Identifying Differences in Space Programs

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Abstract—From its inception in the early years of Apollo, NASA has prided itself on pushing the boundaries of science and engineering and knowing how to manage these types of projects. However, pushing the management boundaries requires a careful adaptation of risks, resources, and procedures, and projects must clearly assess the complexities and uncertainties of the task. The purpose of this study was to develop a better understanding of the management of strategic system projects at NASA. Such projects are typically characterized by advanced technology, new types of missions, complex integration of hardware and software systems, and inflexible time frames that are often dictated by "launch windows." To analyze strategic projects, this investigation used the framework of *Strategic Project Leadership*® (SPL) correlated to the management of systems projects at NASA. Of particular interest in this study was the analysis of fit between project type and the appropriate project management style. This research found that there was a good fit between project type and project management style and there is a need to develop a specific NASA framework to assess a project's risk and its appropriate project management style.

I. INTRODUCTION

Both 'project' and 'project management' can be defined in very basic terms [24, 33]. Although there are texts and guidebooks written on project management that give standard definitions, theories, processes, and strategies to apply to projects in general, some have theorized that projects carry a complexity all their own and that no single management style can fit all projects [1, 41, 45]. What is traditionally not well defined is the complex activity of a project and how this activity is managed. In spite of a growing use of project management as a practice, most research literature on the management of projects is relatively young and still suffers from a scanty theoretical basis, and fundamental concepts are still emerging.

In addition, some of the classical studies in project management have often advanced knowledge in a single focused area. For example, the role of research in projects of weapon systems development by Sherwin and Isenson [49]; questions of human resources management in R&D projects Katz and Tushman [21] and Roberts and Fusfeld [34]; communication patterns in technical and R&D projects by [20] and Tushman [54-56]; group and team performance by Goodman [15] and Thamhain and Wilemon [53]; and new product development by Brown and Eisenhardt [4], Eisenhardt and Tabrizi [11], Souder and Song [51], Wheelwright and Clark [58], and Baldwin and Clark [2]. Finally, the project management professional discipline is using a classical project management process, which consists of concept, planning, implementation, and operation; and nine knowledge areas such as, scope, cost, time, integration, quality, human resources, etc. [33].

The complexity of a project alone alters the management style and strategy of a project. Therefore, it should become clear that no one approach can solve the problems of project management, and thus no one strategy is best for any one project [9]. Various strategies for project management are prevalent throughout the literature [19, 30]. Though the project management strategies for building the Space Shuttle or designing a calculator can be effective and efficient, both are very different.

The purpose of this study was to develop a better understanding of the management of strategic system projects at NASA, and in particular, what makes such projects successful or unique. Such projects are typically characterized by advanced technology, new types of missions, complex integration of hardware and software systems, and inflexible time frames that are often dictated by "launch windows." To analyze these strategic projects, this investigation used the framework of *Strategic Project Leadership*® (SPL) correlated to the success of a systems development project through case study research. NASA projects were investigated with various mission objectives. Of particular interest in this study was the analysis of fit between project type and the appropriate project management style. This research found that there was a good fit between project type and project management style in two successful projects while in the non-successful projects this fit was apparently missing. It seems there is a need to develop a specific NASA framework to assess project's risk and its appropriate project management style.

II. THEORETICAL BACKGROUND AND BASIC PROPOSITION

Contingency theory states that an organization's effectiveness is dependant upon its ability to adjust or adapt to environmental uncertainty (external conditions). As uncertainty in environmental conditions increases, the need for integration or congruency among variables increases. As environmental uncertainties increase, a project must begin to function more as a system [8, 52].

Shenhar [45] theorizes that projects carry a level of uncertainty which increases with a level of technological uncertainty, or as this investigation will show, moving toward a higher degree of systems innovation. In organizations, events, situations, or technology can be described with a level of certainty or uncertainty. Certainty can be planned for (routine), structurally managed (bureaucracy), and predicted. The field of project management has only recently recognized that managing uncertainty is critical to project success. Even the Project Management Body Of Knowledge (PMBOK) did not recognize risk management until 1986. Senge's Fifth Discipline, states that "to change the behavior of a system, you must identify and change the limiting factor"—the uncertainty [39]. The failure of all project systems can be linked to a failure to manage uncertainty [23].

Milliken [27] theorized that there are three kinds of uncertainty: environmental state uncertainty, organizational effect uncertainty, and decision response uncertainty. These theories indicate that uncertainty would exist within and among systems. It is also clear that different types of uncertainty exist in all phases and areas of a project [25, 50]. Systems are inherently risky and carry a great level of uncertainty. What is true about today's systems is there is increasing uncertainty and thus they are prone to sudden unexpected changes. The process of systems innovation moves from an initial, ill-defined conception of a problem, through a series of subproblems, to a finished technology [29].

