SYS 612 Final Project
The Hubble Space Telescope - Misalignment and Mismanagement
Stevens Institute of Technology
Systems Engineering and Engineering Management

The Hubble Space Telescope

Misalignment and Mismanagement

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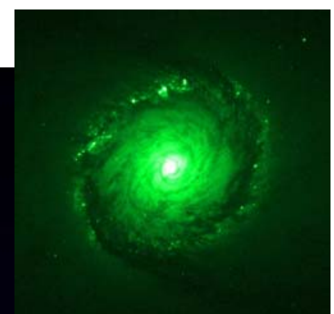

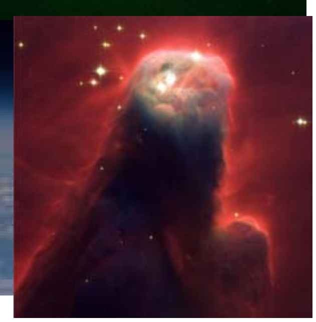

The Hubble Space Telescope
http://www.jackkennedy.net/hubblehuddle.ppt

Executive Summary

"The difficulties with the Hubble and the space shuttle program are very disturbing and, without judging the cause of these two incidents, they have served to reaffirm my strong belief in the need for established quality assurance procedures and strong effective program management by NASA. Both are essential to successful development of the long-term, technically complex programs NASA has under way to explore our solar system, reveal the secrets of distant planets, and uncover the origins of the universe." Senator Al Gore, S. HRG. 101-1087, July 10, 1990. These words by Senator Al Gore lay the foundation of the perceived problems with the Hubble, quality control and effective program management. This paper will use the NCTP Framework Analysis approach to evaluate the style used by the Marshall Space Flight Center HST Program Management team to direct the design and mitigate the risks for the Hubble.

The Hubble Space Telescope (HST) was carried into orbit on Space Shuttle Discovery on April 24, 1990. Three days latter it was determined that the telescope failed to focus correctly. Errors in the polishing of the primary mirror were eventually traced back to Perkin-Elmer, the designers of the Optical Telescope Assembly (OTA). However, failures in Program Management which were also part of the problem could be traced to the Marshall Space Flight Center (MSFC) who was ultimately responsible for the program management oversight. Besides the problems with the primary mirror there were significant cost overruns (463%), a failure to understand the total system testing requirements and a less than harmonious environment between the participating space centers and the major contractors.

The NCTP framework was used to classify the four dimensions of the HST project and comparisons were made to show correlations to the Challenger Space Shuttle NCTP framework. This technique is used to show what went wrong relative to the style used by program management. The assessments show that both the Hubble and Challenger underestimated the Technology and Novelty of the projects. In both cases these incorrect

assessments contributed to the failure of the programs because the incorrect style or environment was used. Significant technical issues arose on both programs but if the correct management "style" had been used those technical risks might have been mitigated.

Background Setting - History of the Hubble

In 1977, Congress funded a 200 million dollar Large Space Telescope which was later named the Hubble Space Telescope after Dr. Edwin P. Hubble. When the Hubble was finally launched in 1990 it had cost 1.5 billion dollars. Images after launch showed that the main 2.4 meter mirror had spherical aberration of about 1/50th the thickness of a human hair. This flaw in the optics prevented the focus of the telescope and jeopardized the entire project.

In 1993, COSTAR was launched aboard the STS-61 and repairs were made on the telescope to correct for the spherical aberration. The estimated cost of the first service mission was 250 million dollars excluding launch costs of approximately 450 million dollars.

The Hubble Space Telescope was completed in December 1985[1] and scheduled to be launched in October 1986. However, on January 28, 1986, the Challenger Space Shuttle exploded 73 seconds after liftoff. This tragic accident pushed HST back as the shuttle was redesigned and improved. During this down time, improvements were made to the Hubble Space Telescope but the spherical aberration with the primary mirror was not found.

The main mirror was built by Perkin-Elmer and required 2.5 years to polish. MSFC approved Perkin-Elmer (PE) as the OTA contractor due in part to the lowest cost proposal. The primary mirror was completed in 1981 a good 9 years before the launch but never tested for the spherical aberration. Several tests on the ground showed that spherical aberration existed in the interferograms and would suggest problems with the OTA. Likewise tests using the refractive null corrector showed spherical aberration. In both cases Perkin-Elmer

[1] http://history.nasa.gov/hubble/index.html

discounted the errors believing that the OTA were more precise than could be measured with these tests. The end-to end test of the OTA was considered to be much too costly and based on the tight cost environment and the potential for program cancellation additional testing was not performed.

The Marshall Space Flight Center (MSFC) was selected over the Goddard Space Flight Center (GSFC) to manage the Hubble Space Telescope. Clearly, GSFC had more scientific expertise but MSFC had a large idle staff. There was a threat of cutbacks within NASA and MSFC really wanted the program.

There existed a certain amount of unhealthy competition between GSFC and MSFC and between Perkin-Elmer and Kodak (who built the backup primary mirror and had bid on the original OTA effort). In addition, PE had worked on spy satellites and there was a definite lack of access for MSFC due to DoD restrictions. All of the communication obstacles inhibited the exposure of the spherical aberration of the primary mirror.

Figure 1 shows the communication and program interactions between the Marshall Space Flight Center (MSFC) and the other members of the Hubble Space Telescope (HST)

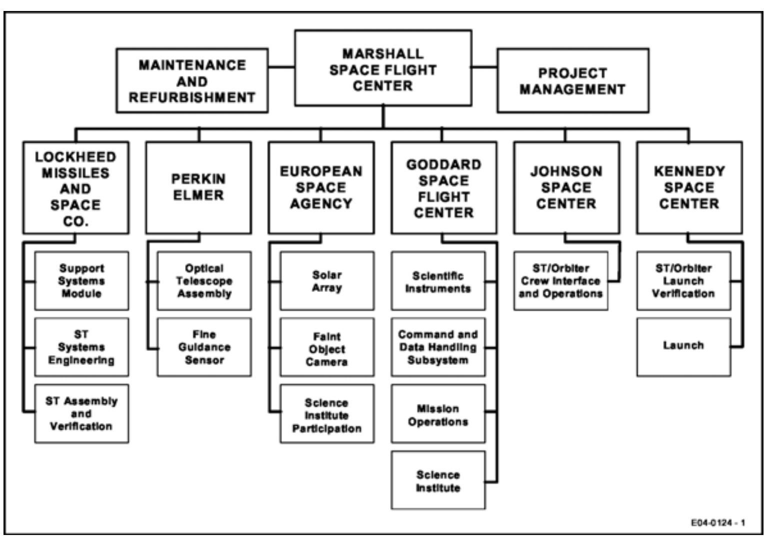

Figure 1 The 1977 HST Program/Communications Interfaces
http://www.afit.edu/cse/casedocs/files/Hubble%20SE%20Case%20Study.pdf

team. MSFC was overall responsible for the program management of the HST program. MSFC selected the prime contractor Lockheed Missiles and Space Company (LMSC) to develop the Support Systems Module (SSM) and supervised many subcontracts. LMSC selected the second prime contractor Perkin-Elmer Corporation (PE) to design and test the Optical Telescope Assembly (OTA), including the fabrication of the primary and secondary mirrors. Goddard Space Flight Center (GSFC) was responsible for the development of some of the scientific instruments and eventually operating the telescope. The European Space Agency (ESA) was added to the team and provided the solar arrays.

