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Why projects fail? How contingency theory can provide new insights – A comparative analysis of NASA's Mars Climate Orbiter loss

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Abstract

When important projects fail, the investigation is often focused on the engineering and technical reasons for the failure. That was the case in NASA's Mars Climate Orbiter (MCO) that was lost in space after completing its nine-month journey to Mars. Yet, in many cases the root cause of the failure is not technical, but managerial. Often the problem is rooted in management's failure to select the right approach to the specific project. The objective of this paper is to enrich our understanding of project failure due to managerial reasons by utilizing different contingency theory frameworks for a retrospective look at unsuccessful projects and perhaps more important, potential prevention of future failures. The evolving field of project management contingency theory provides an opportunity at this time to re-examine the concept of fit between project characteristics and project management, and offer deeper insights on why projects fail. After outlining several existing contingency studies, we use three distinct frameworks for analyzing the MCO project. These frameworks include Henderson and Clark's categorization of change and innovation, Shenhar and Dvir's NTCP diamond framework, and Pich, Loch, and De Meyer's strategies for managing uncertainty. While each framework provides a different perspective, collectively, they demonstrate that in the MCO program, the choices made by managers, or more accurately, the constraints imposed on them under the policy of 'better, faster, cheaper', led the program to its inevitable failure. This paper shows that project management contingency theory can indeed provide new insights for a deeper understanding of project failure. Furthermore, it suggests implications for a richer upfront analysis of a project's unique characteristics of uncertainty and risk, as well as additional directions of research. Such research may help establish new and different conceptions on project success and failure beyond the traditional success factors, and subsequently develop more refined contingency frameworks. The results of such research may enable future project managers to rely less on heuristics and possibly lead to a new application of "project management design."

Keywords: Project management; Contingency theory; Project failure

1. Preface

Space exploration involves enormous risk and poses unprecedented scientific, engineering, and managerial challenges. Almost every mission is "first of its kind," and is often characterized by extensive media coverage and public interest. Successful programs produce valuable scientific information as well as create great national pride. But space research and exploration is highly risky, and sometime involves painful failures. The failure of NASA's Mars Climate Orbiter (MCO) was perhaps one of the most unfortunate examples. MCO was part of NASA's Mars Surveyor Program, which was initiated in 1993 and included the missions of MCO and Mars Polar Lander (MPL). MCO was supposed to circle Mars and collect the planet's weather data as well as act as a relay station, assisting in data transmission to and from MPL, which was designed to land on Mars' South Pole. MCO was launched on schedule on December 11, 1998 and traveled in space nine and a half months before it approached the vicinity of Mars. As soon as it began its insertion maneuver, however, the orbiter's signal was lost, and never recovered again. A retrospective peer review committee confirmed engineers' assessment that small forces of

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velocity changes used in orbit insertion were lower than expected by a factor of 4.45. Later on, a Mishap Investigation Board (MIB) concluded that the root cause of MCO's loss was a failure to use metric units in the coding of a ground software file. The failure of MCO was defined by NASA as a technical error and its investigation produced a collection of lessons learned and recommendations [9]. But often project failure goes beyond technical reasons. A retrospective look at MCO suggests that management could have prevented this failure by a better upfront assessment of the program's uncertainty and complexity, and by installing the proper managerial systems that would detect such errors ahead of time. But how can one know what to do ahead of time? That is the focus of this paper.

2. Introduction

Projects have clearly become a central activity in most organizations and companies are investing increasing resources in projects such as new product development, process improvement, or building new services. Many studies have demonstrated, however, that most projects do not meet time and budget goals, or fail to satisfy customer and/or company expectations [11–16]. Yet, project success means more than just meeting time and budget goals. It involves additional success dimensions such as business results or preparing for the future [40]. Regardless of the success criteria, researchers have tried for years to find the reasons for project success or failure. One of the most common approaches is the search for critical success factors [17–20]. The assumption in these studies is, that projects succeed or fail because of similar reasons and the researcher's objective is to identify these reasons. These studies produced list of typical factors such as, project mission, planning, communication, politics, control, top management support, technical tasks, etc. Yet, in spite of their popularity, critical success factors studies have had little impact on project management practices and few organizations or managers are actually using the findings of these studies to improve their managerial processes.

This paper utilizes a different stream of research – the adoption of organizational contingent theory to project management. The contingency approach to project management investigates the extent of fit or misfit between project characteristics and project management approach. Potentially, in analyzing real cases, the detection of misfit may help better explain project failure. More important, understanding the elements of such misfit may provide recommendation for a preferred managerial approach before a project is launched, or for bringing a troubled project back on track. Thus the objective of this paper is to enrich our understanding of project failure due to managerial reasons by utilizing different contingency theory frameworks for a retrospective look at unsuccessful projects. Our goal is to demonstrate the power of contingency theory beyond traditional success and failure studies and to offer avenues for further contingency research.

Contingency theory is not a new concept in organizational research. Classical contingency theory has gradually evolved since the late 1950s. Dealing mostly with enduring organizations, the theory suggests that organizational effectiveness is dependent upon the organization's ability to adjust or adapt to the environment, and that there is a need for congruency between the environment and structure [24–26]. The contingency theory view started perhaps with Woodard [28] who argued that technologies directly determine differences in such organizational attributes as span of control, centralization of authority, and the formalization of rules and procedures. This was shortly followed by Burns and Stalker's famous research [29] that introduced the concepts of mechanistic versus organic organizations, and suggested that the more turbulent dynamic environments should be addressed by an organic organization. Three of the most influential works in the development of this theory appeared simultaneously in the mid 1960s. They included Lawrence and Lorsch [25] who showed how different rates of change can effect the organizations ability to cope; Thompson [33] who showed that coping with uncertainty is a core problem for complex organizations; and Perrow [35] who used an integrated viewpoint on technology and complex organizations to identify four types of organizations. In 1977, Galbraith [36] published his landmark book in organizational design, which paved the way for a stream of followers in studying organizational contingency theory (e.g., [24] or [26]). Drazin and van de Ven explained the context-structure–performance relationships in structural contingency theory to show that fit is an important interpreter of performance.

While the concept of structural contingency has been well established in the organizational theory literature, only recently has it been applied to project management research [39,40,42]. In this paper, we provide an overview of project management contingency frameworks that have been mentioned in the literature over the past 25 years and discuss their relevance. We then use three of the leading contingency frameworks to analyze the management of NASA's Mars Climate Orbiter. We show how these different frameworks demonstrate the power and richness of contingency theory, not only for a better explanation of project failure, but also for an upfront analysis of project characteristics and adaptation of a preferred project management style. We will conclude with a discussion of future research direction and its potential contribution to theory building and managerial practices.

