Case Study

The Mars Pathfinder Project

Introduction

In 1992 budgets throughout the U.S. government were being slashed as the post-Cold War drawdown gathered momentum. Support for expensive space exploration projects was waning and the National Aeronautics and Space Administration's (NASA) relationship with politicians and the general public had been strained by recent high-profile, expensive project failures. "The new NASA Administrator determined that the United States must continue to do space science missions despite the government-wide belt tightening that had squeezed the NASA budget, began talking about 'Faster, Better, Cheaper.' The catch-phrase summed up a philosophy that was right in step with the new administration's practical thinking" (Muirhead & Simon, 1999).

For NASA, this mantra meant increasing the number of planetary missions, spending less than $150 million (US) on each mission and taking no longer than 36 months for implementation. Projects that took longer or cost more would be canceled. With this philosophy, NASA teamed with the Jet Propulsion Laboratory (JPL) and embarked on a project to land a scientific exploration module on the planet of Mars. This project was known as the Mars Pathfinder (MPF) mission.

More than three years later, NASA and JPL received their last scientific data transmission from the MPF. This transmission marked the culmination of a phenomenal mission that far exceeded all rightful expectations. Both in terms of science and management, the MPF project was hugely successful and won the Project Management Institute's coveted "Project of the Year Award" for 1998 (Project Management Institute, n.d.). Many factors led to the project's success. This case study analyzes aspects of project management and innovation that led to the success of the MPF mission.

The case study covers various Project Management Knowledge Areas (Project Management Institute, 2004) within four project phases: inception, development, implementation, and closeout. Within each project phase, the activities, accomplishments, and performance shortcomings in the Initiating, Planning, Executing, Monitoring and Controlling, and Closing Process Groups' processes are discussed. The case study is structured to allow an evaluation of the appropriate processes of various Project Management Knowledge Areas at the end of each phase (see Figure 1). An overall assessment of performance is then conducted (see Figure 2), resulting in a numeric evaluation of the management of this project, including areas of strength, opportunities for improvement, and lessons learned.

The Inception Phase

The Discovery program, a series of low-cost, short time frame space exploration projects began in 1992 under the NASA mantra of Faster, Better, Cheaper. The 1976 Viking missions to Mars had taken six years and a budget of $1.5 billion (US), approximately $3 billion (US) in 1998 US dollars Maloney, 1998). In contrast, the MPF mission cost was an order of magnitude less (1/10) and time was cut in half.

MPF's goal was to demonstrate the technological feasibility of delivering a stationary lander and a robotic surface rover onto the red planet for scientific exploration purposes. "According to the original goals set by NASA, just getting the spacecraft to Mars and landing it in one piece means we have already succeeded" (Muirhead & Simon, 1999). The stringent project constraints necessitated a new management approach of "doing things differently." Wherever possible, scope was minimized through the use of existing technology and systems were built around off-the-shelf hardware and software components. Effectively, project scope was based on a capability-driven design instead of requirements.

The JPL Pathfinder procurement and contract procedures were integral to the success of the MPF project. The project was awarded to JPL as an in-house development effort with significant portions of the project deliverables requiring the resources of outside partners, vendors, and consultants. The outside procurement effort required JPL to develop and implement precise controls and management to ensure a successful project.

The mantra of Faster, Better, Cheaper defined the mission for the procurement team. As with the other project team members, the hardware acquisition team was tasked with securing the necessary components and systems within a tightly controlled budget and inside an even tighter schedule. Also, the products and components needed to be of the highest quality and robustness. The responsibility of the hardware acquisition team was to develop a new procurement program that would break with space program tradition and still deliver the required quality and reliability.

At the inception stage, the hardware acquisition team was faced with procedures that laid the groundwork for procurement and delivery problems. The procurement team instituted strict systems and controls for measuring, updating, and solving procurement issues throughout the project. As part of that process the team implemented a monthly report called the "Procurement Planning Summary." This report was published and reviewed monthly by the entire project team and tracked each major deliverable and subcontractor. This report highlighted problem areas prior to critical importance and allowed the entire team to comprehend the status of the individual subcontractors and deliverables.