A. Systems Engineering

The attempt to understand the lifecycle of modern systems has been through the engineering of systems or systems engineering. Systems engineering (SE) is "the management technology that controls a total lifecycle process, which involves and which results in the definition, development, and deployment of a system that is of high quality, trustworthy, and cost effective in meeting user needs" [36, 37]. SE provides a process by which the organization, application, and delivery of systems can be managed, also called systems engineering management [42]. A key success driver in SE is the process by which the integration of people, processes, problem-solving mechanisms, and information come together, commonly called concurrent engineering [37]. Historically, principles of SE have largely been utilized and developed in the government with projects such as Apollo, nuclear-powered submarines, communications satellites, launch vehicles, aircraft, and deep-space probes. It is projects such as these in the aerospace/defense industry that carry characteristics like high complexity of the system with high technological risk, extreme design constraints, desire for complete answers, and auditability [31]. Even within SE there are different types of projects that can be characterized by various management styles and practices.

B. Large Systems Projects

Large Systems Projects (LSP) carry a high level of complexity, uncertainty, and reliance on an understanding of the fundamental concepts of systems and can begin to define NASA projects and projects. LSPs consist of customized, interconnected subsystems, carry high cost, are designed for one customer, are produced in low volume, require broad and deep knowledge and skills, engage multiple collaborators, involve the customer and suppliers throughout the life cycle, and have strong political considerations [12, 26]. Examples of LSPs are the Space Shuttle, the B-2 "Stealth" Bomber, the NY/NJ Mass Transit System, and the Hubble Space Telescope.

The knowledge base of LSPs is limited in the area of systems innovation and only recently has this area been largely recognized and investigated. There is limited theory on how LSPs develop and are managed. This has become even more important as there has been increasing attention on LSPs in the economic activities of firms, industries, and nations [17]. Hobday, Rush, and Tidd [18] state conventional innovation wisdom is derived from research on high volume consumer products; new evidence, models, and concepts are needed to properly understand the innovation process in complex products and systems. Even Morris and Hough [28] stated that "the application of conventional systems development for ordinary projects have been found to be inappropriate for complex projects." There is still much advancement that must occur before we have an adequate understanding of systems innovation [1].

III. FRAMEWORK FOR ANALYSIS

Shenhar has worked toward the development of a theory to address the strategic, operational, and human issues of systems innovation and add strategic direction to a project. He theorizes that not all projects are the same and thus they should not be managed the same [45]. He has proposed a typology based on an elemental foundation in contingency theory for managing different types of projects (e.g. systems projects), called Strategic Project Leadership (SPL).

SPL is an integrated, formal, strategically focused approach to project management to address the human issues of systems innovation. SPL has a foundation built upon the research of the National Science Foundation Grant, *Strategic Project Management: Making Projects Our Next Competitive Weapon* (Shenhar, Merino, and Reilly, March 1998) and theorizes a framework for project managers for the planning and execution phases of a project [44]. Fundamental to SPL is that "one size does not fit all projects." SPL focuses on the effectiveness and efficiency of a project while maintaining a perspective on strategy, operation, and the human factor. While traditional project management stresses getting the job done on time and within budget, SPL focuses on the product, scope, and strategy to strategically position a project to be successful.

Assessing the environment and the task, a project is classified on four dimensions, and the right project management style to fit to the project type. Shenhar states that projects carry contingencies based on the four dimensions of novelty, complexity, technology, and pace [41, 48], the NCTP Model:

- *Novelty:* Defined by the products uniqueness to the market and existing technology, and has an impact on the project definition and market related activities. To categorize product novelty, Shenhar uses Wheelwright and Clark's [58] definition of new product development: derivative, platform, and breakthrough.
- *Complexity*: Defined by the way a project is organized, its scope, and the interconnection between project elements. As the complexity of a project increases thus does the project size, extent and detail of planning, coordinating, documentation, and bureaucracy. Shenhar classifies project complexity as assembly, system, and array.
- *Technology*: Defined as the uncertainty centered around a technology's development, maturity, and knowledge. As technical uncertainty increases, so do requirements for technical and professional skills, development efforts and time to completion, communication, and the impact and significance of project results. Shenhar classifies projects on technical uncertainty as low-tech, medium-tech, high-tech, and super high-tech. As both technological uncertainty and system complexity increase so does the employment of systems engineering techniques, problems of systems integration, the employment of configuration management, and risk management techniques [46].
- *Pace*: Defined by the urgency and criticality of time goals for a project. Time constraints on a project can dictate varying project structures and management attention.

Once a project is classified based on these four dimension, it defines certain characteristics of that project that make it unique in how it is managed. Figure 1 shows that connecting the NCTP classification with a straight line to form a diamond, gives a representation of the level of risk associated with a project. The greater the area of the diamond, the greater the degree of risk. While there is not a linear relationship between the area of the diamond for correct and incorrect project risk, it can represent a difference in the degree of risk.

