Risk Management Support Using ACEIT[1,2]

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Abstract—Risk management during space system acquisition is an increasingly complex challenge that requires the utmost skill of cost modelers and program managers. This paper explores two complexities integral to risk management: risk allocation and element correlation. It is hoped that this will assist program managers in applying informed skills and using the best available tools to achieve sound risk management. This paper will show that program managers wishing to properly resource program requirements should understand correlation of program elements and manage risk at the lowest possible levels.

INTRODUCTION

Program managers have increasingly adopted a tendency to manage risk within a program acquisition environment at the lowest possible level. The logic process supporting this tendency is that risk at the lower element levels, if assessed, allocated, and managed properly will allow managers to quickly ascertain negative performance and apply resources readily, having anticipated the potential in advance. This tendency is very apparent in the Department of Defense (DoD), where Earned Value Management has explosively re-emerged on the scene as a crucial program management tool. The fundamentals of earned value dictate that you plan programs to a low level of work breakdown structure (WBS) indenture, assess risk at those levels, and assign resources accordingly.

Proper risk assessment at these levels is obviously vital. The process and product associated with this facet of risk management is assumed to be sound for the purpose of this discussion (a huge assumption) and is saved for another paper. Given then that risk assessment has been adequately performed and risk distributions assigned at low levels of WBS indenture, the question for the cost modeler and program manager becomes, is it sound management practice to allocate risk resources at these levels?

The answer from most program managers is an emphatic *yes*. Cost modelers supporting program management are less decisive. The mathematical consequence of the risk simulation in cost models is that risk results at specific confidence levels do not "sum" up through the WBS. This penalty is magnified the lower and more specifically risk resources are allocated.

Let us examine the system shown in Table 1 as a simplistic example. This system is composed of seven WBS elements: the total system and six sub-elements at indenture level one. The total program (baseline cost of $3,100) has been assessed for risk, and a distribution assigned, resulting in an estimated cost at 80% confidence of $3,442.

Table 1. Risk Allocation Example

WBS Desc.	Baseline	Statistic @ 80%	Std Dev	Allocation	Allocated @ 80%
Total	3,100	3,442			3442.346
Known Cost	500	500.00			500
Low Cost, Minimal Risk	200	202.51	2.788	-0.89	201.62
Small Cost, Low Risk	200	225.10	27.882	-8.87	216.23
Large Cost, Low Risk	1,000	1125.48	139.414	-44.34	1081.14
Small Cost, High Risk	200	262.77	69.706	-22.17	240.60
Large Cost, High Risk	1,000	1313.62	348.542	-110.85	1202.76
Sum of Element Risk		3629.5	588.332		
Total Risk Result - Sum of Element Risk		-187.1			

[1] 0-7803-8155-6/04/$17.00©2004 IEEE
[2] IEEEAC paper #1282, Version 5, Updated January 30, 2004

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If, in addition, the program manager wished to assess risk at the sub-element level and did so with results and distributions as indicated by the sub-element descriptions, the corresponding statistics show that the sum of the sub-element risk is \$3,625.50, or an increase of 5.4% to the resources required for program implementation. This may initially seem to be relatively insignificant, but if you consider this percentage against a program estimated to require several hundred million dollars, the net effect is far from trivial. In addition, we will demonstrate later that this percentage is relatively small in part due to the simplicity of this example, and that an estimate of more realistic complexity could result in a penalty of as much as 17% at an 80% probability interval. Even so, this "penalty" may be unnecessary and overly burdensome for a program manager scratching for every dime. Or, in a more practical program management sense, a manager may wish to budget to the higher level and allocate to sub-managers at the lower, holding the differential in a top-level reserve. In recognition of this dilemma, Tecolote Research cost modelers have developed within the Automated Cost Estimator (ACE) a risk resource allocation method that uses the *standard deviation* from the sub-element risk distribution to allocate risk at the sub-element level, while avoiding the mathematically imposed penalty. This method takes the *standard deviation* as a percentage of the sum of the risk elements and applies that percentage to the total penalty. The resulting resource is then subtracted from that sub-element allocation, thus eliminating the penalty. Performed across all sub-elements where risk has been statistically applied, this eliminates the entire penalty, while achieving the result of sub-element risk resource allocation. For the uninitiated, ACEIT—*Automated Cost Estimating Integrated Tools*—is a revolutionary, automated architecture and framework for cost estimating and other analysis tasks, developed by and for analysts. Similarly to how Microsoft Office provides a suite of applications to automate office functions, ACEIT provides a suite of applications to automate cost estimating functions. Within this suite of tools is ACE. ACE is used to build cost models, conduct trade studies, perform RI\$K analysis, and document the estimate.