The MPF team succeeded largely as a result of proactive risk management. They identified risks early in the project and worked diligently at mitigating them. For example, MPF management decided early on that volume, cost, and schedule constraints required a largely single-string design, which added a new layer of risk. Knowing this up front, the MPF team selected only the most reliable parts in an effort to mitigate the risk associated with single-string design. In the words of the project manager, "For most elements of the spacecraft, we were one resistor, one transistor, one integrated circuit, one mechanical devise away from potential disaster" (Pritchett & Muirhead, 1998).

The MPF mission had an overriding belief that each member of the team should be personally responsible for and committed to quality. Quality was a driving factor in every aspect of the project and was an underlying reason for the success of the mission. The nature of the project was one of joint cooperation between all project team members and vendors. The traditional approaches were in many cases abandoned and new innovative approaches were embraced and developed to meet the project mantra of Faster, Better, Cheaper.

In the inception phase, the quest for quality began and the baseline of the quality program was set. The project management team identified quality management and control as vital to the success of the project. In space exploration, one loose fitting, one glitch in the control software, or one component not meeting specifications could result in disaster for the mission and possibly the entire program. The project management team assigned the responsibility and accountability for quality to each individual member of the team from inception. They collocated the project team together at one site, which led to increased communications between project team members. The atmosphere was one of shared responsibility, thereby increasing the interaction between team members, which led to better communications and reduced the risk of components or deliverables not meeting the desired quality.

As with the rest of the project, the team approach adopted for the MPF project was an innovative one. This was evident in their team member selection, organizational structure, and team leadership expectations.

The radical requirements of the project raised the level of expertise needed within the project team. On most projects at JPL, resources for a new project were drawn from a pool of internal candidates that were between projects, but this project was different. MPF tapped the existing resources of JPL and others, at times even competing for those knowledgeable resources with other highly visible projects. Such was the case with the chief engineer, who was considered by some to be the best electronic and software expert in JPL.

The original leader of the team that built the Sojourner Rover pointed out that information flows quickly, and some of it is not absorbed. People process information differently and the goal of communications is to get information to be absorbed in the minds of the team (Shirley, 1997). Good team communications are almost always behind the success of a project. For the MPF project, an even more robust level of communications was required. Each team member was willing to share information with anyone that needed to know. What teamwork was to a successful project, good communication was to teamwork. Yet, there were many means and styles of communication, some formal, some tactile, some visual, some verbal, some through E-mail, or a combination of these. The more stimulated the senses, the more impact the communication had on individuals.

Assessment and Analysis

1. Please complete your evaluation of project management during this phase, using the following grid:

Project Management Area	**Inception Phase**
Scope Management	
Time Management	
Cost Management	
Quality Management	
Human Resource Management	
Communications Management	
Risk Management	
Procurement Management	
Integration Management	

Rating Scale: 5–Excellent, 4–Very Good, 3–Good, 2–Poor, 1–Very Poor.

2. Please highlight the major areas of strength in the management of this phase of the project:

3. Please highlight the major opportunities for improvement in the management of this phase of the project:

The Development Phase

Budget constraints forced innovation. Instead of orbiting the planet in order to slow down the spacecraft prior to entry, the team opted for a less expensive direct-entry approach. If the lander entered too quickly, it would burn up during entry. Once in the Martian atmosphere, failure to decelerate sufficiently prior to landing could result in serious damage to the lander. Both of these possibilities presented new engineering challenges. (Tillman, n.d.).

According to the original goals set by NASA, just getting the spacecraft to Mars and landing it safely equated to a successful mission. More specifically, "MPF's purpose is to demonstrate an inexpensive system for cruise, entry, descent, and landing on Mars. Other objectives for this mission are to demonstrate (1) a simple, low-cost system, at a fixed price for placing a science payload on the Mars surface at considerably less than the cost of the Viking mission, and (2) the mobility and usefulness of a microrover on the Martian surface." Scientific objectives were secondary on MPF, but included:

- Investigate Martian atmosphere, surface metrology, and geology;
- Characterize surface features;
- Analyze the elemental composition of rocks and soil at the landing site;
- Monitor atmospheric conditions as they varied over the course of the mission with photographic and analytical instruments (NASA, n.d.; Tillman, n.d.).

