



Subsystem-Level CERs and Their Application to the Component Level

- Note that application of subsystem-level CER is NOT a problem when the analogy method is used
- For the analogy method, suppose there are N components, all with equal weights and equal costs, and that the weight of the subsystem is W_0 . Then the a-value for the subsystem-level CER is

$$a' = \frac{\text{Actual Cost}}{W_0^b}$$

- Since all weights and costs are equal, the a-value for each component is

$$a'' = \frac{\frac{\text{Actual Cost}}{N}}{\left(\frac{W_0}{N}\right)^b} = \frac{\text{Actual Cost}}{W_0^b} N^{b-1} = a' N^{b-1}$$

- Thus the subsystem-level roll-up of the component-level estimates is

$$Na'' \left(\frac{W_0}{N}\right)^b = Na' N^{b-1} \left(\frac{W_0}{N}\right)^b = a' W_0^b$$

which is the same as the subsystem-level estimate



Solution to Challenge #3: Develop Component-Level CERs

- To keep from mis-applying the subsystem-level multivariate CERs, there are three choices
 - Apply a correction factor to the subsystem-level multivariate CERs
 - Calibrate subsystem-level multivariate CERs to component-level data (i.e., adjust the “a-value” using the analogy method technique)
 - Develop CERs at the component-level, i.e., develop CERs using component-level data
- In 2006, MSFC embarked upon the development of component-level estimates for Ares launch vehicles
 - Developed component-level estimates for thrust vector control and avionics
 - Where sufficient data were available, developed component-level CERs
 - Where 2-3 data points were available, calibrated existing subsystem-level multivariate CER
 - Where no data were available, applied subsystem-level multivariate CER with a correction factor (as described)



Development of Component-Level Estimates

- Developed specific spreadsheet models that enable component-level estimates for Ares I and Ares V launch vehicles
- Simple user interface, incorporated risk directly in the spreadsheet using the method of moments
- Developed 17 component-level CERs for this effort

Amplifier	Antenna	Battery	Camera	Controller
Diplexer-Multiplexer	Gyro	Instrumentation	Power Cables	Power Distribution and Control
Processor	Receiver	Solar Array	Tank	Transmitter
Transponder				



Example of Spreadsheet-Based Model: Screenshot

WBS - Component Level Avionics for Ares I Upper Stage

Model Inputs

Model Outputs

Component	QNHA	Unit Wt	Total Wt	New Design	Mfg. Meth.	Eng. Mgt.	Test App.	Int. Comp.	Fund. Avail.	Pre-Dev	TMI	Launch Year	DD 2006\$M
LAUNCH VEHICLE AVIONICS			6,584.5										\$1,319.363
UPPER STAGE AVIONICS			3,195.9										\$633.670
UPPER STAGE AVIONICS HI/W			3,195.9										\$298.468
Command & Data Handling System (C&DHS)			588.6										\$188.698
Flight Computer (FC)	4	60	240.0	0.79	25	50	75	75	25	25	9	2012	\$112.575
Command & Telemetry Computer (CTC)	2	25	50.0	0.79	25	50	75	75	25	25	9	2012	\$33.129
Data Acquisition Unit (DAU)	6	25	150.0	0.79	25	50	75	75	25	25	9	2012	\$33.129
Operational Instrumentation Electronics (OIE)	4	25	100.0	0.79	25	50	75	75	25	25	9	2012	\$9.129
J2 Engine Control Unit (ECU) (Book kept with USE)													
Data Bus Isolation Amplifiers (DBIA)	9	5.4	48.6	0.79	25	50	75	75	25	25	8		\$0.735
Bus Interface Adaptor (BIA)	0	17	0.0	0.79	25	50	75	75	25	25	9	2012	\$0.000
Radio Freq Communication System (RFCS)			42.8										\$3.433
S-band Transponder	2	6.5	13.0	0.79	25	50	75	75	25	25	9		\$1.320
S Band Power Amp (PA) (Includes TWT & EPC power & weight)	2	4.6	9.2	0.79	25	50	75	75	25	25	8		\$0.631
Traveling Wave Tube (TWT)													
Electronic Power Conditioner													
S Band Antennas	4	0.7	2.8	0.79	25	50	75	75	25	25	8		\$0.610
S-band Diplexer	2	2	4.0	0.79	25	50	75	75	25	25			\$0.291
S-band Bandreject Filter (BRF)	2	0.44	0.9	0.79	25	50	75	75	25	25	9	2012	\$0.008
S-band Bandpass Filter (BPF)	2	0.44	0.9	0.79	25	50	75	75	25	25	9	2012	\$0.008
RF Switch	2	0.5	1.0	0.79	25	50	75	75	25	25	9	2012	\$0.013
Forward / Reflected Power Sensor	2	2.5	5.0	0.79	25	50	75	75	25	25			\$0.506
Coax	60	0.101	6.1	0.79	25	50	75	75	25	25			\$0.045
Flight Safety System (FSS)			127.1										\$13.550
FSS RF Subsystem			78.0										\$6.844
Command Receiver/Decoder (CRD)	2	10.22	20.4	0.79	25	50	75	75	25	25	8	2012	\$1.606
Antenna	2	7.68	15.4	0.79	25	50	75	75	25	25	8		\$2.207

