Predicting Final CPI

Estimating the EAC based on current performance has traditionally been a point estimate or, at best, a range based on different EAC calculations (CPI, SPI, CPI*SPI, etc.). NAVAIR is in the midst of revising their EVM Toolkit, which incorporates the formation of an EAC. This paper provides the EVM analyst with a predicted Final CPI (and thus EAC), and also provides a confidence interval around the predicted value. This will enable analysts to determine where the program EAC falls on the cumulative probability distribution and to calculate the likelihood of achieving a favorable Final CPI (e.g., the probability of a Final CPI of 1.0 or better). The rule of thumb that EACs never improve over their values at 20% complete is analyzed and found to be generally true, but with some exceptions.

This paper is based on work by Michael Popp on distributions of Final CPI given Current CPI and % Complete for both development and production programs. This follow-on paper explores the larger patterns at work and discovers overarching trends in CPIs.

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Presented at the 2003 SCEA-ISPA Joint Annual Conference and Training Workshop - www.iceaaonline.com

Predicting Final CPI

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4th Joint Annual ISPA/SCEA International Conference
Orlando, June 2003

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Outline

- Objective
- The Data
- Development
  - Predicting the Final CPI
  - Predicting the Standard Deviation
- Production
  - Predicting the Final CPI
  - Predicting the Standard Deviation
- Conclusions
- EVM Tool
- The Road Ahead

Also presented at ASC Cost and Schedule Spring Workshop – 2003

Objective

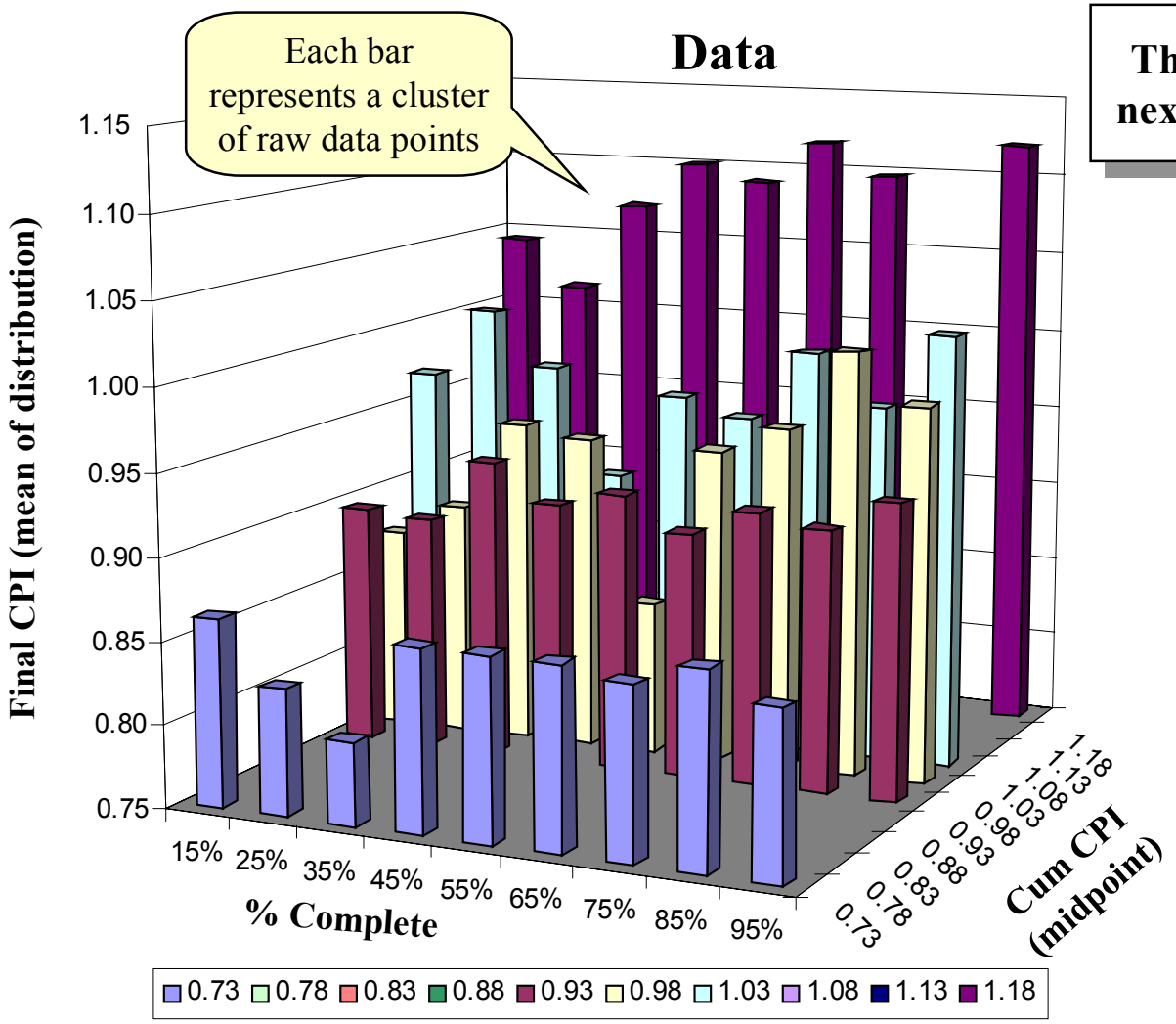
- **NAVAIR is in the midst of revising their EAC Toolkit**
  - **They are incorporating work by M. Popp on distributions of Final CPI given Cum CPI and % Complete**
- **NAVAIR lead cost risk analyst Steve Van Drew asked TASC to take a look at the data**
  - **Objective was to see if some quick work might add value**
- **TASC's objective was to see if there were any larger patterns discernable, or some overarching principles**