3. Mars Climate Orbiter story

Mars Climate Orbiter (MCO) was to be the first in a series of missions in the next steps of Mars exploration. Jet Propulsion Laboratory (JPL) in Pasadena, CA was commissioned to lead this program, and it selected Lockheed-Martin Astronautics as an industry partner to develop the spacecraft. The intensive competitive contract would give Lockheed-Martin the opportunity to compete for eight spacecraft for Mars exploration. The intention was that by duplicating the spacecraft for every mission, the spacecraft development would become "carbon copies" for subsequent opportunities. JPL believed that this could result in immense cost savings in the long-term. NASA at that time was greatly influenced by the hallmark of "faster, better, cheaper" (FBC) policy, which advocated smaller and cheaper missions compared to any previous time in the agency's history.

As a project, MCO was to design, develop, test, launch, and operate an orbiter that would collect weather data from Mars. MCO was to have mission duration of two years where it would accomplish its entire science objectives. It was then planned to operate as a relay station for the Mars Polar Lander (MPL) for an additional period of three years. MCO was jointly developed with MPL, which was designed to land on the South Pole of Mars and follow shortly after MCO. Under the policy of BFC, a team of 300 people from JPL and Lockheed-Martin were given a financial cap of about $184 million (covering development of the spacecrafts, scientific payloads, and the ground operations systems). The project was also constrained by a schedule of 37 months before launch, dictated by celestial mechanics.

All budgets were structured by fixed-cost contracts, which included the planning and engineering development of MCO and MPL, (and were about half of those spent some years earlier on the successful Mars Pathfinder program). Using a predetermined launch vehicle and competitively selected payloads, the technical requirements were frozen early on to make sure time constraints were met. The team's perception was, that even slight changes would result in significant cost and time overruns. The MCO team worked under extreme combined constraints of cost, schedule, and technical requirements that were unheard off in any new interplanetary mission before. In addition, MCO had to adopt a cumbersome "earned value" technique used by the defense department. While such technique may work well on a standard, less risky program, its use in MCO only complicated things since the program was far from being standard, with its high levels of uncertainty, complexity, and risk.

To lower technological uncertainty, MCO tried to use many subsystems, including computers, attitude control, and propulsion technology from previous programs such as Mars Global Surveyor. As it turned out, the dependence on these systems eventually became a contributing factor to the failure of MCO. Inheriting subsystems from previous missions, allowed for a reduction in time, cost, and uncertainty in development, but it did not reduce the need for elaborative integration of such inherited subsystems. Indeed, the root cause of MCO's failure as stated by the Mishap Investigation Board (MIB) was related to modeling of the spacecraft's velocity changes. Inadequate verification and validation of the ground software contributed to excessive uncertainty and ultimately to the loss of the spacecraft.

Schedule and cost pressures led to decisions not to retest some critical systems. While the project followed the standard technical development and review process, it did not have adequate resources to support a full detailed review process. As one of the team leaders stated: "It was mandatory that we cut corners, primarily in the review and the quality engineering processes" [43].

MCO was launched on time on December 11, 1998, and spent the next nine and a half months traversing through space toward Mars. Upon arrival at Mars, MCO started its orbit insertion trajectory, but 4 min later, the spacecraft signal was lost and never recovered again.

Immediately after the loss, the operation's navigation team and the spacecraft engineers discovered that the small forces of velocity changes used by the spacecraft for orbit insertion were low by a factor of 4.45. A JPL peer review committee confirmed these as the likely cause of the Orbiter's lose. The MCO MIB would look independently into all aspects of the failure of the mission, and identified the root cause for the loss of the spacecraft as the failure to use metric units in the coding of a ground software file.

4. Project management contingency theory

The study of contingency theory in project management has gradually emerged during the last two decades. Specific frameworks for project management have often been influenced by research from disciplines such as innovation, organization theory, management, computer science, product development, and engineering. Among some of the early writers in defining a typology of projects were Blake [44], who suggested a distinction between minor change (alpha) projects and major change (beta) projects, and Steele [45] who looked at innovation types in big business. Wheelwright and Clark [46] introduced a well-recognized typology for product development projects, which included derivatives, platforms, and breakthroughs; and more recently, several other authors have suggested additional frameworks in an attempt to categorize and distinguish between different project types [7,23,10,34,3]. Notably, much of this literature was focused on a single industry and often on small projects [47,48]. Finally, the Project Management Institute (PMI) has recognized the need for identifying unique and project-specific project management principles for different project types, particularly with the development of government, Department of Defense, and construction extensions to the *Project Management Body of Knowledge* (*PMBOK*®) [49–51].

To summarize some of the existing frameworks, Table 1 presents a collection of noteworthy studies that have attempted to theoretically ground a classification, categorization, or framework system for project management. While not all studies mentioned are empirically based, many of these frameworks were developed independently, sometimes under the separate but highly relevant realms of innovation or technology management and often in ways that were unique to their particular environment

Table 1
Studies on project classification, categorization, typology, and frameworks.