Note – All inputs and outputs in this screenshots are completely notional. Any resemblance to actual costs for current or past programs is purely coincidental



Challenge #4: Providing Realistic and Comprehensive Risk Estimates

- It can be easy for an analyst to overlook sources of risk and possibly underestimate risk
- On the other hand, it is also tempting to attempt to add every possible source of error, possibly leading to double- and even triple-counting error so that risk is grossly overestimated
- For these reasons, it is desirable to have some way to check risk results against reality
 - How much risk is enough?
 - How much is too much?



Solution to Challenge #4: Use Recent Cost Growth Data

- Cost risk growth data can be used as a means to check the results of risk analyses against reality
- These checks can be used to determine if the amount of risk in the cost risk analyses is too high or too low
- In 2004 Matt Schaffer of NASA HQ collected and analyzed budget data on cost growth for NASA missions
 - Comprised 50 missions from the 1990s – present
 - Cost growth ranged from -25% to +193%
 - Average cost growth was 35%
 - 76% of the missions had budget overruns
 - Similar to studies by Goddard and GAO
 - Data are conservative
 - Does not completely account for changes in requirements and scope before ATP (accounting for this would reduce the reported cost growth for some missions, e.g., Rossi XTE)



Cost Growth And Its Relationship to Cost Risk

- Cost risk is the probability of exceeding the initial estimate
- Cost growth is the actual amount that the initial estimate is exceeded
- Assumption - the initial budgets in the cost growth database are point estimates (no risk is included)
- By assuming that the initial estimates are point estimates, we can relate cost risk to cost growth
 - For example, if the point estimate represents the 30th percentile of a cost risk distribution, then the ratio of the 70th percentile to the 30th percentile represents potential cost growth
- For A, B two points of a cost risk distribution ($A > B$), with B as an initial reference point, the following formula relates cost growth to cost risk
 - $\text{Cost growth} = A/B$
- A cost growth distribution is simply the ratio of various percentiles on a cost risk distribution relative to an initial reference point, such as the 30th percentile



Cost Risk Rule of Thumb

- Assume that the 30th percentile on a cost risk S-curve represents the point estimate (initial estimate)
 - From experience, the point estimate is typically at or below the 30th percentile
- Assume that the risk distribution is Lognormal
- For NAFCOM estimates, the ratio of the standard deviation to the mean is typically between 1/3 and 1/2 of the mean
- The ratio of the 70th percentile to the 30th percentile of a lognormal is

$$\frac{e^{P+0.5244Q}}{e^{P-0.5244Q}} = e^{1.0488Q}$$

- When $\sigma = a\mu$, it follows that

$$Q = \sqrt{\ln\left(1 + \frac{(a\mu)^2}{\mu^2}\right)} = \sqrt{\ln(1 + a^2)}$$

- When $a = 1/3$, the 70th percentile is 41% higher than the 30th percentile
- Thus, a reasonable rule of thumb for the ratio of the 70th percentile to the point estimate is 1.4