Data

- **Data from "*Probability Distributions of CPI at Complete vs. CPI Today*" written by Michael Popp in 1997**
  - Data extracted from the OSD CAIG Contract Analysis System (CAS)
  - Quarterly report information on over 350 programs
    - Development and production programs
  - Over 19,500 records, each containing over 50 fields of information
- **Data consists of fitted distributions for Final CPI, segregated into**
  - Cum CPI bins of *size .05* from *below 0.9* to *1.05 and above*
  - Percent Complete bins of *size 10%* from *20%* to *100%*
    - Note: We will continue to warn that % Complete in this analysis is not cohort data, nor should it be viewed as the passage of time, it is an initial condition
- **Analysis was performed using the following values:**
  - Averages and standard deviations from the fitted distributions
  - The midpoints of each bin

Development Data

Data - Development



This is the data in 3-D, next we will see it in 2-D

Definitions:

Cum CPI, as used in this study, is the cum CPI calculation at a specific level of completion in the life of a program.

% Complete is a forward-looking calculation:

BCWP / (Current Total Allocated Budget)

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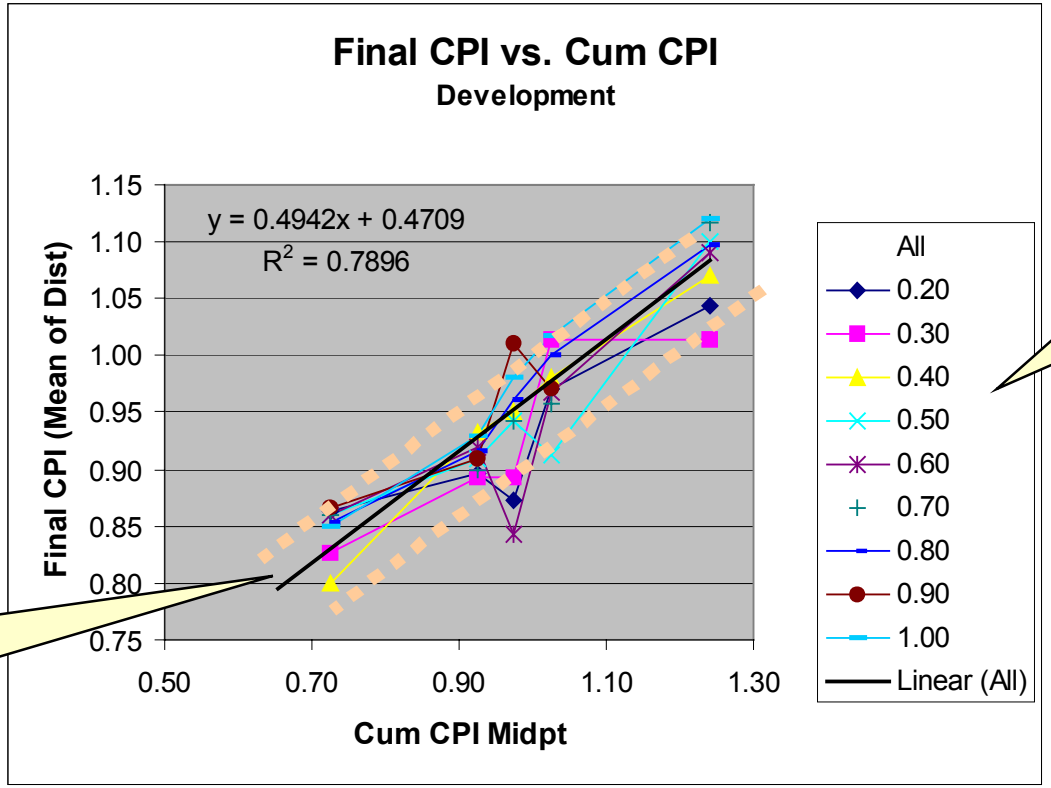
Final CPI and Cum CPI - Development



