TRYING TO DO TOO MUCH WITH TOO LITTLE: HOW POOR PORTFOLIO MANAGEMENT CAN LEAD TO SCHEDULE DELAYS AND COST OVERRUNS

Christian Smart, Ph.D., CCEA
Director, Cost Estimating and Analysis
Missile Defense Agency
christian.smart@mda.mil
256-450-4936

ABSTRACT

Government organizations often try to accomplish too much with the resources with which they are provided. The genesis of new projects in is often the search to spend idle funds. An organization's leadership may discover that it has a relatively small amount of money that can be used to research a new technology or to begin initial development of a new project. New ideas to improve systems, develop better, newer ones, and to advance scientific understanding abound. In order to convince leadership, project managers may provide success-oriented, optimistic projections. Projects require several years to complete, but only the initial year, or seed money, is often considered when starting these endeavors. The initial year, which is only the tip of the iceberg, does not take into account the significant cost of development, production, and operations and sustainment. As a result, projects often begin small, but wind up costing a significant amount of money, putting a strain on the rest of the portfolio, leading to schedule delays, which in turn result in cost overruns. Also, there is a lack of risk analysis at the portfolio level, as well as a tendency to underestimate risk for individual projects. This paper looks at these, and in particular examines the impact of trying to do too much with too little, and quantifies the length of schedule delays and the amount of cost overruns expected due to trying to do too much with too little. The paper concludes with a call for organization level portfolio management and for an objective examination of the impacts of new additions to a portfolio.

INTRODUCTION

Government organizations sometimes try to accomplish too much with the resources with which they are provided. The genesis of new projects in government organizations is often the search to spend idle funds. An organization's leadership may discover that it has a relatively small amount of money that can be used to research a new technology or to begin initial development of a new project. New ideas to improve systems, develop better, newer ones, and to advance scientific understanding abound. In order to convince leadership, project managers may provide success-oriented, optimistic projections. Projects require several years to complete, but only the initial year, or seed money, is often considered when starting these endeavors. The initial year is only the tip of the iceberg, and does not take into account the significant cost of development, production, and operations and sustainment. As a result, these projects often begin small, but wind up costing a significant amount of money, putting a strain on the rest of the portfolio, leading to schedule delays, which in turn result in cost overruns.

In order to understand the impact of budget constraints and schedule delays, the paper begins with a discussion on this topic, and provides recent research and rules of thumb for these effects. Once this is discussed, these research results are applied to portfolio sub-optimization. By means of detailed example it is demonstrated that poor portfolio management can be a significant cause of cost overruns and schedule growth.

The paper ends with a list of issues that lead to poor portfolio management, and provides suggestions for ways to improve this.

QUANTIFYING THE IMPACT OF SCHEDULE DELAYS AND BUDGET CONSTRAINTS ON COST

Cost and schedule are highly correlated and closely linked. An increase in schedule requires additional labor, which results in an increase in cost. On the other hand, a decrease in schedule may also require additional labor due to a suboptimal allocation of resources. For example, some tasks may have to be performed in parallel that work better when performed sequentially. Also, immature technologies may have to be used before they can be fully developed, leading to implementation problems. Thus changes in schedule have a significant impact on cost. Also, changes in cost affect schedule. A funding ceiling or cap can increase overall program cost and lengthen schedule by causing a non-optimal allocation of resources. The purpose of this study is to perform research on how changes in schedule impact cost and how changes in cost impact schedule, leading to the development of equations that quantify these effects. A spreadsheet was developed to implement these algorithms. This spreadsheet also implements a simple phasing tool that allows the user to see the effect of changes in schedule on cost. The Beta distribution is used for all phasing in the spreadsheet.

While the impact of schedule on cost has been extensively studied in the software cost community, less work has been done on the effect on overall spacecraft cost. Previous studies on this subject include research by The RAND Corporation, PRC, the Microgravity Experiments Cost Model, and others. Some cost models, including PRICE, include schedule expansion/compression factors in their models. One way to jointly assess cost and schedule risk is through the treatment of cost and schedule as bivariate probability distributions (Smart, 2008). However, this is most applicable in the early phases of a program, before contracts for development and production are signed. During the early concept phase, cost and schedule are still connected, but there is some amount of independence. Policy makers can choose among of sets of available cost and schedule pairs to achieve the desired joint confidence level. However, once signed contracts are in place, any change in schedule results in a change in cost, which is not the case during the early concept phase. The methods developed for this research task are best applied after the early concept phase, when cost becomes a function of the imposed schedule(s).

Details of prior work and how it compares with the research performed for this task are included in each of the sections that follow.

Cost Phasing

Three connected areas of a program are cost, schedule, and phasing of cost over the schedule duration. For a given cost and a given schedule, cost must be phased, unless all cost is planned to be expended in a single period. This is because budgets are phased annually.

Cost phasing is typically done on a consistent periodic basis, such as a monthly, quarterly, or an annual spread. For a project with a 5 year duration with a total cost equal to $100 million, suppose that the annual costs are: $10 million in the first year; $30 million in the second year; $40 million in the third year; $20 million in the fourth year; and $10 million in the fifth and final year. This phasing is displayed graphically in Figure 1.

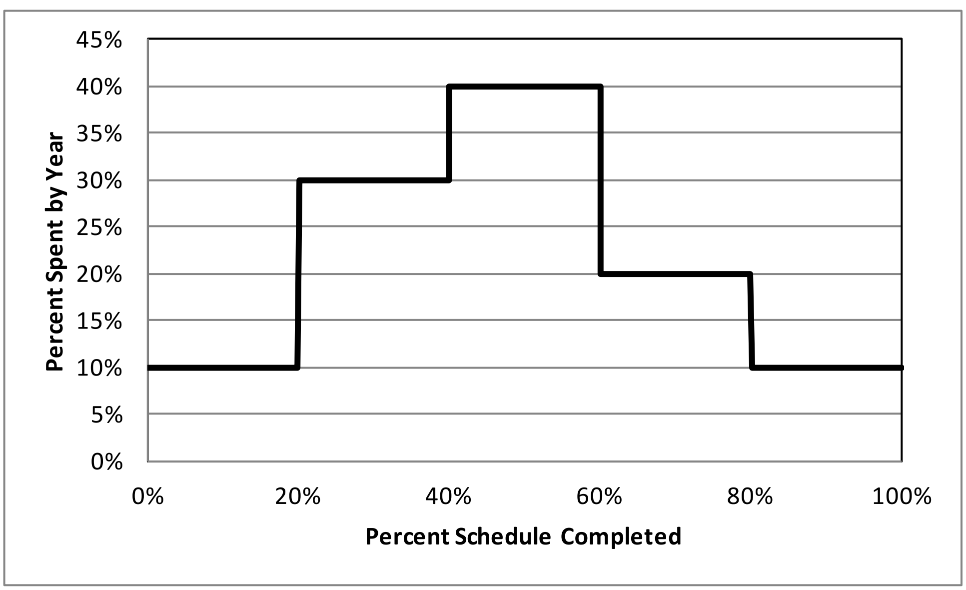

Figure 1. Example of Cost Phasing.

Historically, cost phasing has been model by approximating the phasing using a continuous distribution. The beta, Weibull, and Rayleigh distributions are among the most popular (Burgess 2004, Smart 2005). The beta distribution is often used because of its flexibility. The two parameter beta probability density is defined by the function

$$f(x;\alpha,\beta)=\frac{x^{\alpha-1}(1-x)^{\beta-1}}{\int_0^1 u^{\alpha-1}(1-u)^{\beta-1}du}$$

The denominator

$$B(\alpha,\beta)=\int_0^1 u^{\alpha-1}(1-u)^{\beta-1}du$$

is called the beta function.

See Figure 2 for examples of the graphs of various beta distribution.

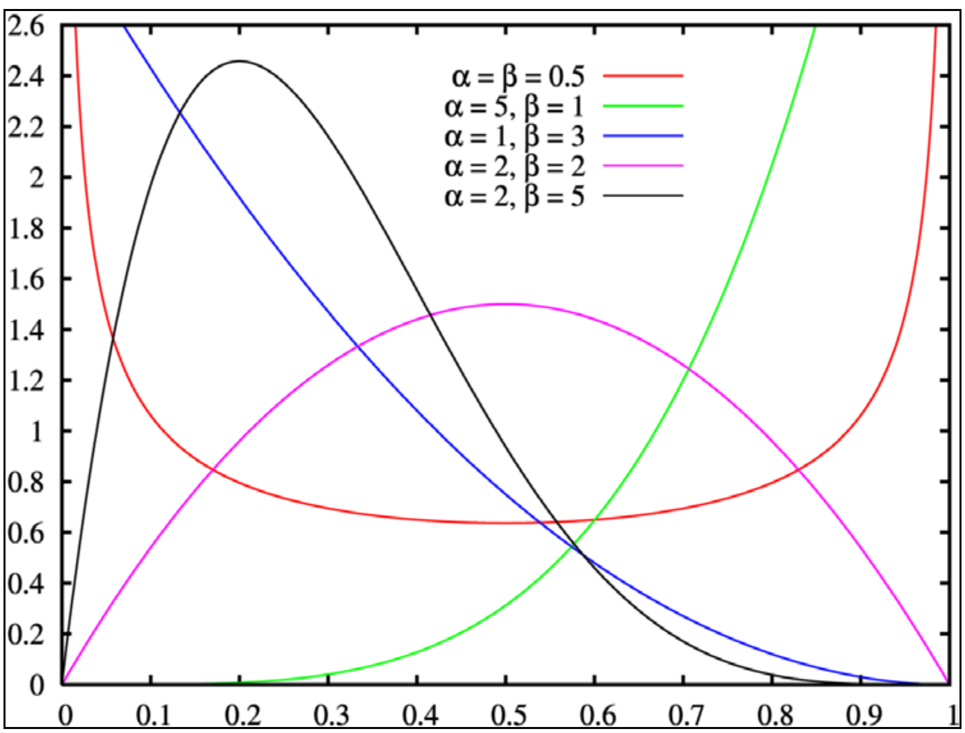

Figure 2.Examples of Various Beta Distributions.