As an aside, there is some controversy within the cost community surrounding the use of *Standard Deviation* in this allocation scheme as opposed to *Variance*. We have found that this method yields a consistently more stable result and does not suffer by allocating too few resources to high-risk, high-cost elements. We also recognize that this will irritate statistical purists. We hope that this will not impede further investigation of this paper's concepts.

At this point, one hopes, we have achieved conceptual common ground. Our next step to further illuminate these concepts is to delve deeper into a more complete space system example and show the tool's utility in implementing this concept.

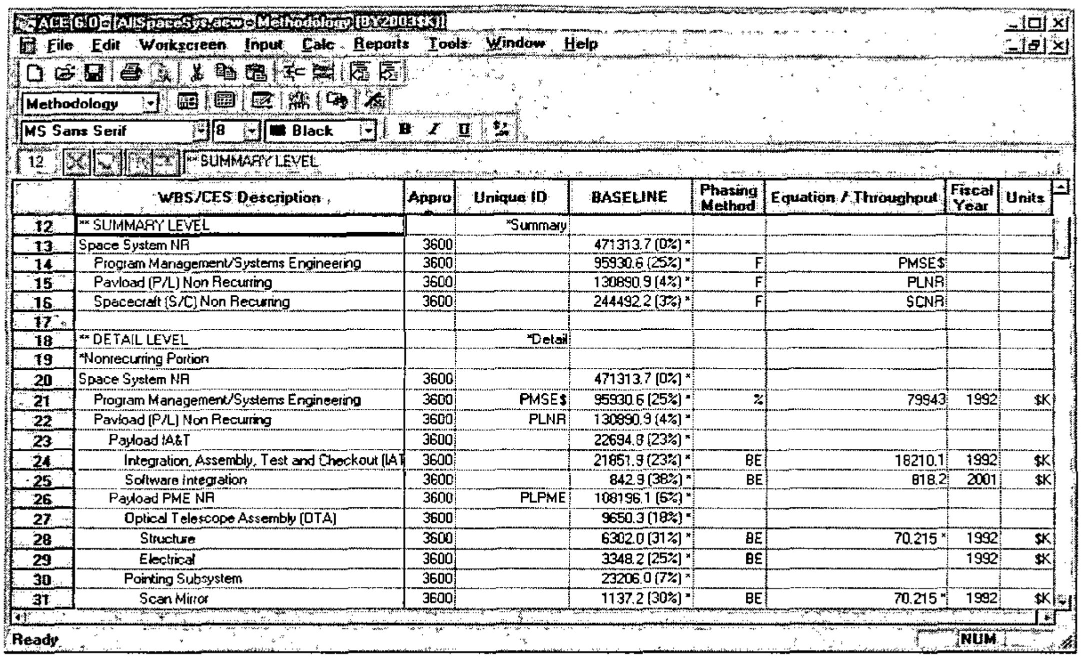
Figure 1 shows a space system WBS indentured to the fourth level. It is important that the cost modeler and program manager work closely in developing this WBS so that elements can be created and defined at the level where risk is to be managed. ACE enables the program manager to easily assign risk management at the first, second, or third level of the WBS. It also allows the manager to pick a mix of levels if deemed appropriate. It cannot be emphasized emphatically enough, that work done earnestly and early in developing a robust and well-behaved WBS will pay large program management dividends in the long term. ACE assists in this process by providing a library of representative WBSs to serve as the foundation for specific WBS development.