Data is grouped by % Complete

Final CPI rises with Cum CPI

Final CPI rises with Cum CPI, but the y-intercept is low. The interpretation of this will require some discussion, which follows after a few slides …

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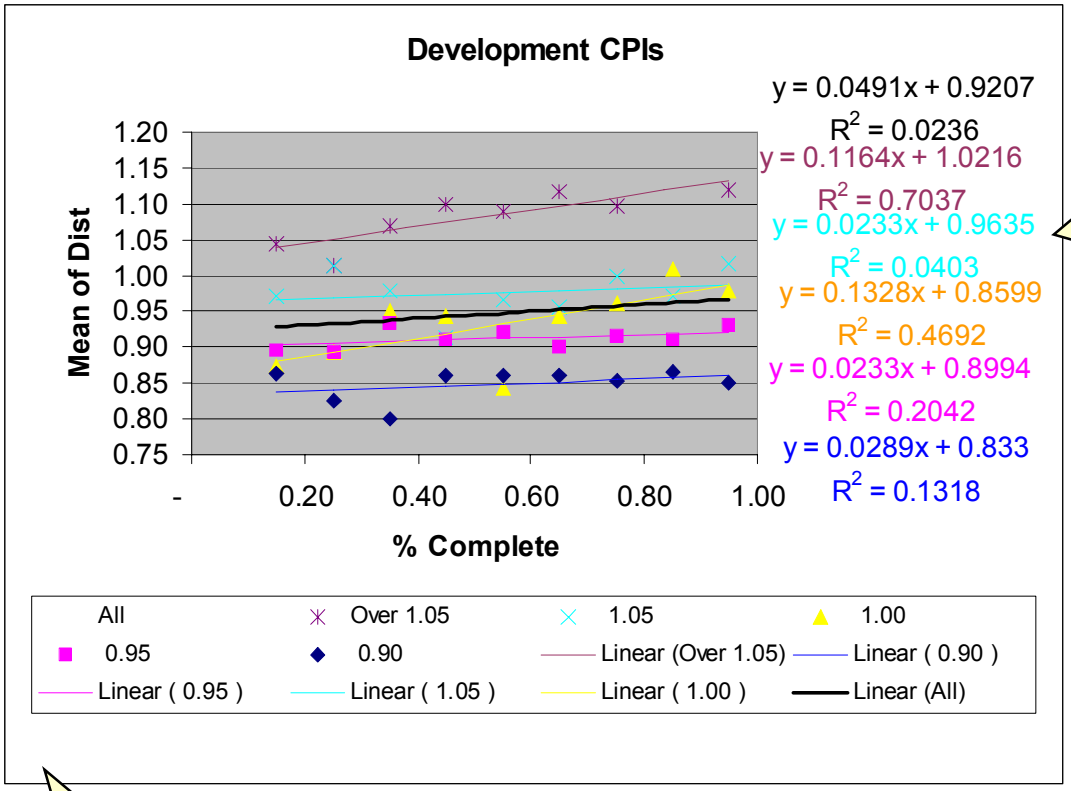
Final CPI and % Complete - Development