Note that the standard two parameter beta probability density function is bounded between 0 and 1, so the value on the x-axis represents the percentage of the schedule completed, so *0.5* on the x-axis of Figure 2 represents the 50% completion point on a schedule. As an example, for a 72 month schedule, *0.5* represents 36 months.

Note that the beta, while flexible, has its limitations. See Figure 3 for a year-by-year beta distribution approximation of the phasing that is graphically displayed in Figure 1.

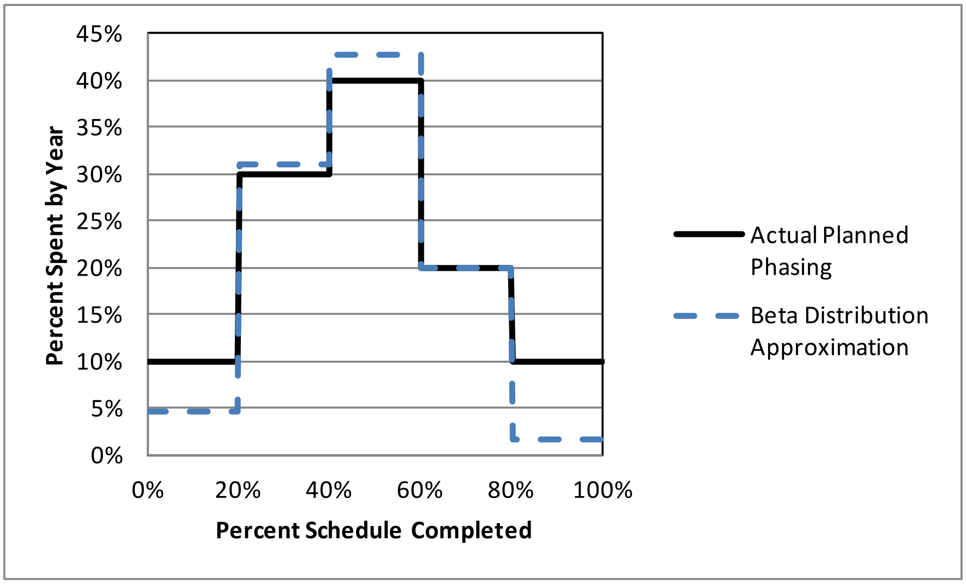

Figure 3. Planned Phasing and Beta Approximation Comparison.

In the author's experience, when beta distributions are used for phasing of cost, they are characterized as the percent spent at the midpoint of the schedule. Development projects tend to be front-loaded, and there is empirical evidence that a beta distribution such that 60% of the cost is spent at the schedule midpoint is appropriate for phasing the cost of such projects (Smart, 2005).

Increases in Schedule and Its Effect on Cost

When a schedule expands, cost increases because of the additional activity required. This can be represented as a stretching of the funding profile to the right. Since the area under the funding profile is equal to the total cost, the extra area created by the schedule increase represents the amount of cost growth. See Figure 4 for an illustration of this concept.

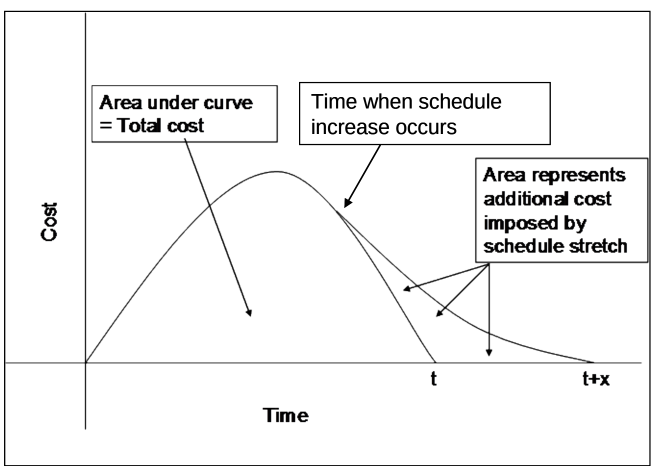

Figure 4. Schedule Expansion and Funding Profiles.

When a beta distribution with parameters α and β is used to represent the cost phasing, a 10% schedule increase that occurs at time $t = z$ will increase the total cost by an amount equal to

$$\int_0^z \frac{x^{\alpha-1}(1-x)^{\beta-1}}{B(\alpha,\beta)}dx + \int_z^{1.1} \frac{x^{\alpha-1}(1.1-x)^{\beta-1}}{B(\alpha,\beta)1.1^{\alpha+\beta-1}}dx.$$

The effect of changes in cost depends upon three factors: the beta parameters, the amount of schedule growth, and the point at which the schedule increase occurs. In order to visualize these impacts, Figures 5-7 contain graphical displays of cost growth as a percentage of schedule growth based on the amount of schedule growth and the point in time at which the schedule growth occurs. Beta distributions as used in cost analysis are often characterized by the amount of the total cost expended at the halfway point in the schedule. For example, Figure 5 displays this effect for a Beta distribution that is front-loaded, with 60% of the total cost expended at 50% in the schedule. The figure displays a response surface.

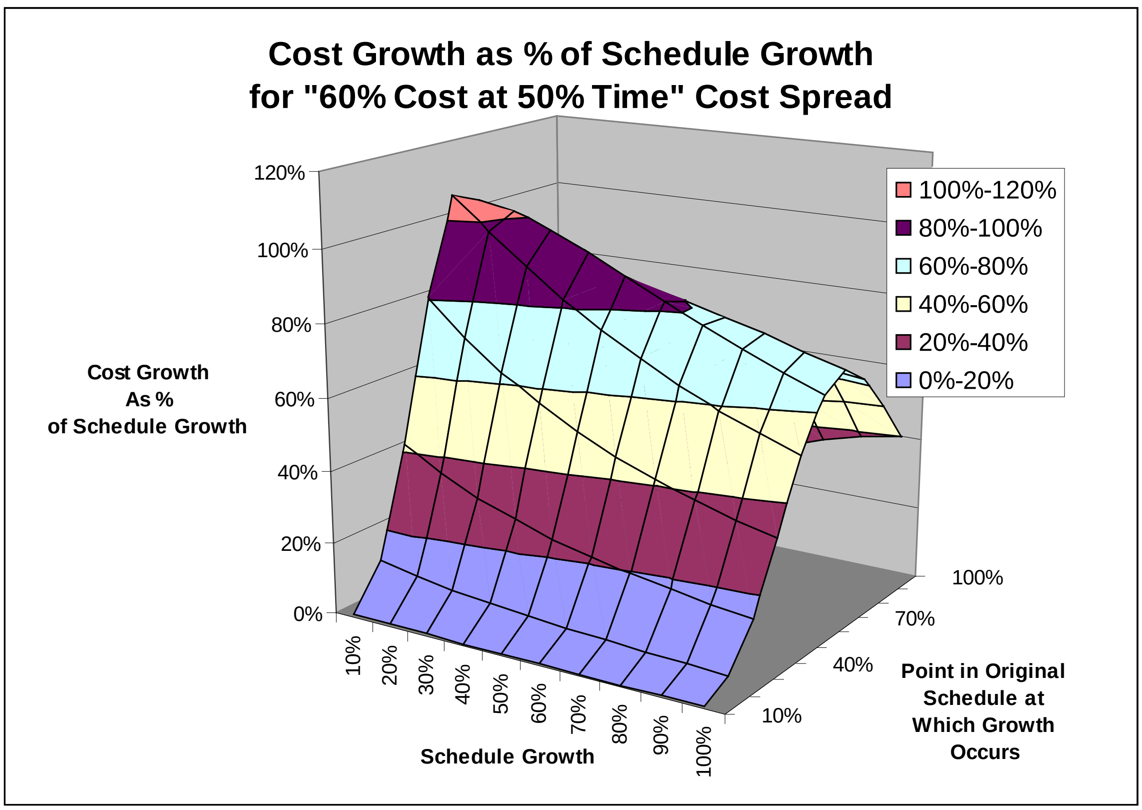

Figure 5. Cost Growth as a Percentage of Schedule Growth for a "60% Cost at 50% Time" Cost Spread.

For any point on the horizontal plane (Schedule Growth, Point at Which Growth Occurs), there is an associated cost growth as a percentage of schedule growth that is represented by the response surface in the figure. For example, when schedule grows by 50% and the schedule growth begins at 40% of the way through the original schedule, cost will grow by 25.2% of the schedule growth, or about 12.6% (i.e., 50% of 25.2%). Figures 3 and 4 display the response surfaces for “50% Cost at 50% Time” and “40% Cost at 50% Time” spreads.