∑ SPACE SYSTEM NONRECURRING

- **Program Management/Systems Engineering**
- **∑ Payload (P/L) Nonrecurring**
  - ***∑ P/L Integration, Assembly, and Test (IA&T)***
    - IA&T and Checkout
    - Software Integration
  - ***∑ Payload PME Nonrecurring***
    - ∑ Optical Telescope Assembly (OTA)
    - ∑ Pointing Subsystem
    - ∑ Focal Plane Assembly (FPA)
    - ∑ Signal Processing Assembly (SPA)
    - P/L Software
    - ∑ Thermal Control Subsystem (TCS)
- **∑ Spacecraft (S/C) Nonrecurring**
  - ***∑ IA&T and Checkout***
    - S/C IA&T
    - Software Integration
  - ***∑ S/C PME Nonrecurring***
    - Structures and Mechanisms
    - ∑ TCS
    - ∑ Electrical Power Subsystem (EPS)
    - ∑ Attitude Determination and Control System (ADCS)
    - Spacecraft Software
    - Telemetry, Tracking and Command (TT&C) Subsystem
    - Communications Subsystem (CS)
    - Propulsion Subsystem (PS)

Figure 1. Space System WBS

Next, baseline costs are assigned or estimated according to acceptable methods and a baseline determined for each element. Figure 2 shows this as accomplished within ACE for a subsection of the WBS shown in Figure 1.



	WBS/CES Description	Appro	Unique ID	BASELINE	Phasing Method	Equation / Throughput	Fiscal Year	Units
12	** SUMMARY LEVEL		*Summary					
13	Space System NR	3600		471313.7 (0%) *				
14	Program Management/Systems Engineering	3600		95930.6 (25%) *	F	PMSE$		
15	Payload (P/L) Non Recurring	3600		130890.9 (4%) *	F	PLNR		
16	Spacecraft (S/C) Non Recurring	3600		244492.2 (3%) *	F	SCNR		
17								
18	** DETAIL LEVEL		*Detail					
19	*Nonrecurring Portion							
20	Space System NR	3600		471313.7 (0%) *				
21	Program Management/Systems Engineering	3600	PMSE$	95930.6 (25%) *	%	79943	1992	$K
22	Payload (P/L) Non Recurring	3600	PLNR	130890.9 (4%) *				
23	Payload IA&T	3600		22694.8 (23%) *				
24	Integration, Assembly, Test and Checkout (IAT	3600		21851.9 (23%) *	BE	18210.1	1992	$K
25	Software Integration	3600		842.9 (38%) *	BE	818.2	2001	$K
26	Payload PME NR	3600	PLPME	108196.1 (6%) *				
27	Optical Telescope Assembly (OTA)	3600		9650.3 (18%) *				
28	Structure	3600		6302.0 (31%) *	BE	70.215 *	1992	$K
29	Electrical	3600		3348.2 (25%) *	BE		1992	$K
30	Pointing Subsystem	3600		23206.0 (7%) *				
31	Scan Mirror	3600		1137.2 (30%) *	BE	70.215 *	1992	$K

