Human Factors in Mission Assurance

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Abstract—Space projects rely completely on people for development and implementation—but project-related risk lists rarely include human factors as significant sources of risk. This paper is an attempt to identify and explain the important human factors that are related to mission success. The paper is based on interviews with Mission Assurance professionals, NASA and military reports and studies, and other literature. It identifies four types of human factors related to mission success: (1) adherence to processes and principles; (2) definition and fulfillment of roles, responsibilities, and relationships for organizations and individuals; (3) individual success factors and (4) communication within the project. There are examples of mission threats or mishaps from causes related to these factors. The paper notes mitigation techniques for risks associated with the human factors—readers are encouraged to come up with as many mitigation strategies as possible, and share them with each other!

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1. INTRODUCTION

Anyone who works in "the space business" has a solid emotional motivation toward mission success. That motivation is reinforced whenever a mission fails, in any way. How? Picture yourself standing on the sidelines at your child's soccer game, and during that hour at least two or three other parents begin a conversation with you by saying, "Hey, what happened to that Mars satellite, huh?"

When a commercial product, say, a coffeemaker, fails in some way, the company that made it and marketed it will hear about the problem from customers. If the problem has enough effect, they may also hear from stockholders, and sometimes the SEC or Federal Trade Commission.

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When a space mission fails, we hear about it from our next-door neighbors. They don't usually consider the complexity and difficulty of what we attempt, nor the delicacy of the technology we employ, nor even the harsh and brutal environment where our products are expected to perform. No, the view our neighbors have is always the same: somebody messed something up.

They are pointing to an important issue, although not the one they think. The kind of space missions typically run by NASA, the military, and other civil agencies, use robotic spacecraft and instruments to gather information, to make some kind of observation and report back to people. These robots, are conceived, built, and operated by people—not by other robots.

So when we have tried to ensure mission success, when we were doing everything we could to mitigate technical and resource risks to the mission, were we considering the human factors that could affect it?

Usually we weren't. That is, until NASA's Integrated Action Team (NIAT) told everyone that paying attention to human issues, individual and team-related, was important. This paper is a start at defining what those human factors are, and how to pay attention to them.

Identifying the Human Factors

I started by conducting interviews with individuals who had personal experience in project mission assurance, some of them on more than one level:

- *John Schlue,* a Mission Assurance line manager at JPL, formerly a project Mission Assurance Manager;
- *Brett Watterson,* JPL's Systems Safety Office manager, a former mission assurance practitioner in the military;
- *James Clawson,* manager of the Reliability Office at JPL, and the Mission Assurance Manager for the Mars Pathfinder project;
- *William O'Neil,* manager of JPL's Galileo project during much of its mission operations phase;
- *Norm Haynes,* former Director for Telecommunications and Data Acquisition at JPL;
- *Sammy Kayali,* manager of JPL's Electronic Parts Engineering Section;

- *Phil Barela,* Mission Assurance Manager for the Mars Reconnaissance Orbiter project;
- *Trish Smith-Araki,* manager of JPL's Occupational Safety Office.

After collecting opinions, definitions, anecdotes and various philosophies from these practitioners, I took a look into written works related to the subject, from papers and articles, to NASA's own web site on Safety and Mission Assurance, to reports and studies regarding both civil and military mission failures.

Of special consideration was the report by NASA's Integrated Action Team (NIAT) entitled "Enhancing Mission Success-A Framework for the Future." The report was developed partly in response to failures of two Mars exploration missions, partly in response to a "close call" involving Shuttle wiring, and partly as an assessment of NASA's "Faster-Better-Cheaper" approach to mission implementation and management.

I sorted out four types of human factors that seemed to relate strongly and consistently to mission success; I've listed them here, and deeper explanations of them make up the rest of this paper:

1. Adherence to processes and principles.
2. Definition and fulfillment of roles, responsibilities, and relationships for organizations and individuals.
3. Individual success factors.
4. Communication among project components.

These factors contain the issues that can make space projects not only successful, but fun and interesting to work on. The same issues, when ignored, can destroy hardware, missions, reputations and careers.

For each of the factors, I've tried to identify some specific examples of the type. When possible, I've included some samples of missions that may have been affected by that factor, and recommendations for addressing that factor.

2. Processes and Principles

Processes are linked activities that input resources and output a product. Procedures are the activities they link, that accomplish specific parts of the work step-by-step. In organizations that produce products as complex as the ones we produce, the work processes have probably been studied, improved, documented, optimized, re-engineered, standardized, and trained. What these organizations have found is that unless the processes are actually *followed,* they have little influence on mission success—and when they are not followed, they have a large influence on mishaps.

