Management and Budget Lessons The Space Shuttle Program

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After each major manned space program, the Johnson Space Center has conducted research, written histories, and analyzed management methods to scrutinize the past for weaknesses and mistakes that can be avoided in the future. These efforts have had three results:

1. Some practices and weaknesses have been **influenced and changed**. Among specific lessons learned are the need for extended program definition phases, resistance to pressures to estimate costs on the low side, incorporation of adequate cost reserves into the planning process, accurate initial estimates to provide program stability, and the increased involvement of NASA analysts in the prediction of program budgets.

2. Some problems have **continued** because the cultural acceptance of practices has made them difficult to modify. For example, the lack of emphasis on the "budget year" throughout the manned space program contributed to budgetary problems, but the practices have remained relatively unchanged from the Apollo program up to the present time.

3. Some obvious problems are inherently a part of government program management systems and are **beyond the capability** of any agency to influence. An example of this is the divided management responsibility, which has been a part of some large NASA programs, compromising the unity of command. In a political society, such compromises are a way of life and cannot be easily changed by the agency itself.

Some reform of the NASA budget process has been called for by study groups, along with closer coupling of the design and cost estimating processes, and improvement of performance management/measurement systems.

Analysis of Previous Lessons Learned

In 1971, at the beginning of the Space Shuttle Program, an extensive interview process was conducted at Johnson Space Center to determine what management lessons had been learned by the aerospace industry which might help avoid problems in managing the Space Shuttle development. A structured set of interviews was conducted with senior managers of teams from the highest technology aeronautical programs then existing. These included the SR-71 Strategic Reconnaissance Aircraft of the United States Air Force (Clarence "Kelly" Johnson, Program Manager, Lockheed Aircraft Co.); the Boeing 700 series of aircraft (George Schairer, Vice President, R&D, Boeing Airplane Company); the B-58 (Robert Widmer, Vice President, General Dynamics/Ft. Worth), and numerous others.

Perhaps the most striking result of the activity was the general management consensus concerning ways to reduce costs in government programs, particularly when the findings are compared to current NASA management practices.

The study reached the somewhat subjective conclusions that to reduce program costs, NASA should:

1. State requirements as objectives, and leave them relatively unconstrained.
2. Not start building flight hardware until all major technological uncertainties have been resolved.
3. Utilize small, hand-picked government program offices and contractor teams.
4. Eliminate (or greatly reduce) government-imposed changes.
5. Allow contractors maximum autonomy.
6. Once program definition has resolved major technological uncertainties, complete the development process as quickly as possible.

NASA management agreed to try many of these potential cost-saving cultural differences. However, the cultural inheritance, a result of using many of the same management and contractor teams from the Apollo program, soon overcame many planning ambitions. Except in a few notable areas, the original culture was not appreciably changed, except where it had to be adapted to survive the newly cost-constrained environment.

These 1971 studies further concluded that program cost estimates made within company engineering departments are generally adequate. However, since bidders usually underestimate costs to increase the likelihood of winning hardware contracts, overruns often occur. Research performed recently supports this finding; in fact, professional cost estimators have found that this buy-in effect has become one of the major contemporary problems of program cost analysis.

The 1971 studies observed that program control techniques similar to the DoD C/SCSC are effective and essential, but excessive control (or micro-management) is a deterrent to good performance. And finally, and probably most important to current and future programs, it was found that concurrent development of mutually dependent, high technology items is especially difficult unless strong unified management is provided.

Lessons Learned from Space Shuttle

Between 1977 and 1979 a series of studies was performed as a result of budgetary problems encountered in the peak funding years of the Space Shuttle program. These studies universally found that although the technical aspects of the program were being managed very well, some management problems existed. For example, the Day Committee, headed by LeRoy E. Day, found that peak funding problems had occurred as a result of almost universal inattention to the "budget year"; i.e., two years into the future. So much was the preoccupation with the current ("operating") year, that little attention was paid to the budget year. Often, contractor estimates were employed with little analysis to predict the program requirements. The Day Committee found that this problem could have been avoided by independent analysis of contractor estimates by the government. The committee also found that NASA in general did not apply enough analytical manpower to programmatic, especially budgetary, tasks. (The results of the studies were never published but are on file in the JSC Cost Estimation Data Bank.)

Prior to his departure from NASA, a Space Shuttle program manager was interviewed extensively to obtain his perspective on lessons learned from the program, particularly in the program management areas, including cost estimating and program control. He made the following observations.

- If the "bottom line" of success is obtaining a successful program result for the least money, then the management systems used were successful.

- No amount of money early in the program would have prevented the technical problems (the Space Shuttle Main Engine development problems and the Thermal Protection System tile problems, primarily).

- Ninety-five percent of the problems with our budget system have nothing to do with the mechanics of program control. They are more related to the way we organize and review our budget; pressures to be over-optimistic in the budgeting process; the interfaces we have with the Congress and the Administration; and coming to grips with problems we predict.

- Over-optimism is popular, and the process encourages it.

- The budget cycle can be improved. Budget calls probably should not dictate a schedule: project personnel should be asked to predict the schedules they can make and the dollars they need to make them.

- The prediction of program cost reserves should receive more emphasis, at all levels of the program. Program reviews should solicit issues and create a climate for resolving budget problems, not only technical issues. Reviews should emphasize the pedigree of cost and schedule estimates, the degree of optimism or pessimism (risk), and the likely program cost growth. Reviews should reflect the best estimates of cost reserves required for contingencies.

- Program control should emphasize quantitative measurement of progress, and focus on future projections based on past performance (e.g., manhours per foot of welds on the External Tank).

Program Control and Management Processes

A number of the factors influencing program success were also explored in a survey submitted to all senior managers of the Space Shuttle Program. Program managers were asked to rank management factors or processes which favorably influenced the outcome of the program. The most highly ranked items were:

1. Actions of the program manager (e.g., timely decision-making, effective management leadership);

2. Adequacy of the original cost estimates;

3. Actions of the program director (e.g., budget leadership, timely resolution of program conflicts);

4. NASA resource management processes employed by the program manager's staff; and

5. NASA resource management processes employed by the program director's staff.

The three least effective influences (neutral, slightly influential, or of negative influence) on program success were found to be: annual funding limitations by the OMB and Congress (this is an example of an influence completely outside the control of program management); the Cost Limit Review Board (CLRB) (a NASA Headquarters body that screened major changes); and the performance management/measurement system, which was ranked so low as to indicate that it might have even been counterproductive. At least, it was never used effectively.

Program managers were also asked to separately rank only the management processes which had had the most influence on the successful outcome of the program.

The most highly regarded process was the independent assessment function performed by the program office at JSC; second, the cost estimation process; third, the budgeting process (despite its flaws); and fourth and least effective, the performance management/measurement system employed.

A few other factors making major contributions to the favorable program cost outcome were: early system definition and configuration change control; change of program content (content was reduced at several points in the program); contractor willingness to accept risk; and good analogous data on which to base cost estimates.

Many of the managers said that too much management time was diverted from significant problems by excessive budget-related problems which occurred at the peak of the program. Six actions were suggested:

1. End overly close alliances with contractors;

2. Allow projects to keep change reserves within their budgets;

3. Plan the program to realistic resource limits;

4. Clarify the responsibilities of all program levels early in the program;

5. Treat escalation realistically; and,

6. Accurately assess development time.

Management responses were far from unanimous on these influences, however. For example, a former program director responded that accurate cost estimates at the outset of a program are often counterproductive, in that they provide ammunition for the opponents of the program. This lent further credibility to the conclusion that program proponents often do not want to know the true costs of a program, as total cost magnitudes can be a deterrent to successfully selling the program in the political environment.

Summary and Conclusions

Perhaps the major lesson to be learned from this type of analysis is that it is extremely difficult, primarily for reasons of cultural inertia, to change a management practice from one program generation to the next. Lessons learned are often either forgotten or not easily incorporated into the management culture.

I shall not repeat here the conclusions of the various studies mentioned above. However, I will describe a pattern that has emerged over two generations of analyses.

First, the **program planning process** has a significant effect on the outcome of a program. Programs with longer definition phases have proven to have the least cost and schedule overruns. Accurate initial budgets, provided by accurate program cost estimates, have universally been cited as a requirement for success. Accurate budgets have a stabilizing effect on the program; inaccurate budgets lead to the spending of inordinate management and other program resources on replanning, rescoping, recosting, and rescheduling activities.

Second, NASA has in the past not done the best possible job of **budgeting** during the peak years of a program, relying too heavily upon contractor cost projections, and not providing agency or program management with enough resource reserve flexibility to respond to program uncertainties. The NASA budget process must be reformed to provide more internal NASA analysis and less reliance upon contractor estimates. Far more emphasis on runout years is needed.

Third, there is enormous pressure at the beginning of a program to estimate the actual costs to be lower than historical trends might indicate. **Lower estimates** simply increase the probability that the program will overrun its costs. Program managers feel that they will be able to do better than their predecessors, and they are often willing to assume high risk in initial program estimates to help sell the program in the political arena.

Because hardware contracts are always competitively awarded, the proposer must tread a fine line between cost estimate credibility and the risk of losing out to a competitor offering a lower price. As David Novick, the father of modern cost estimation, said in 1962, "The incentives to estimate low are much greater than the penalties, if indeed there are penalties." In the quickly changing NASA environment, the contractor knows that if indeed a winning bid is too low, actual costs can be recovered through the acquisition process (usually cost-plus-fee), plus the cost of any changes made.

Fourth, NASA has consistently used three tiers of program offices, often large organizations with different points of view, despite evidence that many of the most successful aerospace programs have been effectively managed by very small program offices.

NASA has evolved to a management style which mixes government and private sector in the technological decision-making processes. This highly interactive style produces a technically superb product, but also causes an enormous change workload that often results in costly program changes. While a former Space Shuttle program manager denies that any nonessential changes were made, the process is driven by thousands of detailed changes, often stimulated by the NASA engineering community itself (as opposed to a process driven by broadly-stated program requirements). This process has been assessed by many senior program managers to be very costly.

Performance management/meaurement systems previously used by NASA have consistently been either ignored or blamed for not revealing problems in time to resolve them. Future systems should be designed to cope with the unique requirements of a particular program environment, as opposed to using systems from previous programs.

FOR FURTHER READING:

Day, LeRoy E. Letter: "Analysis of Space Shuttle Program Control Practices and Procedures," to Distribution. Washington, D.C., August 22, 1979.

Mandell, H. C. Assessment of Space Shuttle Cost Estimating Methods, Denver, Colorado: The University of Colorado at Denver (Doctoral Dissertation), August 1983.

Novick, David. Costing Tomorrow's Weapon Systems (RM-3170-PR). Santa Monica, Calif.: The Rand Corporation, February 1962.

Yardly, John F. Letter: "Analysis of Space Shuttle Program Control Practices and Procedures," to Distribution. Washington, D.C., National Aeronautics and Space Administration, August 21, 1979.