The three figures are interesting because they show how the sensitivity of cost varies due to the loading of the profile and when the schedule growth occurs. Note that these figures indicate that cost growth is most sensitive to schedule growth (as a % of schedule growth) when: schedule growth is small; schedule growth occurs in the middle of the schedule (at peak funding); and the cost profile is back-loaded (peak occurs in out years). This validates hypotheses made (but unverified) by previous research.

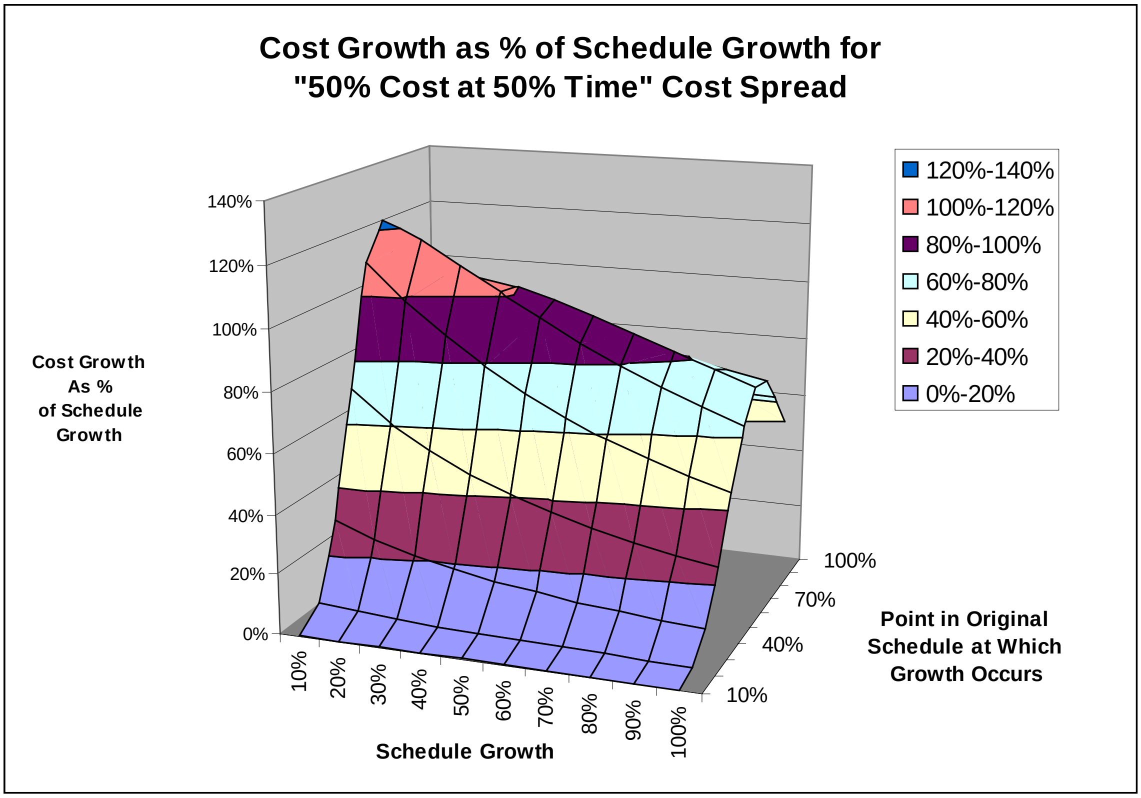

Figure 6. Cost Growth as a Percentage of Schedule Growth for a “50% Cost at 50% Time” Cost Spread.

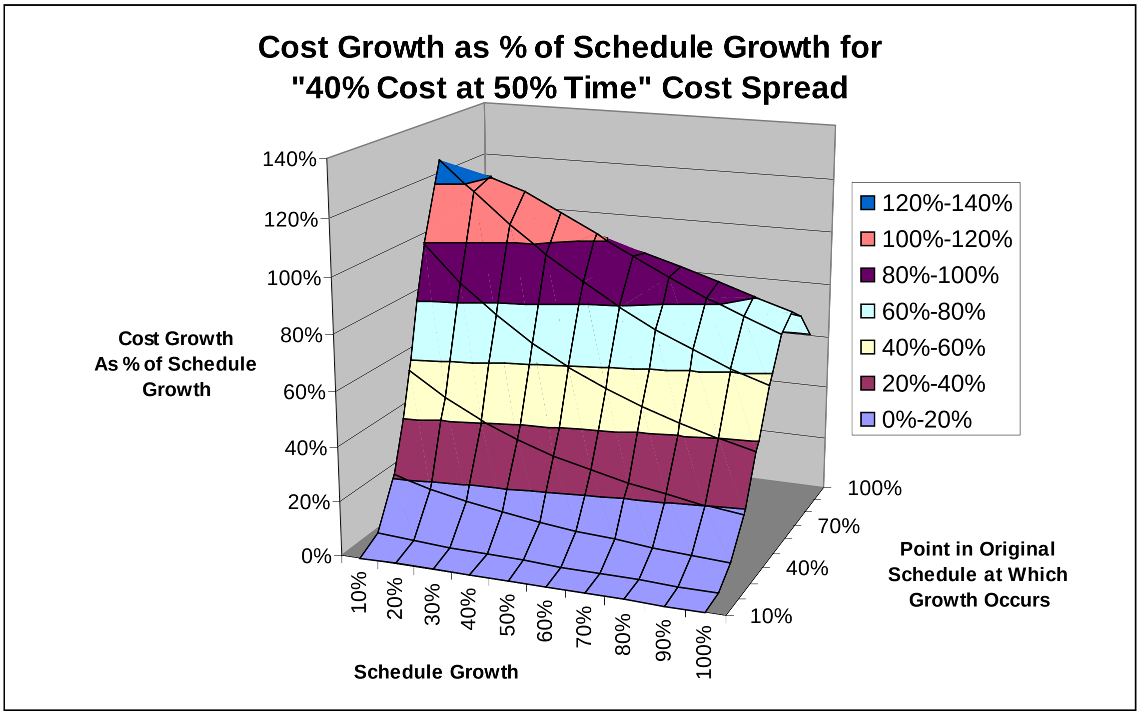

Figure 7. Cost Growth as a Percentage of Schedule Growth for a "40% Cost at 50% Time" Cost Spread.

While valuable, this approach may not match the impacts on actual cost caused by actual schedule slips. For example, schedule slips may cause discontinuous adjustments in cost or cost spreads may not match a beta distribution (or any continuous distribution). As an example, consider the Apollo Crew and Service Module (Apollo CSM) cost profile (Smart, 2005), shown in Figure 8. The total cost profile has several peaks and the use of a standard continuous probability density function to model these costs would at best be a rough approximation.

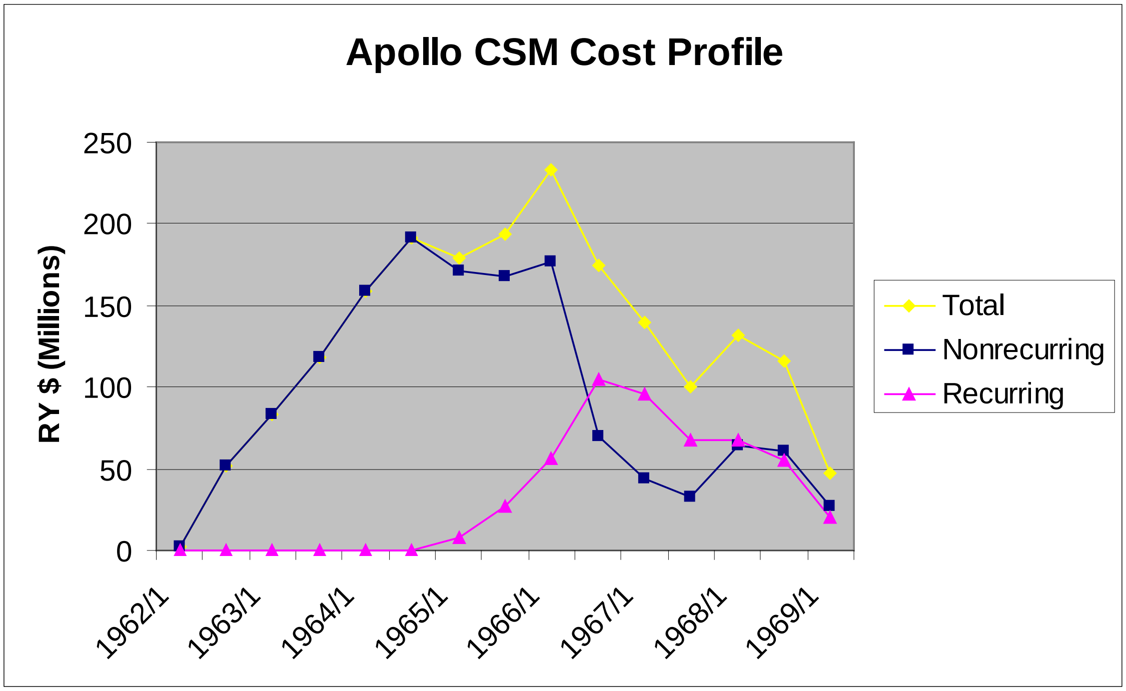

Figure 8. Semi-annual Expenditures for Apollo CSM.

In order to perform a real-world comparison of cost and schedule growth, we compared theoretical results to empirical data based on a case-by-case analysis of cost and schedule growth data by milestone (ATP, PDR, CDR, Delivery, and Launch) for several missions. Also data for over 40 NASA missions were compiled. See Table 1 for a complete list.