Author(s) (Year)	Study description	Findings
Peart [1]	Observed many organizations, in order to understand their reporting and assessment of information on past projects	Reported that most projects use unique numbering systems. Categorization can be further sub-divided into contract type, or similar sub-categories
Henderson and Clark [4]	Demonstrated that the traditional categorization of innovation as either incremental or radical was incomplete and potentially misleading	Presented a 2 × 2 matrix that indicated four categorizations of innovation, and distinguish between the components of a product and the way they are integrated into the system that is the product architecture
Bubshait and Selen [7]	Developed a relationship between the number of project management techniques used and selected project characteristics	Indicated a positive relationship between the number of project management techniques used and the level of complexity involved in the project
Clark and Fujimoto [8]	Described the various rationales for project organization and structures	Specify the significance of "heavy-weight" project management structures in the automotive industry
Turner and Cochrane [10]	Grouped projects based on how well defined both the goals and the methods are for achieving them	Proposed that projects be classified using a 2 × 2 matrix and a definition given of all four types with three breakdown structures
Lindvist et al. [21]	Used a case study methodology to demonstrate how a project typology model can detect error in a systematic complexity context	Suggested a model identified by four different project organization logics related to the importance of 'technological' aspects of the project context
Payne and Turner [22]	Tested the hypothesis that it is better to use a single approach to managing all projects	Showed that people more often report better results for their projects when they tailor the procedures to the type of project they are working on, matching the procedures to the size of the project, or the type of resources working on the project
Floricel and Miller [23]	Described a conceptual framework for project strategy systems	Showed that high project performance requires strategic systems that are both robust with respect to anticipated risks and governable in the face of disruptive events
Shenhar [27]; Shenhar and Dvir [30,31]	Showed how different projects are managed in different ways and proposed a multidimensional categorization scheme for projects	Proposed a four-dimensional categorization tool based on novelty, complexity, technology, and pace (NCTP) for adapting the proper managerial style to the specific needs of a project
Lewis et al. [32]	Explored the nature, dynamics, and impacts of contrasting project management styles with a conceptual framework	Found that styles can differ but are interwoven to monitoring, evaluation, and control activities; use of these activities fluctuates over time; blend of styles enhances performance; and uncertainty moderates project management–performance relationships
Youker [34]	Contends that the most important and useful breakdown of project type is by the product or deliverable of the project	Suggested that projects grouped based on their product bear highly similar characteristics, and therefore require similar approaches
Terwiesch et al. [5]	Demonstrated a classification model for determining alternative strategies based on the adequacy of information in concurrent engineering activities	Presented a model that allows for determining best project planning approaches while distinguishing among project strategies and reasons for choosing them
Pich et al. [3]	Identify three fundamental project management strategies related to information adequacy (uncertainty): instructionism, learning, and selectionism	Present a four quadrant model based on these three strategies that determines a project's style and approach
Archibald and Voropaev [38]; Archibald [37]	Developed of a practical scheme for categorizing projects with similar life cycle phases and one unique process management process	Proposed a project categorization and sub-categorization based on end product or service of the project
Crawford et al. [41]	Identified a system for categorizing projects to determine their purposes and attributes	Two hierarchically ordered presentations resembling a decision tree. The first presents the multiple organizational purposes served by such systems and the second presents the many different attributes or characteristics organizations use to divide projects into groups or categories

[52]. Collectively, the research represented in Table 1 suggests that not all projects are the same, nor should they be managed in the same way. The following discussion is a brief summary of some of these studies.

One of the early writers in this area was Peart [1], who observed that many organizations, in order to better facilitate reporting and access information on past projects, use numeric tagging systems; Henderson and Clark [4] proposed a four factor framework for defining innovation and how this impacts an organization, independent of industry type; Bubshait and Selen [7] examined the relationship between project characteristics and management techniques and presented a categorization where projects are grouped based on industry sector and application area; Turner and Cochrane [10] proposed a categorization matrix that the authors theorized provided a benefit to practitioners in selecting start-up and management techniques; Lindvist et al. [21] used a case study methodology to demonstrate how a project typology model can detect error in a systematic complexity context; Payne and Turner

[22] showed that people more often report better results for their projects when they tailor the procedures to the type of project they are working on; Floricel and Miller [23] were some of the first to present a categorization of projects based on their strategic perspective; Shenhar and Dvir [27,30,31] developed a typological theory of project management and a four dimensional framework for project analysis; Lewis et al. [32] proposed a framework that showed that project management styles fluctuate over time and blending of styles enhances performance; Youker [34] suggested that the most important and useful breakdown of project type is by the product or deliverable of the project; Archibald and Voropaev [38] claimed that project categories and sub-categories serve an essential part in project portfolio management processes; Pich, Loch, and De Meyer [3] demonstrated a strategy model based on complexities and uncertainties of information; and Crawford et al. [41], studied project categorizations and their purposes and attributes, as used by companies around the world and proposed a framework for determining a project management categorization system.

The diversity of project management frameworks as depicted by Table 1 demonstrates, perhaps, that there is currently no accepted common framework to address and analyze project contingencies. In fact, as claimed by Gatignon et al. [53] there is still substantial empirical confusion on the effects of different kinds of innovation on organizational outcomes. Furthermore, while most organizations use a project classification or categorization system [41], not may of these systems are based on rigorous empirical research.

As mentioned, the objective of this paper is to apply a diversity of project management contingency frameworks for the study of a project failure (i.e. MCO) to reveal how applying *different* contingency approaches may provide deeper insights in the analysis of project success and failure, and lead to additional questions for future research and challenges in project management. To achieve this objective we selected three of the frameworks in Table 1 – Henderson and Clark's [4] framework for the analysis of innovation, Shenhar and Dvir's [27,30,31] NTCP contingency framework for project classification, and Pich, Loch, and De Meyer's coping strategies model for uncertainty [3]. This selection was based on the following criteria: First, unlike most categorization systems, these theories go beyond just a classification system. They actually discuss a preferred management approach for different project types. Second, they present potential causes for failure in case of an incorrect classification. Third, all three are based on extensive empirical research and supportive data. Fourth, these frameworks provide richer insights to managers and researchers about the complexities and difficulties of modern projects. Finally, these three frameworks have only a minimal amount of overlap, which potentially enables distinct and different points of view. For example, Henderson and Clark, while fundamentally about innovation, focuses on the management of the technical complexities of product development, fundamental to and often overlooked in project management; Shenhar and Dvir add additional dimensions to the concepts of Henderson and Clark of complexity, pace, and novelty (market uncertainty); and Pich, Loch, and De Meyer address the more recently accepted dimension in successful project management of strategy. Table 2 includes a summary of the concepts of these frameworks, and indicates the strengths and weaknesses of each one. In the following sections we will further describe these frameworks in detail and discuss how they may contribute to the understanding of project failure based on a contingency approach.

4.1. Henderson and Clark's framework for innovation and change

According to Henderson and Clark, products are composed of core technology components and their linkages (architecture). They argue that different types of technological change have fundamentally different organizational consequences. Fundamental to Henderson and Clark's framework for innovation is the distinction between the relationships between the components and the architecture. This distinction requires two types of knowledge: component knowledge and architectural knowledge (knowledge on how the components are integrated). With this fundamental distinction, they have theorized a framework that classifies innovation on two dimensions (see Fig. 1).

Table 2
Strengths and weaknesses of the three frameworks.