Statement of Problem

Much emphasis has been placed on the incorrect shaping of the primary mirror on the Hubble Space Telescope and the lack of end-to-end testing prior to the launch of the Hubble. However, the environment that allowed these mistakes to occur was under the control of the Marshall Space Flight Center HST Program Management. This paper will use the NCTP Framework to analyze the risks the Program Management took during the prelaunch phase of the program. Information used for this analysis is based on publicly available documents. This analysis will compare the “actual” versus the “required” four dimensions of the NCTP to demonstrate that if the management style (work environment) had changed, the likelihood of the failure in the OTA subsystem could have been greatly reduced. How the program management failed in the establishment of an environment which allowed the primary mirror to be built incorrectly and with no end-to-end testing will be addressed in the following analysis.

Overview of the Project

The Hubble Space Telescope was chosen as our project because of the well known problem it had with this primary mirror. This suggested that there might be other issues like program management problems which could have fostered an environment for weak risk mitigation for technical problems. There was also a wealth of information available on the Hubble to use for the NCTP Framework Analysis. No previous NCTP analysis for the Hubble was found but there was a NCTP Framework developed for the Challenger Space Shuttle. The Challenger disaster occurred during the development of the Hubble and a comparison of the two NCTPs might suggest systemic problems within NASA. In addition, it is believe that the Hubble was a sufficiently complex system and represented a real challenge for program management within NASA.

The focus of the project will be to evaluate how the program management style needed to change to insure program success and not the technical issues with the primary mirror.

Approach

The NCTP Framework analysis of the Hubble Space Telescope is based on how the Marshall Space Flight Center actually managed the Hubble Space Telescope between 1977 to 1990. The specific technical failure of the Hubble during this time was the incorrect fabrication of the Primary Mirror which was built by Perkin-Elmer. The mirror was incorrectly fabricated and an end-to-end test which would have found the problem was never performed. However, other mitigating issues helped establish an environment which allowed this failure to happen.

The approach that was used to analyze the problems with the program management of the HST will include a NCTP Framework analysis of the actual versus required management styles. This risk analysis tool stratifies four dimensions of the program management into the actual and required levels within Novelty, Complexity, Technology and Pace or the four dimensions of the NCTP Framework. Each dimension has multi levels and the actual levels were determined based on a review of publicly available documents which were collected from the web. Since the Hubble was effectively a disaster in the early years a proposed new required management style is recommended based on the perceived issues within each dimension.

To facilitate the analysis a spreadsheet was created for each dimension and for both the actual and required views. Each worksheet contained the various levels, characteristics, and managerial styles for each level. A score was created for closeness to each characteristic and the level with the largest number of selected characteristics became the level for that dimension of the NCTP. For the required NCTP Framework view, an assessment was made for each dimension to determine if the actual levels were adequate.

Results - Hubble

The actual versus required NCTP Framework analysis of the PM style relative to the Hubble Space Telescope during the prelaunch period shows some noticeable issues as can be seen in Figure 2. In most cases, the required level for each dimension needs to increase from the actuals with the exception of Pace. Below are the justifications for the actuals and required level selections.

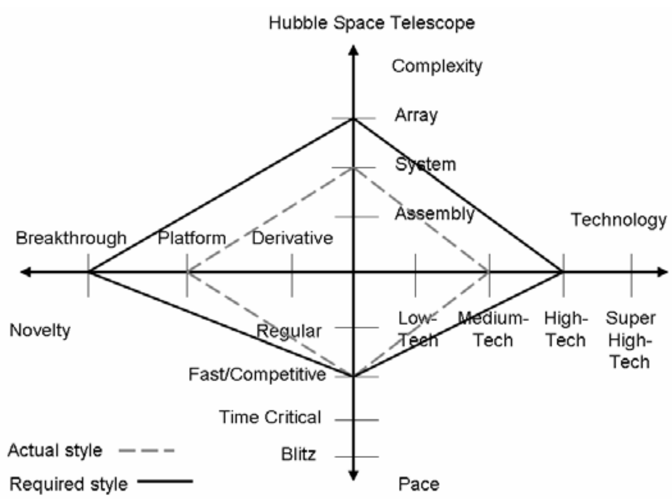

Figure 2 NCTP Framework for Hubble Space Telescope

Actuals - Hubble

Novelty (Platform) – Marshall may have treated the Hubble as an extension of the LSTs that previously were built but failed. Based on lessons learned, they could have believed that with some upgrades the Hubble could be produced as a successful design. In addition, based on the possible early freeze of requirements and reduction in the size of the primary mirror, they could have been more confident in the design and test methodology than should have been. This may also demonstrate the nativity of Marshall in accessing the design risks.

Complexity (System) – Clearly Marshall had problems with Perkin-Elmer which resulted in a management style that was less ridged. Part of the managerial style was a direct by product that DoD may have limited access to some of the technical oversight for security reasons. This forced Marshall to trust Perkin-Elmer more with the design and test of the OTA resulting in a weaker technical oversight.

Technology (Medium Technology) – “Limited development and some testing” and early requirements freeze may have caused Marshall to underestimate the technology dimension of the NCTP. Marshall also had access to the bids from the three OTA contractors and was aware that Perkin-Elmer did not include end-to-end testing which the other contractors bid. This lack of end-to-end testing was a gross oversight and ultimately enabled the failure.

Pace (Fast/Competitive) – The design appears to have been managed with more emphasis placed on cost verses schedule. A quicker pace was not deemed necessary. From a Pace standpoint the timelines was interrupted due to the Challenger disaster. Although the system was ready for its 1986 launch it was postponed until 1990.

Required – Hubble

Novelty (Breakthrough) – Marshall should have managed the Hubble as a totally new systems regardless of previous systems. It was truly "New to the World" and very important to the study of the universe. For years, scientists had dreamed of a space based telescope like Hubble and Marshall should have managed the project as a Breakthrough. This would have helped ensure that all systems including the OTA would have received proper focus.