For the missions in Table 1, cost and schedule growth were normalized. External effects such as strikes, launch vehicle unavailability, and large scope changes were removed. While these effects are important, they only act as noise in attempting to discern the true impact of schedule growth on cost growth.

Some available research indicates that “most” schedules are longer than optimal. The Microgravity Experiments Cost Model and a report by PRC claims that most schedules contain inherent slack, perhaps as much as 20%, and that a typical schedule can be compressed while resulting in cost savings. It is true that some programs have been able to cut cost by optimizing schedule. In the most dramatic instance, the Delta 180 program cut both cost and schedule by more than 50%. Also, Rossi XTE experienced significant cost and schedule savings from ATP to launch. NASA conducted an experiment in this regard in the 1990s with its “faster, better, cheaper” policy. While there were some success stories such as

Rossi X-ray Timing Explorer (XTE), overall this paradigm was unpopular and often ineffective for high-risk projects. There were several high-profile failures such as Mars Climate Orbiter and Mars Polar Lander that may have been directly due to schedule (“faster”) and cost (“cheaper”) constraints. More than one cost analyst published reports indicating the increase in risk due to this policy

ACE	GRACE	OSO-8
ACTS	HEAO-1	Saturn V
AE-3	Hessi	Shuttle Orbiter
AMPTE-CCE	HETE-II	SORCE
Aqua	HST	Spitzer Space Telescope
Aura	ICESAT	Stardust
C GRO	IMAGE	SWAS
CONTOUR	Landsat-1	Swift
Dawn	Landsat-7	TDRS-H
Deep Impact	Lunar Orbiter	Terra
DMSP-5D	Lunar Prospector	TIMED
EO-1	Magellan	TIROS-M
FAST	MAP	TIROS-N
FUSE	Mars Exploration Rovers	TRACE
GALEX	Mars Observer	TRIANA
Galileo	Mars Odyssey	VCL
Genesis	Messenger	Viking Orbiter

Table. 1. Missions Included in the Schedule Expansion Research.

(Mosher, Bitten, et al.). The overall failure of the "faster, better, cheaper" policy demonstrates that most schedules are not longer than optimal. With tight schedules and funding constraints in the 1990s, mission success rates dropped from over 90% to approximately 75% (Tosney, 2000). If there had been sufficient slack in most schedules, the dramatic increased in mission risk would not likely have occurred. For the missions included in this study, the average schedule slip is approximately 30% and over 80% of the missions experienced some schedule growth. Surely if most schedules contained some slack schedule growth would not be as persistent nor as large as indicated by recent experience. Indeed, if anything the available data point to the opposite conclusion: the average program schedule is optimistic. However, lengthening the schedules does not save much if anything in the way of cost since increasing schedule in turn increases labor costs associated with the program.

See Figure 9 for a scatter plot of schedule and cost growth for the spacecraft in Table 1.

Note that in Figure 9, "growth" is indicated as a multiple of the original cost or schedule. For example ***schedule growth = 1.2*** in the plot means that schedule grew by 20%. The missions in red are projects with spacecraft cost less than or equal to $50 million. Schedule growth has little effect on cost for these missions. Indeed two of these missions had cost savings over more than 10% from the original budget.

Only the missions in blue were included in the calculation of the relationship between schedule and cost growth. Note this the equation is summarized as

$$\textit{Cost Growth (\%)} = 0.15\left(\textit{Schedule Growth (\%)}+1\right)^2 + .05\left(\textit{Schedule Growth(\%)}+1\right) - 0.2$$

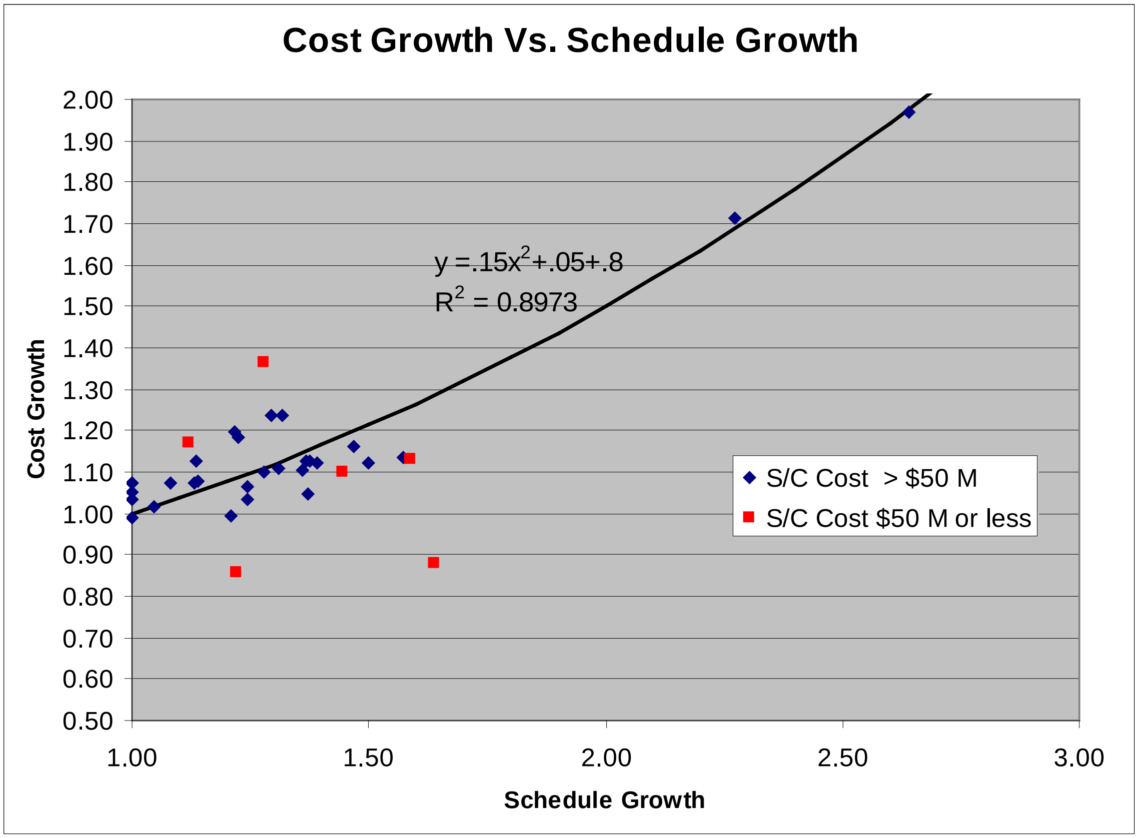

Figure 9. Cost and Schedule Growth for Over 40 NASA Missions.

For example schedule growth equal to 47% translates to cost growth equal to ***0.15*(1.47)2+0.05*1.47-0.2 = 0.20***, or 20%, which is 42% of the schedule growth.

The relative results of the theoretical analysis are confirmed by the data, but the assumption that schedule changes are continuous results in consistent underestimation of the effects of schedule increases on cost by a factor of two on average. The spreadsheet model implements the theoretical results derived earlier in this section by using a series of lookup tables, multiplied by a cost realism correction factor equal to 2 in order to bring the schedule growth in line with historical experience.

The results of this research have been incorporated in a model developed by the author for NASA call Quantitative Techniques for Incoporating Phasing and Schedule (QTIPS). This model also has the capability to assess the impact of schedule compression on cost. See "NAFCOM

Improvements: Assessing the Impact of Phasing and Schedule on Cost" (Smart, 2009) for more details.

Funding Constraints

For each project, there is an ideal funding profile, one that ramps up as the design work gets underway, and then ramps down as fabrication and assembly nears completion and testing ensues. For large complex programs, the ideal funding peak may exceed the budget for an entire directorate, requiring funding caps that constrain expenditures in some fiscal years. If this constraint flattens the funding profile it will necessarily lead to delays in activities. The funding profile peak will be delayed and may shift the profile from being front-loaded to back-loaded. This will in turn lead to schedule and cost growth, because activities will not be scheduled at optimal times. Tests may be delayed, which may lead to expensive re-designs later, or design work may be fragmented and communication across design groups limited, leading to integration issues that will take additional time and money to fix at a later date. If the constraint is severe enough, it may only provide enough funding for the program to avoid laying off staff, keeping critical people on board performing non-essential activities that do little to aid forward progress. This latter state is akin to making the interest payments on debt without paying down any principal. These kinds of constraints are particularly onerous and can lead to costs that spiral out of control.

See Figure 10 for an example of a change in the funding profile due to an annual funding constraint.

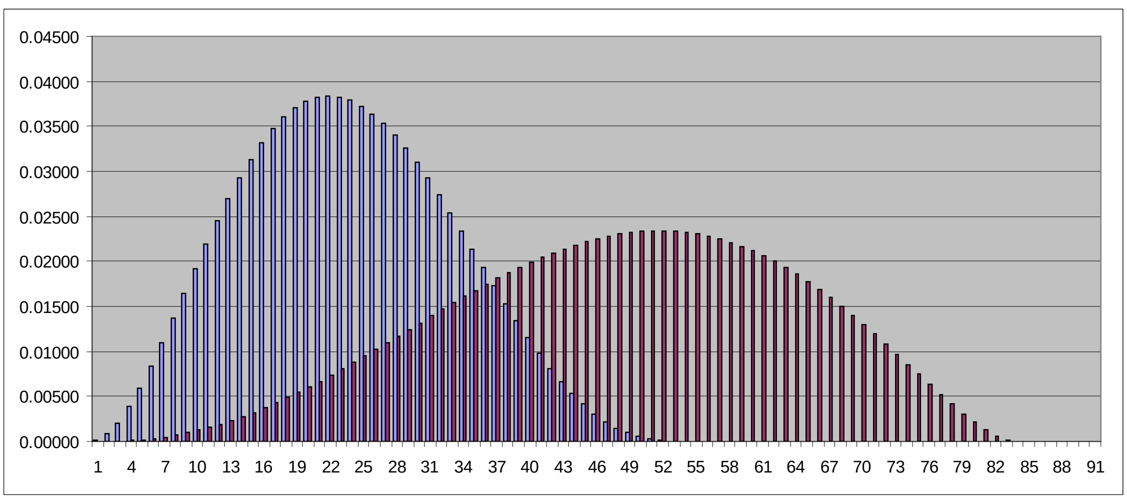

Figure 10. Funding Profiles Before and After Cap Is Applied.