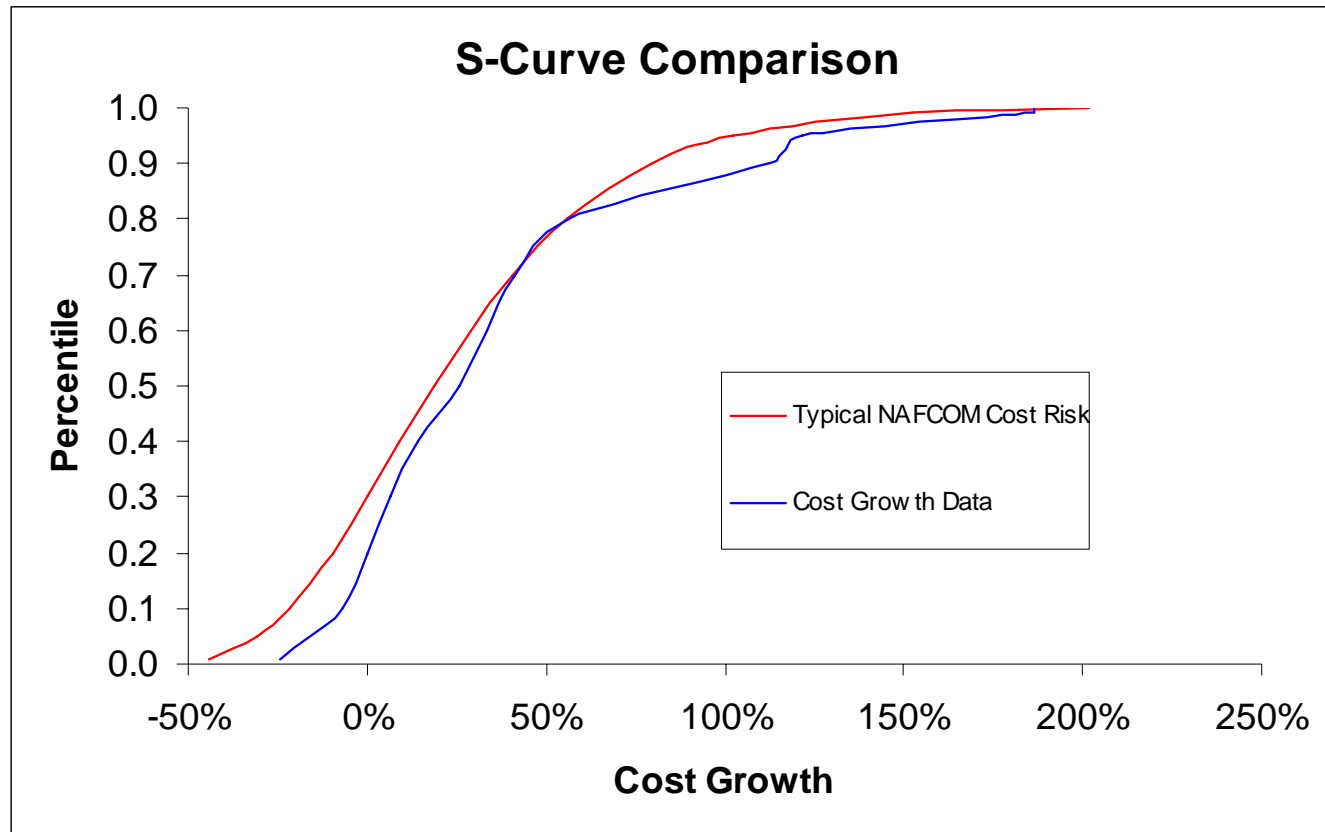


Converting Cost Risk to Cost Growth

- The derivation of the rule of thumb on the previous chart provides a method to convert cost risk into cost growth
 - Select a reference point, and divide each percentile by the initial reference point
 - In this analysis, it is assumed that the 30th percentile is the reference point
 - Once the cost risk has been normalized to a cost growth curve, it can be directly compared to the cost growth data
 - Assume that $a = 1/3$ for “typical” risk



Cost Risk Reality Check S-Curves



- Notice how closely a “typical” NAFCOM risk distribution fits the bulk of the actual cost growth data
 - Provides confidence that cost risk estimates produced by NAFCOM are realistic