Complexity (Array) – Marshall needed to insure that the telescope was ready to fly and that it would meet the requirements. Regardless of the DoD influence, Marshall was responsible as well as Perkin-Elmer to insure that the OTA was built correctly. This should have required more technical oversight by Marshall.

Technology (High Technology) – Marshall should have realized that the OTA had not been bid correctly because of the lack of end-to-end testing bid. A closer review of test data and closer scrutiny of the OTA design was Marshall's responsibility and adequate staffing should have been in place to oversee the task. It may have been prudent to engage the other OTA bidders to help with some of the technical reviews. If additional funds were needed for testing, Marshall should have championed this added expense.

Pace (Fast/Competitive) – The actual and required Pace for this system are in agreement and no changes are suggested.

Results – Challenger

July 1969, Neil Armstrong was famously quoted for saying "That's one small step for (a) man, one giant leap for mankind." This marked the early beginnings of what has become a remarkable entry into space by humankind. Over the last several decades, humans have landed on the moon, sent deep space probes into the furthest reaches of our galaxy, and collected enough data to analyze for years to come. And while curiosity and audacity propels humans to explore space, the journey comes at a cost. On January 28, 1986, the cost was paid by the lives of seven astronauts onboard the space shuttle Challenger – STS flight 51-L - when their shuttle exploded in mid-flight, just shortly after takeoff. After the disaster, a Presidential Commission was launched to investigate the cause of the accident. The Commission, headed by William P. Rogers, uncovered some very revealing problems within the National Aeronautical and Space Administration (NASA). From a program management perspective, the investigation illuminated the importance of properly classifying project and to develop a framework in which to govern the major forces in the project. *In the case of NASA and the space shuttle program, the inaccurate classification of this program contributed to the challenger disaster.*

Figure 3 shows the NCTP Framework for the Challenger Space Shuttle.

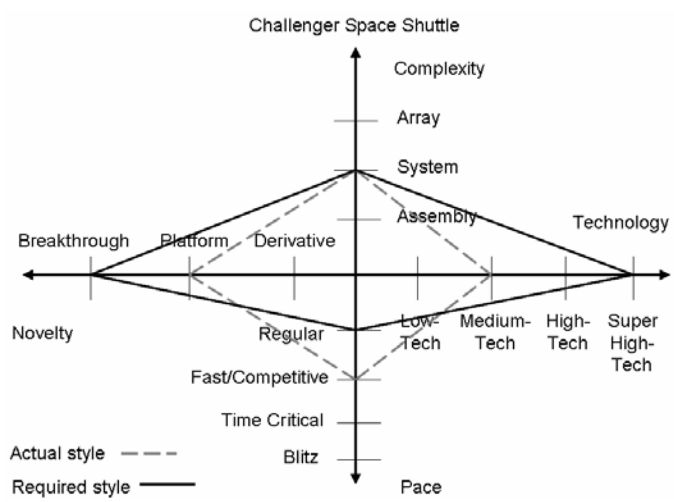

Figure 3 NCTP Framework for Challenger Space Shuttle

Actuals – Challenger

Novelty (Platform) – One of the intriguing factors associated with NASA's framework was the attempt to manage the Space Shuttle program as a platform product. The perception by NASA was the customer was familiar with what this product embodies by virtue of the Apollo program. The decision to manage by product novelty may stem from NASA's belief they could leverage from the knowledge, technology, and experience gained from sending vehicles, such as Snoopy, Eagle, and Spider, into space. This would be a miscalculation on the part of the program management.

Complexity (System) - The complexity factor actually espoused by NASA and what was required is in agreement with each other. There is no disagreement that the Space Shuttle was a "complex collection of interactive elements and subsystems…" (p.15, How Projects Differ, Shenhar, et al) Many field agency's and contractors were involved in the management and production of the various components necessary to fly the final product. The organization was setup in a manner to allow management of the product across organizational borders.

Technology (Medium Technology) - The Apollo capsule design was considered the "Safest, most reliable and affordable approach…"[2] Yet, many new technologies and a new design was developed to support the Shuttle's mission. Unlike the Apollo vehicles, the Shuttle's mission varied. The vehicle was expected to serve as a laboratory, a payload delivery vehicle, and a service vehicle for other things such as Hubble, the International Space Station, etc. Furthermore, even the shuttle design significantly differed and required new technology. The Apollo program used a capsule design that was better suited for delivering it into space; however, the Shuttle was intended for reuse. With the advent of new technologies to protect the shuttle during reentry, and designing the shuttle in an aircraft like configuration, the Shuttle was reusable. This was certainly new technology and the

[2] http://www.nasa.gov/mission_pages/exploration/spacecraft/cev_faq.html

management of it needed to reflect this fact in the form of a super high-tech project.

Pace (Fast/Competitive) – NASA’s pace was artificially set political and budgetary forces. The pressure applied on NASA dictated the shuttle must sustain a high operational tempo. The national reliance of the shuttle grew, especially its ability to perform servicing missions and deliver payloads. This pace was unrealistic and caused an environment within NASA that pushed the technology, the knowledge, and experience currently present to the point of failure. This was part of the issue that led to the Challenger disaster. NASA was under significant pressure to increase its flight rate, while also coping with decreasing budgetary support to maintain the fleet. The Rogers Commission revealed that the management structure was overly consumed by these issues that disregard for safety and reliability was acceptable. One of the findings of the Commission identified a organizational structure in which those personnel responsible for safety were nearly non-existent – two people, applying only 10 to 25 percent of their time, oversaw safety and reliability issues. (p.570, Safeware, Levenson)

Required – Challenger

Novelty (Breakthrough) - The Space Shuttle program may have been just as challenging, if not more challenging than the Apollo program. Unlike the Apollo vehicles, the Space Shuttle was to be reusable, carry a larger crew, and deliver payloads into space. This is drastically a different mission from that of the Apollo program. In the case of the Challenger, the reuse of existing rocket technology for use by the fleet proved to be a critical flaw. The attempt to reuse a preexisting design allowed NASA to freeze the Shuttle Design earlier to ensure earlier time-to-market. If NASA treated this program as a breakthrough, an assumption could be made that designers could have found a better design for the SRB. This could have been accomplished by more prototyping, increased tests, etc, which was the staple of the Apollo program. In either case, the Shuttle program should have been classified as a breakthrough, primarily due to the amount of unknowns.

Complexity (System) – The required and actual styles are in agreement. No proposed change is recommended.