In order to assess this effect, we measure the amount of decrease in the budget peak in percentage terms, and compare it to cost growth increases for available historical data. Two prominent missions that experienced significant schedule growth due to funding constraints were Shuttle Orbiter and the Hubble Space Telescope (Emhart PRC, 1988). Both elements of HST,

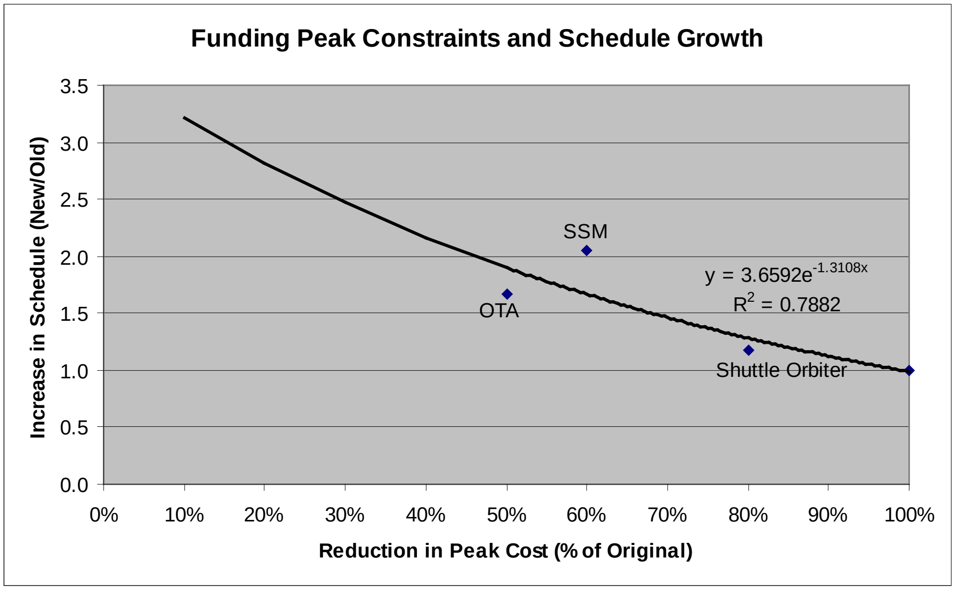

Figure 11. Comparison of Funding Peak Constraints and Schedule Growth.

SSM and OTA, experienced large schedule increases due to funding constraints. These data, with a trendline fit to the data, are displayed in Figure 11.

In Figure 11, the x-axis represents the reduction in peak cost due to funding constraints, measured as a percentage decrease from the original, planned peak. The y-axis represents the increase in cost as a multiple of the original cost (New/Old). For example, Shuttle Orbiter experienced a 20% funding constraint, in the peak year of funding, from the original planned peak. That is, in the peak year of funding, which was Fiscal Year 1976, the Orbiter expenditure was only 80% of that planned at the commencement of the Shuttle Orbiter program in 1972. As a result of this cap, Shuttle Orbiter schedule grew by 16.7% (Heppenheimer,1988). The equation graphed in Figure 11 is

$$\textit{Schedule Growth (\%)} = 3.6592e^{\left(-1.3108 * \left(1 - \%\textit{Reduction in Peak Funding}\right)\right)} - 1.$$

For example, if the reduction in peak funding is 30%, the predicted increase in schedule is 46%.

While based on a small data set, funding constraints for major programs are not an everyday occurrence, And despite the size of the data set, this equation closely agrees with an equation developed by Edwin Dupnick, (Dupnick, 1988). Dupnick’s equation was based on his experience with “modest-sized” NASA programs at Johnson Space Center. See Figure 12 for a comparison of the equation in Figure 11 and Dupnick’s equation.

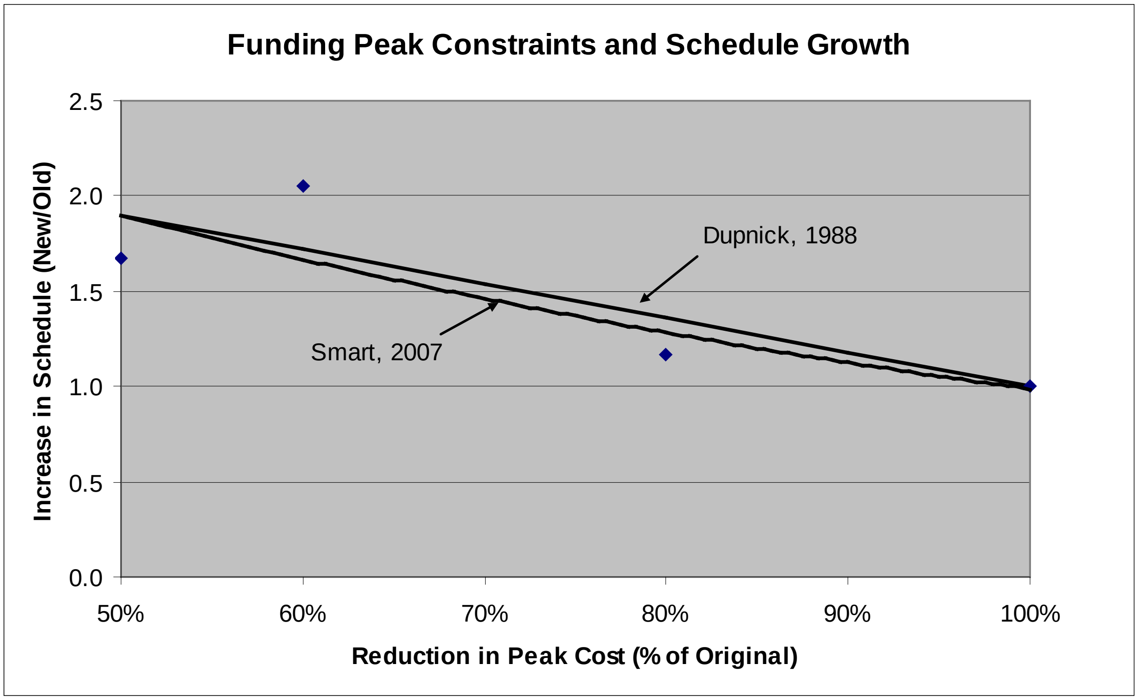

Figure 12. Comparison of Two Equations Effect of Reduction in Peak Cost on Increase in Schedule Growth.

Dupnick's equation is linear. Funding constraints should have a nonlinear relationship with schedule, since as the reduction in peak cost continues to increase, the amount of time required should increase at an increasing rate.

In the implementation of the equation, the algorithm takes into account the month of the fiscal year in which the task begins. This is needed to determine in which fiscal years, if any, the funding cap reduces planned funding.

The algorithm for applying the funding cap follows several steps. In order to be an effective cap, the funding constraint must reduce peak funding in at least one year. As mentioned in the previous paragraph the first step is to determine the year(s) to which the funding cap applies. This could be none, one, or multiple years. When the funding cap applies, the amount of money that is planned to be spent in that particular year exceeds the maximum amount represented by the cap. The excess of the planned funding over the cap is referred to as "overage." When funding caps effectively constrain spending in multiple years, the maximum overage is used to represent the overage for the entire funding profile. That is,

$$Overage = Max\{ Overage_1, Overage_2, ..., Overage_N \}$$

where $Overage_i$ represents the overage for the i^{th} year. The percentage reduction in peak cost due to the funding constraint is then calculated as

$$\frac{Annual\ Cap}{Annual\ Cap + Overage}$$

The percentage reduction in peak funding is then used to calculate the schedule increase. The algorithm for cost impact due to schedule expansion is applied in order to determine the amount of cost increase. If the cap is effective, Excel Solver is used to find a beta distribution to phase the adjusted cost over the adjusted schedule, taking the cost cap into account. The numerical optimization routine finds the parameters of the beta that most closely match those of the beta distribution originally input by the user. The objective function used is the sum of squared differences between the parameters. The rationale behind this optimization is that the original profile has desirable properties, otherwise it would not have been selected. Thus the best adjusted profile should be the one that is as similar as possible to the original profile.

One issue with a funding cap is that it could potentially be tight enough that it would not be possible to fund a program with a realistic profile. For example, if the cap is less than the total cost, and the plan calls for the program to be completed within one year, this is clearly an impossible situation. Either more money is needed for that year more time is required to complete the program. Similarly tight caps imply uniform or nearly uniform phasing, which are not realistic. Once the cost cap is applied, and then schedule and cost impacts are determined, if the resulting cost and schedule cannot be phased in the Excel implementation, the user receives an error message that the cost and schedule cannot be phased with such a cap, that is, the funding cap is too constraining for a beta distribution to phased the cost within the given schedule.