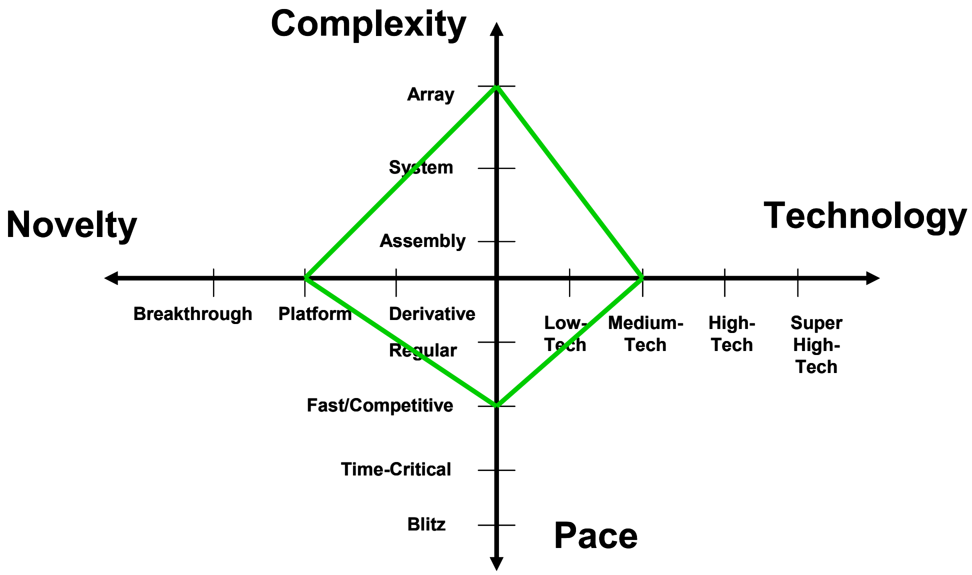

Fig. 1. NCTP Model

IV. MANAGEMENT INITIATIVES IN SPACE PROGRAMS

Historically in the aerospace industry, projects have been difficult, large ventures that inevitably carried high costs. What resulted were expensive products, long development processes, complex management, the need for larger rockets, cost overruns that lengthened missions, and some troublesome failures [22]. Therefore, there have been concerted efforts within industry and government to try and understand the development of these large systems projects.

Robert Bless [3] stated in his article "Space Science: What's Wrong at NASA" that the three areas that left NASA's scientific programs less effective and more costly were an overreliance on the Space Shuttle, a propensity for big projects, and poor management. The increasing trend of launch delays and spacecraft redesigns that sprouted from the Space Shuttle Challenger accident resulted in larger and less frequent missions. What resulted was what Greg Davidson [7] described in his article "Our National Space Science Program: Strategies to Maximize Science Return" as big versus small missions, multiple simple spacecraft versus servicing, a culture of risk avoidance, unrealistic budget planning, institutional and political forces, and linkage to the manned space program.

In the late 80s, NASA was struggling with its own issues on how to manage its high-tech programs and projects as a result of the tragic loss of the Space Shuttle Challenger. In compliance with Executive Order 12546 of February 3, 1986, NASA issued the *Report of the Presidential Commission on the Space Shuttle Challenger Accident* [35]. This report exposed many managerial issues within NASA and prompted change throughout the agency. Also at this time the Reagan-Bush Administration was pushing for a reinventing of the government and NASA. On April 3, 1998, NASA issued a NASA Procedures and Guidelines document, *Program and Project Management Processes and Requirements* (NPG 7120.5A), that described and defined NASA program/project management. Although NPG 7120.5A defined NASA program/project management procedures and guidelines, it left an open interpretation of how NASA management practices should be performed. In March 2000, NASA again attempted to define how it performed program and project management when it formed the NASA Integrated Action Team (NIAT) to assess and develop recommendations for NASA programs and projects as a result of some costly failures [16]. As a result of the NIAT's recommendations, NASA revised NPG 7120.5A to produce NPD 7120.5B. More recently, the tragic loss of the Space Shuttle Columbia has forced NASA to take an even deeper look at how programs and projects are managed.

In NASA's long history of project management experience, it has conducted numerous projects of various kinds. However, in spite of several attempts and suggestions, there is still no agency-wide framework for distinction among projects, and there are no guidelines on how to manage different projects in different ways. NPD 7120.5B does not address differences among projects or the ways they should be managed. Previous research even suggested that some tragic events, such as the two Space Shuttle accidents, or other project failures could be the result of incorrect project management style used in projects [6, 16, 40].

V. RESEARCH METHOD

This research evaluated theories around the how and why of NASA projects that were trying to achieve systems innovation. A case study research methodology was chosen because it allowed for the characterization of real-life events, such as organizational and managerial processes, and there was no requirement for control over behavioral events; thus, allowing for the capture of holistic and significant experiences [10, 14, 59]. Eisenhardt [10] states in "Building Theory from Case Study Research" that case studies can provide description, test theory, or generate theory. She describes a fundamental difference in case study research as compared to experimental research is in the selection of the sample population. Cases are chosen for theoretical reasons, not statistical reasons. One of the reasons for this, and why case study research was chosen for this investigation is to extend emerging theory. Case study research provides a conduit to go from theory to data and back to theory. To describe the cases and provide a protocol for data collection Shenhar's [43] "Real Life Project Analysis – Guidelines", Shenhar and Dvir [48] "How Projects Differ and What To Do About It?," and Shenhar [47] "Strategic Project Leadership: Toward A Strategic Approach to Project Management" were used. Four cases that represented failures and successes in NASA projects were chosen.