Technology (Super High Technology) - The reality was NASA managed the technology aspects of the Shuttle program by considering it medium-tech. The idea was the base technology was present in the form of the Apollo program. The reuse of the technology would mitigate risk and aid in the development of the Shuttle, while still allowing for the introduction of new features and technology yet being developed.

Pace (Regular) - While NASA managed under a competitive pace, the required pace should have been regular. Because the space shuttle supported a wide variety of missions, there was no need to execute the program under a fast pace. The missions the Shuttle supported could have still been accomplished in a more regular pace. The effort should have been to develop the Shuttle into a more stable platform and find ways to increase its reliability and decrease its cost.

Summary & Conclusions

Both the Hubble and the Challenger suffered technical failures which drew national and international attention. Both programs underestimated the Novelty and Technology of the design by trying to reuse technology from other programs. Design reuse is a common concept used to reduce development costs and reduce test time. However, the misapplication of reuse can lull the program management team into a false sense of security and an incorrect assessment of the design maturity, development costs and risk assessments. Without appropriate test and development time, the program can actually cost more in terms of dollars and human lives due to redesigns and loss of hardware. It is always better to build it right in the first place and test before it is flown.

The Complexity dimension of the Hubble and Challenger differed in that the required Hubble Complexity was Array while the Challenger was System. This seems somewhat confusing but if Complexity translates into many subcontractors with a need for overall program management supervision and technical oversight then the suggestion is that the Challenger Complexity dimension should be increased to Array.

The Pace for both programs could have been slowed to make sure that the design was sound and the product was flight worthy. For the Hubble, the Pace was artificially slowed by the Challenger disaster and not because of program management per se. The Challenger should have been slowed to ensure that no design issues existed and adequate safety and reliability were included.

The NCTP Framework appears to struggle with both cost and reliability because no dimension addresses specifically either constraint. The Regular level of Pace also seems to need more characteristics because a “Regular” Pace may be taken to insure that the product reliability is achieved. (The design is going slow because the risks are so high and it needs to be done right.) Finally, the characteristics typically used for complex space or defense programs do not include marketing the product once the contract has been awarded. Instead, the focus is on keeping the customer happy and involved with the product development.

In the end both the Hubble and the Shuttle programs have been tremendously successful and NASA has much to be proud of. However, the cost pressures persist and new systems promise to be even more complex (James Webb Space Telescope and the Crew Exploration Vehicle). NASA must use management tools, like the NCTP Framework, to help establish the correct working environment for future success.

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Appendix – Q & A

Questions and Answers

1. What is your NCTP classification of the project you have chosen?

Ans: Based on available information it is believed that the actuals NCTP Framework used by the Program Management on the Hubble Space Telescope (HST) were:

Novelty = Platform
Technology = Medium-tech
Complexity = System
Pace = Fast-Competitive

2. Is this project using the correct approach based on your analysis with the NTCP framework? Why?

Ans: No, Marshall did not apply the correct style to manage HST especially when it came to the OTA built by Perkin-Elmer.

3. What is the project doing right and what should the project do differently based on what the NCTP analysis has showed you?

Ans: The Novelty, Technology and Complexity dimension of the NCTP Framework were all underestimated by Marshal.   However, the Pace seems to be correct even when there was a time lag introduced into launch because of the Challenger disaster. The required NCTP dimensions are:

Novelty = Breakthrough

Technology = High-tech

Complexity = Array

Pace = Fast-Competitive

4. Classification frameworks should be unique for organizations. Based on what you learned from the project you analyzed, how would you change the NCTP framework to better fit the organization this project came from? Or would you develop a different framework and what would it look like?

Ans: Marshall and indeed all of NASA typically work on programs that are very difficult. Failures often are public and there is a great deal of financial pressure being bought to bear on all space programs. However, NASA needs to continue to maintain and fund technical and managerial oversight on all programs. Money continues to be a problem and NASA needs to continue to prioritize jobs based on need and probability of success. Regarding Frameworks for complex systems and NASA, it is recommended that an NCTP framework will fit the dynamics of a program. The NCTP framework should evolve based on the perceived needs in the project design cycle and contractor. To properly manage a program some contractors may need more direction and oversight to be successful while other contractors need less because of their experience.

Appendix - Hubble Optics Failure

The Hubble Space Telescope (shown in Figure 4) was designed so that researches could get a better view of the galaxy by observing space through a telescope outside of the earth's atmosphere. Telescopes on earth suffer from distortion due to the atmosphere and clouds, as well as lights from human development. The answer was to build a telescope that could orbit the earth free from these distortions.

The problems with the program began from the very beginning when an unrealistic estimate of schedule and cost were used to sell the project. The initial estimates of the cost of the program were between \$570 million and \$715 million dollars. NASA pressured the program for a cost target of around \$300 million so that the program could be sold. At the HST launch, the program was well over cost at a total of \$2.2 billion dollars, not including the flight to put it into space. The HST experienced many delays in the program which caused it to miss its original launch of 1983. The unit was finally assembled in 1985, NASA had the telescope slated to launch in 1986 but after the tragic loss of the Challenger in January of 1986, the launch was delayed once again. Finally after space operations resumed in 1988, the launch date of April 24th, 1990. This time it would be carried into orbit by the space shuttle Discovery.

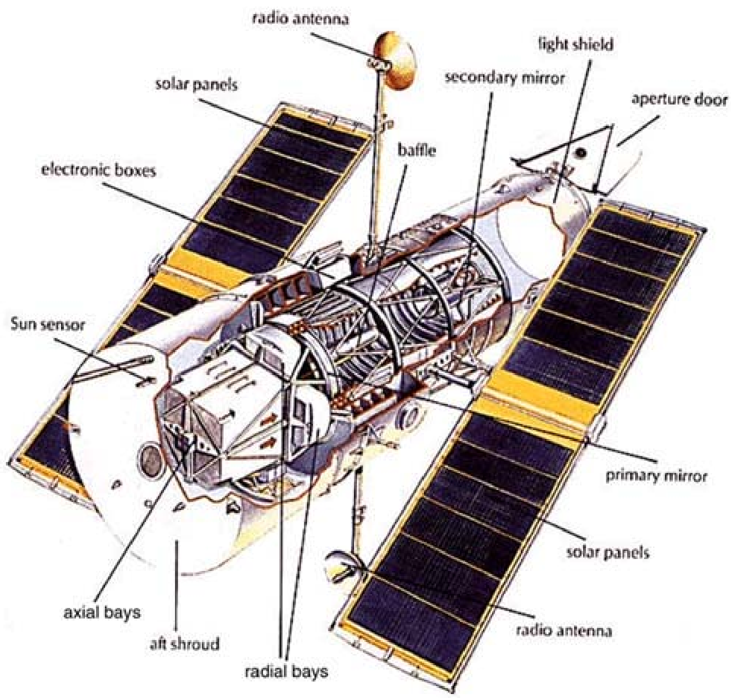

Figure 4 The Hubble Space Telescope
http://www.jackkennedy.net/hubblehuddle.ppt

Shortly after the HST was launched another problem was discovered; the telescope seemed to be displaying distorted images. After a few tests were carried out, it was verified that the primary mirror was causing a spherical aberration due to the primary mirror being out of spec. Analysis of the images from the HST determined that the error rate of the mirror was about ten times greater than the specification in the contract called for.