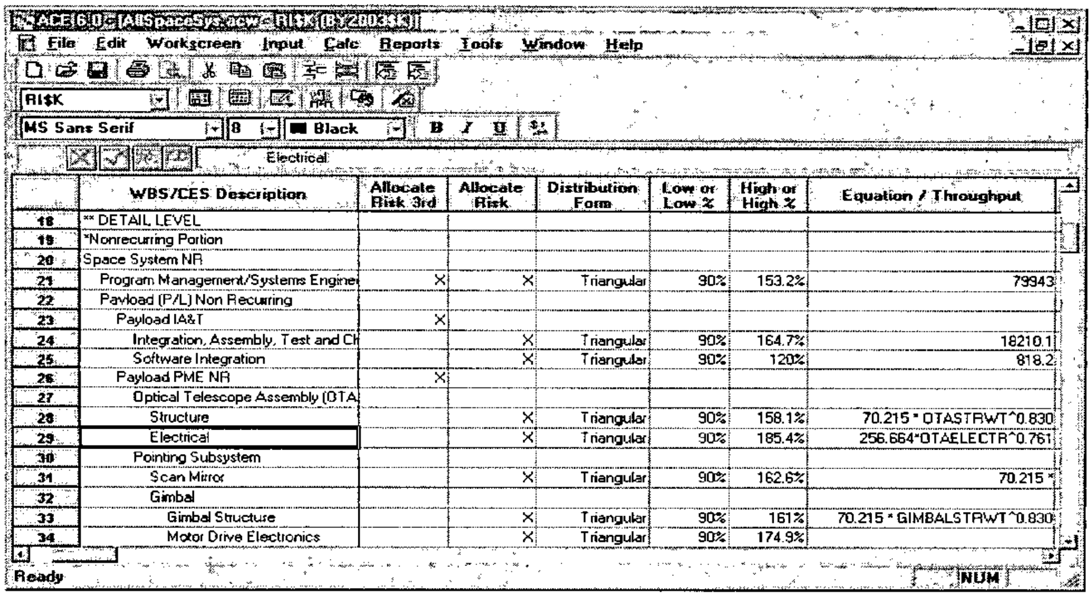
Figure 2. Baseline Costs by WBS Element

For the sake of argument at this point we have removed all definable correlation, either mathematically defined or accommodated by the functional relationships and the related estimating methodologies. So, in this case, each program element moves independently within the defined realm of possibility and according to the assigned distribution. This does not detract from the value of this exercise, and we will deal with this assumption and its impact on program estimated cost later.

Having established baseline costs, the risk assessment process is conducted and conclusions reached for the elements where risk is to be managed. Figure 3 demonstrates the result of this process. Using the tool's category columns, a customized risk allocation scheme can be created and risk allocated at the first, second, or third or lower level as desired.

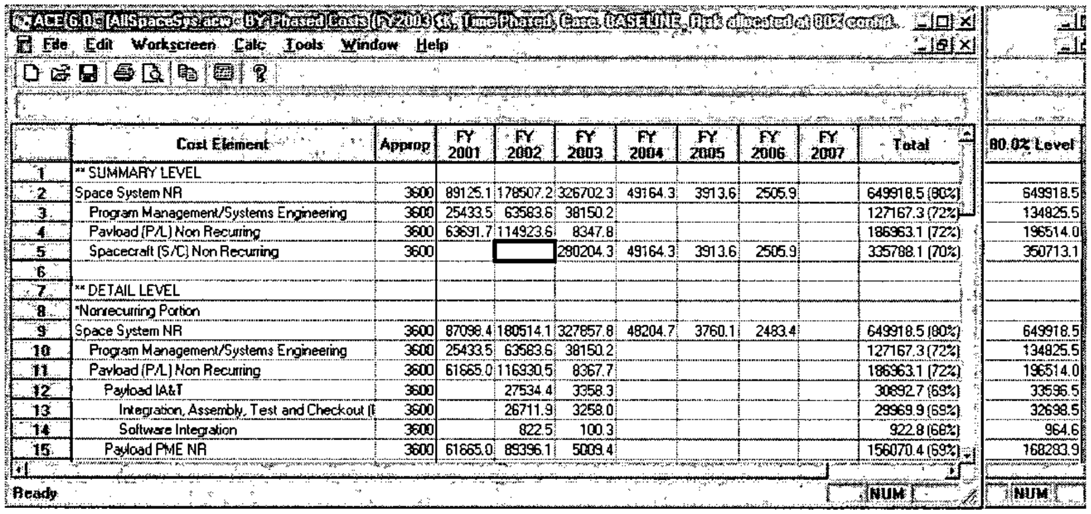
Applying the concepts in the earlier example and instructing the tool to allocate risk resources at the first level for an 80% confidence interval yields an automated result that allocates risk to the identified levels, and yet does not penalize the overall program resource requirement. Figure 4 shows the results of this allocation and compares it with the straight statistical allocation. Notice that the phased report and statistical report show differential at the sub-element level. In this case, at the 80% confidence level, the estimated cost of the example program is $649,949 using the ACE allocation algorithm. Were this not implemented and risk determined at the levels identified, the estimated cost would be $760,142, or a 17% increase. This differential is the sub-element management penalty avoided with the ACE allocation scheme.