The budget for designing, building, launching, and landing the Pathfinder with the microrover Sojourner was fixed at $196 million (US) with a three-year schedule (Pritchett & Muirhead, 1998). Of the $196 million (US) budget for the mission, the development baseline was scoped at $131 million (US), $40 million (US) were held as a reserve due to the associated risks and $25 million (US) were allocated to the rover (Pritchett & Muirhead). The baseline budget was based on a grassroots cost estimate and was developed using a product-oriented work breakdown structure. (Sholes & Chalfin, 1999).

The development schedule for each Discovery mission was not to exceed 36 months. The timeline presented at the July 1993 Review Board was important. Due to the "orbital relationship between Earth and Mars, an opportunity for launch occurs only once every 26 months. And the launch window lasts only 30 days, at most." Miss the window, and the mission would be canceled. Adherence to the near impossible schedule required radical fast tracking. The lines between design, build, test, and implement were blurred and highly iterative. Beyond inception, phases were indistinguishable. Nonetheless, it was clear that all subsystems needed to be ready for assembly by June 1995. Groups of software, hardware, and subsystem teams worked concurrently in repeating cycles of design, build, test, detect errors, correct, modify design, and start again. Throughout development and implementation, there were plenty of obstacles, but each software, hardware, and subsystem group overcame each one as it arose, and most importantly stayed on schedule. Table 1 depicts the major events in the project and provides a general overview of the schedule of major events in the MPF project.

April 1993	Flight System Engineer assigned to the project
July 1993	Review Board meets and MPF passes the first go-no-go decision point
August 1993	Loss of the Mars Observer probe. The team contracted for hardware spares for this mission was subsequently embargoed by NASA for future Mars missions. The loss represented an unexpected $7 million (US) expense to the project and absorbed 15% of cost reserves (Muirhead & Simon, 1999).
October 1993	Funding for the project is approved

December 1993	Ground system engineers run "end-to-end" test demonstrating how signal would be sent from Earth to Mars to the rover to Earth
September 1994	First Critical Design Review passed
April 1995	Test of the Entry, Descent, and Landing system
June 1995	System level assembly begins
December 1996	Launch date
July 1997	Entry, descent, and landing on Mars, and receipt of first panoramic view of the Ares Vallis floodplain

Most of the procurement and contracting groundwork typically occurs in the development stage of a project. The hardware acquisition team needed to establish a minimal set of requirements for the program that would achieve the maximum knowledge within the cost constraints (Jet Propulsion Laboratory, n.d.). The goal was to identify vendors and subcontractors who would become *partners* in the process of developing cutting-edge technology and share in the risks and rewards that the project would offer.

To meet the cost constraint objective, the procurement team managed to purchase more than 70% of the major procurements under fixed-price contracts. This was a tremendous accomplishment in an industry where cost-plus type contracts are predominant. They achieved this goal by creating a long-term vision of the project; this was accomplished in part by focusing vendors on the long-term goals of the Mars Exploration Program. The program aimed to launch two vehicles every 26 months within a $150 million (US) cost constraint per launch. Follow-on contracts served as an incentive for vendors to accept the fixed-price contracts.

The team was successful in creating long-term vendor relationships that led to the continuous infusion of new technology. The integration of the individual components into the overall program ultimately helped produce team synergy throughout the program (Jet Propulsion Laboratory, n.d.).