	Henderson and Clark	Shenhar and Dvir	Pich et al.
Key concept	Categorization based on components of a product and the way they are integrated into the system	Categorization based on initial characteristics of project on independent dimensions	Project as a payoff function that depends on the adequacy of information to choose an appropriate project strategy and infrastructure
Dimensions	Component technology and linkages	Novelty, technology, complexity, pace	Learning and selectionism
Strengths	Simple 2 × 2 model; clear identification of product uniqueness	Context-free categorization to select the right project management style	Simple 2 × 2 model; focus on process of reducing uncertainty and learning
Weaknesses	Static model, no specific indication of project process	Complex model, with many possible classifications	No specific focus on other managerial issues such as scheduling, budgeting, etc.

Linkages between Core Concepts and Components	Core Concepts	**Reinforced**	**Overturned**
	Unchanged	Incremental Innovation	Modular Innovation
	Changed	Architectural Innovation	Radical Innovation

Fig. 1. A framework for defining innovation [4].

The two dimensions in Fig. 1 represent the usefulness of the knowledge of an organization. The horizontal dimension captures an innovation's impact on components and the vertical dimension captures innovation's impact on linkages or integration between components. Based on this framework, a classification is then related to an organization's existing architectural and component knowledge. These individual innovation dimensions are defined as:

(a) Radical innovation (e.g., changing from a ceiling fan to a central air conditioning system) influences an organization's existing project management capabilities, requiring greater attention to a project's knowledge of core concepts and linkages between these core concepts and components. This significantly impacts a project's technical evolution (e.g., design cycles, experimentation, product design), recurrent tasks, organizational experience, information processing, product architecture, problems solving strategies, and communication channels.
(b) Incremental innovation (e.g., improvements in blade design or the power in the motor) has a minimal impact on an organization's standard project management operations and requires no advanced knowledge of core concepts or component linkages.
(c) Modular innovation (e.g., replacing an electric motor with a solar powered motor) influences a project's knowledge of core concepts. This has the most impact on the projects technical evolution, organizational experience, recurrent tasks, and technical knowledge as they relate to component knowledge and less impact on product architecture and communication channels as they relate to component linkages.
(d) Architectural innovation (e.g., the introduction of a portable fan) influences a project's knowledge of linkages between core concepts and components. This has an impact on the projects technical evolution, organizational experience, recurrent task, and technical knowledge as they relate to the component linkages in addition to the product architecture, communication channels, and problems solving strategies.

The importance of Henderson and Clark's work to project management is in the realization that in addition to new technology, the understanding the interplay among modules, subsystems and systems is greatly important to the success of projects.

4.2. Shenhar and Dvir's NTCP diamond framework

Extending classical contingency theory to projects, Shenhar and Dvir suggested a "Diamond Typology" based on four dimensions, novelty, technology, complexity, technology, and pace (NTCP) [54,30,40,27]. This typology assesses the product, the task, and the environment, and suggests what may be the optimal project management style that would fit a project type. Table 3 describes the four dimensions, and Fig. 2 shows how they are described in a diamond-shaped graph that represents of the level of risk associated with a project.

4.3. Pich, Loch, and De Meyer's coping strategies model

Mihm, Loch, and Huchzermeier [55] have shown that executing projects requires an aptitude to coordinate multi-

Table 3
NCTP model definitions.

The NTCP model	
Novelty: The product newness to the market and the customers. It has an impact on product requirements definition and market related activities: – *Derivative*: Improvement in an existing product (e.g., a new color option in a MP3 player; the addition of a search feature in a software program) – *Platform*: A new generation on an existing product line (e.g., new automobile model; new commercial airplane) – *Breakthrough*: A new-to-the world product (e.g., the first Post-it Note; the first microwave oven)	Technology: The extent of new technology used. It impacts product design, development, testing and technical skills needed: – *Low-tech*: No new technology is used (e.g., house; city street) – *Medium-tech*: Some new technology (e.g., automobile; appliances) – *High-tech*: All or mostly new, but existing technologies (e.g., satellite; fighter jet) – *Super high-tech*: Necessary technologies do not exist at project initiation (e.g., stealth bomber; Apollo moon landing)
Complexity: The location of the product on a hierarchy of systems and subsystems. It impacts to coordination, organization and formality of project management: – *Assembly*: Subsystem, performing a single function (e.g., CD player; cordless phone) – *System*: Collection of subsystems, multiple functions (e.g., spacecraft; cars) – *Array*: Widely dispersed collection of systems with a common mission (e.g., New York transit system; air traffic control)	Pace: Project urgency and available timeframe. It impacts time management activities and team autonomy: – *Regular*: Delays not critical (e.g., community center;) – *Fast-competitive*: Time to market is important for the business (e.g., satellite radio; plasma television) – *Time-critical*: Completion time is crucial for success-window of opportunity (e.g., mission to Mars; Y2K) – *Blitz*: Crisis project- immediate solution is necessary (e.g., Apollo 13; September 11, 2001)

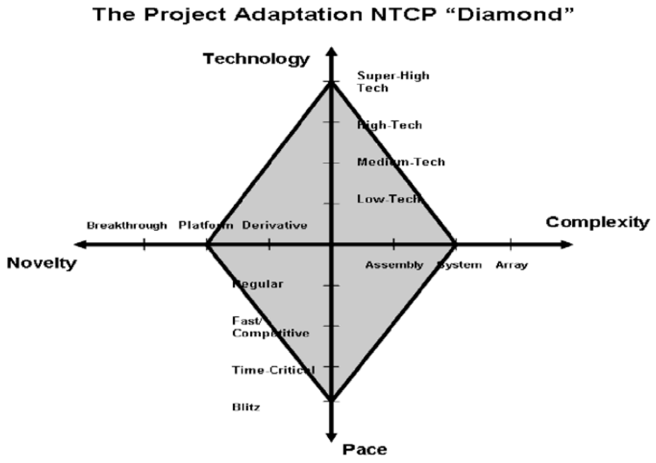

Fig. 2. NTCP framework.

ple organizations in parallel (e.g., concurrent engineering) and the ability to deal with the uncertainty of events or influences. To address the ambiguity between complexity and uncertainty, Pich, Loch, and De Meyer [3] have developed a time-dependent model for determining strategies based on coping with uncertainty in terms of information adequacy. As projects increase in complexity, there is an increase in ambiguity of the information that may influence a project and create an environment that goes beyond the capabilities of the project team. In complex projects, Pich, Loch, and De Meyer contend that tasks are interdependent and coordinated in parallel; therefore, engineers cannot afford to wait for complete information, and will often continue through the project lifecycle while coordinating these activities with preliminary and ambiguous information. Project teams must "actively incorporate" new information and re-plan a project in relation to new activities or policy that require the team to be flexible.