Principles are values—they are basic assumptions about what characteristics (of work or of ourselves) are important to achieving the results we want, or important to achieving a positive attitude about the work and its results. Principles are not imposed rules, they are part of a cultural heritage, they are "the way we do things around here."

Let's take a look at some of the person-to-person processes and principles that clearly contribute to mission success.

Sharing Lessons Learned

Following a series of Titan and Delta launch vehicle mishaps in 1998 and 1999, the U.S. Air Force conducted a Broad Area Review (BAR) to identify and recommend measures of prevention to the Secretary of the Air Force. One of the strongest recommendations to come from the BAR was for the Air Force's Space and Missile Systems Center (SMC), the Aerospace Corporation, and the rocket contractors to share Lessons Learned—across programs and across the many contractor companies. This involved a new and perhaps controversial principle, that of sharing information among competitive contracting companies, for the good of the entire launch program. So the BAR also recommended that the Systems Program Office (SPO) for these launches and the Aerospace Corporation assign a team to develop a formal process for sharing Lessons Learned. This allowed the new principle to be embedded in a new process that had to be practiced, and facilitated assimilation of the principle. As of December 2002, there have been no further launch vehicle failures, even on the first launches of the Evolved Expendable Launch Vehicles, Atlas V and Delta IV.

Both NASA and JPL have had formal Lessons Learned processes for several years. Maintaining a focus on process in managing JPL projects, the Project Support Office is frequently building new Lessons Learned into the Flight Project Practices and Design Principles, JPL's set of principles that guide project implementation. Technical Lessons Learned are continually being built into the technical processes and procedures owned by the Engineering and Science Directorate at a variety of organizational levels.

Proposal Process

Some organizations that run missions must propose to their sponsoring agencies or departments, through task/work plans or through a formal proposal process. Translating science or military requirements into a realistic project plan is difficult for a "first-time, one-of-a-kind" mission.

The environments of "Faster-Better-Cheaper" (NASA) or "Streamlined Acquisition" (DoD)—prevalent for the last ten years—increased pressure to keep costs within arbitrary caps. According to Sammy Kayali and John Schlue, many proposals were not very good deals—even though they were written with the best intentions. Schlue suggests that, since proposal managers could only feel successful if their proposal was accepted, they tried to match unknown

expectations of the judges with regard to cost, schedule, and mission performance—and then write their proposals to match those expectations, rather than real world capabilities and costs.

A JPL Special Review Board investigated and reported on the loss of the Mars Polar Lander (MPL) and Deep Space 2 (DS2) missions, and found that the combined development cost of MPL and MCO [Mars Climate Orbiter], including the cost of the two launch vehicles, was approximately the same as the development cost of the Mars Pathfinder mission. The Board reported, "the complexity and technical challenges for MPL were at least as great, if not greater [than Pathfinder]." Since JPL had to manage the project with a small team to maintain the cost cap, "there was essentially no JPL line management involvement or visibility into the project," and "minimal involvement by JPL technical experts." (For more on line involvement in projects, see the section 3 of this paper.)

One Mission Assurance manager believes that not enough people, and sometimes not the right people, were involved in the proposal process: "Sometimes we [Mission Assurance] think the project people signed up to do the wrong thing. When we [JPL] propose projects, the bid comes from the ivory tower, not from the people who had to do the project! Mission Assurance should be involved from the beginning, in the proposal – but who will pay, who can coordinate the holistic Mission Assurance presence?"

Staffing Projects

The Mars Polar Lander Review Board found that many key technical areas were staffed by only one individual from JPL and that inadequate peer interaction was, in retrospect, a major problem. The Board believed that JPL's technical people had "insufficient time to reflect on what may have been the unintended consequences of day-to-day decisions."

The Review Board recommended that future projects not allow important activities to be implemented by a single individual without appropriate peer interaction, and that JPL establish standards for its own technical involvement in system contracted projects, including line management oversight.

The bottom line of the Board's report? Don't underbid projects, make sure you have enough money available to pay enough people who know what they're doing.

Anomaly Reporting Process

Just about every engineering organization, in just about every industry, has an anomaly reporting process. Whether the process is effective or not depends on how well it is used—and how people are treated who report problems. In organizations with strong "shoot the messenger" cultures, most employees will avoid bringing bad news to members of their management. For organizations with a culture focused most on individual competence and independence, project team members may not bring reports of anomalies to their line organization experts, believing that seeking such help will make them appear incapable.