The result of the funding constraint research has also been incorporated in QTIPS, see the author’s white paper (Smart, 2009) for more information.

TRYING TO DO TOO MUCH WITH TOO LITTLE

Portfolio optimization involves multiple years. Beginning new projects in order to spend all available funds involves portfolio management year-by-year. This can lead to sub-optimal results. This is because the first year of a project is the least expensive, and so the ensuing years can lead to not having enough funds to execute the entire portfolio efficiently, leading to funding cuts for other projects in the portfolio, and significant schedule delays, which result in cost overruns. The process of looking only one year head is an example of what is termed in optimization as a greedy algorithm. A greedy algorithm is an algorithm that follows the problem solving heuristic of making the locally optimal choice at each stage with the hope of finding a global optimum. On some problems, a greedy strategy need not produce an optimal solution, but nonetheless a greedy heuristic may yield locally optimal solutions that approximate a global optimal solution. Greedy algorithms are often characterized as being 'short sighted' or myopic. This type of approach leads directly to trying to do too much (too many programs ongoing at the same time) with too little resources.

See Figure 13 for a notional depiction of life-cycle costs. Research and development is often relatively small compared to the costs of producing, operating and disposing of the system.

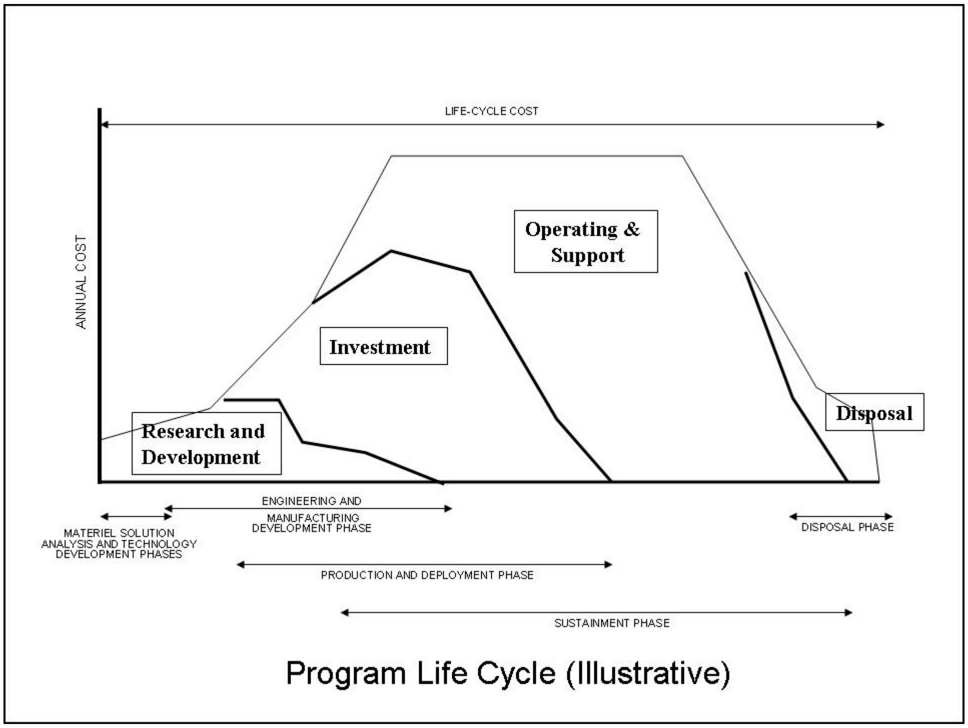

Figure 13. Program Life Cycle and the Tip of the Iceberg. (CAPE, 2012)

This is seen in portfolio management when budget wedges are established; whether for one year, or multiple years, little consideration of the full cost impacts of new projects on the overall portfolio is given when putting into the budget an amount of money that helps get a project started without the full implications for life-cycle cost.

As an example, consider a series of projects, all of which cost \$500 million, as long as there are no schedule delays. Note that in a high inflationary environment, schedule delays can impact budgets significantly simply due to the impact of the time value of money. For the sake of simplicity, we will ignore the effects of inflation in this example. Also assume that the annual budget for the entire portfolio is \$1 billion. Further assume that the cost phasing follows a beta distribution with $\alpha = 2.45$ and $\beta = 3.00$. This is a front-loaded beta distribution such that 60% of the cost is planned to be spent at the schedule midpoint. The spread for five years is: 11% in the first year; 31.3% in the second year; 33.7% in the third year; 20.0% in the fourth year; and 4.0% in the fifth and final year. Thus the cost planned for the first year is \$500*.11 ~= \$55.0 million. Table 3 displays the cost for a \$500 million program spread according to this phasings.

Year	Cost ($ Millions)
1	$55.0
2	$156.5
3	$168.5
4	$100.2
5	$19.8

Table 3. Yearly Planned Phasing for Example.

Now consider the question of how to optimally plan the entire portfolio of programs in order to maximize the number of programs. Assume for simplicity that no other projects exist. Recall that the total annual portfolio budget is a flat, fixed $1 billion. A naïve approach would be to start 18 programs in the first year, since that is what can be afforded in the first year. However, this leads to disaster in year two, since the budget cannot grow for any program, and the annual planned cost will have to be cut by 2/3rd for each program in year two. Under such a scenario, it is likely that none of these programs would be achievable. Assume instead that the portfolio manager instead more prudently decides to take years one and two into consideration, and only begins six programs in year one, since the manager realizes that in year two, $156.5 million *6 = $939.0 million will be required for this portfolio in year two. The entire portfolio is affordable in year one, and in year two there is $1,000 million - $939 million = $61 million. Since "only" $55 million is needed for the first year of a new project, the manager decides to begin a seventh $500 million project. In year three however, there is a budget constraint. Six projects need $168.5 million, and the seventh project requires $156.5 million. The total bill amounts to 6*$168.5 million + $156.5 million = $1,167 million which is $167 million more than is available in the annual budget. Thus funding cuts are now required in year three. Assume that the funding cuts are spread equally among all six projects, resulting in a $167/7 ~= $24 million cut for each project in year three. This funding constraint results in a non-optimal allocation of resources, leading to a delay of schedule. The cut is not significant, only about 14% for each project in that year, so it is assumed that the schedule slips only one year. Applying the QTIPS model, this 20% schedule slip results in an 18% cost growth for the program. Now the total cost for each of the seven programs is $591 million. In year four, there is not enough money to fund project 7 to its full funding – a funding cut of $17.5 million is applied, leading to another year of schedule delay, and a total cost of $699.1 million. After adjusting the phasing to accommodate the additional cost, plus the extra year, and the annual budget cap, the phasing of the seven projects at the end of year three, is displayed in Table 5.

Year	1	2	3	4	5	6	7	8
Project 1	$55.0	$156.5	$144.5	$145.5	$76.5	$13.0		
Project 2	$55.0	$156.5	$144.5	$145.5	$76.5	$13.0		
Project 3	$55.0	$156.5	$144.5	$145.5	$76.5	$13.0		
Project 4	$55.0	$156.5	$144.5	$145.5	$76.5	$13.0		
Project 5	$55.0	$156.5	$144.5	$145.5	$76.5	$13.0		
Project 6	$55.0	$156.5	$144.5	$145.5	$76.5	$13.0		
Project 7		$55.0	$133.0	$127.0	$185.0	$127.0	$61.4	$10.7

Table 5. Phasing for Seven Projects Impacted by Funding Constraints.

The phasing of an individual project, after accounting for the schedule slips, is compared to the original phasing in Figure 14.

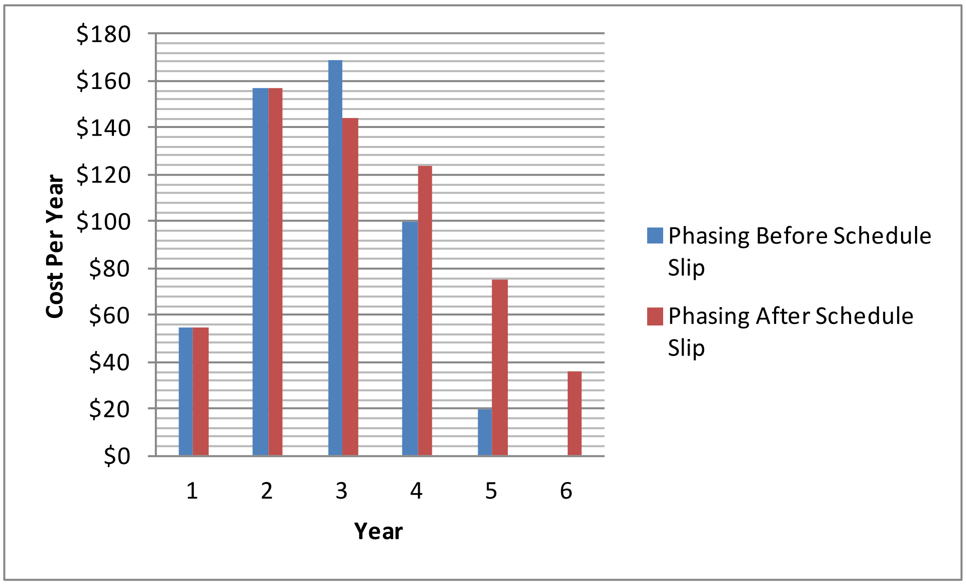

Figure 14. Planned Annual Phasing of Cost Before and After a One-Year Schedule Slip.