Pich, Loch, and De Meyer contend further that traditional project management that structures all projects the same assumes adequate information, which is handled by what they call an "instructionist strategy," when no learning is needed or takes place and simple problems allows for an optimized solution. They showed how this does not work in modern project management and as a project's complexity increases, different approaches are needed. When information is lacking (or changing) and when problems become complex, a "selectionism" and learning strategy is needed instead. They have established a terminology and framework to determine the sufficiency of available information, choose the appropriate combination of strategies, and set a supporting project infrastructure for planning, coordination, incentives, and monitoring. Fig. 3 shows the four-quadrant strategy framework for coping with uncertainty.

5. Our methodology

A descriptive case study research methodology was chosen. 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 [2,56,57]. Eisenhardt [2] described a fundamental difference in case study research as compared to experimental research and suggested that cases should be chosen for theoretical reasons, not statistical reasons. Case study research provides a conduit to go from theory to data and back to theory. To address any threats to validity as defined by Yin [57], multiple sources of evidence should be supported by data source triangulation [57–59], and a study protocol has to be established for future replication and to reduce any bias in the collection of data. To some extent, our study followed Eisenhardt's [2] recommended steps for such studies as described in Table 4.

6. Framework analysis

In this section we analyze the MCO program using the three contingency theory frameworks that we selected. Both projects (MCO and MPL) used a single project budget with extreme managerial pressures for low cost and timely delivery. The MCO project manager would later state, "There is a fine line between success and failure in these one-of-kind missions." Analyzing the MCO project with these frameworks demonstrates how the challenges imposed upon the project were perhaps impossible to achieve. Indeed, man-

	Optimization	**Selectionism**
Learning	*Learning Strategy* ▪ Learn about unforeseen uncertainty ▪ Learn about complex causal effects ▪ Discover new discernable patterns ▪ Respond to new event; original problem solving	*Learning and Selectionism* ▪ Project may be stopped based on favorable progress of another candidate ▪ Exchange information among candidates to increase learning: candidate projects become complements
No Learning	*Instructionist Strategy* ▪ Decision adequate causual mapping ▪ Include buffers in plan ▪ Plan project policy ▪ Monitor project influence signals ▪ Trigger contingent action	*Selectionist Strategy* ▪ Plan multiple trial projects ▪ Performance of trial projects versus hurdles ▪ Variants selected by complex environment ▪ Variants selected after catastrophic unforeseeable events

Fig. 3. Strategies for coping with uncertainty [3].

Table 4
Study design as defined by Eisenhardt's recommended steps [2].

Eisenhardt's recommended steps	Study design
(1) Define research question with a priori constructs	Using constructs from the literature, a research question was defined: "Can contingency theory provide new insights for explaining project failure"
(2) Select case(s) based on specific population and sampling to replicate or extend emerging theory	MCO was used as the sample case because it represented the rise and fall of FBC, was well documented for its success and failure, and although it was well known in the public and the scientific and engineering communities for its failure, major questions remained, which could be summarized as; "How could this happen?"
(3) Craft instrument to promote triangulation among data sources and investigators	Data Collection Plan: *Interviews*: Interviews were planned in a semi-structured, open-ended conversational format, which included only leading questions such as "tell me about ..." Interviewees were allowed to speak freely and openly about their experiences. Six key personnel related to the project were interviewed. These people represented program management, project management, systems engineering, team members, and customer. Notes were taken during the interview, which had also been recorded and transcribed *Documentation*: Formal studies, evaluations, journal articles, survey data, mass media, and physical artifacts (samples of work done) *Archival and Historical Information*: Letters, memoranda, policy statements, regulations, proposals, guidelines, procedures, summary reports, organizational records, and personal records *Participant Observation*: NASA gave permission for participation of our researcher in its advanced project management classes to gain further familiarity with NASA's culture and procedures
(4) Enter field in such a way as to overlap data collection analysis	Data was collected in an iterative process; documentation and archival information was extensively analyzed before interviews were conducted; collected verbatim transcriptions; after each interview, data was compared against documentation and archival information to determine if additional data was needed from any data sources (e.g., follow-up interviews, additional documentation) before the next interview was conducted
(5) Analyze data within and across case(s)	A 40 page case summary was written based on a predetermined case format [6]. Once the case study was completed, the data was coded and analyzed using the three previously described frameworks. A second analysis report of 30 pages was then prepared
(6) Shape hypothesis by looking for replication not sampling logic; iterative tabulation of evidence for each construct; refine definition of constructs	As the analysis with each framework unfolded, the investigators conducted numerous discussions, which created new insights and required additional analysis to shape the emerging relationships between constructs and establish theoretical statement(s)
(7) Enfold literature by comparing results with conflicting and similar literature	Compared our conclusions based on the three frameworks with an extensive review of the literature on contingency theory for project management and frameworks for project management
(8) Reach closure about when to stop iterating between theory and data	Once the final analysis was completed, a final iteration was performed to develop and refine the final theoretical statements about the findings and conclusions

agement later admitted to compromising key issues as a result of these pressures. It seems that success in this project may have been impossible to achieve under the combined requirements of FBC and high project risk.

6.1. Henderson and Clark's framework for innovation

Our analysis of MCO using Henderson and Clark's framework, classified MCO as an architectural innovation [4]. Much of the technology or concepts for MCO were borrowed from previous missions like Mars Global Surveyor and the failed Mars Observer. While the technology or core design concepts were considered proven, the linkages or architecture of the design were new. With minor changes in components (e.g., navigation system), it created new interactions and new linkages with other components in an established product. While Lockheed-Martin and JPL were well-established firms with long histories of space exploration success, according to Henderson and Clark, even established firms often have difficulty in adapting to architectural innovation. The architectural knowledge of this type of innovation often involves subtle challenges and difficulties in recognizing what is and is not required when applying new knowledge.

In addition to the architectural change, MCO also had to implement the BFC approach as a new way of doing business. NASA at that time had no clear guidelines or standard protocol on how to perform FBC missions. In an architectural innovation, this creates an environment that the organization has to determine what core design concepts must remain, and be wary of what it believes is not relevant but may actually hinder the organization.