This example illustrates the utility of the tool and also the penalty paid for pushing risk management down into the details of the WBS. Taking this analysis further and assessing the potential penalty for various confidence levels and varying assignment levels reveals that at 50% confidence the impact of lower level allocation is benign. As Figure 5 shows, however, at higher confidence levels, the penalty for sub-element allocation at lower levels does begin to impact total system resource requirements.



	WBS/CES Description	Allocate Risk 3rd	Allocate Risk	Distribution Form	Low or Low %	High or High %	Equation / Throughput
18	** DETAIL LEVEL						
19	*Nonrecurring Portion						
20	Space System NR						
21	Program Management/Systems Engine	X	X	Triangular	90%	153.2%	79943
22	Payload (P/L) Non Recurring						
23	Payload IA&T	X					
24	Integration, Assembly, Test and Ch		X	Triangular	90%	164.7%	18210.1
25	Software Integration		X	Triangular	90%	120%	818.2
26	Payload PME NR	X					
27	Optical Telescope Assembly (OTA						
28	Structure		X	Triangular	90%	158.1%	70.215 * OTASTRWT^0.830
29	Electrical		X	Triangular	90%	185.4%	256.664*OTAELECTR^0.761
30	Pointing Subsystem						
31	Scan Mirror		X	Triangular	90%	162.6%	70.215 *
32	Gimbal						
33	Gimbal Structure		X	Triangular	90%	161%	70.215 * GIMBALSTRWT^0.830
34	Motor Drive Electronics		X	Triangular	90%	174.9%	

Figure 3. Risk Analysis Results



	Cost Element	Approp	FY 2001	FY 2002	FY 2003	FY 2004	FY 2005	FY 2006	FY 2007	Total	80.0% Level
1	** SUMMARY LEVEL										
2	Space System NR	3600	89125.1	178507.2	326702.3	49164.3	3913.6	2505.9		649918.5 (80%)	649918.5
3	Program Management/Systems Engineering	3600	25433.5	63583.6	38150.2					127167.3 (72%)	134825.5
4	Payload (P/L) Non Recurring	3600	63691.7	114923.6	8347.8					186963.1 (72%)	196514.0
5	Spacecraft (S/C) Non Recurring	3600			280204.3	49164.3	3913.6	2505.9		335788.1 (70%)	350713.1
6											
7	** DETAIL LEVEL										
8	*Nonrecurring Portion										
9	Space System NR	3600	87098.4	180514.1	327857.8	48204.7	3760.1	2483.4		649918.5 (80%)	649918.5
10	Program Management/Systems Engineering	3600	25433.5	63583.6	38150.2					127167.3 (72%)	134825.5
11	Payload (P/L) Non Recurring	3600	61665.0	116930.5	8367.7					186963.1 (72%)	196514.0
12	Payload IA&T	3600		27534.4	3358.3					30892.7 (69%)	33596.5
13	Integration, Assembly, Test and Checkout (I	3600		26711.9	3258.0					29969.9 (69%)	32698.5
14	Software Integration	3600		822.5	100.3					922.8 (68%)	964.6
15	Payload PME NR	3600	61665.0	89396.1	5009.4					156070.4 (69%)	168283.9