In year four, no new projects are started, but in year five, the total cost of the seven projects is only $644 million, meaning that there is $1,000 million - $644 million = $356 million available to start new projects. Noting that $356/$54.9 ~= 6.5, six new projects can be funded and are started under the myopic policy. This creates no problems in year five, but the planned funding in year six is $144.6 million over budget. Assume that only the six new projects are cut, this means a $24.1 million funding cut in the second year of these six projects, leading to a one year schedule delay, and an additional total cost equal to $591 million. The new profile plans for $173 million to be spent in year three of these six projects; however, the $61.4 million planned for project number 7, plus $173 million *6 results in total planned spending equal to $1,099.4, leading to spending cuts of $99.4 million in year 7, leading to another year schedule delay, and a total cost equal to $699.8 million. In year nine, there is some relief, and the greedy algorithm leads to four additional projects are started. No problems occur in years 9 or 10, and in year 11, five new projects are begun. In year 12, funding constraints are hit again, and the five newest projects receive a $36.6 million funding cut each, out of a total planned $156.5 million. This leads to a one year delay, with a new cost for each of the five projects equal to $591 million. See Table 6 for the cost spreads of all 26 projects completed in a 20-year time frame with this approach.

The end result, after twenty years, is that 26 projects are completed. The total cost of these 26 projects is $15,394 million. The initial cost of these 26 projects was $500 million, which equates to $13,000 million total. Thus poor portfolio management was responsible for over $2 billion in cost growth! Over 70% of the projects experienced both cost and schedule delays. The average project experienced 18% cost growth and the average schedule growth is approximately 19%. As discussed in the author's 2011 ISPA/SCEA presentation (Smart 2011), average annual cost growth for a large database of NASA and Department of Defense missions is 50%, with over 80% of missions experiencing cost growth. While the cost growth exhibited for this example represents only one source of cost growth, it demonstrates that *poor portfolio management may be one of the most significant causes of cost growth*. As cartoonist Walt Kelley wrote on a poster for Earth Day in 1970, "We have met the enemy and he is us!"

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Project 1	$55.0	$156.5	$144.5	$145.5	$76.5	$13.0														
Project 2	$55.0	$156.5	$144.5	$145.5	$76.5	$13.0														
Project 3	$55.0	$156.5	$144.5	$145.5	$76.5	$13.0														
Project 4	$55.0	$156.5	$144.5	$145.5	$76.5	$13.0														
Project 5	$55.0	$156.5	$144.5	$145.5	$76.5	$13.0														
Project 6	$55.0	$156.5	$144.5	$145.5	$76.5	$13.0														
Project 7		$55.0	$133.0	$127.0	$185.0	$127.0	$61.4	$10.7												
Project 8					$55.0	$132.4	$156.4	$164.8	$124.9	$58.4	$7.9									
Project 9					$55.0	$132.4	$156.4	$164.8	$124.9	$58.4	$7.9									
Project 10					$55.0	$132.4	$156.4	$164.8	$124.9	$58.4	$7.9									
Project 11					$55.0	$132.4	$156.4	$164.8	$124.9	$58.4	$7.9									
Project 12					$55.0	$132.4	$156.4	$164.8	$124.9	$58.4	$7.9									
Project 13					$55.0	$132.4	$156.4	$164.8	$124.9	$58.4	$7.9									
Project 14									$55.0	$156.5	$168.5	$100.0	$20.0							
Project 15									$55.0	$156.5	$168.5	$100.0	$20.0							
Project 16									$55.0	$156.5	$168.5	$100.0	$20.0							
Project 17									$55.0	$156.5	$168.5	$100.0	$20.0							
Project 18											$55.0	$119.8	$176.0	$147.2	$78.0	$15.0				
Project 19											$55.0	$119.8	$176.0	$147.2	$78.0	$15.0				
Project 20											$55.0	$119.8	$176.0	$147.2	$78.0	$15.0				
Project 21											$55.0	$119.8	$176.0	$147.2	$78.0	$15.0				
Project 22											$55.0	$119.8	$176.0	$147.2	$78.0	$15.0				
Project 23														$55.0	$156.5	$168.5	$100.0	$20.0		
Project 24														$55.0	$156.5	$168.5	$100.0	$20.0		
Project 25														$55.0	$156.5	$168.5	$100.0	$20.0		
Project 26														$55.0	$156.5	$168.5	$100.0	$20.0		

Table 6. Final Cost Phasing for Projects Completed Within 20 Years.

At this point the reader may counter that while the greedy algorithm may result in cost growth and schedule delays, this may lead to more projects being completed than with other strategies. However, consider the strategy of starting two new projects each year. While this may not make full use of the $1 billion annual budget until year 5, at year 5 and after, the entire budget is utilized, no schedules are delayed, and thus, under the assumptions of this example, there is no cost growth due to portfolio management issues. See Table 7 for a display of the cost for these projects over 20 years. Under this strategy, 32 projects are completed, six more than with the myopic strategy. This is 23% more than with the greedy approach to portfolio management. This is a significant inefficiency for the greedy algorithm to portfolio inclusion. Thus this example also shows that cost growth and schedule delays are not just problems for individual projects, but a larger problem – these issues lead to accomplishing less overall. Thus trying to do too much with too little results in less being achieved in the long run. It is worth spending time and energy, and even dedicated staff, whose sole purpose would be portfolio management. Private firms dedicate significant time and energy to understanding risk at the enterprise level, and it is crucial that public agencies do the same.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Project 1	$55.0	$156.5	$168.5	$100.0	$20.0															
Project 2	$55.0	$156.5	$168.5	$100.0	$20.0															
Project 3		$55.0	$156.5	$168.5	$100.0	$20.0														
Project 4		$55.0	$156.5	$168.5	$100.0	$20.0														
Project 5			$55.0	$156.5	$168.5	$100.0	$20.0													
Project 6			$55.0	$156.5	$168.5	$100.0	$20.0													
Project 7				$55.0	$156.5	$168.5	$100.0	$20.0												
Project 8				$55.0	$156.5	$168.5	$100.0	$20.0												
Project 9					$55.0	$156.5	$168.5	$100.0	$20.0											
Project 10					$55.0	$156.5	$168.5	$100.0	$20.0											
Project 11						$55.0	$156.5	$168.5	$100.0	$20.0										
Project 12						$55.0	$156.5	$168.5	$100.0	$20.0										
Project 13							$55.0	$156.5	$168.5	$100.0	$20.0									
Project 14							$55.0	$156.5	$168.5	$100.0	$20.0									
Project 15								$55.0	$156.5	$168.5	$100.0	$20.0								
Project 16								$55.0	$156.5	$168.5	$100.0	$20.0								
Project 17									$55.0	$156.5	$168.5	$100.0	$20.0							
Project 18									$55.0	$156.5	$168.5	$100.0	$20.0							
Project 19										$55.0	$156.5	$168.5	$100.0	$20.0						
Project 20										$55.0	$156.5	$168.5	$100.0	$20.0						
Project 21											$55.0	$156.5	$168.5	$100.0	$20.0					
Project 22											$55.0	$156.5	$168.5	$100.0	$20.0					
Project 23												$55.0	$156.5	$168.5	$100.0	$20.0				
Project 24												$55.0	$156.5	$168.5	$100.0	$20.0				
Project 25													$55.0	$156.5	$168.5	$100.0	$20.0			
Project 26													$55.0	$156.5	$168.5	$100.0	$20.0			
Project 27														$55.0	$156.5	$168.5	$100.0	$20.0		
Project 28														$55.0	$156.5	$168.5	$100.0	$20.0		
Project 29															$55.0	$156.5	$168.5	$100.0	$20.0	
Project 30															$55.0	$156.5	$168.5	$100.0	$20.0	
Project 31																$55.0	$156.5	$168.5	$100.0	$20.0
Project 32																$55.0	$156.5	$168.5	$100.0	$20.0

Table 7. Final Cost Phasing for Projects Completed Within 20 Years, A Better Approach.

The way to fix this issue is to develop life-cycle cost estimates before programming funds for these projects (no budget wedges). This means developing credible life-cycle cost estimates before any programming of funds occurs. Strides are being made in this direction, as the Office of the Secretary of Defense's Cost Assessment and Program Evaluation (OSD-CAPE) has begun conducting independent cost estimates for some programs at Milestone A.

There are other significant issues that also lead to sub-optimal portfolio management. One of these is the treatment of risk analysis. Risk analysis has been incorporated in many government agencies, but risk is typically considered only on a project-by-project basis. For example the 2009 Weapon Systems Acquisition Reform Act (WSARA) requires the reporting of confidence levels at the Major Defense Acquisition Program level. NASA policy also requires confidence levels for projects and programs. There are no such requirements for portfolio confidence levels.

Portfolio risk is typically not calculated explicitly. Conventional wisdom is that by budgeting at a level greater than the mean, the confidence level for the entire portfolio will benefit from what has been called a portfolio, or diversification effect. (Anderson 2004) In this case, it has been suggested that due to diversification across a suite of missions it is possible to achieve a high level of confidence in the overall budget while setting budgets for individual missions at a lower level. For example, when there are numerous projects in a portfolio, it has been posited that it may be possible to achieve an 80% probability of no cost overruns for the entire portfolio while only budgeting individual projects are budgeted so that there is only a 60% probability of no cost overruns.

