an important potential driver that this study might in turn develop into an independent cost variable.

Table 2.1 Taxonomy of Nontechnical Variables Related to Organization

Work Cited	Variable						
	Organizational Structure	Flatness of Structure	Size of Customer Project Office	Number of Total Integrating Activities/ Organizations	Scale of Project Compared to the Norm	Dynamics of Project Team, Parent Org, and Customer	High Level Sponsorship/ Visibility of Project
Aldridge 2004						●	
Ammeter 2002	●						●
APPL 2004							
Bender 2000							
Connell 2001	●						
Couillard 1995	●						
Elrod 1999							
GAO 2004							
Gross 2001	●						
Hihn 2004	●						
Kerzner 1995	●	●	●	●	●	●	●
Leising 2004							
Mandell 2005	●			●	●		●
McCarthy 2004							
Miller 1993		●	●	●		●	
Moorman 2002							
NAFCOM Model				●			
Needy 2002							
Niehoff 2004							
Pine 2000	●						
PMI 2004				●	●		●
PRICE Model							
Prince 2002							
Rosenberg 2004							
SAIC 2002				●			
SEER Model							
Smart 2004	●						
Young 2001/2003	●	●		●	●		●

Table 2.2 Taxonomy of Nontechnical Variables Related to Project Manager and Team

Work Cited	Variable					
	PM Authority	PM and Team Experience and Age	Team Stability	Teamwork and Use of Product Development Teams	Sense of Mission at Outset	Effectiveness of Human Capital Usage (Training, Rewards, etc.)
Aldridge 2004						
Ammeter 2002		●		●	●	●
APPL 2004			●	●		
Bender 2000		●	●	●		
Connell 2001						
Couillard 1995		●				
Elrod 1999		●		●		
GAO 2004						
Gross 2001						●
Hihn 2004	●	●				
Kerzner 1995	●	●		●	●	
Leising 2004	●	●		●		●
Mandell 2005						●
McCarthy 2004						
Miller 1993	●					
Moorman 2002		●	●			
NAFCOM Model		●				
Needy 2002						●
Niehoff 2004						
Pine 2000						●
PMI 2004			●	●		●
PRICE Model		●				
Prince 2002						
Rosenberg 2004		●				
SAIC 2002						
SEER Model		●				
Smart 2004						
Young 2001/2003						

Table 2.3 Taxonomy of Nontechnical Variables Related to Tools and Processes

Work Cited	Variable							
	Risk Management, Degree Used	Level of Planning (Using CPM, PERT, WBS, EVM, etc.)	Quality Management System	Electronic Tools	Fidelity of Up-front Planning Accomplished	Initial Cost, Schedule, and Performance Margin	Prototyping; Rapid Prototyping	Design to Cost and/or CAIV
Aldridge 2004					●	●		
Ammeter 2002								
APPL 2004								
Bender 2000				●			●	
Connell 2001								
Couillard 1995		●			●			
Elrod 1999								
GAO 2004	●	●			●	●		
Gross 2001				●		●		
Hihn 2004	●				●			
Kerzner 1995	●	●	●		●	●		●
Leising 2004	●	●	●	●	●	●		●
Mandell 2005				●	●	●		
McCarthy 2004		●						
Miller 1993		●					●	
Moorman 2002	●					●		
NAFCOM Model	●				●		●	
Needy 2002								
Niehoff 2004								
Pine 2000				●				
PMI 2004	●	●	●	●	●	●		
PRICE Model								
Prince 2002	●				●			
Rosenberg 2004						●		
SAIC 2002	●	●						
SEER Model				●				
Smart 2004							●	●
Young 2001/2003	●	●	●		●	●		