Figure 4. Risk Allocation with Risk Statistics

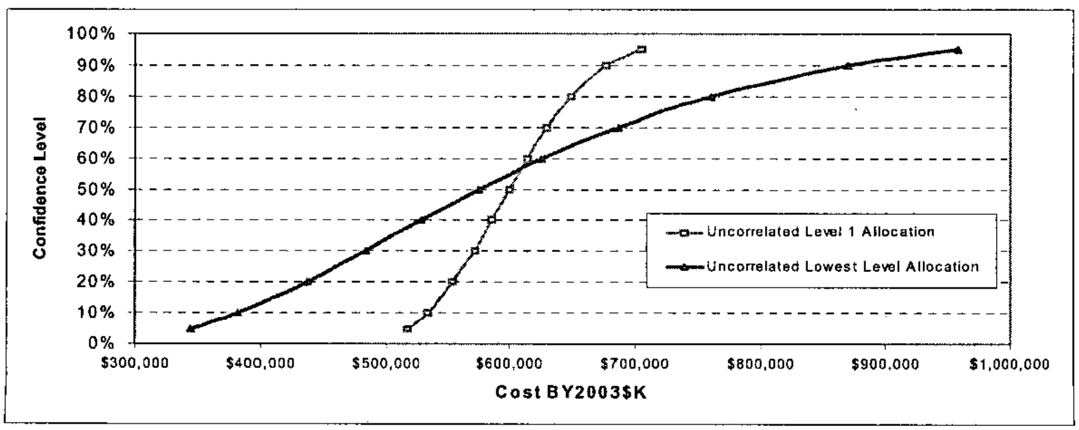
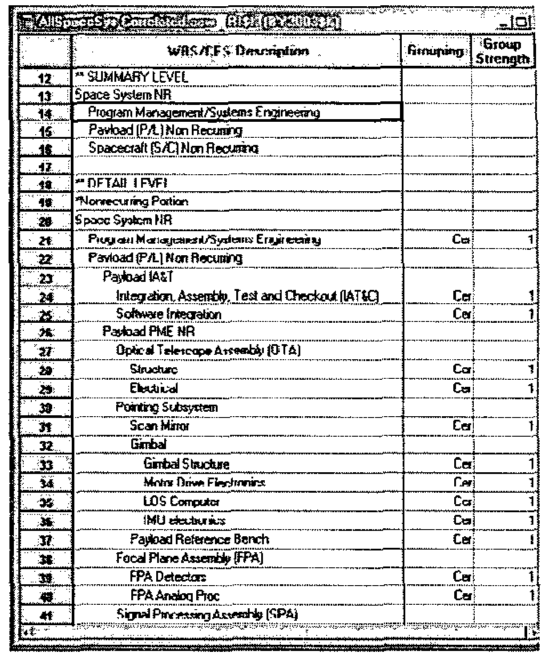


Figure 5. Nonrecurring Cost at Various Confidence Levels for Different Allocation Schemes

IMPACT OF CORRELATION

No discussion of program risk and its management occurs without it devolving into a heated debate over the analysis and impact of risk correlation between WBS elements and sub-elements. These debates are varied, impassioned, and fruitful only in a theoretical sense. The fundamental question is, if WBS elements and their risk are correlated from a schedule, technical, and cost perspective, how many more resources are needed to implement the program plan? Arriving at an answer to this is largely divorced from the analytical process for interpreting the cost impact due to correlation. All roads lead to Rome within one or two percentage points. The practical side of this issue is that regardless of how you capture correlation within the cost model, it is intuitive that correlation will require additional program resources. The remainder of this discussion will deal with verifying this intuitive conclusion and validating that the cost model behaves properly and assesses the combined impact of correlation with sub-element risk allocation.

The first step in this process is to take the previous example that did not include correlated risk elements and insert correlation into the model. This process within ACE requires the assignment of correlated elements and a correlation or group strength assessment. The practicality of this method as opposed to determining a correlation matrix for an array corresponding to the size of the WBS is intuitively apparent. Program managers rarely have the information or the time to complete the matrix and, as mentioned, even if they did the resulting difference would be negligible. The results of implementing the correlated element method are shown in Figure 6.



	WBS/CES Description	Grouping	Group Strength
12	** SUMMARY LEVEL		
13	Space System NR		
14	Program Management/Systems Engineering		
15	Payload (P/L) Non Recuring		
16	Spacecraft (S/C) Non Recuring		
17			
18	** DETAIL LEVEL		
19	*Nonrecurring Portion		
20	Space System NR		
21	Program Management/Systems Engineering	Cer	1
22	Payload (P/L) Non Recuring		
23	Payload IA&T		
24	Integration, Assembly, Test and Checkout (IAT&C)	Cer	1
25	Software Integration	Cer	1
26	Payload PME NR		
27	Optical Telescope Assembly (OTA)		
28	Structure	Cer	1
29	Electrical	Cer	1
30	Pointing Subsystem		
31	Scan Mirror	Cer	1
32	Gimbal		
33	Gimbal Structure	Cer	1
34	Motor Drive Electronics	Cer	1
35	LOS Computer	Cer	1
36	IMU electronics	Cer	1
37	Payload Reference Bench	Cer	1
38	Focal Plane Assembly (FPA)		
39	FPA Detectors	Cer	1
40	FPA Analog Proc	Cer	1
41	Signal Processing Assembly (SPA)		

Figure 6. Correlation Results

Figure 6 shows that correlation has been assigned with consistent group strength at the lowest level available for the WBS elements. This correlation case with risk allocated to the first level of sub-element indenture and at the lowest level of indenture was calculated within the cost model, with the following graphically represented results shown in Figure 7.