Typically, there are two key concepts for understanding the ways in which components and architectural knowledge should be managed within an organization. The two concepts are summarized in Table 5 with a representative statement of how MCO misrepresented these concepts. The first concept is that of dominant design. According to Henderson and Clark, "emergence of a dominant design, which signals the general acceptance of a single architecture, firms cease to invest in learning about alternative configurations... New component knowledge becomes more important than new architectural knowledge... Successful organizations therefore switch their limited attention from learning a little about the many different possible designs to learning a great deal about the dominant design." Since the contract called for the development of eight Mars exploration spacecraft, Lockheed-Martin believed that duplicating much of the dominant design of the successful and already in progress, would allow for reduced development time and the need for acquiring design knowledge.

The consequences of MCO's early decisions to fully commit to this dominant design were reflected in the ultimate technical failure – the integration of the navigation system. Some of the people working on the navigation system were working halftime on MCO and halftime on another project. These people would be working the same type of subsystem for each project while the process in each project was different. This was identified as causing confusion for the engineers, and resulted in engineers applying the wrong process to MCO. The use of the navigation system on MCO was the introduction of a new subsystem to a dominant design. A challenge with architectural innovation is that new linkages are much harder to identify since the core concepts of dominant design are unaffected. The recourse of this is that organizations mistakenly believe that they understand the new technology.

The second key concept in addressing architectural innovation is that of organization's building knowledge around the recurrent task through communication channels, information filters, and strategies. Henderson and Clark state, "The strategies designers use, their channels for communication, and their information filters emerge in an organization to help it cope with complexity." Communication channels are related to an organization's interactions within the organization that are critical to its task (both formal and informal). For any NASA mission this represents the communication between elements, the formal review process, the technical review process, and the interaction with subject matter experts. For MCO, communication between project elements was perceived by most to be inadequate. There was a lack of early and constant involvement of team members and the communication lines, as identified by the MIB, were not open for real-time decision-making. MCO followed the standard NASA technical review and approval process, but there were no adequate resources to support this processes. A project manager stated, "It was mandatory that we cut corners, ... It was mandatory that we didn't get a second set of eyes on everything we needed to. Otherwise we could have never met the cost goals."

Some of the most recognized experts in deep space exploration are employed by JPL. The use of subject matter experts can validate requirements to which a design is built. The MIB contends that this internal expertise and capability was not effectively utilized. Also, an organization's architectural knowledge is usually rooted in these channels, filters, and strategies, and the discovery process usually takes time, which MCO had very little. Therefore, the organization may be attracted to modifying channels, filters, and strategies that already exist. For MCO, not only some of the components were new, but as mentioned, also FBC was still an unproven way of doing business. NASA, at that time, was clearly still pushing the envelope. As Dan Goldin, former NASA administrator said after the failure of MCO, "We pushed the boundaries like never before...And had not yet reached what we thought was the limit" [60].

In summary, Henderson and Clark defined two problems created by architectural innovation. They are: (1) established organizations require significant time (and resources) to identify innovation as architectural, since architectural innovation can often initially be accommodated within old frameworks, and (2) the need to build and apply new architectural knowledge effectively. Table 6 depicts the sources of problems created by architectural innovation, the problems they create, and how these problems were reflected in MCO. Based on this analysis our conclusion is that MCO was indeed an architectural innovation, but was it treated as an incremental innovation. Henderson and Clark assert that in architectural innova-

Table 5
Concepts in the way architectural innovation is managed.

Architectural innovation	Mars Climate Orbiter
Dominant design: signals the general acceptance of a single architecture and product technologies do not emerge fully developed at the outset of their commercial lives	Inheritance from past systems was assumed to reduce uncertainty, but it did not reduce the uncertainty of integration
Organizations build knowledge and capability around the recurrent task that they perform	The Mars Program Independent Assessment Team stated that there were inadequate resources to accomplish the requirements. NASA Headquarters had applied pressure on JPL and Lockheed-Martin to be successful with the concern for loss of business this resulted in knowingly cutting proven engineering practices to meet the cost and schedule demands

Table 6
Problems in architectural innovations.

Sources of problems	Problems created	Mars Climate Orbiter
Established organizations require significant time (and resources) to identify innovation as architectural, since architectural innovation can often initially be accommodated within old frameworks	Information that might warn the organization that a particular innovation is architectural may be screened out by the information filters and communication channels that embody old architectural knowledge. The company may mistakenly believe that it understands the new technology	MCO required a significant level of insight and creativity both technically and managerially, built around a core of talented, experienced people, but cost constraints forced these requirements to be compromised
The need to build and to apply new architectural knowledge effectively	Simply recognizing that a new technology is architectural in character does not give an established organization the architectural knowledge that it needs. It must first switch to a new mode of learning and then invest time and resources in learning the new architecture	When MCO started, they attempted to embrace the reduction in policy and procedure of FBC, but NASA provided little guidance on what policy was critical for FBC success

tion, "established organizations may invest heavily in the new innovation, interpreting it as an incremental extension of the existing technology or underestimating its impact on their embedded architectural knowledge."

6.2. Shenhar and Dvir's NTCP framework

In our analysis of MCO with Shenhar and Dvir's NTCP framework [24,40], we tested whether the project type was consistent with the actual project management approach on the four dimensions of the model. Fig. 4 represents the analysis of MCO based on these dimensions. It also presented the difference between the preferred style and the actual style. As seen in Fig. 4, our analysis suggests that MCO had to be managed as a breakthrough, high-tech, system, and time-critical project. While the project was clearly focused on meeting the time-critical mission, we found that the project management had difficulty in the other dimensions – novelty, technology, and complexity.

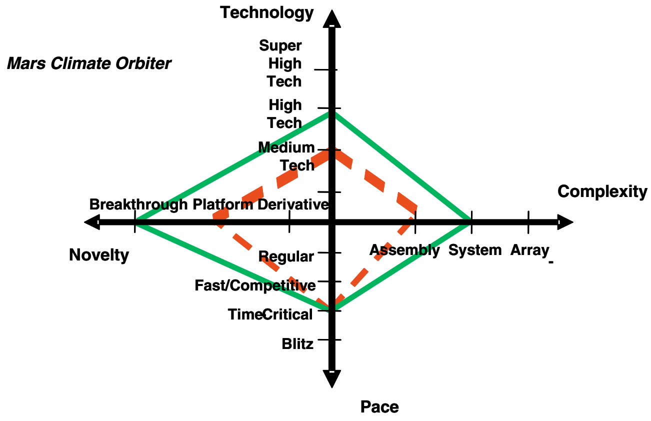

Fig. 4. NTCP classification of MCO. The solid line represents the preferred classification for MCO and the dashed line represents the actual approach. While there is not a linear relationship between the area of the diamond for correct and incorrect project risk, it does represent a qualitative difference in the degree of risk.