Rather than cut corners to meet the constraints of budget and schedule, the MPF team actually added tests. The assembly, test, and launch phase operations were started early enough to give plenty of time to work out issues related to mechanical integration and environmental testing. Allocating adequate time for testing of electronics parts prior to launch reduced the risk of failure during the mission. Functional tests of each element of the entry, descent, and landing (EDL) system were performed. In addition to physical tests, thousands of simulations were performed of EDL scenarios. This planning and testing paid off as several of the simulated problem situations actually occurred and the MPF team knew exactly how to handle them. For example, upon landing the airbags draped over the lander petal, preventing the rover from driving off. This situation had been simulated during testing, and the team knew that it could fix the problem by lifting up a petal and pulling the airbag in further.

The development phase of the program found the team implementing procedures that broke the traditional methodologies for the development and deployment of a space exploration mission. The project managers realized from inception that to be successful they would need to develop a program that would allow their team to be innovative in their approach while maintaining the quality required for space exploration. They encouraged common-sense approaches to problems and encouraged the use of systems and components already developed for other JPL programs. This allowed individual team members to feel a true sense of responsibility and ownership in the project. Instilling a sense of ownership in the individual project personnel and teams ultimately led the individuals to deliver the best possible product.

The mission assurance team at JPL was responsible for testing and certifying each assembled component. The mission assurance program subjected each component to realistic space conditions prior to launch in order to identify any faults or limitations. The mission assurance team was a major quality checkpoint in the program. No assembled component, whether vendor supplied or developed by JPL, was approved until mission assurance qualified the component. According to the JPL Director "The Pathfinder mission assurance innovations saved the project approximately $8 million compared to the cost of using more conventional approaches. This savings allowed the project to achieve its challenging mission objective within a very constraining cost cap." (Ainsworth, 1997).

The organizational structure of the project team was certainly not the classic structure, with the boss on top of the chart, a row of managers, and then more and more boxes cascading downward to the lowest level. Such a hierarchical structure can imply that there is always someone above who carries "real" responsibility. The arrangement of the MPF project team's organizational chart was designed to eliminate that drawback. It conveyed the message of "we're in this together." There was a constant interaction and exchange among project team members.

Nothing is more frustrating to a project team than the attempt at controlling information unnecessarily. Although control is maintained, going down the wrong path may waste scarce resources. These and other communications issues were discussed and accepted by the MPF project team, helping them stay synchronized and united.

Assessment and Analysis

1. Please complete your evaluation of project management during this phase, using the following grid:

Project Management Area	Development Phase
Scope Management	
Time Management	
Cost Management	
Quality Management	
Human Resource Management	
Communications Management	
Risk Management	
Procurement Management	
Integration Management	

Rating Scale: 5–Excellent, 4–Very Good, 3–Good, 2–Poor, 1–Very Poor.

2. Please highlight the major areas of strength in the management of this phase of the project:

3. Please highlight the major opportunities for improvement in the management of this phase of the project:

The Implementation Phase

Project objectives were clear at inception. However, their achievement in subsequent phases would require extreme creativity and in many cases involved untried technology. The stringent project constraints necessitated a new management approach of "doing things differently." This meant adopting radical engineering and management approaches throughout the life cycle of the project. Wherever possible, the scope was minimized through the use of existing technology, systems were built around off-the-shelf hardware and software components, and project scope was based on a capability-driven design instead of requirements.

At inception, the scope, budget, and schedule of the project were defined clearly and rigidly. The orbital relationship between Earth and Mars provided an immovable launch window that occurs every 26 months for a period of about 30 days. Hence, schedule was identified as the top priority constraint throughout the project. A common project management philosophy indicates that with a fixed schedule, tradeoffs occur between budget and scope. But on MPF, those two constraints were also inflexible.

The very nature of spacecraft missions brought two additional constraints into play: mass and volume. The amount of space for stowing equipment in the launch vehicle was finite, "there would be only so much space, and we would have to fit all our equipment into it, period." Mass presented another limitation. The mass of the fully loaded launch vehicle would be affected by Earth's gravitational pull at launch and conversely by the gravitational pull of Mars upon landing. If the lander were too heavy, it would burn up during entry into the Martian atmosphere. The design had to come in under the maximum acceptable mass of 1,330 lb (603.28 kg). Mass reserves for the entire project were calculated at inception and doled out sparingly throughout the project phases. Changes in scope, necessarily translated into trade-offs between cost and mass. Accordingly, much of the scope remained unchanged throughout the entire project.