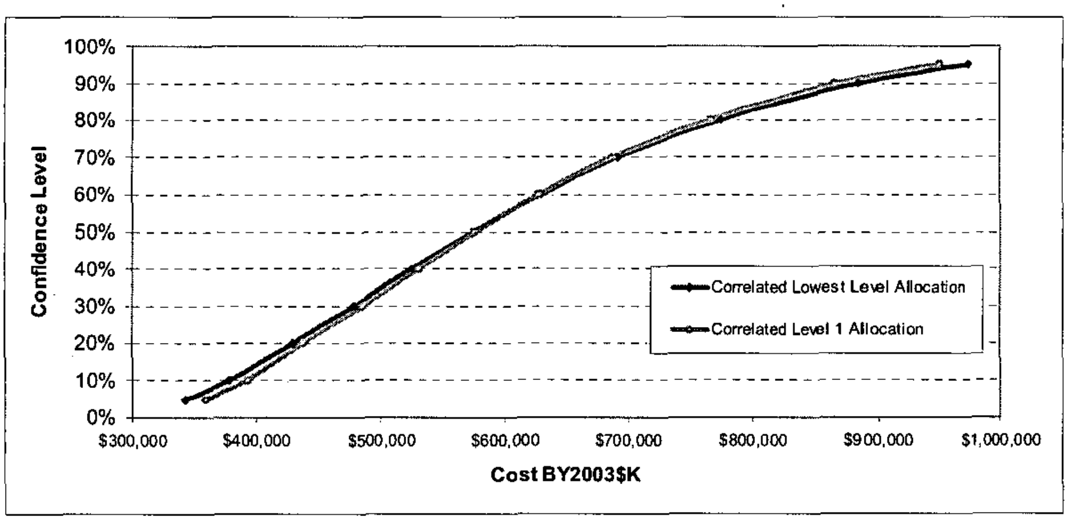


Figure 7. Graphical Depiction of Correlation Results

The analytical response to these results is intriguing. It shows that for a highly correlated estimate, at the 80% confidence level, the allocation of risk resources at either the highest or lowest level yields results within a couple of percentage points (1.08% in the example case). It also shows that correlating estimated program elements results in resource requirements remarkably similar to those required for an uncorrelated estimate with risk allocated at the lowest levels (including the penalty). It also shows that for programs modeled with strongly correlated elements, resources remain relatively constant at the 50% confidence level and that as you wish to increase confidence in program results, the effect of correlation yields additional (but insignificant) requirement for resources. Intuitively this makes sense. As more program elements are correlated or as program elements are more strongly correlated, the risk range is broadened. In simple terms, if you win on one element you win on many and, conversely, as you lose on one you lose on many. In an uncorrelated case, the wins and losses are able to offset each other, thus narrowing the uncertainty range. So what? What does a program manager take from this?

CONCLUSION

A program manager needs to either understand the interrelationship of program elements as they are correlated in the cost model, and/or model and manage risk at the lowest possible program element level. This will budget enough money to protect a manager from coming up short. It follows then that a program manager who wishes to manage risk at the lowest levels of a program where elements of cost can vary independently will need more resources (money) than one willing to assign and manage risk at the very highest level. ACE provides a method to equate the required resources to that of high-level risk assignment and still allocate risk resources at the lowest levels. If however, a manager understands the potential interrelationship of cost elements and how they are correlated, or even believes that they behave together in groups, and that manager wishes to resource the program at a fairly high confidence level (~80%), the level at which risk is allocated/managed is not important. Additionally, that manager is safest in ignoring correlation, assigning risk at the lowest possible level, budgeting according to that resource curve, and using ACE to allocate resources to the element managers while holding the remainder as program manager reserve.

BIOGRAPHIES

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