Managing Projects -- An Industry View

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The project manager is the leader of a team of people charged with converting a broad set of mission objectives into an operating system. Project management is the set of principles and processes used by a team to manage a project from its birth to the end of its life cycle. These principles and processes encompass all the skills needed to plan, organize, direct, staff, and control the project. My comments in this article are based on nearly 30 years of experience in industry serving a variety of customers, including NASA, DoD, other government agencies, and industrial and commercial end users. My examples are drawn from the Space Shuttle project.

Essential Concepts: Dynamic Process, Committed People, Communications

Today's manager must thoroughly grasp these three concepts -- have a working knowledge of them -- in order to successfully run a major project.

First, project management is a dynamic process. Managers operate in an environment where priorities shift and decision criteria change as a project progresses. Technology progress usually occurs differently than planned: funds are being expended, new people are coming aboard, and schedule commitment dates are coming closer. As a project gains momentum, it becomes harder and harder to shift direction and increasingly more important to make timely decisions.

Second, project success is achieved through the hard work of committed people. They are willing to overcome the hurdles, surprises, changes, problems, and heartbreaks that occur during project life. These people can be found at every level: on the factory floor, at the engineering workstation, in the schedule control office, at the shipping desk, in the launch Center, at mission control, in the controller's office, in the program office, within the congressional staff, and also within the executive offices. It takes committed people from all functions within all involved organizations to ensure that a project stays within performance, cost, and schedule commitments.

Third, communicating relevant information about the project -- upwards, sideways, and downwards -- is the cohesion that keeps the total team in a consistent direction. Information needs are different at each level of the project organization. Information needs at Headquarters to support a decision made by Congress on future funding are different than those of a Center project manager to support a decision on the allocation of resources among project elements. Still different are the needs of an industry line manager to support a decision on staffing for a six-month period, or a subcontract manager to allocate resources among companies. We often make the faulty assumption that all those involved in the project know what is going on. Communicating relevant information, either on project status or sharing a problem, is a principal mechanism for ensuring that the project will be successful.

However, before discussion of dynamic process, committed people, and communicating relevant information it is further necessary to understand two related subjects: quality and requirements.

Understanding Quality: An Attitude

Quality as a concept is often misunderstood. The contemporary definition is "meeting the requirements established for the system." For example, the functional requirements at the system level, specifications at the end-item level, the inspection process at the manufacturing level, and documentation at the test level are all requirements to be met.

Confusion often arises among the concepts of quality, safety and reliability, and product assurance. In both manned and unmanned space systems, stringent requirements are established for safety and reliability on the basis of the consequences of losing the payload or the launch vehicle. However, safety and reliability are similar to other performance requirements, although their priority in the requirements tree might be quite high. Similarly, a set of requirements is established for the processes needed to implement product assurance. Quality, in my view, is an attitude of commitment to perform to those requirements.

In systems design, development, and operations, requirements are established to ensure a system will do its intended job. Therefore, no compromise is made with respect to quality. If the system does not meet its requirements, then either it must be fixed or the requirement re-examined and changed to fit the behavior of the built system, if its intended job can still be performed. Although this might seem to be an extremely expensive way to operate, it is my experience that meeting the requirements or equivalently building a quality system is most cost-effective. The issue is making sure the requirements are correct; there are no options on quality. There is no substitute for producing a system that will do the intended job.

Understanding Requirements: The Foundation

When a project is initiated, the manager has three available resources: the mission objectives; the current state of the art technology (in its broadest sense -- tools, devices, standard specifications, and processes); and collective past experience. Very often, the mission objectives are a mixture of requirements and design. The state of the art of technology weaves its way into the requirements by the fact that many requirements are, in reality, point solutions rather than statements of the problem. Past experience is very valuable when properly used, but all too often we embed requirements that solve a problem no longer relevant to the one at hand. These distortions of true requirements can limit our ability to use technology advances creatively.

An essential task for the project management team is to ensure that requirements are precise and operationally valid and that sufficient time is allowed to iterate them in order to assure the simplest implementation. Requirements imposing unneeded constraints and unnecessary complication must be changed. In the ideal world, the "systems engineering process" should ensure that this task is completed before full-scale development begins. Since this does not always happen, it pays to scrub the requirements hard at the beginning, before trouble occurs, rather than wait for a crisis. I can guarantee that there will be many occasions to review the requirements during the life of the project.