The budget constraint forced innovation. Instead of orbiting the planet in order to slow down the spacecraft prior to entry, the team opted for a less expensive direct-entry approach. Landing presented another set of engineering challenges to be overcome.

The software, hardware, and subsystem groups each faced scope issues. As each team moved into the development phase, the scope required progressive elaboration. Each group had to meet a set of tactical deliverables that would support the overall strategic goals of the mission. While working on these tactical goals, leaders of each group had to remain focused on the Faster, Better, Cheaper mentality as well as the strategic goal.

In terms of managing the project, schedule took top priority. At the outset, the flight system engineer (project manager) established a schedule reserve of working weeks based on the degree of perceived risk. His guideline for managing the schedule was, "set hard limits of how much you'll let go of in each period throughout the project, and stick to it" (Muirhead & Simon, 1999). In terms of the schedule, none of the reserves were expended until after system assembly and testing began. This was near the halfway mark in the project schedule. He demanded that subsystem managers delivered their respective products to the test facility in accordance with the original delivery schedule.

The ground systems manager used an innovative and radical approach in developing the end-to-end signal (Earth to Mars to Rover to Earth). By using hardware and software left over from earlier projects, he created an extremely low-cost system in a much shorter time frame. The successful early testing of this component in December 1993 provided the team with an early win. It marked a significant milestone in the project and boosted the team's morale. The practice of testing components early in the development cycle became the norm on other subsystems as well. Arduous early testing became the accepted method of reducing schedule risk.

In early 1994, a potential problem was looming. The avionics organization was to design a pointing device that could precisely zero in on an antenna on Earth. The group was not accustomed to working under tight budget and schedule constraints and was not stretching sufficiently to rise to the challenge. Their talents were needed in other areas of the project and alienating them was not an option. The project manager resolved the roadblock by announcing a design competition. He invited the JPL Mechanics Systems section to come up with a design for the device. When the designs were ready, the project manager and a representative from each design team (Avionics and Mechanics) made the decision. This was definitely an innovative approach for JPL—but it worked.

In July 1994 the team was scheduled to face a critical design review. Preparing for reviews usurped time from the project. The project manager, cognizant of the make-or-break nature of reviews, orchestrated a peer review and uncovered a host of problems:

- Progress had stalled on development of mechanical interfaces that describe how the physical pieces fit together. Without mechanical interfaces, a large number of engineers would be unable to proceed with their designs.
- The lander design was falling behind.
- Airbag design was beginning to come together.
- Resources were being allocated to higher priority projects.

Fortunately, the team was able to have the review delayed until September 1994. "The bottom line: the panel was not happy with us but didn't find the situation serious enough to call for a Cancellation Review XC56,4. So in essence we passed" (Muirhead & Simon, 1999).

The implementation phase followed the success of the inception and development phases by maintaining the relationships with vendors and team members. The program stressed the continuous improvement of all project elements and achieved a team atmosphere where vendors and subcontractors performed and exceeded all program levels.

Throughout the implementation phase, the procurement team continued to maintain responsibility for the procurement effort. The utilization of tracking documents such as the green, yellow, and red reporting charts allowed the project manager and procurement personnel to identify any components, vendors, and subcontractors who were underperforming before they could negatively affect the project. The procurement team assigned two full-time team members to monitor and interact with the major vendors and subcontractors on the project. These personnel were responsible for maintaining the relationship with vendors and interceding if any negative influence impacted the relationship.

The implementation phase was very successful and the project met both its budgetary and time constraints. As the world watched, the Mars Pathfinder successfully entered the atmosphere of Mars and deployed Sojourner Rover on the surface of Mars. The mission and components operated flawlessly and stood as a testament to the success of the project and the systems and controls that managed the project.