The mode of analysis for this project used a systematic measure of the attractiveness of alternatives to a set of attributes (i.e. SPL). This method works best when alternatives must be evaluated to determine which alternative performs best. It allowed for comparison among what people do, what people intend to do, and what they should do. The following steps were followed:

1. Analysis of the decision situation: This involves the definition of the cases to be evaluated, the framework in which the cases were described, and the possible alternatives and their consequences. The framework for collection and formulation of the data was with Shenhar's "Real Life Project Analysis – Guidelines," and the possible alternatives and the consequences were defined by Shenhar and Dvir's [48] "How Projects Differ and What To Do About It?" and Shenhar's [47] "Strategic Project Leadership: Toward A Strategic Approach to Project Management."

2. Inquiry of existing evaluation structures: This defines the techniques for data collection. Data collection was performed using the following sources of evidence:

a. *Interviews*: Project team members were approached through e-mail or telephone via personal contact or through a colleague. Each potential interviewee was provided with a one-page letter of introduction that included a statement of the research project, purpose/rational, people conducting and sponsoring the study, and background on SPL. Interviews were conducted in a semistructured, open-ended conversational format to allow interviewees to speak freely and openly about their experiences. Interviews ranged from 30 minutes to 2 hours based on the interviewee's availability and depth of information. A single interview session was performed with each subject, with follow-up interviews on an as-needed basis. At least five key personnel related to each project were interviewed. These people represented program management, project management, administration, team member, and customer. Each interview was recorded on audiotape and transcribed.

b. *Documentation (related to the project, but not a product of the parent organization)*: Formal studies, evaluations, journal articles, survey data, mass media, and physical artifacts (samples of work done).

c. *Archival and Historical Information (directly related to or a product of the project or parent organization)*: Letters, memoranda, policy statements, regulations, proposals, guidelines, procedures, summary reports, organizational records, and personal records.

d. *Participant Observation*: NASA gave permission for participation in its Academy of Program and Project Leadership training programs. This included project management training classes.

3. The alternatives-versus-attributes matrix: Attributes are defined as preference-related dimensions of a system, or variables. Attributes characterize and describe a project, with each attribute having a set of alternatives. Alternatives define and describe the attractiveness of the attributes for a case. Once a case study was completed, an alternatives-versus-attributes matrix was used to evaluate the project. For this research, the alternatives and attributes were defined by Shenhar and Dvir's [48] "How Projects Differ and What To Do About It?" and Shenhar [47] "Strategic Project Leadership: Toward A Strategic Approach to Project Management." For example, an attribute in the NCTP Model would be Technology and the alternatives would be Low-Tech, Medium-Tech, High-Tech, and Super High-Tech.

4. Utility functions: Utility functions serve as a measure of the attractiveness of an alternative with respect to its attributes; are a measure that makes attributes comparable; and reflect the values or intentions of an individual, group, or organization. For this research, the utility functions were defined by Shenhar and Dvir's [48] "How Projects Differ and What To Do About It?," Shenhar's [47] "Strategic Project Leadership: Toward A Strategic Approach to Project Management," and the case studies as defined by Shenhar's "Real Life Project Analysis – Guidelines."

5. Evaluation and discussion: Once all the cases were analyzed, a final iteration was performed to develop and refine a final theoretical statement about the findings. This was defined as the evaluation and discussion. Evaluation and discussion describes the results of the evaluation of each case, provides a cross-case analysis, and offers recommendations for the management of NASA projects.

VI. CASE OVERVIEWS

A. Pathfinder (Mars Exploration Program/Pre-Discovery Program)

In 1993, Congress approved a plan proposed by NASA's Space Science Enterprise for better, faster, cheaper planetary missions called the Discovery Program. To show Congress that it could be done, NASA selected two charter missions: one at the Jet Propulsion Laboratory (JPL) and one at the Johns Hopkins University Applied Physics Laboratory (APL). Mars Pathfinder was chosen at JPL as a scientific mission set out to broaden the understanding of Mars and show that "better, faster, cheaper" (BFC) could be done successfully. As a product, Mars Pathfinder was a single vehicle (lander), with microrover and several instruments designed to demonstrate a low-cost system for cruise, entry, descent, and landing on Mars. Additional objectives included the deployment and operation of various scientific instruments: stereoscopic imager with filters on a pop-up mast, alpha proton x-ray spectrometer (APXS), and atmospheric structure instrument/meteorology package.