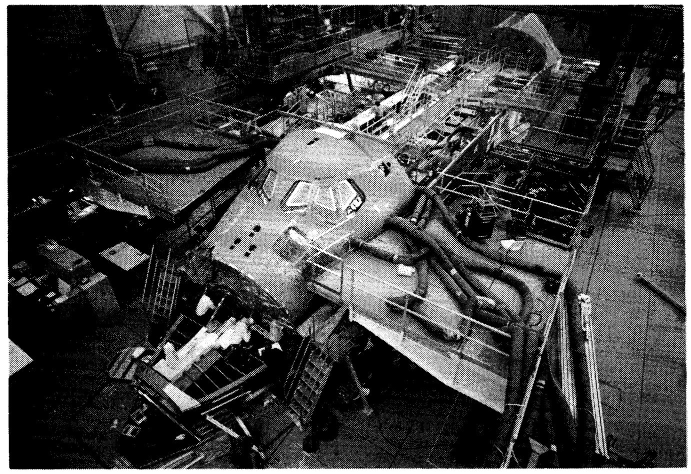
LESSONS LEARNED FROM THE SHUTTLE PROGRAM

The Space Shuttle program was unique in that only a very few key personnel changes occurred from the start of development in 1972 until first flight in 1981. This was true for NASA, at Headquarters and the Centers, and for the prime contractors. Most projects, however, see a greater turnover during a development period as long as this. This particular group of people also had some unique shared experiences, having come through the Moon landing program and the Skylab program together. Many of the people were also involved in the earlier Phases A and B (conceptual and design) studies and had participated in a very large number of trade studies, from configuration to technology to ground support concepts.

My experience did not include the early programs or trades; and as I started on the Shuttle, I felt as if I were jumping aboard a racing train. As soon as I became involved in the decision-making process, it became apparent that external ground rules and constraints were changing, that resources needed to be shifted, and that many of the technology choices would have to be re-examined. The project stayed at this pace throughout the development cycle. Further, it was a resource-constrained program, constantly trading schedule for current dollars -- similar to many of today's programs. I will review some of the situations that occurred during the Shuttle development and extract some beneficial lessons.

Requirements and Early Design. During the early design phase, there is constant pressure to meet drawing release schedules; often mistakes can be made by releasing drawings before an adequate number of design iterations occurs. On the Shuttle project, experienced designers often withstood these pressures and ensured that their designs would meet performance requirements while staying within cost and schedule constraints. Sometimes -- due to pressure or inexperience -- they did not achieve this balance, for there is a fine line between being ready to release and embellishing the design.

The biggest payoff for reducing cost and improving operating characteristics occurs in the early design cycle. Current concepts, such as "Simultaneous Engineering" and "Total Quality Management," involve the total team (engineering, manufacturing, test, logistics, etc.) early in the design cycle. The objective of these concepts is to simplify the total production process, recognizing the value of design iterations.



The Space Shuttle Discovery final assembly and installation operations took place at Palmdale, CA.

The system implementation is reflected in a series of plans, i.e., engineering, software, procurement, quality assurance, manufacturing, etc. As iterations are made to improve performance, cost, and/or schedule, these plans must be kept in step. Early attention to long-lead items, critical processes, facilities tooling, and test needs will prevent future problems. These plans, when properly formulated, are the means to communicate direction to the project team and measure project progress. As a project manager, one must keep the pace moving quickly. One must always balance schedule pressure, the quality of the technical output, the implementation risk, and cost.

Mid-course Correction. The time span from preliminary design review (PDR) to critical design review (CDR) varies from project to project. It is a period of significant change: expenditures are increasing as prototypes and breadboards point to the need for technical changes. Often annual funding limits and other external events result in considerable schedule pressure, causing severe competition for funds among project elements. As project manager, one almost has to anticipate where the problems will arise and be prepared to make adjustments. Problems can take the form of schedule, dollar, design, or requirements changes.

During this period, there is time to change the implementation characteristics of the system. However, project managers should ensure that the data they are receiving are real (i.e., they must spend time visiting the development contractors -- within the company and at subcontractor and associate contractor sites). When these implementing organizations understand the need, the project manager will find that their ability to react to change is far better than either might think. Not making a decision to adjust can be far worse than a non-optimal decision. Conversely, constant changes can result in chaos. It takes a seasoned team to make the right decisions and maintain configuration control.

The Build Cycle. In the ideal world, production fabrication occurs only after the design is thoroughly reviewed, all parts function as specified and are received on time, all software is received on time and perfectly matches the hardware, all subassembly qualifications are complete, all assembly and installation processes are perfect, and the expenditures of those functions that have finished their work are rapidly decreasing. In the real world, this rarely occurs.