Incorporating a $40 million (US) reserve at initiation and then metering it down throughout the life of the project mitigated financial risk. One strategy MPF management used was to not overcommit reserves early in the project so that potential growth during assembly, test, and launch operations could be funded. A set of de-scope options were developed as a backup plan in the event that the reserve was inadequate. As the reserves covered the cost increase, the de-scope option was not used.

Given the nature of the mission, there were inherent risks related to the creativity and innovation of solutions. The MPF team did an outstanding job of ensuring that new ideas passed rigorous tests and were aligned with NASA's Faster, Better, Cheaper objective.

A testament to the quality control on the MPF mission were the statistics of the mission assurance team. The cost related to mission assurance was less than one third that of traditional projects and the problem/failure rate was less than one quarter of normal (Sholes & Chalfin, 1999). The statistics proved the level of quality that was inherent within the project as evidenced by the problem/failure rate being substantially lower than that of other programs at JPL. The lower problem/failure rate is directly related to the lower cost for the mission assurance department.

During the implementation phase of the project, the team focused heavily on quality and execution of the mission. The project team ensured success and quality by holding more than 100 peer-review sessions throughout the life of the project. These sessions were a forum where open discussion, honesty, and accountability all played a role in ensuring that each component and process was reviewed and re-reviewed for quality and adherence to specifications. These sessions allowed all team members to discuss and bring to the table issues and problems that they felt would impact the project. The open, honest discussions often uncovered project deficiencies and proposed solutions, thereby reducing the overall risk of the project and ensuring quality.

The organizational chart had related groups of functions such as hardware and software. These groups represented expertise in required areas such as propulsion and telecommunications. There were three project leads and administrative support. The leaders' tasks were to find the right expert to match the skill requirements for various elements of the project.

But the team leader's function did not stop there. It takes one or more leaders to make *teamwork* work. The MPF leaders recognized that their people, each working on one part of the whole, had only a partial and hazy grasp of the overall picture. The project team members were totally immersed in their daily activities and could not reasonably be expected to appreciate how their own efforts and goals tied into the grand destination. It was essential for the leader to create the atmosphere and set the tone of focus and commitment. The project manager said, ". . . these essentials generated in all team members a willingness to put aside the internal competitiveness and office politics that rule many workplaces, and replace them with an attitude of people supporting people, and attitude of . . . We are all in this together" (Muirhead & Simon, 1999).

Although there are many methods of improving communications, there are also many ways to choke them. An incident that occurred in the MPF project in 1994 helped but also stifled communications. The Internet was then in the infancy of its use. In one of the team meetings, someone suggested using the Internet to post the MPF software as a way of quickly sharing pieces of code between teams. It worked wonders as expected, but soon after, they were being investigated for violating the International Traffic in Arms Regulations. The incident took a lot of the team's time. It turned out much later that their unhappily gained knowledge of Internet security issues would become a valuable lesson as Web use exploded through the ensuing years.

Additionally, the MPF team learned that at times it might take a while for two or more parties to synchronize. Their recommendation was to persevere. During the development of the land rover that would eventually scale the hills of Mars, the local team sent what was believed to be the correct solution to a problem. The international team sent back viewgraphs with their understanding of the particular situation in order to prepare for an international teleconference. The local team was confused and felt that the international team must not have read what was sent to them. Finally, on the third or fourth teleconference, a person in the local group said, "What if we do it this way?" reiterating only what the local team had been urging all along. "Oh," said the other team. "What a great idea!" to the amazement of the local team. It took that long for the idea to sink in. The lesson learned by the project team was that good communication took extra effort for the sake of clarity. They also learned that perseverance is important in resolving conflict.

Assessment and Analysis

1. Please complete your evaluation of project management during this phase, using the following grid:

Project Management Area	Implementation Phase
Scope Management	
Time Management	
Cost Management	
Quality Management	
Human Resource Management	
Communications Management	
Risk Management	
Procurement Management	
Integration Management	

Rating Scale: 5–Excellent, 4–Very Good, 3–Good, 2–Poor, 1–Very Poor.