As a project, Mars Pathfinder, at the time one of the most complex planetary exploration projects in space science history, was to design, test, and develop a lander and rover to launch and safely land on the surface of Mars. With 3 years for development and a total cost no greater than $280 million (including the launch vehicle and mission operations), Mars Pathfinder was to demonstrate a simple, low-cost system, at a fixed price for placing a science payload on the surface of Mars at 1/15 the cost of Viking (Viking cost $2.8 billion in 1997 dollars). On July 4, 1997, Americans watched the first pictures come back from Mars, marking one of NASA's most celebrated, historic, and accomplished days. A whole new generation was being introduced to the Red Planet through television and the Internet, as Mars Pathfinder shattered records for web site hits, peaking at 1 million in a day. From its start, Mars Pathfinder had project constraints that were unmatched by another NASA project and science objectives that would return an unparalleled amount of data to the largest science community associated with a NASA mission. For all of Mars Pathfinder's interest and success, it was not the landing on Mars that marked its success (Viking I and II accomplished this in 1976 and 1978 respectively)—it was the means by which it was accomplished that made it unique, innovative, and electrifying.

B. Lunar Prospector (Discovery Program)

Lunar Prospector was the first competitively selected mission in the NASA Discovery Program, developed to produce frequent, low-cost missions to explore the solar system. Lunar Prospector was a spin-stabilized spacecraft designed to map the surface composition and magnetic field of the Moon and begin investigating some of the 80 percent of the Moon's surface features, structure, and composition not investigated during Apollo. As a product, Lunar Prospector was a single vehicle (orbiter) and several instruments designed to demonstrate a low cost system for orbiting the Moon and expanding our scientific knowledge of it. Additional objectives included the deployment and operation of various scientific instruments: neutron spectrometer, gamma ray spectrometer, magnetometer/electron reflectometer, Doppler gravity experiment, and alpha particle spectrometer. While much of the technology was known, its application and what Lunar Prospector was planned to accomplish made it different than anything that had been done before.

As a project, Lunar Prospector was to design, test, and develop an orbiter that would obtain scientific data and demonstrate, as the first competitively selected Discovery Program mission, the philosophy of BFC. Lunar Prospector had a development time of almost 3 years and a project cost that included development ($34 million), launch vehicle ($25 million), and operations ($4 million), for a total of $63 million. Lunar Prospector involved 75 to 100 people from Ames Research Center, Goddard Space Flight Center, Jet Propulsion Laboratory, University of California – Berkley, University of Arizona, Lockheed-Martin, Lunar Research Institute (Alan Binder, principal investigator, left Lockheed Martin to establish the Lunar Research Institute), and Los Alamos National Laboratory. Lunar Prospector ended on July 31, 1999, when the spacecraft was jettisoned into a crater near the south pole of the Moon as part of an experiment to confirm the existence of water ice. The mission ran for 19 months and successfully completed all of its objectives. The data collected has allowed for the construction of a detailed map of the surface composition of the Moon, and the information gathered was far more comprehensive than any data ever collected.

C. CONTOUR (Discovery Program)

As the sixth mission in NASA's successful Discovery Program, the Comet Nucleus Tour (CONTOUR) was a joint project between Cornell University and Johns Hopkins University Applied Physics Laboratory (APL), along with 14 other university, government, and industry co-investigators to study three major near-Earth comets. With a budget of $159 million and a development time of almost 3 years, it was scheduled to fly within 60 miles of each of three comets. From 2003 to 2008, CONTOUR would take images, make spectral maps, and analyze dust flowing from the comets to substantially improve the knowledge base and expand the understanding of comets. As a breakthrough product, CONTOUR was a single spacecraft and six scientific instruments designed to provide a detailed look at comets and answer questions about how comets act and evolve. While much of the technology was known, its application and what CONTOUR was planned to accomplish made it different from anything that had been done before. No one in the history of space exploration had brought a spacecraft as close to a comet as CONTOUR would. While using predominantly existing, off-the-shelf technology and technology from previous missions (NEAR and Stardust), CONTOUR was flying for the first time a non-coherent DOPPLER navigation system and a Solid Rocket Motor (SRM) that had not been thoroughly tested with the spacecraft.

As a project, CONTOUR was to design, test, and develop an orbiter that would obtain scientific data on comets and reaffirm the success of BFC. CONTOUR could be described as a high-tech project. While much of the technology was proven from the Stardust and Near Earth Asteroid Rendezvous (NEAR) spacecrafts, its application and its unprecedented scientific objectives made it different than anything that had been done before. CONTOUR was on track to be a storied success for both Cornell and APL, but the loss of communications on August 15, 2002 could not have been expected. On that day, CONTOUR was scheduled to accelerate the spacecraft and place it on a trajectory toward its first comet. While operations continued based on the assumption that the firing took place on schedule, no signal was received from the spacecraft. From August 16 through August 21, three objects were identified near the expected position of CONTOUR. Communications attempts continued with the spacecraft once a week through December 2002, and the mission was declared officially lost after the December communication attempts failed.