6.2.1. Novelty

Novelty is related to a product's uniqueness to the market and uncertainty in requirements. Although NASA had been successful with missions to Mars (e.g., Mariner, Viking I and II, Mars Global Surveyor, and Mars Pathfinder) not one successful mission had been repeated, and each mission had a great degree of unproven mission requirements. Furthermore, four of the seven Mars missions since Viking – Mars Observer, MCO, MPL, and Deep Space 2 – have failed. Thus MCO had to be treated as a breakthrough project. Yet, MCO believed that they were building upon the success and technology of past missions and approached this project more as a platform project. This gave the perception that MCO would be a next generation in existing set of missions. Fast prototyping, one of the requirements Shenhar and Dvir define as important for a breakthrough project, was compromised by inadequate testing and streamlined reviews. For example, the navigation software system was the most novel and uncertain of all the systems on MCO, but it received no more testing or review than any other system. In addition, the interaction with customers was less than optimal and was sometimes defined as "confusing." A senior manager said, "We were 'lean and mean' at the time. We essentially had no checks and balances on the program as we do today. I could not possibly execute that program under the environment that we live in today."

6.2.2. Technology

Although some of the technology on MCO had been developed prior to the project's inception and building an orbiter spacecraft was not new, MCO was the first of its kind in integrating all these technologies into one space vehicle. For example, MCO combined two different instruments: a pressure modulator infrared radiometer to provide detailed information about Mars' atmospheric temperature, dust, water vapor, and clouds, and a Mars color imager that would observe the interaction between the atmosphere and the surface of the planet. One can thus conclude that MCO was a high-tech project. Shenhar and Dvir describe a high-tech project as requiring long periods of design, development, testing, and redesign with multiple design cycles. With the extensive testing that is required for a high-tech project like MCO, in-depth, technical reviews are mandatory, and in conjunction with these reviews, communication has to be frequent and active. However, the pressures, constraints, and challenges to push the boundaries of FBC on a limited budget restricted MCO's ability to fully recognize its technological challenges, thus MCO was managed more as a medium-tech project. There was not enough testing, reviews, communication, technical skills, or flexibility for design changes to manage a high-tech project. Many of these key elements were reduced to meet cost and schedule constraints, while some were just overlooked.

6.2.3. Complexity

As a complex collection of interactive elements and subsystems, jointly dedicated to a wide range of functions to meet a specific operational need, MCO was a system project. As the first in a series of Mars missions, MCO was to integrate some mature technology into a new and untested spacecraft. In addition to its own complexity, MCO was designed to work with the Mars Polar Lander when it arrived at Mars. MCO had multiple key customers from industry, public, government, and the scientific community that were all vested in MCO's development and success. As a system project, MCO required extensive integration of hardware and software, hundreds or thousands of activities, tight and formal control, financial and schedule issues, reviews with customers and management, and extensive documentation. Unfortunately, cost constraints limited control of subsystem integration and there was an absence of end-to-end verification and validation, key in a systems classification. While much of the project was treated as a system, certain subsystems with high levels of uncertainty were managed as assembly projects (i.e. navigation), and key people were balancing time with multiple projects. This was compounded by a lack of communication and transition between phases and subsystem operations. Key to any system is an understanding of the impact change and risk has on any subsystem. To treat any part of a system as an assembly is to treat the entire system as an assembly.

6.3. Pich, Loch, and De Meyer's coping strategies model

Understanding MCO's failure with Pich, Loch, and De Meyer's [3] uncertainty coping strategy model suggests yet another perspective. Since MCO faced extensive uncertainties, we believe that a learning strategy would have been appropriate for managing the program. However, the challenging environment of FBC, administrative pressures, and resource restrictions forced the management team into an instructionist strategy.

A learning strategy is based on signals that come from incongruence with a project team's calculations, and which can allow for the modification of policy, practices, and design in response to these observed events. Pich, Loch, and De Meyer state that project managers have to plan for variation or they will resort to "firefighting" to keep a project on target, which becomes an exhaustion of resources. Because the coping strategy model deals with adequacy of information, uncertainty can be defined by the knowledge of the problem solver as well. That is, do they understand the structure of the problem, but lack the knowledge concerning the value of its variables? In a learning strategy a project manager will increase testing and implement training of inexperienced engineers to address future uncertainty.

One of the uncertainties for MCO involved the software related to the navigation system. Limited actions were taken to understand such uncertainties. Indeed, in retrospect, inadequate verification and validation of the software contributed to loss in performance. Post failure analysis indicated that an extensive testing program should have been implemented to fully integrate the navigation software. But MCO could not afford a learning environment and thus relied on inheritance of technology. While inheritance allows for a reduction in the time, cost, and effort in technology development, it does not reduce the uncertainty associated with the integration of inherited components.

In an instructionist strategy, a project assumed to exhibit very little uncertainty and there is typically no competition of alternate solutions, which can respond to an environment that is amenable to change. Sometimes in an agile instructionist strategy, a project will allow some degree of variation up to a certain threshold, and then only respond when the threshold is crossed. For MCO, there was not much flexibility to begin with, and although the project approached the development as a series of iterations, there was no true modularity in the design. This was evident in the decisions to use much of the science from the failed Mars Observer, and to award a contract for spacecraft development that would result in up to eight identical spacecraft. A contractor program manager said that the potential success of MCO could have been judged falsely had it worked on Mars and got tremendous science results. "If MCO had been successful and MPL had failed, you would say 50/50, we got one out of two. Faster, better, cheaper approach can work and you would cruise on... [to the next identical crafts]. So the failures said to people, Whoa, this faster, better, cheaper, is not all that it is cranked up to be, at least not the way we are trying to implement it."