Final CPI seems to rise slightly with % Complete

Warning: The % Complete axis is not a time axis, it is an initial condition axis

Data is grouped by Cum CPI

The apparent slight correlation between Final CPI and % Complete is *not* statistically significant *taken alone*

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Final CPI with Cum CPI and % Complete - Development

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.906022836
R Square	0.82087738
Adjusted R Square	0.812139691
Standard Error	0.036011476
Observations	44

82% of the variation in Final CPI is explained by the Cum CPI and the % Complete

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	0.24366522	0.121833	93.94674	4.8931E-16
Residual	41	0.053169881	0.001297		
Total	43	0.296835101			

The regression model *is* statistically significant

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.437698673	0.037937911	11.53724	1.88E-14	0.361081465	0.51431588	0.361081465	0.514315881
% Midpt	0.056523755	0.021124814	2.675704	0.010668	0.013861305	0.0991862	0.013861305	0.099186205
CPI Mdpt	0.49678628	0.036775714	13.50854	1.09E-16	0.422516177	0.57105638	0.422516177	0.571056382

As % Complete increases, the Final CPI increases

Both variables are statistically significant *when taken together*

As the Cum CPI increases, the Final CPI also increases

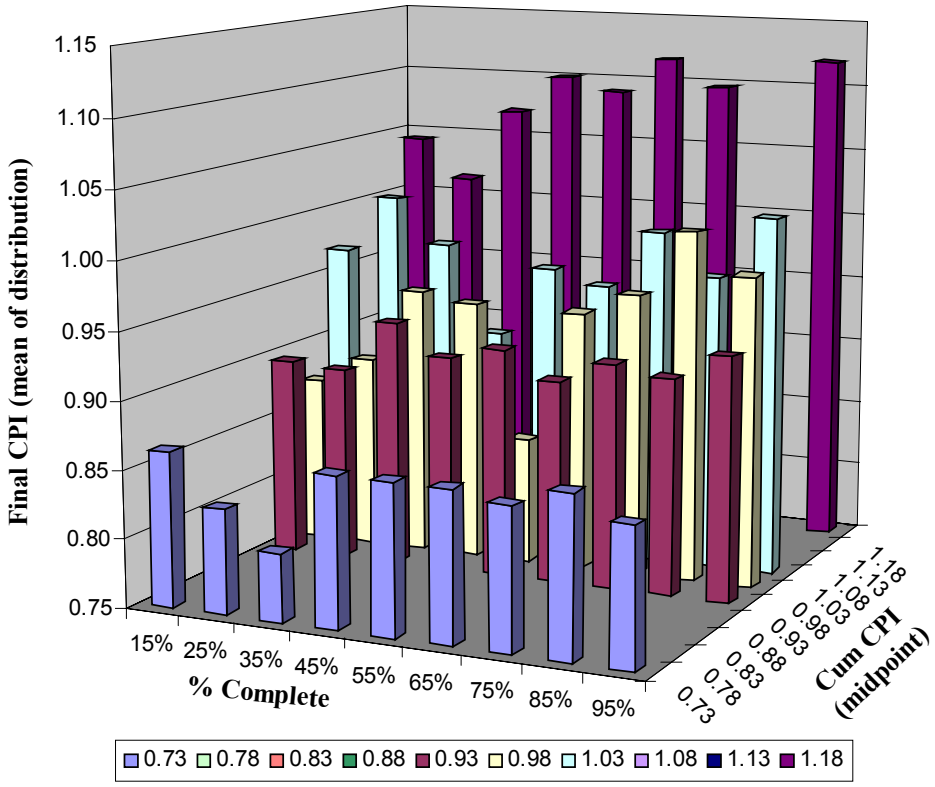
Final CPI = 0.438 + 0.057(% Complete) + 0.497(Cum CPI)