D. Mars Climate Orbiter (Mars Surveyor Program)

In 1993, NASA started the Mars Surveyor Program to develop a series of missions to study Mars. A Mars Program Office was established and given the responsibility of defining the objectives of these Mars exploration missions. Chartered under this office would be two missions with biennial launching opportunities (Mars Climate Orbiter and Mars Polar Lander). The Jet Propulsion Laboratory (JPL) created the Mars Surveyor Project '98 (Mars '98), which would be responsible for these missions. One of these missions, the Mars Climate Orbiter (MCO), was a strategic project that would help build a sustained position in space exploration with recent successes in Mars exploration (Mars Pathfinder and Mars Global Surveyor). MCO would build upon those successes and lay the groundwork for several planned Mars exploration missions over the next 15 years. MCO was a tangible product of a spacecraft, orbiter, and scientific instruments, which required a significant level of insight and creativity both technically and managerially, built around a core of talented, experienced people to produce a valued product.

As a project, MCO was to design, test, develop, launch, and operate an orbiter that would collect weather data from Mars and act as a relay station for 5 years, assisting in data transmission to and from the Mars Polar Lander (MPL). Jointly developed with the MPL and 300 people from JPL and Lockheed-Martin, the project had a 37-month development schedule, with spacecraft launch masses of a medium-light class launch vehicle and a financial cap of about $184 million (covering development of the spacecraft, scientific payloads, and the ground operations system). On September 23, 1999, MCO began its orbiter insertion maneuver, but shortly after beginning, the signal was lost from MCO, and on September 24, search for the orbiter was abandoned. On September 30, a JPL peer review committee reported that small forces of velocity changes reported by the spacecraft engineers used in orbit insertion were low and the likely causes of the MCO loss. On October 6, an MCO Mission Failure Investigation Board was appointed by NASA to independently investigate all aspects of the failure of the mission. On November 10, the Board released its report that idenified the root cause for the loss of the MCO spacecraft as the failure to use metric units in the coding of a ground software file.

VII. RESULTS

There is a fundamental difficultly with NASA programs when attempting to define their novelty, technology, complexity, and pace. The shear fact that a project is attempting to explore the universe or launch into space, can define the project as high-tech; the level of risk and integration associated with such missions define their complexity no less than a system; and the technological challenges and requirements of space exploration can make them a breakthrough.

Figure 2 shows how the projects were managed based on the NCTP Model. The successful projects not only applied the right project typology, but also the right approaches for that typology. The projects that failed showed differences in their approach to the required typology. Connecting the NCTP classification with a straight line to form a diamond, gives a representation of the level of risk associated with a project. The greater the area of the diamond, the greater the degree of risk. Fig. 2 also represents how each of the projects differed in their level of risk and how the projects were approached with a lower level of risk. The solid lines represent the correct project classification. The dashed lines represent how the project was managed. While there is not a linear relationship between the area of the diamond for correct and incorrect project risk, it does represent a difference in the degree of risk.

To explain further, Table I is an overview of the actual and required project adaptation for each of the projects. Table I shows that for Mars Pathfinder and Lunar Prospector the required and actual approach were equal. For CONTOUR and Mars Climate Orbiter cost constraints and pressures to be successful resulted in management making heuristic decisions on what to cut back to save costs. These items became important to the success or contributed to the failure of the projects.