Table 2.4 Taxonomy of Nontechnical Variables Related to Environment

Work Cited	Variable			
	Requirements Stability or Volatility	Funding Stability	International Project	Business Base
Aldridge 2004				
Ammeter 2002				
APPL 2004	●			
Bender 2000		●		
Connell 2001				●
Couillard 1995				
Elrod 1999				
GAO 2004				
Gross 2001			●	
Hihn 2004				
Kerzner 1995	●		●	
Leising 2004	●	●		●
Mandell 2005	●	●		
McCarthy 2004				
Miller 1993				●
Moorman 2002	●			
NAFCOM Model		●		
Needy 2002				
Niehoff 2004				
Pine 2000				
PMI 2004	●			●
PRICE Model				
Prince 2002				
Rosenberg 2004				
SAIC 2002	●		●	
SEER Model	●			
Smart 2004	●			
Young 2001/2003	●	●	●	

The June 2005 paper suggested a total of 29 nontechnical variables, as shown in Tables 2.1 through 2.5. Some of these nontechnical variables were mapped into more than one variable in the final database. Some were used directly. Others were found not to be researchable. As will be seen in the database discussion in Chapter 4, approximately 12 nontechnical variables were ultimately identified and successfully researched for the 122 projects. In the end, as will be discussed in Chapter 5, some of these were eliminated when the regression statistics were examined.

Table 2.5 Taxonomy of Nontechnical Variables Related to Management Concepts

Work Cited	Variable			
	Motivation or Behavioral Theories	Management Systems	Reward-Based Theories	Best Business Practices
Aldridge 2004		●		
Ammeter 2002				
APPL 2004				
Bender 2000				
Connell 2001				
Couillard 1995				
Elrod 1999				
GAO 2004		●		●
Gross 2001		●		
Hihn 2004				
Kerzner 1995	●			
Leising 2004	●	●		
Mandell 2005				●
McCarthy 2004				
Miller 1993	●		●	
Moorman 2002				
NAFCOM Model				
Needy 2002				
Niehoff 2004				●
Pine 2000			●	
PMI 2004	●	●		●
PRICE Model				
Prince 2002				
Rosenberg 2004				
SAIC 2002				
SEER Model				
Smart 2004				
Young 2001/2003		●		●

Literature Review of Nontechnical Variables in Current Cost Models

This part of the literature survey was concerned with canvassing the more narrow body of literature on existing space project cost models to document the extent to which they addressed any of the nontechnical variables found in the first part of the study. There are three major off-the-shelf parametric cost models in use in the aerospace industry, which are widely discussed in the literature.

1) The NASA Air Force Cost Model (NAFCOM) is an in-house NASA model currently maintained by SAIC for NASA.

2) PRICE (specifically PRICE H, which is used for hardware cost estimating) is a commercial off-the-shelf model developed and marketed by PRICE Systems LLC.

3) SEER (specifically SEER H, which is used for hardware cost estimating) is a commercial off-the-shelf model developed and marketed by Galorath, Incorporated.

Each of these models (described below), to some extent, deals with nontechnical influences on cost. The major nontechnical variables in these models are derived from descriptions in the open literature.

NAFCOM Model Nontechnical Variables

Engineering Management: The level of design changes, experience of the design team, and the environment of the design effort.

Funding Availability: The appropriate anticipated funding availability. Choices for Funding Availability include: (1) Funding is assured—no delays, (2) Some infrequent delays possible, and (3) Funding is constrained—delays likely.

Risk Management: The amount of risk being accepted and indicated by the planned test program. Choices for Risk Management include: (1) High risk with minimum testing, (2) Moderate risk with qualification at prototype level, and (3) Low risk with qualification at the component level.

Integration Complexity: The expected number of interfaces involving multiple contractors and/or centers. Choices for Integration Complexity include: (1) Minimal major interfaces involving multiple contractors/centers, (2) Moderate major interfaces involving multiple contractors/centers, and (3) Extensive major interfaces involving multiple contractors/centers.

Pre-Development Study: The magnitude of the study efforts that were conducted or are being conducted prior to the start of design and development. Choices for Pre-Development Study include: (1) Two or more study contracts in Phases A&B—Greater than 9 months of study, (2) One study contract—between 9 and 18 months of study, and (3) Less than 9 months of Pre-Phase C/D study.