The Predictions - Development

Warning: The % Complete axis is not a time axis, it is an initial condition axis

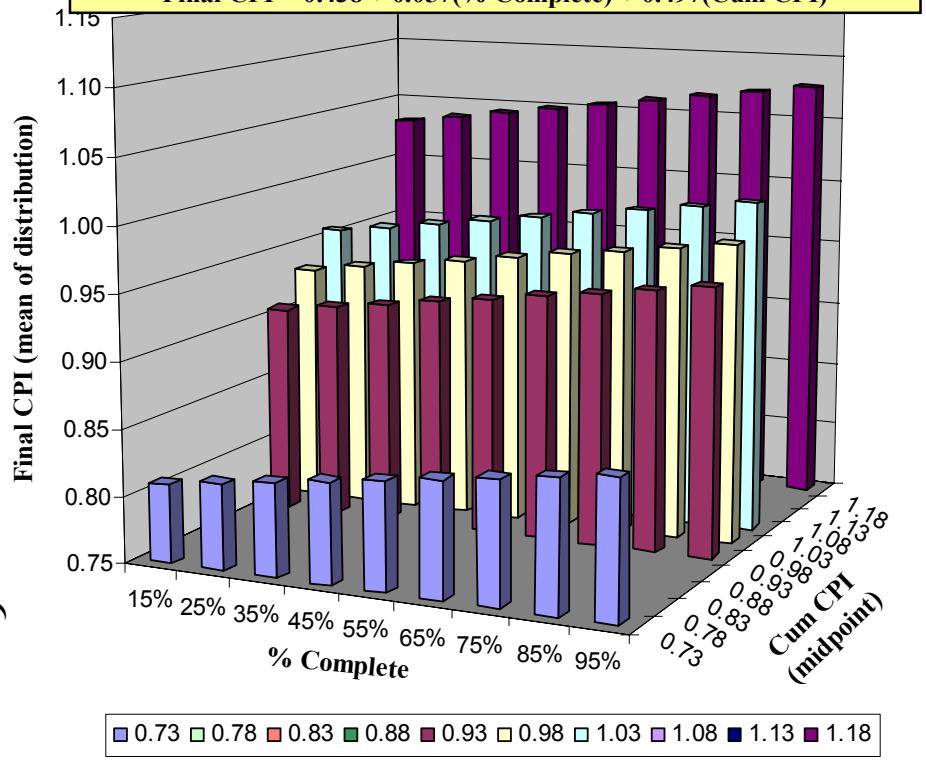
This is the model in 3-D, next we will see it in 2-D

Raw Data



Prediction Equation

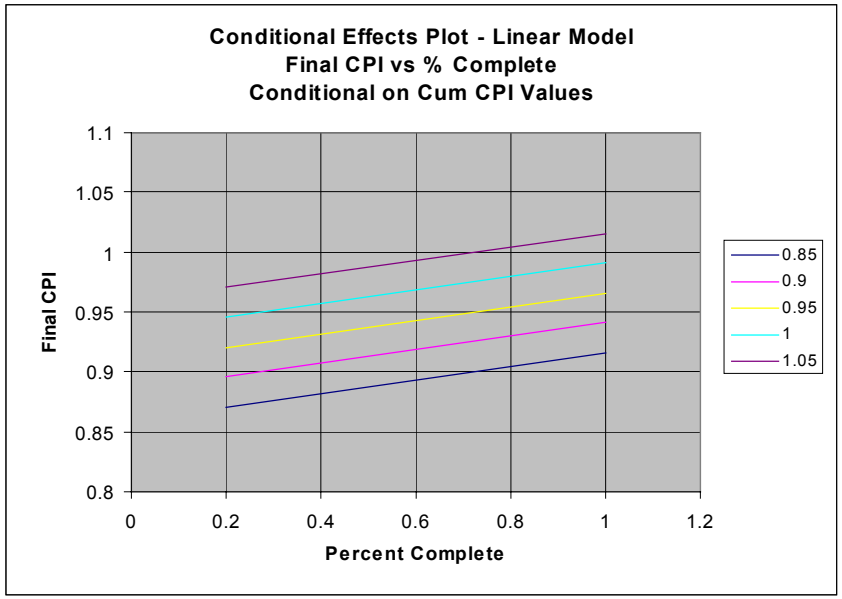
Final CPI = 0.438 + 0.057(% Complete) + 0.497(Cum CPI)