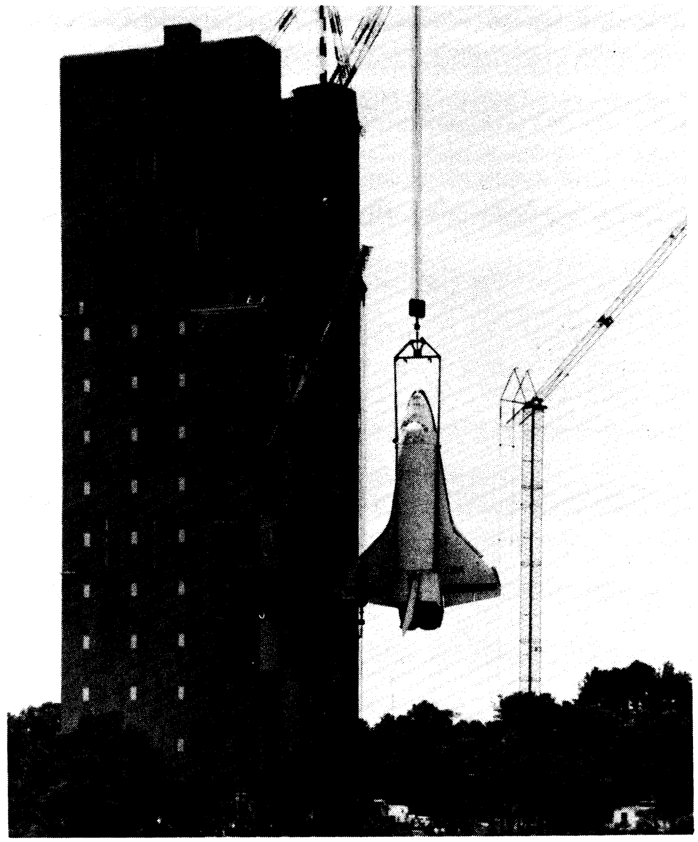
Hopefully, the requirements cycle has produced good paper specifications and processes, and the quality attitude of meeting requirements is well established. If not, the project manager is operating on quicksand -- this is not the time to find out one has missed some critical mission objective. The responsiveness of the project management team is critical during this period. Resources almost always need balancing to meet the real rate of progress. The project rarely has adequate financial reserves to cover every problem, and manpower reserves to meet every contingency. However, at this time, the manager will also find that all the scheduled tasks do not have to be completed in exactly the sequence specified. There is considerable independent parallel activity off the critical path. With proper contingency planning, a responsive organization, and timely decision-making, performance requirements can still be met within cost and schedule commitments.

Performance of the Space Shuttle's thermal protection system has exceeded expectations.

I well remember deciding to scrap a marginal lot of strain isolation pads (SIPs) used in bonding the thermal protective tiles to the Shuttle vehicle. During screening tests, it appeared that 1 to 3 percent of this lot was bad. There was enough SIP material to install at least 1,000 tiles, and this obviously would mean that 10 to 30 tiles might not have the proper strength. The post-installation tile acceptance tests would probably catch the bulk of the problem. However, manufacturing and material people developed a workaround plan that allowed us to wait for a new lot with minimal schedule impact to the total vehicle flow. We chose to wait. We updated our process specifications at the supplier and at our factory to eliminate the possibility of problem reoccurrence. We set the example to our floor personnel that we would accept no less than a quality product. And as a result, the thermal protection system on the orbiter has performed well, even better than expected.

Qualification and Preparing for Flight. One of the least understood risks in project management is caused by lack of attention to the acceptance and qualification testing required to prepare for both flight testing and operations. Too often, proper resource allocation in this phase is neglected. (This means too little as well as too much.) Each of the technical disciplines seems to have its own criteria as to what needs to be proved by test versus how much can be proved by analysis. Cryogenic and hypergolic devices always seem to provide test surprises. For the Shuttle program, simulation of complete structural loads (including the thermal, vibroacoustic, and mechanical acceleration loads) was very difficult. Software and avionics integrated testing is always questioned relative to its completeness. (Are all the possible cases covered, including the fault conditions?) Testing to prove life limits can become very expensive, if not impractical. (Consider proving 10- or 30-year life with adequate margins.) The physical size of an end item and its operational modes (i.e., is it reusable, does it have asymmetrical orientations?) will determine whether environment test chambers can be used.