In its "Report on Project Management in NASA," the Mars Climate Orbiter Mishap Investigation Board identified a "lack of discipline in reporting problems and insufficient follow-up" in the MCO mission." They reported: "This was at the heart of the mission's navigation mishap. If discipline in the problem reporting and follow-up process had been in place, the operations navigation team or the spacecraft team may have identified the navigation discrepancies, using the Incident, Surprise, Anomaly process, and the team would have made sure those discrepancies were resolved."

The Air Force directed implementation of its policy on Operational Safety, Suitability, and Effectiveness (OSS&E) as a result of flight mission mishaps related to performance not aligned with appropriate processes and practices. A B1 bomber mishap, for example, was traced to a flawed design in which best design practices were not consistently followed. The crash of a C-21 commercial Lear jet, with the Acting Secretary of the Air Force on board, was traced to the flight crew not following the latest technical procedure used to correct a fuel imbalance problem.

3. Roles, Responsibilities, Relationships

Project-Line Interaction

In September 1999, NASA's Mars Climate Orbiter (MCO) mission was lost during the maneuver that should have inserted it into orbit around Mars. JPL's Special Review Board investigated and reported on the loss of the mission, determining that the loss was "precipitated by an error in the software program that generated the Angular Momentum Desaturation (AMD) files."

When analyzing why such an error was not recognized either prior to launch or during cruise when trajectory corrections were being made, one of their most important findings was that there was "insufficient interaction between the MCO project and the line organization." Their report expanded on this theme: "A timely involvement of experienced navigation experts would have revealed the small forces inconsistency or, failing that, should have led to an appropriate characterization of the targeting uncertainty."

Most aerospace organizations that actually build something are matrix enterprises and have both programmatic and line organizations. (This includes JPL, as well as a lot of companies.) Since the line organizations are the residence of long-term, comprehensive functional and discipline knowledge, they are the logical place for programs or projects to get technical help with development or operations anomalies.

JPL has published guidelines for the way projects and line organizations are supposed to work together, under the title "Implementing Projects in JPL's Matrix: Project-Line Interaction." The roles of each are defined clearly, and the responsibilities of each toward project work are listed and explained. The document describes the process by which project and line agree on what work will be done, and what products or services will be provided. These guidelines are institutional policy, "owned" by JPL's Deputy Director, and are taught during management training for both project and line managers. Project and line managers document their commitments in Work Agreements, formal statements of the work to be performed, its duration, its final products or services, and its cost.

Project-Contractor Interaction

In many ways, a contractor company is another version of a line organization. But that resemblance is on the surface, according to James Clawson. He pointed out that the cultural imperatives of a government organization (either military or civil) might be very different than those of a commercial, profit-making company.

An example: most contractor organizations are not used to *writing down* an anomaly in a formal resolution process. Commercial corporate cultures frequently embed the "shoot the messenger syndrome" to a degree rarely seen among government agencies, which are used to documenting every smallest discrepancy as a part of the "CYA syndrome." Often, contractor personnel want to learn more about a problem and discuss it from all sides before writing it down and invoking a formal resolution processes—which would involve their management's cognizance.

For government agencies running a mission, the difference between actual costs and planned costs is reserve, and can be applied to the work when necessary to improve technical performance, reduce risk, or correct problems. For a company working on a mission, the difference between their costs and the amount they charge their sponsor is profit, something their shareholders and management like to see maintained and not used for anything except dividends. This distinction influences decisions made regarding risk and performance, at every level of the company.

Do contractors care about more than the bottom line, though? John Schlue suggests that project leaders must pay attention to what contractors want from the relationship with their sponsor, and that it's usually more than money. Contractor personnel working on the project have the same drives for achievement, creative endeavor, recognition, and self-actualization the project leader does. If the sponsor's project leaders are the "brains" and the contractor people are just the "hands" of the work, contractors have no motivation for superior performance. (Behavioral scientist Frederick Herzberg studied human motivation in the workplace for over twenty years, and demonstrated through his research that achievement, peer recognition, and creative impact are the strongest motivators for superior performance. He found that hygiene factors such as high pay and good working conditions did not motivate superior performance, but demotivated workers when they were not present.)

The Role and Relationship of Mission Assurance

James Clawson believes Mission Assurance and the project organization should spend some time defining boundaries, overlaps, and interfaces for how they will work together to complete the project: "There are Mission Assurance Principles, Flight Project Practices, and Design Principles, there should be Human Interaction Principles that guide how people work and work together on projects."