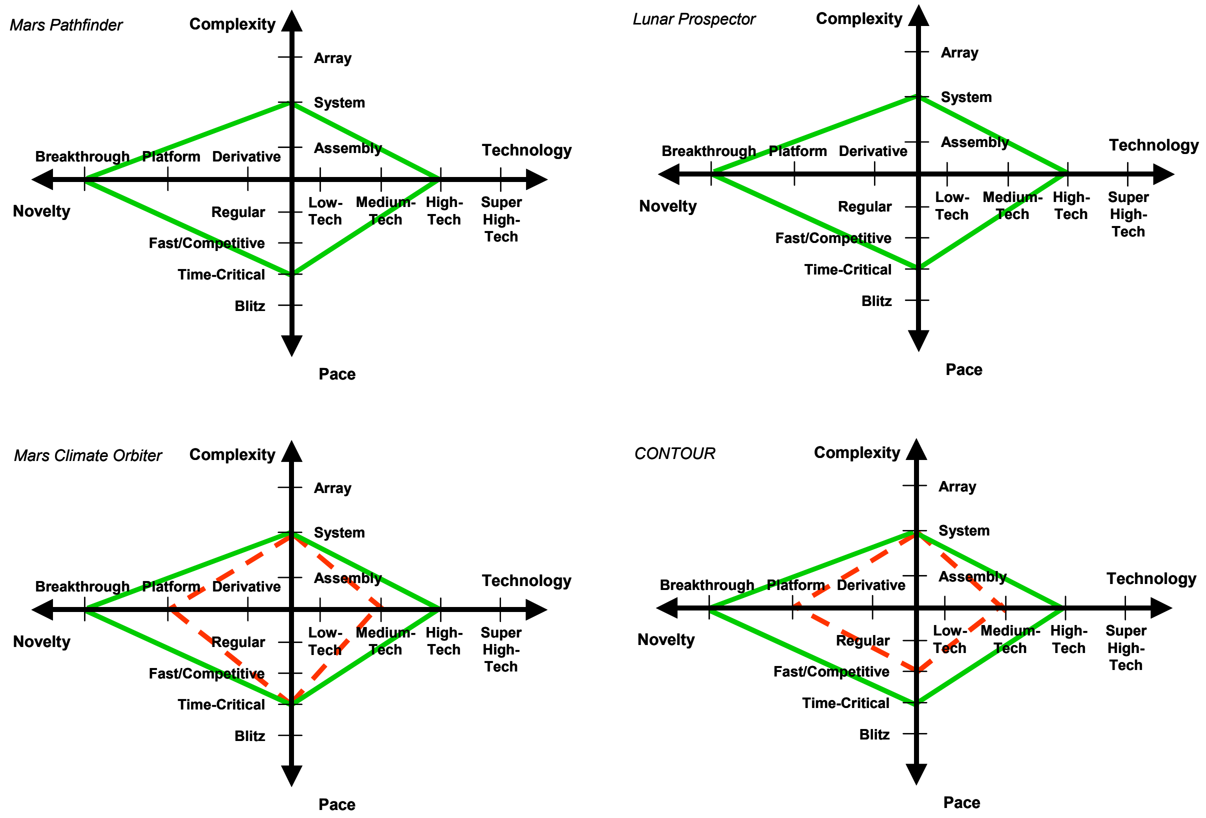

Fig.2. NTCP Model – Case Analysis

TABLE I: NCTP – REQUIRED AND ACTUAL

Mission	Novelty	Complexity	Technology	Pace
Mars Pathfinder *Required/ Actual*	**Breakthrough** Introduced to the world a new way of landing on Mars, and more significant, a robotic rover to traverse the planet.	**System** Complex collection of interactive elements and subsystems, it functioned as one unit to meet its operational needs.	**High-Tech** While most of the technology was COTS, a significant portion of the technology was new to planetary exploration.	**Time-Critical** Schedule, cost, and technology had limited margins with a fixed launch window.
Lunar Prospector *Required/ Actual*	**Breakthrough** New use for existing technology that had not been seen before; it pushed the boundaries of cost-effective space exploration.	**System** Complex integration of scientific instruments and spacecraft subsystems.	**High-Tech** Although most of the technology was COTS or borrowed from other proven spacecraft, it was innovative in its application.	**Time-Critical** Schedule, cost, and technology had limited margins with a fixed launch window.
MCO *Required*	**Breakthrough** Integrated mature technology with a new and untested spacecraft.	**System** A complex interaction of subsystems and elements that would function in Mars' orbit and with the MPL.	**High-Tech** Much of the technology was developed prior to the project's inception, but MCO was the first of its kind.	**Time-Critical** Time was critical for project success and delays would only equal cancellation.
MCO *Actual*	**Platform** Cost constraints resulted in fast prototyping that compromised testing and reviews.	**System** Cost constraints limited control of subsystem integration and the absence of end-to-end verification and validation.	**Medium-Tech** Pressures to push the boundaries of BFC affected costs, testing, reviews, communication, and technical skills.	**Time-Critical** Schedule, cost, and technology had limited margins with a fixed launch window.
CONTOUR *Required*	**Breakthrough** Integration into a new product with first-time-used systems; no one in history would bring a spacecraft this close to a comet.	**System** A systems project that relied on the integration and complexity of that integration to develop a spacecraft.	**High-Tech** Significant improvements were made to the technology to develop CONTOUR from its original design.	**Time-Critical** From project start, they were under pressure to meet specific launch opportunity with a strict schedule.
CONTOUR *Actual*	**Platform** Management believed they were building upon the success and technology of past missions.	**System** Integration testing was performed late in development, resulting in an inadequate understanding of the system uncertainty.	**Medium-Tech** Approached as a non-revolutionary improvement to past missions, thus assuming a lower level of uncertainty.	**Fast-Competitive** Events such as integration and testing could occur late; team members for most of the project life cycle worked 40-hour weeks.

VIII. CONCLUSIONS

This investigation addressed two basic questions: (1) NASA projects require a unique model or framework for project management and (2) the NCTP Model provides a fundamental framework for analyzing, planning, and managing NASA projects. There is no question that NASA projects are unique and have distinctive constraints and as an agency, NASA has a vision and a legacy of taking on extraordinary and unprecedented projects, thus the principles for managing these types of projects should be unique as well. Their technological challenges are unique, thus should be their project management practices. In the projects that failed, it was not a fault of the talent, but as the NCTP framework helped to explain, the complexities and challenges faced by the team made it difficult to relate the correct project management style to the risks of these projects. It is believed from this case analysis that the projects that failed were forced to work under constraints that were impossible to achieve under the requirements of high project risk. While the NCTP Model provides a fundamentally unique and applicable framework for NASA projects, which may have helped in the projects that failed, it is still not an exact fit.