The mirror in question had been manufactured by the Perkin-Elmer Corporation, so an investigation began on tracing what went wrong in the manufacturing of the optics. The team identified that the Reflective Null Corrector (RNC), a set of optics used to test the primary mirror (shown in Figure 5) was not built correctly. The device is constructed of two mirrors and a lens spaced apart from each other. The spacing of these components was out of spec which threw the polishing of the primary mirror off. The problem was that Perkin-Elmer never carried out any verification of the RNC's dimensions. After much research it was determined that the tests to ensure that the mirror was polished into the correct geometry may have been set up incorrectly, this raised many questions about the manufacturing and the quality inspection of the mirror.

Figure 5 Primary Mirror
http://www.jackkennedy.net/hubblehuddle.ppt

The manufacturing of the mirror was exposed to a single point failure; Perkin-Elmer relied on a single test to verify the mirrors accuracy. Even though signs of the trouble with the primary mirror were present during manufacturing, they were ignored, leading to a very costly repair required. The repairs of the HST required that roughly $20 million dollars were required to repair the spherical aberration of the primary mirror. The mirror itself was not designed to be replaceable so the solution was remarkably similar to what an optometrist would do to fix a humans eye. This mission was called COSTAR, Corrective Optics Space Telescope Axial Replacement. Its purpose was to replace the high speed photometer, and use special relay mirrors on movable arms to correct the light entering the primary mirror removing the spherical aberration.

The Hubble Space Telescope project management had failed two key management points, quality and communication. The Perkin-Elmer team should have looked into the RNC failure further rather than risk a misshapen mirror. Instead no alternate tests were conducted and a mirror ten times out of specification was delivered to NASA for use in the telescope. If the team had communicated its suspicions that the mirror may be out of spec and followed quality procedures, the defects would have been detected and a back up mirror being produced by the Kodak Corporation could have been delivered in its place.

Appendix – Challenger

Following on the heels of the Apollo program, NASA conceived the Space Transportation System (STS). This new program would see to the construction and deployment of a “manned Mars expedition, a space station in lunar orbit, and an Earth orbiting station serviced by a reusable ferry.” (Leveson, 2001, p. 569) In order to realize STS, the level of investment in effort and resources required needed to match, if not exceed that of the Apollo program. This factor weakened the government’s support for STS; ultimately, NASA regrouped and refocused STS primarily around the space shuttle program. Figure 6 identifies the various NASA field centers and their responsibility to the program. Also,

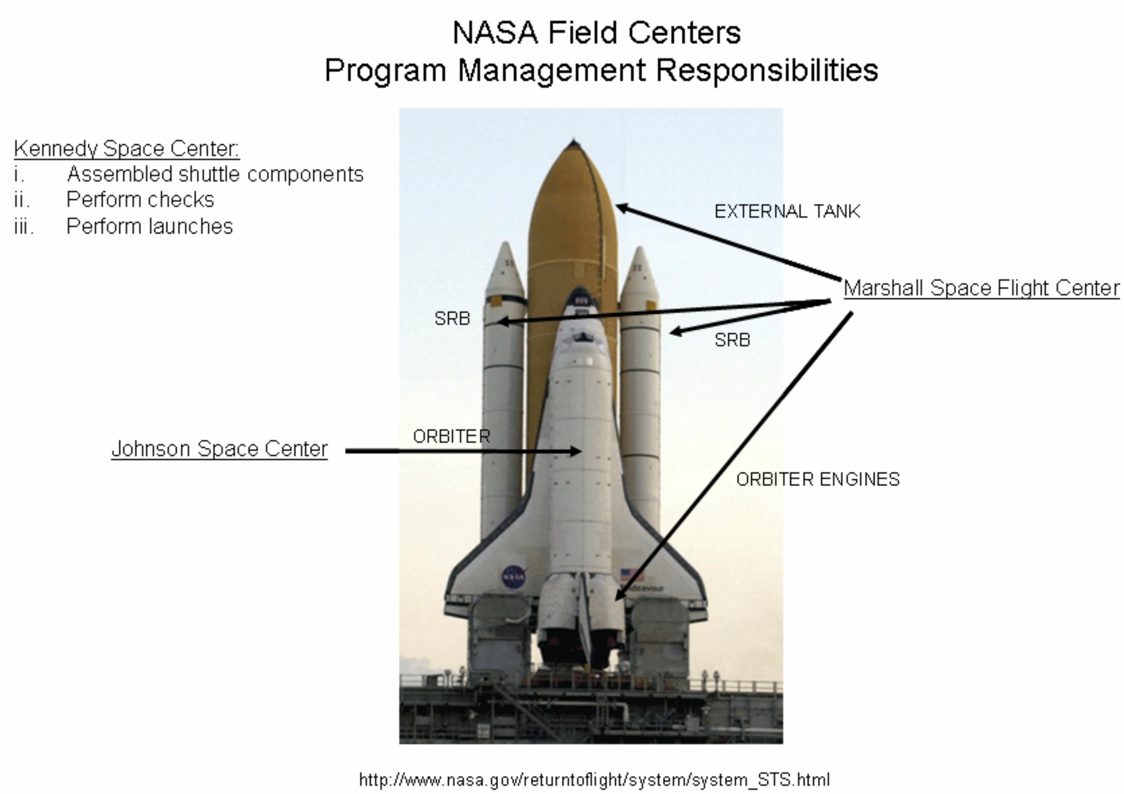

Figure 6 NASA Field Centers for the Challenger Space Shuttle

Figure 7 identifies the contractors involved in the construction of the shuttles main three systems.