PRICE Model Nontechnical Variables[1]

Engineering Complexity Factor—Complexity of Engineering: The experience, skill, and know-how of the assigned individuals or team, as applicable to the specified task. A measure of the complicating factors of the design effort.

SEER H Model Nontechnical Variables[2]

Developer Capability & Experience: Rates the overall development team's engineering capability and experience with a similar design challenge.

Development Tools & Practices: Use of modern development practices, methodologies, processes, and automated tools available. These streamline the development process and reduce some analytical and data costs of the program. This rating should reflect the state of design tools that are in place and being used at the time hardware development begins.

Requirements Volatility: Anticipated frequency and scope of changes to the system requirements baseline after the requirements analysis phase is complete. Minor changes include subsystem functionality changes or configuration changes that do not

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[2] Copyrighted material used by permission of Galorath, Incorporated

impact other Work Elements. Moderate changes include such things as tighter system performance requirements that do not impact other Work Elements. Major changes include such things as changes in system performance requirements that alter the system configuration throughout most Work Elements.

While all three models treat nontechnical factors in some way as a management variable, their implementations of how these variables influence cost were considered to be improvable by this study. This statement is not a criticism of the capabilities of any of the existing models. All three models are both widely used and widely respected in the industry—PRICE and SEER are used in many industrial sectors in addition to space projects. The models were developed with a focus on parametric estimating in an environment where detailed technical information exists and trade studies are likely occurring at levels of the WBS where this technical differentiation is needed.

First, compared to NAFCOM, the model being developed by this dissertation operates at the total project level on automated spacecraft projects only and is meant to provide early and quick results on the likely effects of decisions on project cost while the project is in early formulation and adjustments can still be made relatively easily. NAFCOM, on the other hand, estimates a wider variety of space projects including space launch and transportation systems and human-rated missions, and requires more detailed information at the subsystem and major assembly level of the WBS, which is usually not available early. In addition, this dissertation has a different set of technical and nontechnical variables than NAFCOM. For example, the model here uses Power, Design Life, and Data Rate as technical independent variables, which are not explicitly part of NAFCOM independent variables. And the model here uses a number of nontechnical variables that are not used in NAFCOM. Also, the database for this dissertation includes a more extensive set of automated spacecraft projects (122 versus roughly 70 for NAFCOM) and many of the projects are more current than the NAFCOM database. (Because NAFCOM is designed to operate at lower levels of the WBS than the model here, NAFCOM requires more time to analyze any given project, introduce it into the NAFCOM database, and revise the cost estimating relationships (CERs)).

Compared to the PRICE Model, the model developed in this dissertation again operates at a higher level of the WBS and can generally be used earlier in the project life cycle. PRICE is designed to estimate a very wide range of project types. It generally offers only the Engineering Complexity Factor as the principal management influenced nontechnical variable, while the dissertation model here offers a more extensive list. This is not to be interpreted as a criticism of the PRICE Model—that model offers a much richer set of technical variables than the model here and is widely used throughout the industry for very detailed estimates at much lower levels of the WBS, which is essential for detailed trade studies. Finally, the PRICE Model database and resulting algorithms are proprietary to PRICE Systems, while the CERs developed in this dissertation are transparent.

Compared to the SEER, the model here also operates at a higher level of the WBS. SEER is designed to estimate a very wide range of project types. SEER offers only the principal management variables, while the model here offers a more extensive list. Once again, this is not to be interpreted as a criticism of the SEER model, which is designed for different requirements than those being addressed by this dissertation. And just as with PRICE, the SEER model database and resulting CERs are not open literature, while the equations developed here are.

In summary, the model here has significant differences from the models in the literature. This dissertation model:

- is focused on automated spacecraft projects only;
- uses a database that includes many very current space projects;
- is designed to be used earlier in the project life cycle and at the total project level;
- has a transparent and auditable database and regression analysis;
- offers a different set of technical variables; and
- offers a more extensive set of management variables.