Six major steps a project leader can take to minimize such risks are: (1) include seasoned test personnel on the project team; (2) consider the test requirements early in the project life; (3) review the test requirements before testing begins (e.g., testing gaseous oxygen flow control valves, tile test panels, and structural and mechanical devices where the culprit was the test requirement, test fixture, or procedure rather than the device under test); (4) pay attention to ground and flight test results -- especially where actual performance diverges from predicted performance -- since these are potential trouble spots; (5) be prepared to make some tough decisions on the acceptability of test results versus redesign and retrofit versus limited life designation; and (6) not flying until problems that affect mission success have been resolved.



Shuttle ground vibration test operations took place at the Marshall Space Flight Center.

Operations. No matter how well one comes through the previous phases, the operational period will present some unique challenges. Flight results, technology evolution, turnaround improvements (if reusable), repair and wearout, new missions, the desire for increased performance, and the next version of the system will demand additional effort.

Frequently, those who authorize additional funds, be they Congress or Headquarters program personnel, are not prepared to continue investing during the program life. By this point, the project team should have some proven measures to judge the value of any change to the system. Too often changes are made without an operational set of priorities and the result is that systems degrade in performance rather than improve. The need for adequate technical development, maintenance of configuration data, and properly planned change points is as great now as at any other time.

Any change will impact the full range of operational tasks, from test and checkout procedures to training. Careful screening of changes and implementation planning will keep the system operating successfully for many years. Interaction with the ground and flight teams will assure that valuable past lessons are not lost and that implementation proceeds smoothly. Not responding to valid needs for evolutionary change will shorten useful life and increase operating costs.

People: Building Commitment and Attitudes

Project success will depend on the commitment and attitudes of the people involved in the project. The leadership of the project manager and team is a dominant factor in establishing a motivational environment. Too often we focus on organizational structure rather than behavior. The organizational structure of a project can vary from a direct-line project team (everyone working for the project manager) to a highly matrixed organization. Which one is the best depends on many factors, such as the length of the project, the size, the skill mix, and the history of the parent organization. All need to be considered, while care is taken to balance project responsiveness and organizational needs.

When we had to replace a multiplexer on the Shuttle Columbia on the pad at KSC during countdown, the only available spare was in Palmdale, 3,000 miles away. Within 24 hours the spare was delivered, installed, and checked out in Columbia; the faulty unit was returned to the manufacturer; and the fault isolated to ensure we did not have a generic problem. Without the commitment of every person involved -- managers, technicians, logisticians, engineers, and pilots (at NASA, Rockwell, and the subcontractor) -- two or more days would have been lost, resulting in increased costs as well as some very unfavorable criticism.

Crew technicians complete a timely repair of STS-2.

Similar events happen every day in the life of a project. The approach the project manager and the team take has a great deal to do with instilling the commitment and attitudes necessary for success. The following are techniques I have seen others use and have used myself.

Building Teamwork. It is important to treat all people and organizational elements fairly. There is no substitute for ethical behavior and technical integrity. Open and honest communication among all team members is essential. Praise goes much further than blame; and criticism should be constructive, especially in large meetings. The manager and the rest of the team must work hard to establish a project outlook, a customer outlook, an end-user outlook, and a "can do" attitude. Getting these views accepted will obviate many organizational squabbles. It is extremely important also to build trust and teamwork among organizational entities: government, prime contractor, subcontractors, suppliers, Headquarters, and Centers.

Building Consensus. Since decisions are required at every level, effective interchange must take place with all involved parties. The manager listens carefully during the discussions and then works hard to get everyone to accept the decision as the agreed-upon course of action. Rarely are every person's desires met. While differences of opinion are acceptable, dissension is not. Furthermore, if new information becomes available, the issue must be revisited.

Quality is Mandatory. Since a quality product is the project's objective and requirements drive the entire system, all those involved know that their commitment to meet requirements will foster product excellence. Establishing the means to re-examine requirements, processes, and procedures will also foster product excellence. This applies to every aspect of the job: to letters and reports, as well as the hardware products. Everyone must understand the job to be done. In working to clean up processes and procedures, the project manager will do well to involve the doers as well as the writers. This will maintain an attitude of excellence and result in a quality product.