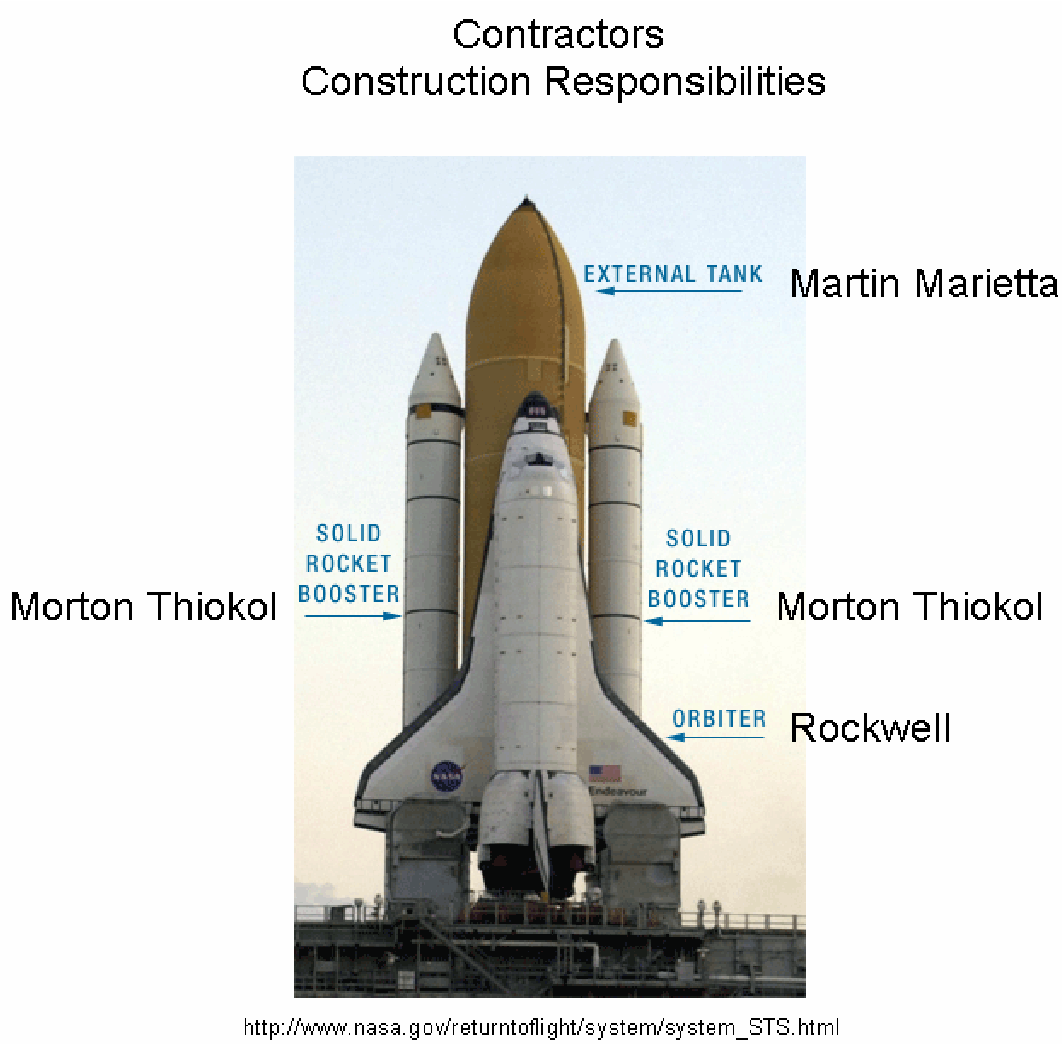

Figure 7 Major Contractors who Worked on the Challenger

Unfortunately, the rescaling of STS to focus primarily on the shuttle program did not ensure the adequate environment needed to construct and maintain the space shuttle program. In fact, budget cuts and constraints continually plagued NASA. Many compromises and sacrifices were made, such as reducing the number of orbiters constructed from five to four. During the operational phase, conditions did not improve. In fact, despite the heavy reliance on the Shuttle to deliver payloads into space, there was "… relentless pressure on NASA to increase the flight rate." (Leveson, 2001, p. 570,) Attempts to increase the flight rate caused reciprocal problems by compressing training schedules, reducing availability of parts, decreasing the amount of skilled personnel to sustain the desired flight operations, etc. The Rogers Commission even noted an alarming perception where NASA assumed "less safety, reliability, and quality assurance activity would be required during routine Shuttle operations." (Leveson, 2001, p.570)

Technically, the Rogers Commission concluded the accident was "…a failure of a pressure seal in the aft field joint of the right solid rocket motor." (Leveson, 2001, p. 570,) The design concept for the solid rocket boosters (SRB) was reused from the U.S. Air Force Titan III rocket. The Titan rocket was used by the U.S. Air Force as a booster rocket to deliver large-class payloads into space and was considered one the best and most reliable. When the Shuttle program reused the Titan's design, modifications were made. Once such significant modification was the addition of a second O-ring, as backup, should the primary seal fail. Unfortunately, adding a second O-ring, engineers lengthened part of the joint and made it susceptible to bending and rotation during combustion pressures.

A Marshall engineer, Leon Ray, noted the bending and rotation caused a "loss of the secondary O-ring as a backup seal." (Leveson, 2001, p. 571) This problem served as a point of contention between NASA and Morton Thiokol. Both sides agreed there was bending or rotation at the joint, but they disagree on the implications. Morton Thiokol "did not believe joint rotation would cause a problem." (Vaughan, 1996, p. 99) Despite these differences, NASA classified the problem 1R in 1980. Classifying the problem as 1R, NASA therefore believed the secondary O-ring was a redundancy and the secondary O-ring would seal if the primary seal failed.

There was another problem contributing to the Challenger disaster. During several exchanges between Morton Thiokol and NASA, the classification of the problem changed from 1R to 1. A classification of 1 indicates a failure could cause the loss of life or vehicle. (Leveson, 2001, p. 751) The Rogers Commission noted that this information did not enter NASA's tracking system. Furthermore, since the data did not enter the system, managers were basing their decisions on incorrect information. This may explain the events surrounding STS flight 41-B, when Morton Thiokol filed a problem report that indicated the secondary O-ring would still seal in the event of a primary seal failure. Both Morton Thiokol and NASA engineers disagreed with this report and believed the O-ring erosion experienced by flight 41-B indicated the O-ring was compromised and would not seal should a primary seal fail.