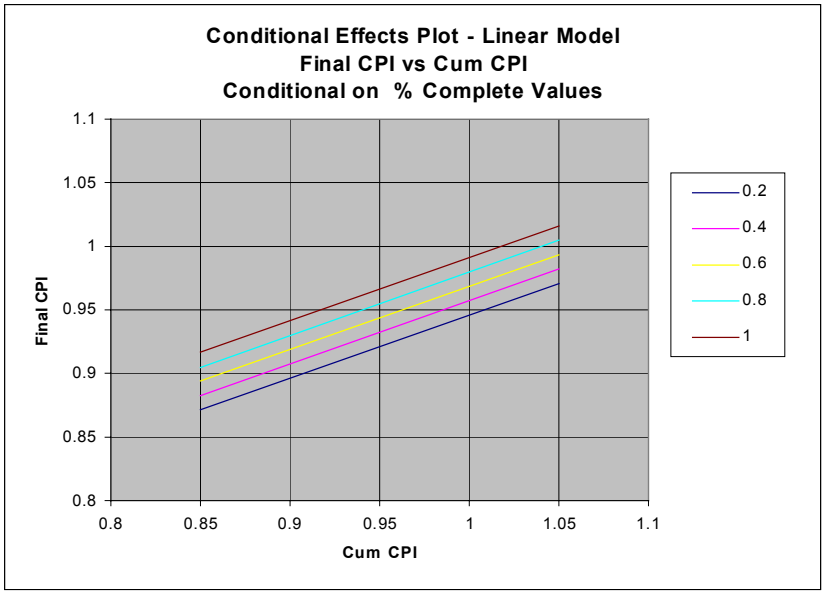
Conditional Effects Plots - Development

As Percent Complete rises, Final CPI rises gently

Curves of constant Cum CPI are widely separated



Warning: The % Complete axis is not a time axis, it is an initial condition axis



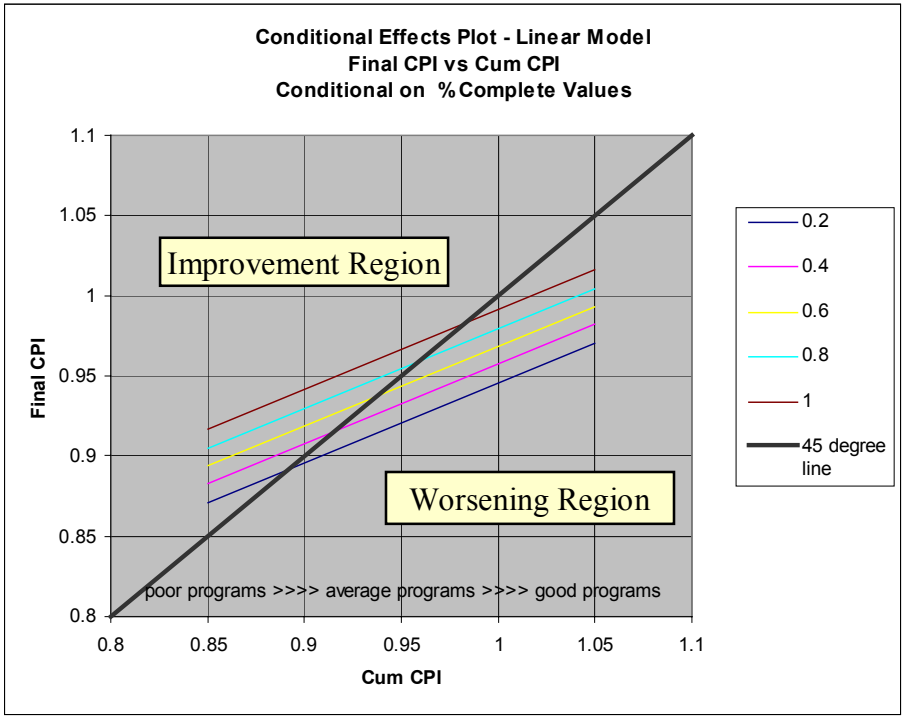
As Cum CPI rises, Final CPI also rises

Curves of constant % Complete are slightly separated

What do we know about the Final CPI? - Development

- **Final CPI rises with Cum CPI**
- **Final CPI rises slightly with % Complete**
- **Final CPI is *often* worse than Cum CPI**
  - **E.g., For development programs, Final CPI only gets better than Cum CPI if Cum CPI < 0.93 at 50% Complete**