However, as demonstrated in three papers presented as ISPA-SCEA annual conferences, the author showed that the portfolio effect is more mythical than factual (Smart 2008, 2009, 2010). Therefore, the portfolio effect cannot be relied upon to replace a thorough, portfolio-level risk analysis. Risk should be aggregated to the total portfolio level, and measured at the portfolio level. The risk analysis process should not stop at the project level. Accounting for risk at the total portfolio level will demonstrate the high degree of risk in trying to maintain too many projects.

Analyzing projects in isolation without looking at the full portfolio level ramification is like the blind men who studied an elephant. Using their sense of touch to try to determine the characteristics of an elephant, one touched a leg; a second the tail; the third the trunk; the fourth the ear, and the fifth the tusk. The blind man who felt a leg says the elephant is like a pillar; the one who felt the tail says the elephant is like a rope; the one who felt the trunk says the elephant is like a tree branch; the one who felt the ear says the elephant is like a hand fan; and the one who felt the tusk says the elephant is like a solid pipe. Each is partially correct, but none of them truly understands that these are different features of a single animal. In the same way, if we do not analyze cost and risk at the portfolio level, we are blind to the consequences of the impact of project decisions on the entire portfolio.

Another major issue is a failure to account for a realistic amount of risk. As discussed by the author in a paper presented at an ISPA-SCEA annual conference (Smart 2011), project risk is significantly under estimated in practice. An all-too common situation is that there is a severe disconnect between the cost risk analysis and the final cost. See Figure 15 for an example. Figure 19 displays normalized cost, so the lowest value on the S-curve was assigned a value equal to 1, and the remaining values were normalized based on their value relative to that lowest cost. The Tethered Satellite System was a joint project between NASA and the Italian Space Agency (ASI). It consisted of a space tether connected to a 1.6 meter electrically conductive satellite, and was deployed from the Space Shuttle to which the tether was anchored. As the first tethered satellite, the project required significant technology development, so it is no surprise that it was inherently risky. Two separate risk analyses were completed at the concept stage, one in May 1981 and another in March 1982. The two S-curves displayed are the results of a Monte Carlo simulation (MSFC 1981, MSFC 1982). Note the steepness of these S-curves. It is hard to see much of an "S" in the shape of the second S-curve. It appears to be what has been pejoratively referred to as an "I-beam" rather than an S-curve. Also note that while the initial budget is actually on both S-curves, the 95th and 100th percentiles from the Monte Carlo simulations are much less than the actual cost of the project. The cost growth for this project was extreme, more than 300% from beginning until launch. Note that the analyses were conducted very early in the project's life, as true design and development beyond the concept stage did not begin until 1984 (MSFC 1992).

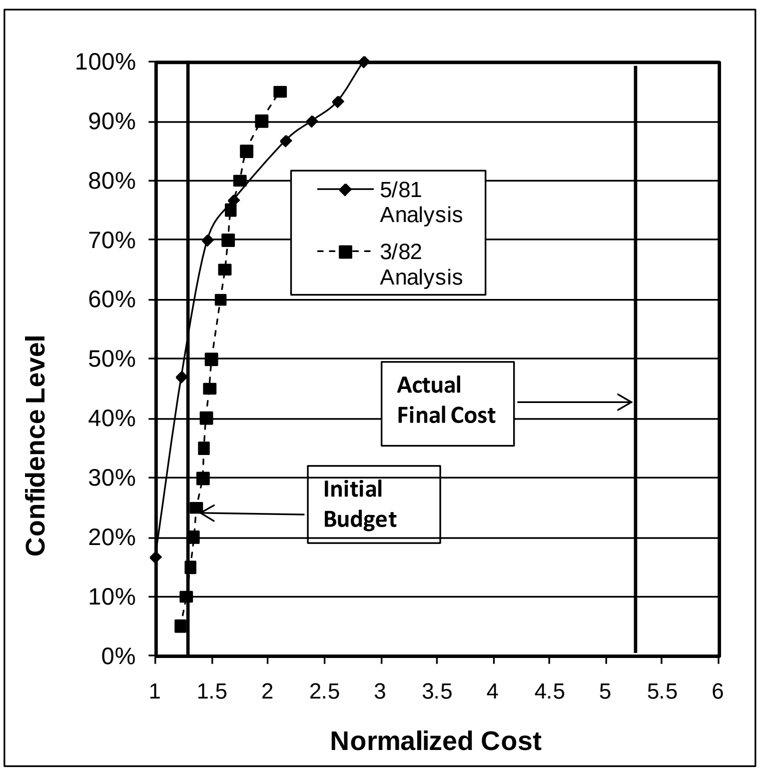

Figure 15. S-Curves and Final Actual Comparison for TSS.

More accurately accounting for cost risk will also counter over-optimism at both the project and portfolio level, and help avoid trying to accomplish too much with limited resources.

SUMMARY

Cost, schedule, and the phasing of cost over schedule are intrinsically linked. Changes in schedule for an established program result in cost growth. Reduction in annual funding also leads to schedule growth, which in turn leads to cost growth. Indeed there is ample empirical evidence that schedule delays and funding constraints are strongly correlated with cost over runs.

Portfolio management is critical to containing cost growth. A lack of planning in the portfolio management process is seen to lead to schedule delays and cost growth. Properly introducing new programs in a timely fashion can lead to getting more done in the long run, which is of primary importance. Other issues at the portfolio management level are a lack of risk analysis at the portfolio level, and under accounting for risk at the project level. Relying upon a chimerical portfolio effect is not a substitute for calculating risk at the portfolio level. Also, incorporating sufficient risk is critical for project realism. Addressing these issues will go a long way towards addressing endemic cost growth in government projects and programs, which will result in accomplishing more. This is especially critical in the current budget environment, during which the government must get as much done as possible with the limited funding available.

REFERENCES

Anderson, T. P. (2004) “The Trouble With Budgeting to the 80th Percentile”, 72nd Military Operations Research Society Symposium, Monterey, CA, 22-24 June 2004 .

Bearden, D.A., “A Complexity-Based Risk Assessment of Low-Cost Planetary Missions: When Is a Mission Too Fast And Too Cheap?” Fourth IAA International Conference on Low-Cost Planetary Missions, JHU/APL, Laurel, MD, 2000.

Burgess, E. L. “Time Phasing Methods and Metrics,” 37th Annual Department of Defense Cost Analysis Symposium, 2004, Williamsburg, VA, 2004.

Office of the Secretary of Defense – Cost Assessment and Program Evaluation, *Operating And Support Cost-Estimating Guide*, 2012.

Coonce, T., Personal correspondence, 2010.

Dupnick, E., Correspondence with Joe Hamaker, REDSTAR Document 121-1373, 1988.

Emhart PRC, “An Assessment of Schedule Extension Effect on Estimated Cost,” REDSTAR Document 121-1373, 1988.

Freaner, C., and B. Bitten, SMD Cost Data Base, Excel spreadsheet containing cost and schedule growth for 34 missions, 2008.

Galbraith, J.K., *The Affluent Society*, 40th Anniversary Edition, Houghton Mifflin Company, New York, 1998.

Heppenheimer, TA, Development of the Space Shuttle, 1972-1981, Washington D.C., Smithsonian, 2002.

Mosher, T., et al., "Evaluating Small Satellites: Is The Risk Worth It?", 13th AIAA/USU Conference on Small Satellites, Utah, 1999.

Marshall Space Flight Center (MSFC), "Tethered Satellite System Risk Analysis," REDSTAR Document #121-5511, May, 1981.

Marshall Space Flight Center (MSFC), "Tethered Satellite System Risk Analysis," REDSTAR Document #121-5507, March, 1982.

Marshall Space Flight Center (MSFC), "TSS, OTA, OMV, ET, SSME, SRM Historical Growth Cost Drivers," REDSTAR Document #121-4955, January 1992.

SAIC, Microgravity Experiments Cost Model, 1994.

Schaffer, M., Personal Correspondence, 2004.

Smart, C.B., "Faster, Better, Cheaper Reconsidered," NASA Cost Symposium, Orlando, FL, 2002.

Smart, C.B., "Cost Profiles," SAIC Working Paper, 2005.

Smart, C.B. and David Cowart, "Cost Risk Correlation for Constellation," SAIC Working Paper, 2007.

Smart, C.B., "Integration of Cost and Schedule Risk," Space Systems Cost Analysis Group, Noorwijk, The Netherlands, 2008.

Smart, C., "The Fractal Geometry of Cost Risk," presented at the Joint Annual ISPA/SCEA Conference, Noorwijk, the Netherlands, May 2008.

Smart, C.B., "NAFCOM Improvements: Assessing the Impact of Phasing and Schedule on Cost," Final Report, January, 2009, Prepared for NASA HQ.

Smart, C., "The Portfolio Effect and the Free Lunch," presented at the Joint Annual ISPA/SCEA Conference, St. Louis, June 2009.

Smart, C., "Here There Be Dragons: Considering the Right Tail in Risk Management," presented at the Joint Annual ISPA/SCEA Conference, San Diego, June 2010.

Smart, C.B., "Covered with Oil: Incorporating Realism in Cost Risk Analysis," presented at the 2011 Joint Annual ISPA/SCEA Conference, Albuquerque, New Mexico, June, 2011.

Tosney, W.F., "Faster, Better, Cheaper: An Idea Without a Plan," NRO Presentation, 2000.

U.S. Congress, "Weapon Systems Acquisition Reform Act of 2009," Public Law 111-23, May 23, 2009.