Phil Barela suggests that one of the most important human factors in Mission Assurance is the relationship between the Mission Assurance Manager (MAM) and the people in the various technical disciplines, both inside and outside the Mission Assurance organization. "MAMs should consult regularly within their line organization; they need group meetings to help them balance their way of looking at the project. They need regular contact with discipline peers and management, to keep line management engaged in the project work."

Barela also believes that the Mission Assurance Manager and Project Manager should spend time "working out the best ways to work with each other, and establishing clear definitions of priorities on every subject."

Sammy Kayali identified three different roles that a Mission Assurance specialist can play, with regard to the project team. "You are a team member of the project, but you can be a 'policeman,' a 'repairman,' or a 'social worker' in the way you work with the others. Sometimes you are a little of all three."

He defines the "policeman" role as most distant emotionally from the rest of the project team, "making people stop their work and fix their problems before going on." The "repairman" role is the opposite, taking on the work of fixing the project's problems yourself. The "social worker" role is most difficult, "acting as a consultant to steer people away from problems, helping them prevent their own problems rather than just bailing them out."

4. Individual Success Factors

"Individual success factors" is the name I give to aspects of the individual worker's relationship to the work. These factors all contribute to the individual's ability to complete the work successfully (where success is defined by project leadership). The individual has control or influence over some of these factors -- people always play a role in

developing their personal capability and competence, for example. Organizational management has control over others, such workload and project assignments, maintaining a safe working environment, and empowerment for various levels of working decisions.

Health, Safety, and Workload

The Health and Safety section of NIAT's report indicates that increased demands placed on employees have caused significant stresses on physical and psychological health and "increase the potential for safety-related errors." The report states, "The greatest factor contributing to this stress is not having enough people with the proper skills, combined with an increase in workload. The basic nature of the work of NASA—high visibility and high risk—can create stress that is further compounded by short deadlines, increasing hours, and fatigue. Stressful situations at work exact an emotional, physical, and productivity toll on the performance of NASA's employees and organizations. They also create the potential for safety-related errors."

The Review Board for the MPL mission loss identified a similar issue, and pointed out the danger of "single-string" project assignments. The Board recommended that JPL "Revise institutional policies and procedures as necessary to preclude personnel working excessive overtime (paid or unpaid)...without senior line management approval."

Norm Haynes described the cultural character of JPL employees as contributing factors to personal stress: "They have a character of perfectionism and perseverance, which may make for Lab success, but sometimes not for mission success. Stress comes from an inability to predict or control what's going to result from your work, from deadlines and milestones that cannot be stretched [in planetary missions]. Frustration comes from not being able to do the work the way JPL perfectionists want to do it; they can't keep up with the demands on their energy."

Empowerment

Defining criteria for empowerment and independence on the project team involves finding cooperative ways of enforcing independence. Unfortunately, the term "empowerment" is frequently used interchangeably with "authority" (which has a different meaning), and without its true context of personal responsibility.

Individuals on project teams will feel responsible for mission success, and exercise their best judgment in finding and resolving problems or risks, if they feel comfortable in calling attention to those risks, and if they are expected to solve those problems in their own corporate culture. Dr. Charles Elachi, Director of JPL, recently told Systems Division employees in an informal meeting, "Don't think that you work for Division 31, you don't. You work for JPL, and through JPL you work for NASA. Your concerns must be for the overall success of the Laboratory and the Agency's missions, not local in your discipline."

The MCO Investigation Board pointed out in their report, "The primary, structured problem-reporting procedure used by the Jet Propulsion Laboratory—the Incident, Surprise, Anomaly process—was not embraced by the whole team. Project leadership did not instill the necessary sense of authority and responsibility in workers that would have spurred them to broadcast problems they detected so those problems might be articulated, interpreted and elevated to the highest appropriate level, until resolved."

Capability and Competence

The NIAT report includes a section on Development of the Workforce, which recognized that "the increase in projects accompanied by a reduction in experienced practitioners demands greater attention to the process of developing and supporting the workforce."

The report explains: "Teams are successful when they have the right people with the right skills at the right time. The single, most important aspect of project success is the performance of the project team. The right staffing of project teams includes consideration of technical skill, interpersonal skills, and resources." NIAT charges project managers to ensure that teams are composed of competent personnel and to select the right team skills for the current phase of the project's life cycle.

Both NASA and the military have traditional programs for development of project personnel competence, and both have considered certification processes for selection into key project leadership positions. Human development has become so great an issue in NASA that the latest set of project management instructions, NPG 7120.5B, includes an entire section explaining Agency expectations regarding the management and development of the people who work on projects.