Up until the Challenger disaster, NASA enjoyed 24 successful launches spanning 57 months. Unfortunately, the problems accumulated over the years would prove insurmountable, and the day prior to the Shuttle launch would seal the fate of the seven crewmembers onboard. This was a day when a temperature mattered. On the January 27, 1986, a Morton Thiokol engineer, Robert Ebeling, called for a meeting with the engineering staff. Mr. Ebeling was concerned about the safety of the Shuttle operating in weather conditions below the certified levels. This was a legitimate concern, considering STS flight 51-C launched in 53 degree environment and experienced "as bad or worse than previously experienced…" (Leveson, 2001, p. 573) This prompted several rounds of meetings between NASA and Morton Thiokol throughout the day and night. During these meetings, Morton Thiokol engineers reviewed the O-ring erosion problem and voiced serious concern for safety of flight. Their recommendation for a delay in launch was staunchly rebuffed by NASA officials – primarily program managers from Marshall. In the end, Morton Thiokol management, and not the engineering team, relented to the pressures of NASA to maintain the launch schedule. The information and events of the meetings between Marshall and Morton Thiokol never reached the higher levels of NASA. So, on January 28, 1986 the crew of the Space Shuttle Challenger perished.

	Novelty	Technology	Complexity	Pace
Actual	Platform	Medium-tech	System	Fast-Competitive
Required	Breakthrough	High-tech	Array	Fast-Competitive

The following worksheets were used to score or grade the Hubble relative to the four dimensions of the NCTP Framework for the actuals and required.

This information was translated from the article "How Projects Differ, And What to Do About It" by Shenhar, S. J., & Dvir, D. (2003, June).

http://webct.stevens.edu/SCRIPT/104962007A/scripts/serve_home

Novelty	Derivative	score	Platform	score	Breakthrough	score
Definition	An extension or improvement of an existing product	0	A new generation in an existing product family	1	A new-to-the-world product	0
Data on Market	Accurate market data exists	0	Need extensive market research Careful analysis of previous generations, competitors, & markets	1	Non reliable market data Market needs not clear No experience with similar products	0
Product Definition	Clear understanding of required cost, functionality, features, etc. Early freeze of product requirements	1	Invest extensively in product definition. Involve potential customers in process. Freeze requirements later, usually at mid project	0	Product definition based on intuition, and trial and error. Fast prototyping is necessary to obtain market feedback. Very late freeze of requirements	0
Marketing	Emphasize product advantage in comparison to previous model. Focus on existing as well as gaining new customers based on added product features and varieties	0	Create product image. Emphasize product advantages. Differentiate from competitors	1	Creating customer attention. Educating customers about potential of product. Articulate hidden customer needs. Extensive effort to create the standard	0
		1		3		0

Max = 3

Choice = Platform

Novelty	Derivative	score	Platform	score	Breakthrough	score
Definition	An extension or improvement of an existing product	0	A new generation in an existing product family	0	A new-to-the-world product	1
Data on Market	Accurate market data exists	0	Need extensive market research Careful analysis of previous generations, competitors, & markets	0	Non reliable market data Market needs not clear No experience with similar products	1
Product Definition	Clear understanding of required cost, functionality, features, etc. Early freeze of product requirements	0	Invest extensively in product definition. Involve potential customers in process. Freeze requirements later, usually at mid project	0	Product definition based on intuition, and trial and error. Fast prototyping is necessary to obtain market feedback. Very late freeze of requirements	1
Marketing	Emphasize product advantage in comparison to previous model. Focus on existing as well as gaining new customers based on added product features and varieties	0	Create product image. Emphasize product advantages. Differentiate from competitors	0	Creating customer attention. Educating customers about potential of product. Articulate hidden customer needs. Extensive effort to create the standard	1
		0		0		4

Max = 4
Choice = Breakthrough

Complexity	Assembly	Score	System	Score	Array	Score
Definition	A collection of components and modules in one unit, performing a single function	0	A complex collection of assemblies that is performing multiple functions	1	A widespread collection of systems functioning together to achieve a common mission	0
Examples	A system's power supply; a VCR, a single functional service	0	A complete building; a radar; an aircraft; a business unit	1	A city's highway system; an air fleet; a national communication network; a global corporation.	0
Customers	Consumers or a subcontractor of a larger project	0	Consumers, industry, public, government or military agencies	1	Public organizations, government or military agencies	0
Form of purchase and delivery	Direct purchase or a simple contract; Contract ends after of product	0	Complex contract; payments by milestones; Delivery accompanied by logistic support	1	Multiple contracts; sequential and evolutionary delivery as various components are completed	0
Project organization	Performed within one organization, usually under a single functional group; almost no administrative staff in project organization	0	A main contractor, usually organized in a matrix or pure project form; many internal and external subcontractors; technical and administrative staff	1	An umbrella organization – usually a program office to coordinate subprojects; many staff experts: technical, administrative, finance, legal, etc.	0
Planning	Simple tools, often manual; rarely more than 100 activities in the network	0	Complex planning; advanced computerized tools and software packages; hundreds or thousands activities	1	A central master plan with separate plans for subprojects; advanced computerized tools; up-to ten thousands activities	0
Control and reporting	Simple, in-house control; reporting to management or main contractor	0	Tight and formal control on technical, financial and schedule issues; reviews with customers and management	1	Master or central control by program office; separate additional control for subprojects; many reports and meetings with contractors	0
Documentation	Simple, mostly technical documents	0	Many technical and managerial formal documents	1	Mostly managerial documents at program office level; technical and managerial documents at lower level	0
Management style, attitude and concern	Mostly informal style; family-like atmosphere	0	Formal and bureaucratic style; some informal relationship with subcontractors and customers; often political and inter-organizational issues	1	Formal, tight bureaucracy; high awareness to political, environmental, and social issues	0
		0		9		0

Max =	9
Choice =	System

Complexity	Assembly	Score	System	Score	Array	Score
Definition	A collection of components and modules in one unit, performing a single function	0	A complex collection of assemblies that is performing multiple functions	0	A widespread collection of systems functioning together to achieve a common mission	1
Examples	A system's power supply; a VCR, a single functional service	0	A complete building; a radar; an aircraft; a business unit	1	A city's highway system; an air fleet; a national communication network; a global corporation.	0
Customers	Consumers or a subcontractor of a larger project	0	Consumers, industry, public, government or military agencies	0	Public organizations, government or military agencies	1
Form of purchase and delivery	Direct purchase or a simple contract; Contract ends after of product	0	Complex contract; payments by milestones; Delivery accompanied by logistic support	0	Multiple contracts; sequential and evolutionary delivery as various components are completed	1
Project organization	Performed within one organization, usually under a single functional group; almost no administrative staff in project organization	0	A main contractor, usually organized in a matrix or pure project form; many internal and external subcontractors; technical and administrative staff	0	An umbrella organization – usually a program office to coordinate subprojects; many staff experts: technical, administrative, finance, legal, etc.	1
Planning	Simple tools, often manual; rarely more than 100 activities in the network	0	Complex planning; advanced computerized tools and software packages; hundreds or thousands activities	0	A central master plan with separate plans for subprojects; advanced computerized tools; up-to ten thousands activities	1
Control and reporting	Simple, in-house control; reporting to management or main contractor	0	Tight and formal control on technical, financial and schedule issues; reviews with customers and management	0	Master or central control by program office; separate additional control for subprojects; many reports and meetings with contractors	1
Documentation	Simple, mostly technical documents	0	Many technical and managerial formal documents	0	Mostly managerial documents at program office level; technical and managerial documents at lower level	1
Management style, attitude and concern	Mostly informal style; family-like atmosphere	0	Formal and bureaucratic style; some informal relationship with subcontractors and customers; often political and inter-organizational issues	0	Formal, tight bureaucracy; high awareness to political, environmental, and social issues	1
		0		1		8