Academic Argument for Research and Approach

The aerospace industry, both in the contractor community and the government organizations such as NASA and the Department of Defense (DoD), utilize parametric estimating methods for early predictions of the cost of space projects. Current space cost models employ CERs based on historical projects, which regress technical variables of these past projects against the known cost of the past projects. This approach, the current state of the art, works marginally well. But the cost equations typically have large variances, which lead to wide prediction intervals around any estimate.

One commonly used model at the Jet Propulsion Laboratory (JPL) (Table 2.6) shows a percent difference between actual and estimated costs of up to 89% (Hihn 2004) when used on historical space flight missions. While this model has an average error of 15.8%, which perhaps does not seem all that bad, this statistic reflects the cancellations of positive and negative errors. The standard error of 41.75% provided by Hihn is probably a better value to describe the variability and such an error is cold comfort to a project manager having to depend upon the model to predict a project.

Table 2.6 JPL Cost Model Variability between Actual and Estimated Cost

Reference Mission	± Percentage Difference Between Actual Costs and Estimated Costs
Mission 1	–19.0%
Mission 2	–2.3%
Mission 3	–8.2%
Mission 4	–1.6%
Mission 5	–5.5%
Mission 6	16.2%
Mission 7	53.1%
Mission 8	0.4%
Mission 9	23.2%
Mission 10	89.5%
Mission 11	89.4%
Mission 12	–45.6%
Average	15.8%
Std. Dev.	41.75%

Smart (2005) provides a similar computation in Table 2.7 for NAFCOM. The statistics indicate that NAFCOM accuracy is, to the first order, no better than the JPL model in terms of estimated versus actual costs.

Table 2.7 NAFCOM Variability for Selected Data Points

% Deviation			
	DDT&E	First Unit Cost	Total
FAST	–26.0	–56.7	–33.1
Mars Observer	–9.4	–20.1	–11.1
NEAR	12.9	53.1	23.9
STEP 0	5.7	–19.0	0.2
GRO	–30.7	–18.5	–28.7
HST-SSM	–5.2	–5.5	-5.3
TDRSS	–13.5	41.3	–8.0
Spacelab	2.9	2.7	2.9
COBE	18.3	46.7	24.1
CRRES	18.7	–1.8	14.7
Orbiter	2.4	–0.1	1.9
ET	21.5	36.0	22.7
SRB	–4.8	54.4	–1.2
SRM	50.7	28.3	49.6
IUS	–17.0	–8.2	–16.6
Average	1.8	8.8	2.4
Absolute Average	16.0	26.2	16.3
Standard Deviation	20.9	32.8	21.9

Tables 2.6 and 2.7 show that current space project cost models leave a very significant amount of variability unexplained. It is the thesis of this dissertation that some significant part of the variance in the historical cost of space projects that is not being adequately treated in current cost models could be caused by nontechnical differences between the projects, which is not being captured in the traditional cost models.

The literature survey found a rich discussion of the theoretical cost implications of nontechnical factors on projects and project cost, in a qualitative sense. Yet, the current cost models available to the aerospace industry do a less than totally satisfying job of relating management approaches to cost outcomes using nontechnical variables. All the current models suffer from one or more of the following criticisms:

- A limited number of nontechnical variables (all models),
- A requirement for a fairly mature, lower level definition of the project (all models),
- A limited and/or less than current database (NAFCOM), or
- Proprietary database and algorithms (PRICE and SEER).

This dissertation sought to extend and improve upon the implementation of nontechnical variables beyond the capabilities and utility offered by the existing models in the literature to give engineering managers a tool to access the cost consequences of decisions they make in these nontechnical areas. This work attempted to develop a model that can be used very early in the project life cycle. The database and CER development will be transparent, statistically sound, and not proprietary. These goals seemed to offer adequate justification for the effort.