5. COMMUNICATION

NASA's Integrated Action Team report emphasized the importance of communication to mission success: "The essential knowledge for success is embedded in the systems and processes used within the Agency and the skills of NASA employees and partners. This knowledge is what makes NASA uniquely capable. It is not easy to capture and share information and key lessons across the Agency. To succeed, NASA must sustain an open learning environment that is facilitated through an effective communications process."

Team-to-Team Communication

JPL's Special Review Board for the Mars Climate Orbiter loss found that a lack of team-to-team communication was a

factor in the MCO failure. They pointed out that the problem during flight could have been resolved with better communication among the navigation team, the spacecraft team, project management, and line management—examples of communication that needed improvement are:

- Navigation team to spacecraft team communication to diagnose the Y-axis force level
- Navigation team to project management communication to stress the level of concern
- Project management to spacecraft communication to get action on the issues raised by the navigation team

The Board recommended that future projects emphasize cross-team knowledge and team-to-team communication through system and subsystem orientation seminars and training sessions. It also recommended that individuals on each system or subsystem team be designated as points of contact for technical issues raised by other teams.

Building Teams and Trust

The NIAT report describes trust as one of the most important enablers to effective communication: "Team members must feel free to express concerns without fear and openly communicate potential risks and issues... Barriers that can inhibit effective communication, such as lack of effective tools, travel constraints, organizational and cultural barriers, fear, and lack of trust, must be minimized."

Many projects conduct focused team development aimed at creating an environment of trust, right at the beginning of the project. In a paper on project team leadership, former JPL program office manager Frank Schutz said, "Establishing team-building processes addresses the need to build the trust and confidence of the people, who are responsible for the work, both internal to the team and with the team leadership. The leader must be confident that the team is going to do what it collectively and individually says, through its work plans, that it will do. When the team trusts its leadership, it develops confidence that its planning approach is acceptable and that it will be measured only against the plans that it created."

6. Optimizing the Human System

In 1998, NPG 7120.5A, "NASA Program and Project Management Processes and Requirements," established a disciplined, defined risk management process, that requires all projects to develop a risk management plan, and present their critical risk list during the formulation phase for review by their Governing Program Management Council (GPMC). Where new risks arise, they are incorporated into the risk management process and reviewed by the GPMC, creating a reward structure for finding problems first.

Since there are clearly human factors that create project schedule, budget, and performance risk, these factors should be included in every project's Risk Management Plan. They should be mitigated with as much enthusiasm and integrity as technical risks are, until they are either retired or accepted. I have included some ideas on mitigation that may not be suggested in the rest of the paper.

Processes and Principles

Every project should develop and teach principles and processes for human interaction. They should devise a flow of interactions and communication, and especially a process for identifying and resolving personal conflicts, whether those conflicts are idea-based or related to disagreements about roles, responsibilities and relationships. Both contractors and sponsors should be included in the process development, and in process implementation.

Roles, Responsibilities, and Relationships

Every project should develop role and responsibility definitions for all of its key project team members. Every project element should do the same. These are not items that can be left to assumption, or to line management to take care of, they must be done within the context of the project.

Individual Success Factors

Project leaders should interact with the members of their own team on a regular basis, and pay attention to their health, focus, and individual capability. If project personnel require additional competence, project leaders should identify sources for acquiring that competence, and support the people in getting it.

Project leaders should make sure the members of the project team understand, and resonate with, the meaning of their work—how it affects the success of the project as a whole, the success of their agency or company, and their own, personal development. Creating meaning in a project team's work life provides an emotional and intellectual support for the acceptance of responsibility for successful work.

Communication

Every project should conduct focused team building at project start, including sponsor representatives and contractors in the activities.

Project leaders should create a recognition system that rewards project team members for identifying risks and problems, and for working to develop mitigations and solutions for them.

Summary—Optimizing the Human System

Four types of human factors seem to affect mission success strongly and consistently, and project leaders must pay attention to these factors:

1. Adherence to processes and principles—adopting, using and adapting the values and methods that are proven most likely to produce successful results.
2. Definition and fulfillment of roles, responsibilities, and relationships for organizations and individuals—making certain that expectations about work, accountability, and interaction among people are clear and understood.
3. Individual success factors—ensuring that individuals working on the project are personally capable, and the structure of the project allows them to use their abilities effectively.
4. Communication among project components—allowing and encouraging individuals and groups in the project to exchange not just information, but the *meaning* of that information to the common goal of project success.

Attention to these factors will help make our national space program successful, and allow our technical excellence to show and shine.

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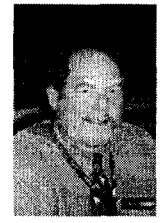

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