Can programs improve?
- **Good programs *do not* improve**
- **Average programs *sometimes* improve**
- **Poor programs *often* improve**



"Crossover Point" for Cum CPI - Development

- **Where are we likely to see improvement?**
- **From the regression equation, we have**

$$\text{Final CPI} = a + b*\%\ \text{Complete} + c*\ \text{Cum CPI}$$

- **Improvement happens where Final CPI > Cum CPI**
- **To determine the "break even point", set**

$$\text{Final CPI} = \text{Cum CPI}$$

$$a + b*\%\ \text{Complete} + c*\ \text{Cum CPI} = \text{Cum CPI}$$

$$\text{Cum CPI} = (a + b*\%\ \text{Complete}) / (1 - c)$$

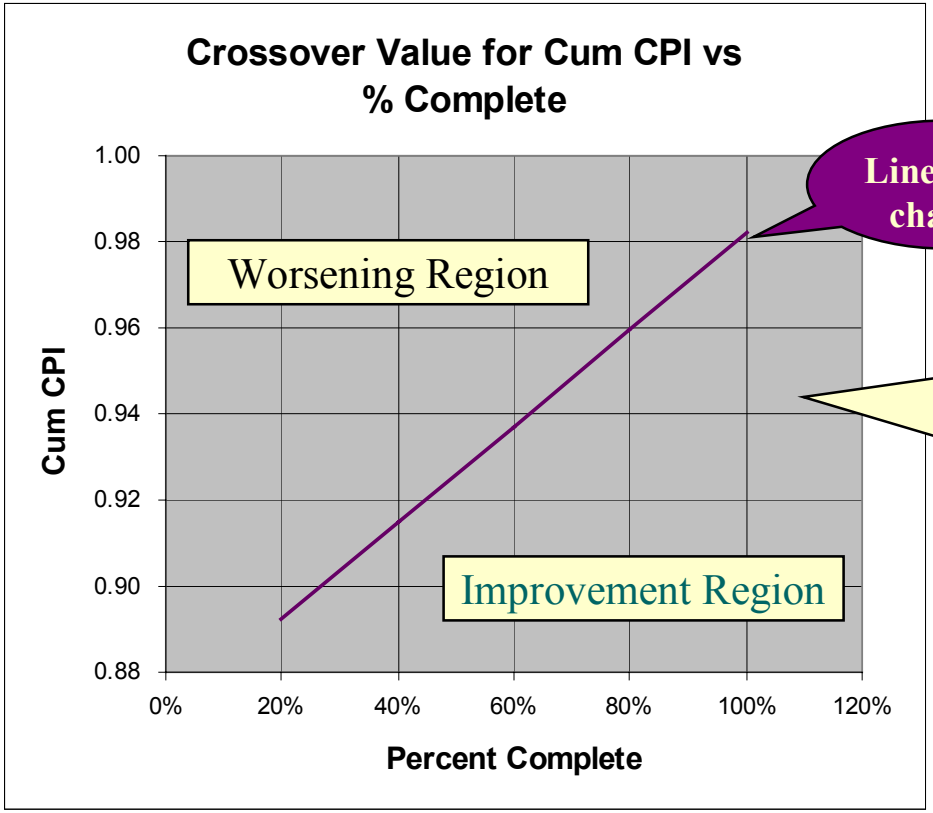
This is the "line of no change" on the next slide.

- **We have c < 1, so improvement occurs where**

$$\text{Cum CPI} < (a + b*\%\ \text{Complete}) / (1 - c)$$

Improvement region is below the line (see next slide).