Pich, Loch, and De Meyer state that the challenge of many projects is finding a balance between planning and learning. While the two require distinct management styles and infrastructure, it is the balance that can have great impact on project success. For MCO the cost of duplication should have been less than the cost of starvation, because for a Mars exploration project, starvation means termination and rarely do projects that are put on hold get done later. A second project manager stated that when

	Optimization	**Selectionism**
Learning	*Learning Strategy* The Mishap Investigation Board stated that the navigation team was inadequately trained, did not understand the spacecraft, and did not pursue known anomalies.	*Learning and Selectionism*
No Learning	*Instructionist Strategy* There was a heavy reliance on the inheritance of technology from previous missions. MCO used many subsystems, computers, attitude control, and propulsion technology from other missions, but the project manager stated that the dependence on these systems eventually became a contributing factor in the loss of the MCO.	*Selectionist Strategy*

Fig. 5. MCO strategies for coping with uncertainty.

he entered the project around critical design review "they had excessive hardware development problems and extreme weight challenges, which meant a lot of new development. This became very difficult on an already bare bones budget... Don't you dare go back to headquarters and ask for more money because you are not going to get it... [although] I had strong company backing because this was important in getting us back into the Mars business." But the backing did not come in resource allocations.

In summary, MCO used an instructionist strategy when a learning strategy would have been more effective considering the lack of knowledge and experience, the resource constraints on testing, and the need for emergent behavior to cope with unforeseen uncertainty. The two coping strategies are summarized in Fig. 5 with a representative statement of how MCO expressed these concepts.

6.4. Comparing the analysis based on the three frameworks

Based on our analysis we may conclude that the failure of Mars Climate Orbiter was managerial, not technical. In retrospect, management did not (or could not) correctly appreciate the level of complexity, uncertainty, and time pressures involved with MCO. With a new mindset of 'better faster cheaper' at NASA's executives assumed that some previous successes indicate that such policy could work for all projects. Yet some projects are always more uncertain, more risky, or more complex than others, and such constraints may not work for the every case. The assessment of MCO with the selected three frameworks verified this both in their independent and collective assessment.

Independently, the selected three frameworks gave us different prospects on the managerial issues. Henderson and Clark's framework revealed problems and cautions that can result from an architectural innovation that was overlooked because of organizationally imposed constraints. Alternatively, it was not able to give any specific indication of what would be project success. Shenhar and Dvir's NTCP framework showed a misfit between project type and project management style on three dimensions, novelty, technology, and complexity. Pich, Loch, and De Meyer's model illustrated that an incorrect strategy of learning was used to deal with highly uncertain and complex information. As valuable as information flow and quality is in an organization, there is limited focus on many other key managerial issues.

Collectively, these frameworks showed that an incorrect perception of MCO's difficulties resulted in an improper managerial approach, and they provided a rigorous way to analyze a failed project to explain the failure in more depth than before. But more importantly, these frameworks provided a strong support for the strategic importance of an upfront identification of the right approach to any project, with the ability to predict potential difficulties if such approach is not selected.

In summary, the three frameworks revealed that an incorrect approach was used in managing the MCO project, which led to its failure and reaffirmed that it was impossible to succeed under the project's given constraints. MCO affirmed that an attempt to use the FBC approach within an organization that was built for taking high-level risk is doomed to fail when the organization sacrifices its previous practices, which were designed to address such high-levels of risk in the first place. Indeed, this finding reinforces the view that perhaps FBC cannot be used in cases of extremely high risk [61,62]. In retrospect, one should note that NASA, as an organization dealing with extreme risks, has not been immune to managerial challenges and failures (e.g., Space Shuttle [61–66], Hubble [67], scram jet [68], and numerous others [69]). The analysis of MCO under the FBC policy may provide some suggestions on how to deal with some of this risk in future programs.

7. Conclusion

7.1. The contingency approach and future research

Project management research is still in its early stages. While much research has been devoted to critical success factors, not many studies have been focused finding alternative frameworks that allow us to understand why projects fail and what can be done about it. This study showed that project management contingency theory can provide new insights for a deeper understanding of project failure, but more importantly, it suggests implications for additional theory development in project management. First, it established a new and different direction for further studies of project success and failure beyond traditional success factors. Furthermore it can stimulate additional success and failure studies by identifying specific contingency theory success factors [70]. Second, this study provided another demonstration that "one size does not fit all." In studying project success or failure we need not just asking, "was it good or bad management," but "was it the right management to the situation, the task and the environment." What works well in one situation may not work in another. Future investigations could seek additional variables of situation and management and explore richer and wider opportunities for analyzing the fit of managerial styles. Third, this paper shows that there is more than one dominant contingency theory. Each of the three frameworks used have strengths and weaknesses (see Table 2), thus, independently they may not be as valuable as they were collectively. Therefore, coming research may continue to identify strengths and weaknesses of existing theories and offer more developed theories that would serve different research goals. Fourth, new and more effective frameworks built on a contingency approach may enable project managers to rely less on heuristics and help establish a new field of "project management design." If we could better understand what works and what does not in what situation, we may be able to provide the rules for priory selections of the right approach, thus preventing failure before it may happen. Defining the project and providing a fundamental framework for planning and managing a project with a correct approach may open up numerous new directions of research. Finally, while we have used three existing frameworks for analyzing a project and determining an appropriate management style, these frameworks are clearly not the only ones. Further research may look into project categorization of other factors such as application area (e.g., software, or hardware), client and customer (consumer, industrial, and government), geographical area, etc. In summary, more research is needed to better correlate project management categorization systems to appropriate management styles and practices or help in potentially predicting success, or failure, and even provide warning signals in an on-going project.

7.2. The contingency approach: potential contributions and challenges to project management

At this stage the current project management practice has not adopted an explicit, well-accepted way to identify project uniqueness at project initiation and select the right management style. Since almost no project is done in isolation and most organizations are involved in more than one project, this suggests that organizations would benefit from developing their own organization-specific frameworks for project categorization and teach project managers how to adopt the right approach to the right project. A possible way to approach this is using Crawford, Hobbs, and Turner [41], distinction between two types of categorization systems, doing the right project (strategic alignment) and doing the project right (capability alignment). Doing the right project will be used for project selection and portfolio management and doing the project right will be used for adapting project management to specific project type. NASA is no exception [71,72]. As this research shows, the agency would greatly benefit from developing its own way for project management categorization and adaptation.

As with any approach or model, it is not perfect. With the frameworks we demonstrated, we are still left with some key questions unanswered:

- How do you know when you have correctly classified a project and how can this be verified to some level of confidence?
- How do you determine the most effective and efficient cost and resources to a project classification?
- How can a correct or incorrect classification quantitatively correlate to project risk?
- What is the consistency in using the framework among different practitioners?
- How do you address discrepancies in a classification, and who is held accountable?
- What is the significance or impact of an incorrect classification on any single dimension?

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