2. Please highlight the major areas of strength in the management of this phase of the project:

3. Please highlight the major opportunities for improvement in the management of this phase of the project:

The Closeout Phase

Budget, schedule, and mass constraints impacted project scope. Minimizing scope and scope changes became paramount for each group. This radically impacted the management of the project, both in terms of product and project processes. Doing things differently involved:

- "Single string: using only one of everything wherever possible, making an exception only where we couldn't build in enough margin or demonstrate high reliability through testing" (Muirhead & Simon, 1999). Single string demanded robustness of every subsystem. Robustness demanded that everyone continually ask, "Can I make this more reliable? Have I tested for every possible scenario?" Care was taken to ensure that adding robustness did not result in an expanded feature set.

- Willingness to be radical in taking risks, but not to fail. Taking risks was the norm, but risks were mitigated through exhaustive testing.

Abiding by these two concepts mandated an unprecedented level of quality on all components. Everything had to be done right and work right.

There were several reasons for the financial success of MPF. The project reserve was planned in great detail and was time-phased throughout the project based upon estimated time of need. Detailed analysis was done to determine real and potential cost growth requests that would require the release of project reserves. People were used efficiently and were smoothly transitioned to other projects at the end of their assignments. A system was developed for generating memorandums of understanding for spare hardware transfers between MPF and other JPL projects, which resulted in $750,000 (US) in cost credits to MPF (Sholes & Chalfin, 1999). This arrangement resulted in reduced schedule and lower costs for the receiving project by eliminating procurement and testing lead times. Applying a reduced burden rate to MPF resident field personnel at The Kennedy Space Center during the launch campaign resulted in $300,000 (US) savings (Sholes & Chalfin). The MPF project benefited from existing JPL multimission infrastructure that permitted the ground data system and mission operations development to be completed for under $10 million (US), a substantial reduction from what had been historically spent for missions of similar scope (Muirhead & Simon, 1999). JPL worked closely with its vendors, national laboratories, and other NASA centers to develop innovative designs while controlling costs.

The bottom line is that the MPF project was completed approximately $400,000 (US) under the NASA cost cap without reducing its original scope of work (Muirhead & Simon, 1999).

System assembly and test started early, a full 18 months before launch date. Starting early and testing thoroughly became trademarks that appeared again and again throughout the project. In the final analysis, the approach worked and worked well. The Pathfinder was assembled, tested and "ready to launch on 2 December 1996—the first day of the launch window. However, due to weather and other considerations, the actual launch took place on 4 December 1996" (Sholes & Chalfin, 1999).

The closeout phase of the project involved a multiple-day meeting of all the project teams where the vital information of the project was documented. The team had successfully implemented new and innovative processes and procedures for developing a space exploration program. In related stories and articles published since the conclusion of the project, many of the senior managers agreed that the project did not follow the traditional project implementation procedures that had been established as part of the space program. They also conceded that if the same mission were undertaken today, the likelihood of success would not be as great due to the information technology driven organizational culture.

Though risky, the MPF project was certainly not reckless. There was unbending accountability and the only acceptable outcome was getting to Mars on time and within budget. The JPL team's instructions were clear, "take risks, but don't fail" (Pritchett & Muirhead, 1998). This meant that they were expected to innovate, but had to pay close attention to risk management. JPL's response was to craft solutions that were tolerant to uncertainties. The team did an outstanding job of building in margin to cover tolerance to changes, miscalculations, and new environments. Ideas were exposed to relentless testing and constant critique. People were assigned to simulate problems to see if the solutions measured up. This approach found the vulnerable points that needed improvement. By subjecting solutions to early scrutiny, the team was able to take out much of the risk early on. Although the testing did not guarantee a perfect mission, it did prepare the team well.

Mission success and the methods by which that success was achieved were documented in the closeout phase. The project leadership scheduled a multiday closeout session where the project team gathered to discuss and document the project approach, the successes and failures, and the lessons learned. As a result of the session, vast amounts of project information were documented and recorded so that future project managers and JPL personnel could review the methods and approaches that made the MPF mission a success.