Max =	8
Choice =	Array

Technology	Low-tech	Score	Medium-tech	Score	High-tech	Score	Super High-tech	Score
Technology	No new technology	0	Some new technology	0	New, but existing technologies	1	Key technologies do not exist at project's initiation	0
Typical industries	Construction, production, utilities, public works	0	Mechanical, electrical, chemical, some electronics	0	High-tech and technology based industries; computers, aerospace, electronics	1	Advanced High-tech and leading industries; electronics, aerospace, computers, biotechnology	0
Type of products	Buildings, bridges, telephone installation, build-to-print	0	Nonrevolutionary models, derivatives or improvement	0	New, first of its kind family of products, new military systems (within state of the art)	1	New, non-proven concept beyond existing state of the art	0
Development and testing	No development, no testing	0	Limited development, some testing	1	Considerable development and testing. Prototypes usually used during development	0	Develop of key technologies needed. Small-scale prototype is used to test concepts and new technologies	0
Design cycles and design freeze	Only one cycle. Design freeze before start of project execution	0	One to two cycles. Early design freeze, in first quarter	1	At least two to three cycles. Design freeze usually during second quarter	0	Three to five cycles. Late design freeze, usually during third or even forth quarter	0
Communication and interaction	Mostly formal communication during scheduled meetings	0	More frequent communication, some informal interaction	1	Frequent communication through multiple channels; Informal interaction	0	Many communication channels; Informal interaction encouraged by management	0
Project manager and project team	Administrative skills. Mostly semi-skilled workers, few academicians	0	Some technical skills. Considerable proportion of academicians	1	Manger with good technical skills. Many professionals and academicians on project team	0	Project manager with exceptional technical skills. Highly skilled professionals and many academicians	0
Management style and attitude	Firm style. Sticking to the initial plan	0	Less firm style. Readiness to accept some changes	1	More flexible style. Many changes are expected	0	Highly flexible style. Living with continuous change, 'looking for trouble'	0
		0		5		3		0

Max =	5
Choice =	Medium-tech

Technology	Low-tech	Score	Medium-tech	Score	High-tech	Score	Super High-tech	Score
Technology	No new technology	0	Some new technology	0	New, but existing technologies	1	Key technologies do not exist at project's initiation	0
Typical industries	Construction, production, utilities, public works	0	Mechanical, electrical, chemical, some electronics	0	High-tech and technology based industries; computers, aerospace, electronics	1	Advanced High-tech and leading industries; electronics, aerospace, computers, biotechnology	0
Type of products	Buildings, bridges, telephone installation, build-to-print	0	Nonrevolutionary models, derivatives or improvement	0	New, first of its kind family of products, new military systems (within state of the art)	1	New, non-proven concept beyond existing state of the art	0
Development and testing	No development, no testing	0	Limited development, some testing	0	Considerable development and testing. Prototypes usually used during development	1	Develop of key technologies needed. Small-scale prototype is used to test concepts and new technologies	0
Design cycles and design freeze	Only one cycle. Design freeze before start of project execution	0	One to two cycles. Early design freeze, in first quarter	0	At least two to three cycles. Design freeze usually during second quarter	1	Three to five cycles. Late design freeze, usually during third or even forth quarter	0
Communication and interaction	Mostly formal communication during scheduled meetings	0	More frequent communication, some informal interaction	0	Frequent communication through multiple channels; Informal interaction	0	Many communication channels; Informal interaction encouraged by management	1
Project manager and project team	Administrative skills. Mostly semi-skilled workers, few academicians	0	Some technical skills. Considerable proportion of academicians	0	Manger with good technical skills. Many professionals and academicians on project team	0	Project manager with exceptional technical skills. Highly skilled professionals and many academicians	1
Management style and attitude	Firm style. Sticking to the initial plan	0	Less firm style. Readiness to accept some changes	0	More flexible style. Many changes are expected	1	Highly flexible style. Living with continuous change, 'looking for trouble'	0
		0		0		6		2
Max =	6							
Choice =	High-tech							

Pace	Regular	Score	Fast-Competitive	Score	Blitz-Critical	Score
Definition	Time not critical to organizational success	0	Time to market is a competitive advantage, and has an impact on business success	1	Time is critical for project success. Delays mean project failure	0
Examples	Public works, government initiative, internal projects	0	Business related projects, new product introduction	1	Crisis situations, war, fast response to natural disasters, fast response to business related surprises	0
Organization	Matrix or functional	0	Matrix, teams, subcontractors	1	Pure project, special task force	0
Personnel	(none)	0	Qualified to the job	1	Specifically picked	0
Focus	No particular focus	0	Strategically focused on time to market	1	Swift solution of the crisis	0
Procedures	No specific attention	0	Structured procedures	1	Shortened, simple, nonbureaucratic	0
Top Management Involvement	Management by exception	0	Go ahead at stages	1	Highly involved and constantly supportive	0
		0		7		0

Max =	7
Choice =	Fast-Competitive

Pace	Regular	Score	Fast-Competitive	Score	Blitz-Critical	Score
Definition	Time not critical to organizational success	0	Time to market is a competitive advantage, and has an impact on business success	1	Time is critical for project success. Delays mean project failure	0
Examples	Public works, government initiative, internal projects	0	Business related projects, new product introduction	1	Crisis situations, war, fast response to natural disasters, fast response to business related surprises	1
Organization	Matrix or functional	0	Matrix, teams, subcontractors	1	Pure project, special task force	0
Personnel	(none)	0	Qualified to the job	1	Specifically picked	0
Focus	No particular focus	0	Strategically focused on time to market	1	Swift solution of the crisis	0
Procedures	No specific attention	0	Structured procedures	1	Shortened, simple, nonbureaucratic	0
Top Management Involvement	Management by exception	0	Go ahead at stages	1	Highly involved and constantly supportive	0
		0		7		1

Max = 7
Choice = Fast-Competitive