Time is of the Essence. Creating a sense of urgency is essential for project success. Schedules are established to ensure that all project tasks are synchronized and resources are properly applied. Since the manager's actions and team decisions are examples for everyone, they should be timely. Adequate time must be allocated and the schedule adhered to. The project manager must clearly expect schedules to be met or beaten and must follow up to make sure the proper resources are being applied. If difficulties arise, then searching for a workaround and eliminating the root cause is much more productive than looking for someone to blame.

Cost is a Driver. Cost is an essential element of the contract, and cost-effective performance is everybody's job. All organizational elements need to recognize and commit to the cost objectives. Getting quality and schedule performance are major factors in cost performance, and driving for simpler implementation improves both. The project manager has to ensure that enough time is allowed to get the simplifications at the design level and the participation of needed disciplines. Life costs must be a visible part of the decision-making process.

Keeping in Touch. Too often the project manager and team are consumed by meetings, requests for status, and myriad other duties which keep them in their own offices. This is an easy trap to fall into. But the project manager's presence is needed out on the floor, within the organization, at peer organizations, and at the contractors' sites. This presence will motivate the workforce, demonstrate concern, improve the information flow, and increase team responsiveness.

Selecting the Right Team. Since there is no substitute for talent, the project manager must select people who are technically strong (i.e., in engineering, manufacturing, scheduling, contracts, etc.) and who display the commitment expected. Often, rotation of the people into different assignments will help keep the talented people involved and committed to the project. Those who do not fit should be encouraged to find other tasks better suited to their talents. A strong team will create the peer pressure so vital to ensuring an effective attitude.

Reward and Recognition. There are many opportunities to reward performance. All too often in relations between the government, contractors, and subcontractors, profit is used as a negative incentive. If contractors meet their commitments, they have earned profit. If they have stayed responsive to overall project needs, they have earned a good share of the profit. If possible, unawarded period profits can be effectively rolled forward to provide additional incentives. Similarly, budget underruns can be used to initiate needed work earlier if project resources allow. Incentive and fixed-price contracts often allow sharing of cost savings that result in additional profits for the contractor while saving significant dollars for the government. Gainsharing is becoming a popular way of passing performance incentives to the individuals.

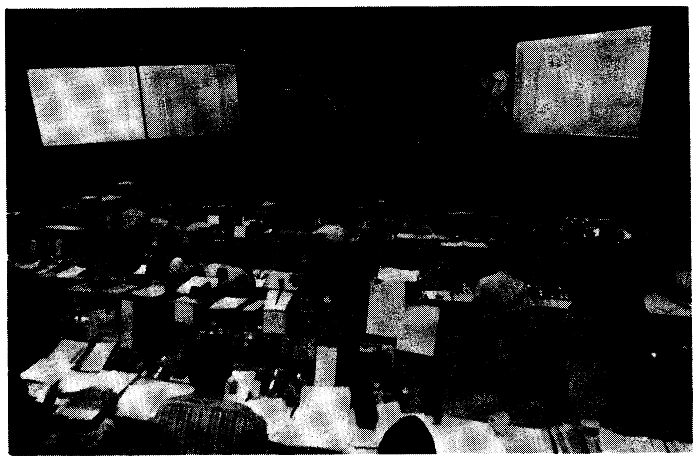
There are many ways to provide non-monetary incentives to a project team. Commendation letters, formal awards, public acknowledgment, and a simple, spoken "well done" will go a long way to building the commitment and attitude needed for project success.

Communicating Relevant Information

Some people believe that the answer to all our information needs is an infinitely large, automated data base with embedded expert systems to help us extract the information we need to make decisions. Others believe that all the key data can be put on three-by-five cards and carried by the project team through the life of the program. I would like to share a situation to help explain my view of what constitutes relevant information.

During the approach and landing test on the Shuttle program, the Rockwell team had responsibility for the vehicle prior to rollout from the hangar. We completed the pre-rollout tests, moved the vehicle out, and passed control to mission control at JSC. On one particular flight, we were having some difficulties with the inertial measurement unit's alignment. A decision had to be made as to whether the observed drift rates would be acceptable for flight. Although they were within specification and met all the criteria, there was obviously something going on that was different from our expectations. We had only a few minutes to decide whether we were "go" or "no-go" for that day. I met with the two responsible engineering managers and their recommendation was "go." The information that I needed was their technical rationale and how they conveyed the data. It was more than the numbers: it was also their confidence. Information needs are dependent on the problem at hand and the people involved. Information consists of more than computer-storable or written data.