Summary of Project

The quality program at JPL was in the end proven to be highly successful. The project leadership maintained a hands-on approach throughout the project and continually instilled within the team the personal accountability and the employee's ability to take risks and redefine processes to meet the project goal. When the Sojourner Rover finally stopped, the data collected and the smooth operation of all the systems and teams confirmed the success of a top-notch quality program.

In their book *High-Velocity Leadership,* Muirhead and Simon (1999) symbolized the roles of a leader as "glue and grease." Glue was the ability of melding the people together into a team, keeping the system together and the team together, and providing the strength of vision needed to reach the goal. The grease was the ability to smooth the skids to make sure the team succeeds, as well as knocking down the barriers and roadblocks that would otherwise hinder their progress. They described that sometimes the "glue and grease" principle works against the managers. Such was the case with the project manager's boss who sometimes wanted to be involved at too detailed a level. They added that making allowances for the style of the boss should be part of everybody's work practice. They referred to this as "managing up." Similarly, team leaders found it easier to encourage people to be creative by ensuring that leadership was constantly nurtured, starting with the people at the top of the organization.

Other significant and radical differences in the MPF project team that other teams in JPL did not have were (1) the collocation of entire project team to a single open area (i.e., it made it practical for managers to be on hand for highlight events without having to go on an excursion to take part), (2) the team's momentum was maintained even in the face of adversity, (3) as a worker finished a job, he or she would take on a new role that he or she had never handled before, and (4) use of human archiving (i.e., instead of searching through the archives for information, team members just asked those involved to get the answer).

The MPF team used user-friendly "peer reviews" and the "Problem Failure Report" as communications tools. For the peer review, a small number of team members focused on a particular aspect or narrow range of topics. Each tool took only a few days of preparation by the people who presented the work. The communications and learning from these sessions helped the team stay within the constraints of schedule, volume, mass, and money, and also helped assure that key decision-makers understood what was happening. The Problem Failure Report was an electronic report used for tracking problem resolution, ranking them, and documenting the actions taken for resolution and closure.

MPF operated on the surface of Mars three times longer than expected and returned a tremendous amount of new information about Mars. In November, 1997, JPL announced that NASA's MPF mission is winding down. Brian Muirhead, MPF's Project Manager said "We concede that the likelihood of hearing from the spacecraft again diminishes with each day... Given that, and the fact that Pathfinder is the first of several missions to Mars, we'll say 'see you later' instead of saying goodbye" (Jet Propulsion Laboratory, 1997).

On January 3, 2004, six-and-a-half years after the landing of the MPF on Mars, NASA's Mars Exploration Rover Spirit, a traveling robotic geologist, landed on Mars successfully and started to send stunning images of the area around its landing site (NASA, Jet Propulsion Laboratory, 2004).

Assessment and Analysis

1. Please complete your evaluation of project management during this phase, using the following grid:

Project Management Area	Closeout Phase
Scope Management	
Time Management	
Cost Management	
Quality Management	
Human Resource Management	
Communications Management	
Risk Management	
Procurement Management	
Integration Management	

Rating Scale: 5–Excellent, 4–Very Good, 3–Good, 2–Poor, 1–Very Poor.

2. Please highlight the major areas of strength in the management of this phase of the project:

3. Please highlight the major opportunities for improvement in the management of this phase of the project:

Summary of Project Assessment and Analysis

1. Please complete your evaluation of project management for this project and calculate the average rating, using the following grid:

Rating Scale: 5–Excellent, 4–Very Good, 3–Good, 2–Poor, 1–Very Poor.

Project Management Area	Inception Phase	Development Phase	Implementation Phase	Closeout Phase	Average
Scope Management					
Time Management					
Cost Management					
Quality Management					
Human Resource Management					
Communications Management					
Risk Management					
Procurement Management					
Integration Management					
Average					

2. Please highlight the major areas of strength in the management of this project:

3. Please highlight the major opportunities for improvement in the management of this project:

4. Please highlight the major project management lessons learned from this project: