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# ESTIMATING THE COST OF MAJOR ONGOING COST PLUS HARDWARE DEVELOPMENT PROGRAMS

By J.C. Bush

Space Systems Project Office

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16. Abstract

This memorandum develops approaches for forecasting the cost of major hardware development programs while these programs are in the design and development C/D phase. Three approaches are developed: a schedule assessment technique for bottom-line summary cost estimation, a detailed cost estimation approach, and an intermediate cost element analysis procedure. The schedule assessment technique was developed using historical cost/schedule performance data.

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TECHNICAL MEMORANDUM

# ESTIMATING THE COST OF MAJOR ONGOING COST PLUS HARDWARE DEVELOPMENT PROGRAMS

## INTRODUCTION

The initial cost estimates for major hardware development programs at MSFC are performed by the Program Development Directorate during phases A/B. Once these programs move into phase C/D, the cost forecasting is primarily done by the Program Control Office of each program. The cost estimates of active C/D programs then become a function of each contractor and the experience and approaches of individuals within the Program Control Offices. Therefore, the approaches to cost estimating vary widely from program to program.

This report is to initiate uniform approaches to cost estimating. Three techniques are presented: a bottom line schedule assessment technique (SAT), a detailed cost estimation (DCE) approach, and an intermediate cost element analysis (CEA) procedure.

## SCHEDULE ASSESSMENT TECHNIQUE (SAT)

The SAT is a procedure to determine current and outyears funding requirements based on past schedule trends. The best way to determine where you are going (cost and schedule) is to look at where you have been. This technique looks at historical schedule performance and forecasts this performance into the future. This projected future performance is compared with the latest plan to provide delta costs required to complete the program.

SAT is a bottom-line approach. It provides a uniform top-level assessment technique for all projects. The validity of the estimated cost is a function of how long the program has been in existence. That is, the longer the schedule trend, the more accurate the forecast. The results of SAT will usually be startling, but experience shows that projected program overruns are consistently underestimated.

The SAT utilizes rollover of work, new work, actual costs, and actual schedule loss to determine current-year and next-year cost estimates. Rollover, new work, and average historical cost increases and schedule loss rates are used for forecasting outyears impacts.

The following is a step-by-step explanation of the SAT. A calculated SAT example follows this section.

NOTE: All fiscal year (FY) phasing of funds must be converted to constant year dollars.

## CURRENT FY

- Determine roll-over from previous fiscal year
- Determine new work
- Determine schedule loss cost impact.

### Rollover

1. Determine how much cost (underrun/overrun, –/+) was rolled over from the previous FY and unaccounted for in the current year plan.

### New Work

2. Determine known content changes to be added to the current FY. Express this as months. Divide the dollar value by the average planned burn rate for the quarter(s) the content is to be added to the current plan.

### Schedule Loss Cost Impact

3. Determine how far behind schedule the project currently is in months.

4. Determine schedule loss rate from item No. 3 in ratio of months/month.

5. Determine schedule remaining in current FY in months.

6. Determine burn rate ratio of actual/plan cost expenditures to present time from beginning of FY.

7. Determine planned burn rate for remainder of FY.

8. Determine work remaining in months:

$$\text{Items } (2+3+5) \times (1+ \text{ Item } 4)$$

9. Determine measurable work as percentage of total for current FY.

10. Determine cost of remaining work for current FY:

$$[(\text{Item } 8 - \text{Item } 5) \times \text{Items } 6\times7\times9] + (\text{Item } 5 \times \text{Items } 6\times7) + \text{Item } 1$$

## NEXT YEAR

### Rollover

11. Determine how much work from the current year will be rolled over into the next year (in months work).

[current year cost ceiling – actuals – Item 10] [Item 9/actual burn rate]

+ [Item 5] [efficiency loss] [reduced burn rate/next year burn rate]

### New Work

12. Repeat step 2 for this FY.

13. Determine burn rate plan for next FY.

14. Determine measurable work as percentage of total for next FY.

15. Determine delta months of measurable work for next year

(Item 11 + Item 12 + next year's planned months) × [Item 14] × (Item 4)

+ Item 11 + Item 12

16. Determine cost of next year's delta measurable months

Item 15 × Item 13 × Item 6

17. Determine initial planned cost of next year planned months

Planned months × Item 13

18. Determine total cost for next year versus plan

Item 16 + Item 17 versus Item 17

## OUTYEAR

### Rollover

19. Determine how much measurable work from the next FY will be rolled over into outyears (in months).

[next FY ceiling (months) – Item 15] .

**New Work**

20. Repeat Item 2 for outyears.

21. Determine total planned runout months remaining in program by program phase.

22. Determine remaining outyear work in months

$$(\text{Items } 19+20+21 \text{ [in months]}) \times M_s$$

where $M_s$ is the outyears schedule multiplier which is a function of $S_f$ and where you are in the program. $S_f$ is a schedule loss rate factor defined as $S_f$ = [1 + Item 4]. Table 1 gives the $M_s$ as related to $S_f$ and program phase.

Table 1. $M_s$ as a function of $S_f$ and program phase.

Where $S_f \leq 1.5$

| | Outyears Schedule Multiplier ($M_s$) | | |
|---|---|---|---|
| Current Time | PRR-PDR | PDR-CDR | CDR-DEL |
| ATP-PRR | 1.5 | 1.5 | 1.7 |
| PRR-PDR | $S_f$ | 1.5 | 1.7 |
| PDR-CDR | – | $S_f$ | 1.7 |
| CDR-DEL | – | – | $S_f$ |

Where $1.5 > S_f < 1.7$

| | | | |
|---|---|---|---|
| ATP-PRR | $S_f$ | $S_f$ | 1.7 |
| PRR-PDR | $S_f$ | $S_f$ | 1.7 |
| PDR-CDR | – | $S_f$ | 1.7 |
| CDR-DEL | – | – | $S_f$ |

Where $S_f > 1.7$

| | | | |
|---|---|---|---|
| ATP-PRR | $S_f$ | 1.7 | 1.7 |
| PRR-PDR | $S_f$ | $S_f$ | 1.7 |
| PDR-CDR | – | $S_f$ | $S_f$ |
| CDR-DEL | – | | $S_f$ |

23. Spread Item 22 in proportion to the initial baseline outyears planning from the nearest appropriate major milestone. For example, if you are at critical design review (CDR), use the remaining baseline plan months to ratio the increased months. For example, a planned milestone which was halfway between CDR and delivery will remain halfway between.

24. Determine outyears cost

$$[(\text{Total program planned cost}) \times C_f] - \text{actuals}$$

where $C_f$ is multiplier depending upon where you are in the program and the burn rate ratio ($B_r$) (Item 6). (See table 2.)

Table 2. $C_f$ as a function of Br and program phase.

When Br ≤ 1.6

| Current Phase | Out-years Cost Multiplier ($C_f$) |
|---|---|
| ATP-PRR | 1.6 |
| PRR-PDR | 1.5 |
| PDR-CDR | 1.4 |
| CDR-DEL | 1.1 |

Where Br > 1.6, use Br as $C_f$

Where Br < 1, use Br as $C_f$

25. Spread outyears cost at same proportion as initial baseline plan. For example, if you are in the pre-CDR phase and the initial CDR expenditures plan called for 50 percent of cost, then spread the forecast costs similarly.

26. Convert the constant year dollars to real year dollars.

## SCHEDULE ASSESSMENT EXAMPLE

**Assumptions**

| | FY1 | FY2 | FY3 | FY4 | FY5 |
|---|---|---|---|---|---|
| 5-Year Program Authority to Proceed (ATP) | | | | | |
| | PRR | PDR | CDR | MAN | DEL |

Current status is 8 months into FY2.

Plan burn rate FY1 is \$4M/M; FY2 \$5M/M; FY3 \$6M/M; FY4 \$5M/M; FY5 \$3M/M.

Rollover from FY1 is \$4M.

Known content changes \$1.25M in FY2, \$3M in FY3, \$1.25M in FY4.

Project is 2 months behind schedule (from ATP) not including rollover.

Actual burn rate for FY1 has been same as plan.

Actual burn rate for FY2 has been \$5.5M/M.

Measurable work is 75 percent of total (for FY2 and FY3).

Preliminary design review (PDR) is mid-FY2.

CDR is mid-FY3.

Manufacture start is mid-FY4. Manufacturing/assembly/testing are not excessively complex.

Delivery (DEL) is end FY5.

Assume FY2 and 3 are capped at \$60M and \$72M.

All dollars are constant FY1 dollars.

1. Unaccounted cost rollover from FY1 = 0.

2. Known content change for FY2 is \$1.25M, which gives \$1.25M/\$5M/M = 0.25 months.

3. Program is 2 months behind schedule (given).

4. Schedule loss rate is 2 months/20 months = 0.1 month/month.

5. Remaining schedule in FY2 is 4 months (given).

6. Burn rate ratio for FY2 is \$5.5M/M actual/\$5M/M = 1.1.

7. Planned burn rate for remainder of FY2 is \$5M/M (given).

8. Work remaining is:

$$[0.25 \text{ (Item 2)} + 2 \text{ (Item 3)} + 4 \text{ (Item 5)}] \times (1 + 0.1) \text{ (Item 4)}$$

$$(0.25 + 2 + 4)\ (1 + 0.1)$$

$$6.8 \text{ months}$$

9. Measurable work is 0.75 (given).

10. Cost of remaining work for current FY is:

$$[6.8 \text{ (Item 8)} - 4 \text{ (Item 5)}]\ (1.1 \text{ (Item 6)} \times 5 \text{ (Item 7)} \times$$

$$0.75 \text{ (Item 9)}] + 4 \text{ (Item 5)}\ [1.1 \text{ (Item 6)} \times 5 \text{ (Item 7)}] + 0 \text{ (Item 1)}$$

which is:

$$[6.8 - 4][1.1 \times 5 \times 0.75] + 4[1.1 \times 5] = 11.6 + 22 = \$33.6\text{M} .$$

## NEXT YEAR

### Rollover

11. Assume funding cap for FY2 is $5M/M $\times$ 12 = $60M. Actuals of $5.5M/M $\times$ 8M = $44M plus runout of $36.6M puts a funding problem of $17.6M. We only have $16M for the remainder of FY2 so we have to reduce the FY2 burn rate. Therefore, we push $17.6M into the next year which is at the FY2 actual burn rate and 75 percent measurable gives 2.4 months. Note, however, that by reducing the FY2 burn rate by 27 percent over the remaining 4 months, we would reduce efficiency as well. Assume we had a maximum efficiency of 75 percent, then, we would achieve 3 months of work at $4M/M and push 1 more month into FY3. This 1 month at $4M/M versus $6M/M would equate to 0.67 FY month. Therefore, we push a total of 3 months into FY3.

### New Work

12. Known content changes (given):

FY3 = $3M @ $6M/Month = 0.5 Months

13. $6M/M burn rate for FY3 (given).

14. Measurable work for FY3 is 0.75 (given).

15. Delta months of measurable work for FY3:

[3 months (Item 11) + 0.5 months (Item 12) + 12 (FY3 months) $\times$

(0.75) (Item 14)] $\times$ 0.1 (Item 4) + 3 (Item 11) + 0.5 (Item 12)

= 4.7 measurable months

16. Cost of next year's delta measurable months:

4.7 (Item 15) $\times$ 6 (Item 13) $\times$ 1.1 (Item 6) = $31M

17. Planned cost of next year's planned months:

12 (planned months) $\times$ 6 (Item 13) = $72M

18. Total cost versus plan

$31M (Item 16) + $72M (Item 17)

$103M versus $72M

Delta of $31M

## OUTYEARS

### Rollover

19. Measurable work from FY3 to be rolled over:

4.7 months (Item 15) since FY3 is capped at $72M (12 months at $6M/M)

### New Work

20. Known content change for FY4 is $1.25M (given).

$1.25M/5M/M = 0.25 months

21. Total planned outyears runout months is 24 (FY4 and 5).

22. Total remaining outyear work in months:

[4.7 (Item 19) + 0.25 (Item 20) + 24 (Item 21)] $M_s$

where $M_s$ = 1.7, because $S_f$ = 1.1 < 1.5 and program phase is PDR-CDR and outyears are CDR-DEL, which gives = 49 months.

23. For the outyears spread Item 22, the new months required to complete the project on the same percentage as the initial plan. From the 8th month of FY2 percentage of time was 22/40 to manufacturing start, 40/40 to delivery or 55 percent manufacturing, 100 percent to delivery. Therefore, time to manufacturing start is 55 percent of 65 (remaining time in FY2 + FY3 + Item 22), 100 percent of 65 to delivery. CDR slips 5 months (Item 15).

| | WAS | IS |
|---|---|---|
| CDR | Mid-FY3 | End of FY3 |
| Manufacturing Start | Mid-FY4 | 9th Month of FY5 |
| Delivery | End FY5 | 1st Month of FY8 |

24. Outyears cost:

Total planned program cost × $C_f$ − actuals; $C_f$ = 1.4 where 1 < $B_r$ < 1.6, $B_r$ = 1.1

FY1 + FY2 + FY3 + Rollover (Item 18) + FY4 + FY5 − actuals (FY1 + FY2 + FY3)

[($180M + $31M + $12M × $5M/M + $12M × $3M/M) × 1.4] − ($180M)

[($307) × 1.4] − $180M = $250M

25. Spread costs in proportion to baseline:

| PLAN | FORECAST | | ADJUSTED |
|---|---|---|---|
| FY1 $48M | $48M Actual | | |
| FY2 $60M | $60M Ceiling | | |
| FY3 $72M | $72M Ceiling | | |
| FY4 $60M | | } | $250M |
| FY5 $36M | FY8 | | |

| | % | $M | % | $M | % | $M |
|---|---|---|---|---|---|---|
| CDR | 52 | 144 | 52 | 223 | 44 | 180 |
| Manuf. St. | 76 | 210 | 76 | 327 | 76 | 327 |
| DEL | 100 | 276 | 100 | 430 | 100 | 430 |

Since FY1–FY3 were capped at their ceilings (and for the most part actuals) we could not cost $223M at CDR, but instead $180M. However, the outyears funding profile was developed as if we had costed $180M at CDR and then the difference between $223M–$180M = $43M was spread over the timeframe between CDR and manufacturing start. This funding spread was developed in direct proportion to the baseline plan considering months between milestones and varying burn rates. This resulted in the following forecasted funding profile.

| | FY1 | FY2 | FY3 | FY4 | FY5 | FY6 | FY7 | FY8 |
|---|---|---|---|---|---|---|---|---|
| $FY1(M) | 48 | 60 | 72 | 87 | 66 | 45 | 34 | 6 |

26. Convert to real year dollars (at 5% escalation)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $FY(M) | 48 | 63 | 79 | 100 | 79 | 56 | 44 | 8 |

## DISCUSSION

Using this example's $S_f$ of 1.1, $B_r$ of 1.1 (both of which are relatively low), and program phase of between PDR and CDR (which dictates an $M_s$ of 1.7 and a $C_f$ of 1.4) gives a projected total program slip of 1.43 which compares with NASA's recent experience on major programs of 1.50 and a cost overrun of 1.56 which compares with recent experience of 1.6.

This example was worked based on nominal experience. That is, usually the operating year and the next year have funding constraints and the outyears are flexible. For academic purposes, we could work two other opposite scenarios:

1. All funding of FY1–FY5 is capped and therefore all schedule loss rates and increased costs would be pushed beyond FY5. This approach gives a resultant "plan" which is totally unrealistic.

2. We could also determine to complete the program within the calendar 5 years. This would necessitate a significant increase in burn rate to accommodate the increased measurable work due to the schedule loss rate. However, if the increased funding were available (highly unlikely), and the contractor could accommodate such an increase, this would be the least expensive and preferred approach.

If we chose to ignore other program's historical data and the use of $M_s$ and $C_f$, but rather used only the $S_f$ and $B_r$ of this particular program, we would have forecast a projected total program slip of 1.15 and a cost overrun of 1.17. Essentially, using recent program cost/schedule performance can give quite accurate forecasting for the current and next FY. But, without the use of historically derived cost and schedule multipliers ($M_s$ and $C_f$), the outyears forecasts would only project continuing the same past performance. This, in most cases, would be significantly in error because the contractor performance varies with the program phases. For this example, without the use of $M_s$ and $C_f$, we would have forecasted delivery 16 months (23%) earlier and cost at $107M (25%) less than SAT. Therefore, in forecasting the outyears, one should use these derived multipliers which more accurately reflect recent NASA programmatic history. If one chooses to use other multipliers, then a strong substantive rationale must be developed that is devoid of wishful thinking, unbridled optimism, and fear of the consequences of "truth in forecasting."

NOTE: The outyears multipliers (cost and schedule) were determined using recent NASA program history. See SAT Supporting Rationale.

## SAT SUPPORTING RATIONALE

For the SAT to be accurate, it is imperative that schedule performance as related to the schedule baseline be accurate. However, this is mandatory in any program that is managed properly regardless of the use of SAT.

The recognition that programs slip schedule is nothing new. Also, the recognition that schedule is money is nothing new. However, very seldom is past schedule performance of an on-going program used to forecast future schedule and cost performance. Generally, the contractor will come in with an estimate-to-complete (ETC) ignoring past schedule performance and basing the forecast on optimism.

In early 1964, a NASA task team researched and studied the actual schedule history of 312 individual items of flight and ground hardware and determined a slip factor for each. The average slip factor was 1.71,[1] that is, it took 70 percent longer to complete the task than planned. This same study showed that schedule slippage accelerated after approximately 65 percent of the original baseline schedule had transpired. These data were based on NASA programs when these programs and NASA were new.

A more contemporary evaluation of schedule loss is provided in Augustine's Laws where Norman Augustine used congressional data that illustrated that most all military systems were delivered an average of 1.33 times their baseline schedule (at an average of 1.52 times the initial cost).

The most recently completed major hardware programs at MSFC were surveyed to determine the cost overrun and schedule loss rate factors as a function of program phase. These factors are listed in tables 4 and 5 in the appendix. For example, the SSME DDT&E project yielded a cost factor of 1.5 and a schedule factor of 1.4.

It should be noted that the SAT factors are based on very limited data. These factors could significantly change if the initial optimistic schedules and cost of new programs become more pessimistic (or realistic) in the future. Also, these factors would be refined by inclusion of more historical data.

For a detailed discussion of the limited data and its interpretation, see the appendix.

## DETAILED COST ESTIMATION

This section contains a compilation of questions and data that should be addressed in detailed forecasting of program runout costs. All of these data are not of the same relative magnitude and some data are more applicable deending upon the individual program. This information is presented topically as follows:

Phase A/B
Budget Impacts
Contractors
Integrated Plans
Schedules
Manpower
Cost Reporting

[1]Letter No. CP10-75-219, from CP01 to DA01, dated May 2, 1975.

Performance Measurement System (PMS)
Design/Manufacturing/Test
Contract Changes
Changes
Design Reviews
Other

**Phase A/B**

- Was there an adequate phase A/B?
- Were there major changes from A/B to C/D?
- Were there significant scope/funding changes in negotiations?
- Was there a buy-in?
- Were there requirements deletions with associated excessive funding deletions?

**Budget Impacts**

- Has there been significant FY budget rephasing without a bottoms-up ETC?
- Were budget cut impacts assessed by the subcontractors or just estimated by the prime?
- Has the prime signed up to lower funding levels without significantly reducing scope?

**Contractors (Prime and Subs)**

- Have there been comparable programs or experience?
- What is the experience of the people on the program (from managers to manufacturers)?
- What is the union/management relationship?
- What is the management approach?
- What is the business base? How much is Federal? How much is NASA? MSFC?
- Are the critical people 100 percent dedicted to the program or shared with other programs?

- Do the managers come off the program too early or too late?
- Does the prime have an adequate cost/schedule control system?

**Integrated Plans**

- Is there a detailed integrated cost/schedule/manpower/vendor plan?
- What is the basis of this integrated plan?
- What is the spread of technical and nontechnical manpower to the major program phases?
- Are these ratios changing with the program progress?
- What do these trends forecast?
- What is spread of time, cost, and vendors in relationship to the major milestones?
- Do they correlate with each other – with the manpower spread?

**Schedules**

- Do detailed baseline schedules exist? Is there an adequate schedule configuration control system? Is it implemented in accordance with proper procedures?
- Are the schedules integrated with cost/vendors?
- Are there logic networks?
- What level do the schedules breakdown to?
- Are the schedules "user-friendly?"
- Were the schedules developed by the performing work breakdown structure (WBS) managers?
- Do the inhouse technical personnel agree with the schedules?
- Are the schedules used and statused daily?
- Is there a proliferation of informal schedules?
- Is there adequate critical path definition?
- Are these resources/facilities included in budget to cover "slack" times?

- Is the schedule loss rate being tracked?
- Are there real workarounds?
- What about costs on shifts required for workarounds?
- Is there a milestone tracking system?
- Are the milestones weighted?
- Are the significant milestones lost in the milestone count?
- What are the schedule trends?

## Manpower (Primes and Subs)

- Is the manpower profile consistent with schedules and tasks?

  Often the cost and manpower profile just reflect the FY funding constraints and not real planning.

- What is the allocation of manpower by discipline: Engineering, manufacturing, etc.?
- What is the technical to nontechnical manpower ratio? You will often find that as scope slips out due to budget constraints that the nontechnical manpower increases percentage wise. This could put one into the position of appparently having adequate resources to do the tasks (i.e., cost and manpower), but there is in reality insufficient technical manpower to do the technical job.
- What are the technical/nontechnical manpower plans to Preliminary Requirements Review (PRR), PDR, CDR, delivery, etc.? Is there visibility of this for each change order? Often the manpower to the near term milestone will increase, but the total manpower will remain the same. This obscures a reduction in planned manpower to achieve the outyears milestones.
- What are the manpower trends overall and per subsystem?
- What are the plans to accommodate roll-off of manpower? Is there an adequate business base to allow this?
- What are the manpower levels for sustaining engineering?
- Are there sharp breaks (curves, trends) in the manpower plan? What is the rationale to substantiate this?
- Is there adequate systems engineering manpower? What is the ratio of systems engineering manpower to other disciplines? Other programs? History?

## Cost Reporting

- What are the planned burn rates?
- Are these rates consistent with planned work?
- What are the actual burn rates?
- When work is falling behind, can the contractor increase burn rates to catch up?
- Is the contractor using the salary level of employees bid and negotiated? Often more expensive salaried people are on the program versus what is bid. This expense adds up over several hundred people over a few years.
- On the 533, are the overhead rates "predicted" rates or actuals? What is the history of overhead rate adjustments? What are the likely circumstances and times to increase rates? Rates always go up. The best thing to do is anticipate this and plan for it.
- What is the history on general and administrative (G&A) (costs)? What are the drivers and the likelihood of change?
- What is the validity of the contractor's estimate to completion (ETC)? Was this a delta ETC? Did the contractor management/project control office just "pass through" a compilation of costs without a thorough review? Were the outyears assessed?
- What has been the experience of the contractor's forecast on this program? Other programs? Is he consistently low?

## Performance Measurement System (PMS)

- Is there an adequate PMS? Is it being fully utilized? Most often, the PMS is a "hoop" the contractor jumps through and ignores its potential. Also, the Program Offices view PMS as a nuisance. The PMS and the schedules must be used by management and the project engineers for managing the program or else they become a useless expensive facade.
- What is the relationship between level of effort (LOE) and measurable manpower? LOE should be kept as low as practical. Often a contractor will front load a PMS with significant LOE thereby obscuring the real performance measurements.
- What is the method for taking earned value? It should reflect actual work accomplishment versus resources expended. Many times a prime will use "bookings" as a method for taking earned value on a subcontract. This is a worthless technique.
- What are the PMS trends? No matter what one does, the PMS trends are most often understated by a value of 2 or 3. However, the trends are usually accurate.

- One ought to have an inhouse automatic technique for calculating and displaying PMS trends at the lowest level reported. This technique would then forecast future performance based on continuation of past performance. It can also calculate "improved performance" required to get back on plan. Critical path areas should be particularly monitored.

### Design/Manufacturing Test

- Too many "to be determineds" (TBD's) in equipment (EQ) specs, too many changes in EQ specs, and too late definition/incorporation of EQ specs spell increased costs.

- Drawing release lists by project should be planned and actuals tracked. Engineering change orders (ECO's) should also be tracked. Trends and forecasts can be made using this.

- Technical issues/problems not expeditiously resolved cause serious cost trouble.

- Are there adequate manufacturing and deliverable spares? There must be visibility and tracking between the two.

- Is there more than one material supplier? Are there any high risk materials that a contingency source should be considered and potentially funded?

- What tools and handling equipment are required? Are these defined? Are they scheduled appropriately? Are the schedules realistic? Large programs have been known to come to a grinding halt because these items were overlooked or casually thought about.

- What are the required logistics for movement through this phase? Are the facilities adequate? Are the facilities old and have not been used in a long time? Are the facilities brand new? Are they automated? Are they complex? Are the facilities available? Are there any other programs that plan to use the facilities? Who has priority? How is priority determined? Any of these items can seriously affect schedule and therefore cost.

- What is the testing schedule? How many shifts and how many people? What is the slack time? If there is a second and third shift planned, will there be enough qualified people available for these shifts? What are the critical skills required? What is the experience base on manufacturing, testing? What was required on similar programs in the past? What was required before with this contractor?

- What is the schedule for electronic, electrical, electromechanical (EEE) parts? Is it adequate? What is the experience of the vendors? What about obsolescence? Are there single source vendors? Can you get a second source? What are your plans if you receive an inadequate lot?

## Contract Changes

A system must be established where both the Program Office and the contractor understand the scope, cost, schedule, and ground rules of changes. Too often there is inadequate communication before changes are issued and the changes come at a price higher than anticipated.

Changes are often not fully technically integrated from a systems aspect which leads to higher cost.

It is standard operating procedure for changes to be issued and months and even years to pass before these changes are negotiated. In addition to poor management, this often reflects unanticipated cost increases due to rates, and the contractor being "smarter;" and there is precious little negotiating room because the contractor has a bag full of actuals.

## Changes

Are there funds set aside for anticipated changes from design reviews? Is there schedule slack anticipated to handle these changes?

What is the rate and size of changes not related to major reviews? This can indicate an inadequate phase B with resulting potential problems.

## Design Reviews

Are there funds set aside to accommodate design reviews? Is the schedule adequate? Often the planning for design reviews will be as if there will be no schedule or cost impact from changes or time spent in review. A review may be planned as if the contractor can keep on working at a high rate whereas the contractor must really wait for NASA review and direction. This can be a very costly underplan in schedule.

## Other

What are the inhouse costs? What is the trend on these? Is there adequate technical involvement to prohibit late changes? Is there adequate manpower planned for reviews? Have all the appropriate inhouse approval authorities agreed to these plans? What inhouse equipment, facilities, tools, are required? Do you have funds set aside to "contribute" your fair share in assuring continued inhouse expertise, equipment, and facilities? Can you allow a little reserve in the inhouse line?

Have the other involved Centers been brought in early enough to be a part of defining requirements, etc., to avoid late changes? A poor working/communication relationship can be a source of unexpected increased costs.

What are the known risks/threats/growth/new content of the program? Are there funds to cover these? Are these funds available in the years these items are anticipated? Reserve funds in the outyears for nearyear changes are like runway behind an airplane—it does not do much good.

Test the logic, rationale, trends behind other contractor cost elements, such as ODC, computer time, travel, supplies, etc.

## COST ELEMENT ASSESSMENT (CEA)

If one is not comfortable with the SAT, or knowledgeable enough or time-limited such that a detailed cost estimation (DCE) cannot be done, then the traditional assessment by using cost element breakdown is done. This CEA is simply an intermediate level assessment between the SAT and the DCE. It also can serve as a confidence level check. As a matter of fact, it would be best to independently do an SAT, CEA, and DCE to see how closely they converge.

For a CEA, one looks primarily at the major cost drivers which can vary from program to program. Most often the major cost drivers are prime manpower and subcontractor cost. In addition to these, other items are assessed such as materials, other direct costs (ODC), other costs (including o/h, G&E, fee), issues, and burn rate.

### Manpower

Use the same questions as listed under the DCE and determine: manpower trends, manpower loading versus major milestones, manpower allocation of technical versus nontechnical. Look at manpower breakdown by project. Graph these manpower allocations and compare the spread with the schedule. Look at the major work content items and compare the content versus manpower allocation. Assuming you have an ongoing project, the best indicator of future performance is past performance. If the contractor is using more manpower to do the job, or as often the case, using the total planned manpower but not getting the total job done, you can project future performance based on this past performance.

The last thing a prime will do is offload his manpower. Budget reductions will usually be passed on to subs not under contract and the prime manpower kept up. If the contractor is forced to reduce manpower, he usually reduces the technical manpower which is required to get the job done. Also, it is difficult to bring manpower down after CDR, especially if there is a low business base.

Break the manpower plan down by work breakdown structure (WBS) or discipline and make future projections based on past performance by WBS or discipline and sum the total. Assume that the outyears manpower (for manufacturing, etc.) plans are underestimated at the same level as current performance.

## Subcontractors

Subcontracts are often awarded late so as to keep prime funds available for inhouse manpower. Sub costs can be notoriously underestimated. One should look at each major sub and determine the basis of estimate (e.g., a prime's rough order of magnitude (ROM), or sub's bottoms-up). Also determine sub's performance if the contract has been awarded. Look at the sub's major cost contributors, schedule, history, etc. Ask yourself the pertinent questions listed under the DCE.

Using this data and past performance, project future performance on each sub and sum the total.

## Materials

This is usually simple. Look at the major cost drivers in the material category. Prepare the cost spread with funding availability, need dates, vendors, second sources, etc. Look for trouble spots such as unique forgings done in only one place or exotic or long lead materials. If historical data are available use them. Determine who needs what and when and assure proper planning.

Estimate materials cost by major materials and potential problems as listed above. Add in the remaining materials costs with a percentage increase the same as the percent you increased the major material items.

## ODC

This approach is similar to materials. Look at the major cost drivers in this category. Test each for reasonableness. Using historical performance and the results of your reasonableness test, forecast future costs.

## Other Costs

Overhead, G&A, and fee should be addressed using questions stated in the DCA. Fee is often planned at 100 percent and performance is rarely at this level. This could leave a small source of funds. Overhead and G&A adjustments will blindside you unless you anticipate it. An unexpected five percent increase in G&A can devastate the program. Also, on the 533, the contractor often reports provisional (planned) rates and not actuals.

Look at the contractor's historical performance; look at the business base. Determine the possibility of and timing of increases and forecast appropriately.

## Issues

An analyst attempting to forecast future costs can get into trouble just using cost data and numbers. One must look at other major potential threats such as major technical or programmatic issues. What are the major problems in the program? What is the likelihood of a budget impact in resolving these issues. Are the resources (manpower, funding, schedule, subs, etc.) adequate or impacted?

After this assessment is done, it is best to adjust the bottom line costs of the previously forecasted cost elements. For example, it may be necessary to increase the manpower estimate because of a known inhouse problem that can only be solved by more manpower.

### Burn Rate

After all of the above items are estimated and summed with threats and reserves, a burn rate analysis should be performed. That is, compare the actual burn rates of total cost, manpower, and subs with the planned burn rates and the forecasted burn rates.

Often you will find that a contractor simply cannot increase the burn rate in time to accomplish the forecast. For example, if in using past performance you forecast a significant burn rate increase in manpower to keep up with the schedule, often the contractor cannot hire and train people fast enough to accomplish this; or, the FY funding constraints would prohibit such an increase.

Therefore, the total bottom line forecast will have to be tweaked in accordance with required versus affordable burn rates and schedule. The schedule often will have to be slipped some, resulting in rate increases.

## WARNING SIGNALS

If the program or contractor demonstrates several of the following characteristics, anticipate a cost overrun.

- Inadequate Phase B
- Significant Scope Changes at Negotiations
- Buy In
- Hardware Poor Program
- Significant Technical Challenges
- Major Design Changes
- Major Budget Reductions/Rephasings
- Bow Wave of Deferred Work
- Parallel Development Interface With Other Programs
- Contractor/Subcontractor Inexperience
- Contractor Organizational Confusion/Shuffling

- Contractor Nonresponsiveness
- Contractor Near Term Focus Mentality
- Little Emphasis on Schedule Control
- No Integrated Schedule/Logic Networks
- No Integrated Schedule/Cost
- No Critical Paths
- Significant use of workaround schedules
- Inadequate Systems Engineering
- Adverse Cost and Schedule Trends
- Inadequate Capability to Validate Baseline
- Lack of Performance Assessment Visibility
- Reluctance to implement appropriate PMS
- Significant TBD's/Number of Changes in EQ Specs

NOTE: These should be a part of every program operating plan (POP) review.

## RECOMMENDED FURTHER RESEARCH

Historical data are most often used to initially forecast an ETC at ATP, but rarely used to apply to ongoing programs. SAT and other techniques should be developed to provide uniform comparative estimates for ongoing C/D programs.

More contemporary NASA programs should be assessed to more accurately determine schedule loss and the cost increase rate factors. These factors should be studied to determine if there is any correlation with other variables. Perhaps the rates are significantly different for manned and unmanned programs. Perhaps they vary as a function of complexity, dollar value, weight, contractor, etc. Particularly, since the Challenger accident, the rates and factors may have significantly increased. Considering this, one may wish to increase both $S_f$ and $C_f$ until the impact of the Challenger adjustments are determined.

A simplified, summary historical data base should be developed reflecting this approach, appropriate data and current Program Development data and techniques. This data base should be readily available to Program Managers and Program Control Chiefs. Instructions to use this data base should be simplified and automated.

The sections on Detailed Cost Estimation and Cost Element Assessment should be reviewed by program personnel - managers, chiefs, cost and schedule personnel. These sections would then be expanded and revised appropriately. A new section should be developed to include as many pertinent historical examples as possible. Charts, graphs, and summary data readily recognizable and useful should be included. The historical examples would illustrate and reflect the findings presented in the SAT, DCE, and CEA sections.

Automation of the SAT should be developed and implemented across all programs.

Uniform cost assessment approaches for other type activities should be developed including small payloads, operations activities, and production programs.

A system should be so devised to keep track of schedule loss and cost increase rates for ongoing programs. This is not done now and real time or recent historical analysis is like pulling teeth with no tools or teeth. This would keep a current data base for revising rates for forecasting as well as give continuous "readout" to management on whether NASA programs are trending in positive or negative directions.

## APPENDIX

This section includes a listing of the limited data available and a discussion and derivation of the schedule and cost factors and multipliers as listed in tables 1 and 2.

Table 3 is a list of schedule and cost performance data for the MSFC space shuttle main engine (SSME), solid rocket booster (SRB), and external tank (ET) design, development, test, and engineering (DDT&E) projects. These data were analyzed, compared with the Holburn, Augustine, and NASA[1] experience, and used to determine the schedule loss rate factors and multipliers for the SAT. Tables 4 and 5 summarize these data.

As you can see, the SSME project demonstrated a project slip from an ATP delivery of July 1977 to an actual of August 1979, resulting in a slip factor of 1.4. Further analyses demonstrates that the slip factor between planned ATP-CDR and actual ATP-CDR was 1.35. The planned (ATP) CDR-DEL time increased by 1.48. This demonstrates the observation by the Earl Hilburn team that schedule slippage accelerates toward the end of the program. Also, please note that if the planned delivery had been slipped by approximately 1.4 (and the planned CDR) at the time of the PDR, delivery would have been accurately forecast 7 years in advance.

Since the SSME was the "leading" project, its slip factors are used in lieu of averaging with the ET slip factor (2.12) and the SRB (1.85). The ET and SRB project deliveries were timed with the SSME. If the SSME project slipped significantly, the ET and SRB schedules were adjusted accordingly. (All the deliveries were within 4 months of each other.) However, a few observations can be made. Both the ET and the SRB projects show accelerated schedule slippage after CDR. Also, if at the ET ATP, the PDR would have been forecast using the SSME slip factor of 1.4, it would have been precisely correct. Using the 1.4 at an estimated SRB project start of December 1972 would have placed the PDR within 1 month of where it actually occurred and forecast with over 90 percent accuracy the CDR. In summary, all three major projects showed consistency with a 1.4 slip factor. However, the SRB and ET schedule slippage after CDR exceeds 1.4 significantly. It is supposed that this slippage was incurred to minimize real year expenditures while maintaining required delivery dates consistent with SSME and orbiter needs. Using the slip factor for SSME and comparing it with the Hilburn, Augustine, and Agency slip factors results in the recommended SAT $S_f$ of 1.6 spread by program phase in proportion to the SSME experience.

In analyzing the cost, the following total cost factors from ATP are observed: ET (0.7); SRB (0.88); SSME (1.5); Augustine (1.5), NASA (70's) of 1.4, and NASA (80's) of 1.6. The SRB began as an inhouse program ano progressed contractually and significant changes were made. Obviously, significant program assumptions/directions were made early on in the ET program. The SRB and ET programs showed no correlation until PDR when forecasts behaved in similar patterns to the SSME project. Therefore, an analysis of these data results in the recommended cost multiplier per program phase for outyears forecasting as listed in table 4.

Tables 6 and 7 list the forecast per program phase (major milestone) for the SSME and ET programs. The POP's were reviewed to determine escalation rates and reduce all forecasts to constant dollars (71$) for comparison. Similar data for SRB are available.

[1]Data from NASA Advanced Project Management Course.

Table 3. Schedule and cost performance data.

SSME

| | | Plans: | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | ATP | PRR | PDR | CDR | DEL | FLT | EAC ($71) | $C_f$ |
| ACTUALS | ATP | 4/72 | | 9/72 | 8/75 | 7/77 | 3/78 | 525 | 1.55 |
| | PRR | | 10/72 | | 3/76 | | | | |
| | PDR | 9/72 | | | 9/76 | 7/77 | 3/78 | | |
| | CDR | 10/76 | | | | 8/79 | 4/80 | 609 | 1.33 |
| | DEL | 8/79 | | | | | 4/80 | 719 | 1.14 |
| | FLT | 4/81 | | | | | | 812 | |

Actual occurrence of planned activity

Schedule dates relative to actual occurrence of previous activity.

SRB

| | | Plans: | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | ATP | PRR | PDR | CDR | DEL | FLT | EAC ($71) | $C_f$ |
| ACTUALS | ATP | 11/73 | | 6/74 | 3/76 | 2/77 | | 372 | 0.88 |
| | PRR | 12/72 | | 11/74 | 9/76 | | | 270 | 1.2 |
| | PDR | 11/74 | | | 7/77 | 6/78 | 10/78 | 215 | 1.5 |
| | CDR | 12/76 | | | | 12/79 | 3/80 | 220 | 1.5 |
| | DEL | 11/79 | | | | | 3/80 | 286 | 1.14 |
| | FLT | 4/81 | | | | | | 326 | |

Actual occurrence of planned activity

Schedule dates relative to actual occurrence of previous activity.

ET

| | | Plans: | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | ATP | PRR | PDR | CDR | DEL | FLT | EAC ($71) | $C_f$ |
| ACTUALS | ATP | 8/73 | 11/73 | 6/74 | 5/76 | 6/76 | | 447 | 0.7 |
| | PRR | 2/74 | | 9/74 | 9/75 | 10/76 | 3/78 | 148 | 2.16 |
| | PDR | 9/74 | | | 12/75 | 6/78 | 10/78 | 187 | 1.7 |
| | CDR | 12/75 | | | | 6/79 | 4/80 | 229 | 1.39 |
| | DEL | 7/79 | | | | | 9/79 | 304 | 1.05 |
| | FLT | 4/81 | | | | | | 319 | |

Actual occurrence of planned activity

Schedule dates relative to actual occurrence of previous activity.

Table 4. Schedule slippage factor $S_f$.

| | SSME | SRB | ET | HILBURN | AUGUSTINE | NASA | $S_f$ |
|---|---|---|---|---|---|---|---|
| ATP - CDR | 1.35 | 1.32 | 0.7 | | | | 1.5 |
| CDR - DEL | 1.48 | 3.27 | 3.38 | | | | 1.7 |
| TOTAL | 1.4 | 1.85 | 2.12 | 1.7 | 1.33 | 1.56 | 1.6 |

Table 5. Cost multiplier ($C_f$).

| | SSME | SRB | ET | AUGUSTINE | NASA (70's) | NASA (80's) | $C_f$ |
|---|---|---|---|---|---|---|---|
| ATP | 1.5 | 0.88 | 0.71 | 1.5 | 1.4 | 1.6 | 1.6 |
| PRR | – | 1.2 | 2.16 | 1.47 | | | 1.5 |
| PDR | 1.4 | 1.5 | 1.7 | 1.4 | | | 1.5 |
| CDR | 1.3 | 1.5 | 1.4 | 1.25 | | | 1.4 |
| DEL | 1.1 | 1.1 | 1.05 | 1.1 | | | 1.1 |

Table 6. SSME DDT&E costs.

**($M)**

| | | FY72 | FY73 | FY74 | FY75 | FY76 | FY77 | FY78 | FY79 | FY80 | FY81 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ATP | POP 72-1M 10/72 (RY $) | 4.6 | 50 | 85.2 | 108.3 | 127.5 | 126.6 | 104 | 43 | 13.2 | 0 | 662 |
| | ESCALATION % | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | |
| | ESCALATION INDEX | .955 | .912 | .871 | .832 | .794 | .759 | .725 | .692 | .661 | | |
| | $71 | 4.4 | 45.6 | 74.2 | 90.1 | 101.2 | 96.1 | 75.4 | 29.8 | 8.7 | | 525 |
| CDR | POP 77-1 3/77 (RY $) | 5.5 | 51.6 | 95.6 | 113.4 | 178.3 | 175.6 | 190.2 | 158 | 83.5 | 38.4 | 1090 |
| | ESCALATION % | 4.2 | 7.4 | 11.5 | 12 | 11.2 | 7 | 7 | 7 | 7 | 7 | |
| | ESCALATION INDEX | .958 | .887 | .785 | .691 | .614 | .571 | .531 | .494 | .459 | .427 | |
| | $71 | 5.3 | 6.6 | 75 | 78.4 | 109.5 | 100.3 | 101 | 78 | 38.3 | 16.4 | 609 |
| DEL | POP 79-2A 8/79 (RY $) | 5.5 | 51.6 | 95.6 | 113.4 | 178.3 | 182.1 | 197.3 | 171.2 | 120.6 | 60.8 | 1090 |
| | ESCALATION % | 5.7 | 5.7 | 7.2 | 10.8 | 11.2 | 8.5 | 7.8 | 9.5 | 8 | 7 | |
| | ESCALATION INDEX | .943 | .889 | .825 | .736 | .654 | .598 | .551 | .499 | .459 | .427 | |
| | $71 | 5.2 | 45.9 | 78.9 | 83.5 | 116.6 | 108.9 | 108.7 | 85.4 | 55.4 | 26 | 715 |
| FLIGHT | SPO PROVIDED (RY $) | 5 | 57.1 | 95.7 | 113.3 | 178.3 | 174.5 | 221.8 | 254.8 | 155.3 | 137.9 | 1393 |
| | ESCALATION % | 5.7 | 5.7 | 7.2 | 10.8 | 11.2 | 8.5 | 7.8 | 9.5 | 10.7 | 10.9 | |
| | ESCALATION INDEX | .943 | .889 | .825 | .736 | .654 | .598 | .551 | .499 | .445 | .396 | |
| | $71 | 4.7 | 50.8 | 7.9 | 83.4 | 116.5 | 104.4 | 122.2 | 127.2 | 69.1 | 55.1 | 812 |

Table 7. ET DDT&E cost.

($M)

| | | FY74 | FY75 | FY76 | FY77 | FY78 | FY79 | FY80 | FY81 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|
| ATP | POP 72-1M 10/72 (RY $) | 28.9 | 96.3 | 149.1 | 160 | 114.6 | 44.4 | 1.7 | 0 | 595 |
| | ESCALATION % | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | | |
| | ESCALATION INDEX | .871 | .832 | .794 | .759 | .725 | .692 | .661 | | |
| | $71 | 24.8 | 78.5 | 116 | 117.6 | 80 | 29.4 | 1 | | 447 |
| PRR | POP 74-1 3/74 (RY $) | 12.5 | 28.3 | 53.7 | 44.8 | 30.8 | 21.4 | 7.3 | | 199 |
| | ESCALATION % | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | | |
| | ESCALATION INDEX | .871 | .832 | .794 | .759 | .725 | .692 | .661 | | |
| | $71 | 10.9 | 23.5 | 42.6 | 34 | 223 | 14.8 | 4.8 | | 148 |
| PDR | POP 75-1 3/75 (RY $) | 15.5 | 34.2 | 88.2 | 57.7 | 42.5 | 22 | 11.7 | 2.2 | 274 |
| | ESCALATION % | 5 | 8 | 8 | 7 | 7 | 7 | 7 | 7 | |
| | ESCALATION INDEX | .843 | .776 | .714 | .664 | .618 | .575 | .535 | .497 | |
| | $71 | 13.1 | 25.5 | 63 | 38.3 | 26.3 | 12.7 | 6.3 | 1.1 | 187 |
| CDR | POP 76-1 3/76 (RY $) | 15.5 | 35.3 | 97.5 | 72 | 70 | 63 | 43 | | 396 |
| | ESCALATION % | 5 | 8 | 7 | 7 | 7 | 7 | 7 | | |
| | ESCALATION INDEX | .843 | .776 | .722 | .521 | .485 | .451 | .419 | | |
| | $71 | 13.1 | 23.4 | 70.4 | 37.5 | 34 | 28.4 | 18 | | 229 |
| DEL | POP 79-2A 8/79 (RY $) | 15.5 | 35.3 | 106.6 | 84.7 | 89.3 | 103.3 | 64.4 | 34.6 | 534 |
| | ESCALATION % | 7.2 | 10.8 | 11.2 | 8.5 | 7.8 | 9.5 | 8 | 7 | |
| | ESCALATION INDEX | .825 | .736 | .654 | .598 | .551 | .499 | .459 | .427 | |
| | $71 | 12.8 | 26 | 69.7 | 50.7 | 49.2 | 51.5 | 29.6 | 14.8 | 304 |
| FLIGHT | POP 82-1 (RY $) | 15.5 | 35.3 | 106.6 | 84.7 | 89.3 | 103.3 | 68.9 | 73 | 577 |
| | ESCALATION % | 7.2 | 10.8 | 11.2 | 8.5 | 7.8 | 9.5 | 10.7 | 10.9 | |
| | ESCALATION INDEX | .825 | .736 | .654 | .598 | .551 | .499 | .445 | .396 | |
| | $71 | 12.8 | 26 | 69.7 | 50.7 | 49.2 | 51.5 | 30.7 | 28.9 | 319 |

## APPROVAL

## ESTIMATING THE COST OF MAJOR ONGOING COST PLUS HARDWARE DEVELOPMENT PROGRAMS

By J.C. Bush

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

Sidney P. Saucier

SIDNEY P. SAUCIER
Manager, Space Systems Projects Office

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