Recognize Differing Needs. Each level in the customer, contractor, subcontractor, and user organization has different needs for information. Giving everybody everything is almost as bad as giving them nothing. Communications must, therefore, be planned in light of established performance milestones that measure progress meaningful to the level it is reported to, in a form useful to the receiver, and of value to those who provide it. Status data can be verified by frequent site visits.



In general, the two areas that are served the worst are the top of the program, where information is needed to plan future resource allocations, and the detail working level (including subcontractors), where daily work schedules are made. The top area needs to understand the future consequences of any major event, and the detail level needs to understand current detail status and decisions made that affect in-process work. Some effective communication techniques are discussed in the next sections.

Use Electronic Information. Modern computer-based systems offer tremendous capability to provide detailed information to a very large number of people. They can be used for detailed technical data (drawings, parts list, algorithms, system and software requirements, user notes, procedures, etc.). They can be used also for scheduling and control information (engineering orders, parts ordering, billing, inventory, configuration data, multi-level schedules, etc.) and coordinating information (electronic mail for bulletins, meetings, decision status, etc.).

During Shuttle development, it would have been impossible to complete the program without computer-based information systems. However, difficulty occurred with multi-discipline information and multi-level (different user level) data. The fundamental problem is that data were not structured into logically consistent databases. Inordinate effort was required to translate, manipulate, and reformat information. Therefore, care should be taken on future projects to provide logical structures, standards, and user-friendly interfaces to ensure that electronic techniques are effectively used. (The NASA TMIS, Air Force UNIS, and many corporate information systems are working on this issue.)

Use Meetings to Communicate. During the Shuttle development program, many reviews, panels, and boards were scheduled on a regular basis. Used properly, these were effective means for communicating information, as well as for making decisions. Daily morning meetings between project functions at the contractor, between organizations at the launch site, and between subsystem project managers at the lead Center were used to measure the current pulse of the project and resolve issues that could impede work. Weekly meetings -- such as the avionics review board (ARB), technical status review (TSR), software control board (SCB), change control board (CCB), program review boards (PRBs), and vehicle status reviews -- were ways to facilitate decisions that had longer-term impact and to communicate results to affected parties rapidly. Monthly orbiter management reviews were an excellent means for synchronizing all the functions, as well as measuring cost and schedule performance.

The problem, of course, becomes one of how to do the work with all those meetings going on. With proper attention to meeting duration, participation, and completed staff work, these meetings are very effective. Letting the person who is closest to the issue present the information and the lowest-level person make the decision will speed up the process and spread the work. Written minutes, rapidly prepared, distributed, and posted for all to see will get the information to the "floor" where it is often needed the most.

Consider Contract Data as Important. Too often, the contract and its associated statement of work and schedule of deliverables are known only to a limited number of people in the project chain -- at the customer and at the contractor. Yet, the contract is the document that communicates the official requirements of the work to be done and the schedule for when it is to be done. Since government agencies rarely use the contract as a mechanism within their own organizations and the contractor operates similarly, there is a great misconception about the contract's value: maintaining its configuration, and using it as a mechanism to communicate and control work. Every project team leader should be familiar with the contents of the contract, for it will enable them to maintain a fair and equitable position on many issues that will arise during project performance. Insist on compliance with the contract and initiate contract changes when there is a legitimate addition, subtraction, or change to be made.

Communicate with Your Customer. The project team is both a supplier and a customer. It is very important that the team recognize this dual role. Too often I have seen the team consider its customers (customers are both the next level up in the project chain of command, and those organizations that significantly drive project requirements and funding) as enemies rather than friends. During the course of a long-term project, the information flow is virtually the only product that will assure your customer that the project is on track. Making this flow effective will also produce

understanding of the external environment and its dynamics, which, in turn, will generate better decisions. An open, honest, and timely information flow among the project team, customers, and suppliers is a key ingredient of project success.

Conclusion

Project management, especially as it has developed through NASA's large-scale successes, is an extremely rewarding field. It enables each of us to take part and direct a portion of this nation's progress. In the project manager role, we take on considerable responsibility, for we are accountable for the use of very valuable assets. It is our job to ensure delivery of a system with the required performance, at or before the planned time, and within cost limits. Many skills are required and tools needed to be an effective project manager. Today, the task is being made both a little easier with improvements in communication media and simultaneously harder within our "fishbowl" environment. Building on past success and learning from mistakes are important.

I have discussed what I believe are some essential principles in effective project management. There is no compromise to quality; proper requirements are a solid foundation; things will change; committed people make the difference; and communication of relevant information will keep a team on course.

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