(1) NASA projects require a unique model or framework for project management: NASA's current policy documentation on program and project management, NPD 7120.4B and NPD 7120.5B, outlines the policies and processes of project initiation, approval, planning and execution. Both documents mention the need for tailoring the agency's processes to program and project characteristics and leave much of this interpretation or tailoring to the project manager. However, no formal document makes a distinction among different project types or how to tailor project management to project characteristics. In December 2003, Sherry Bucshmann, NASA Office of the Chief Engineer, stated in a presentation to the NASA/USRA Workshop of Research Topics in Program and Project Management that NASA has identified the need for a project categorization scheme that should be reflected in the new release of NPD 7120.5C [5].

Currently NASA uses Technology Readiness Level (TRL) to classify a project based on its stage of development (see Table II). This classification is based on a technology readiness in relation to being acceptable for launch. While TRL may give some indication as to a technology's developmental state, it does not correlate to any specific project management principles or guidelines.

TABLE II: TECHNOLOGY READINESS LEVEL

TRL	Definition
Level 1	Basic principles observed and supported
Level 2	Technology concept and/or application formulated
Level 3	Analytical and experimental critical function and/or characteristic proof of concept
Level 4	Component and/or breadboard validation in laboratory environment
Level 5	Component and/or breadboard validation in relevant environment
Level 6	System/subsystem model or prototype demonstration in a relevant environment
Level 7	System prototype demonstration in a space environment
Level 8	Actual system completed and “flight-qualified”
Level 9	Actual system “flight-proven” through successful mission operation

For processes in project development, NASA teaches the Visual Process and Vee Model in its program and project management training [13]. More recently NASA has begun to adopt the Department of Defense’s Spiral Development for its Exploration Program. While all of these principles and practices have proven to be successful, they are focused on process issues and are not all used agency wide on all projects.

The projects investigated revealed that NASA has constraints that are inherent in all of its space exploration projects, such as the harsh environment of space, launch window opportunities, and the NASA culture. All the project managers interviewed said they had to modify required project management principles and practices to be successful. In the projects that failed, the NCTP Model can help explain some of the constraints faced by the project managers. For all of the projects, the project managers used heuristics to make determinations on what to cut to meet time and budget constraints. For the two failures, these heuristic decisions resulted in costly failures. A framework may have revealed the project could not have been accomplished under the specified constraints or practices. Perrow [32] states that while a decision may appear perfectly rational, the operator may be using it in the wrong context. An effective framework, while it may not guarantee success, can provide practitioners with the tools so they can rely less on heuristics. While it is clear from this investigation that NASA needs a unique framework for program and project management, the exact principles to define that framework are not clear. This investigation is viewed as the foundation for the development of that framework.

(2) The NCTP Model provides a fundamental framework for analyzing, planning, and managing NASA projects: The projects studied represented a maturation of BFC, and Perrow [32] states that as one becomes more comfortable with a technology (in this case BFC), one is more willing to take the risks that may ultimately lead to failure. In the case of BFC, NASA continued to push projects to be better, faster, and cheaper and Dan Goldin, former NASA administrator, later stated that NASA pushed the “envelope too far.” In *The Challenger Launch Decision: Risky Technology, Culture, and Deviance at NASA*, Vaughn [57] adds to this argument as she claimed that a disaster's roots are found in the nature of an institution’s life. NASA is an institution that was founded on taking high-level risks. Therefore, it could be concluded that BFC was destined to fail over some period of time. Could a framework have obverted or delayed the failure in BFC? Any organization that pushes the boundaries must be willing to accept the consequences of costly, visible failures. However, pushing the management boundaries requires a careful adaptation of risks, resources, and procedures, and projects must clearly assess the complexities and uncertainties of the task. The NCTP Model defined NASA projects well and provided a fundamental framework for planning and managing projects. While NASA’s policies and procedure are written to be adaptable to many project types, the key principles for various project types are not identified. Applying the NCTP Model to the projects showed that a fundamental framework in planning and managing different projects could reveal that a project may not be able to be successful under its constraints. In the projects that were successful, the NCTP Model correlated to the characteristics of the project as described by the case studies. In the projects that failed, the NCTP Model may help explain the difficulty faced by managers in these types of projects. The application of a framework such as the NCTP Model in the project-planning phase may have identified the approach deficiencies that precluded success.

This investigation showed that a framework could be important to the success of NASA projects. Although there is still a need to understand how these results correlate to the discipline of project management of complex systems, the value of a framework for analyzing, planning, and managing a project has been shown valuable to project management. Currently, project frameworks are designed for a limited project typology. Shenhar has theorized a unique framework that can be used for effectively managing all types of projects. This research showed that a framework could effectively be used to define NASA projects. While these projects may have had unique characteristics, they are still representations of project typologies. Therefore, there is validation in the results of how these projects were classified to non-NASA projects in the same classification. Unfortunately, these projects only represented one classification in over 200 potential outcomes in the NCTP framework.

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