"Crossover Point" for Cum CPI - Development



As Percent Complete rises, there is an increase in the *maximum value* for Cum CPI at which there is an expectation of improvement (the "crossover point")

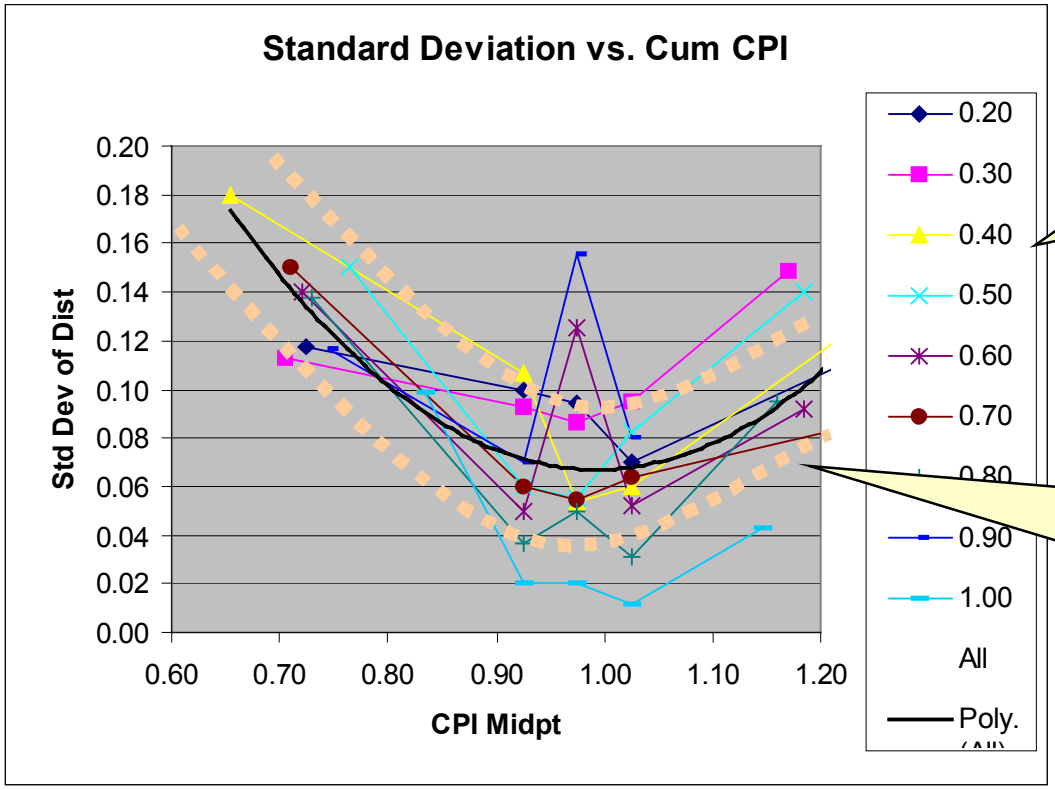
Warning: The % Complete axis is not a time axis, it is an initial condition axis

"Crossover Point" for Cum CPI – Development

- **Christensen, Abba and Christle:**
  - **The final cost variance will be worse than the cost variance at the 20% completion point**
    - **Testing for reasonableness -- after 20% complete, EAC reflects that a program will never get better**
    - **The EAC computed using the cumulative CPI is a reasonable lower bound to the final cost of a defense contract**
- **This study:**
  - **Good programs do not improve** ✓ **Consistent w/ Christensen**
  - **Average programs sometimes improve towards the end of the program**
  - **Poor programs have a chance to improve throughout the program**
    - **At 20%, programs with a cumulative CPI below 0.89 improve**
      - **High CPIs early on tend to get worse (a CPI of 1.0 at 20% yields a Final CPI of 0.95)**
      - **Low CPIs tend to improve (a CPI of 0.80 at 20% yields a Final CPI of 0.85)**
    - **At 80%, programs with a cumulative CPI below 0.93 improve**
      - **As the % Complete rises, the maximum ("crossover") point at which a program has a chance of improving increases … chance for improvement increases as programs mature**

✗ **Close to Christensen, but with some exceptions**

Standard Deviation of Final CPI vs. Cum CPI - Development



Data is grouped by % Complete

There appears to be an x^2 pattern … but this is almost surely just an artifact of the binning!

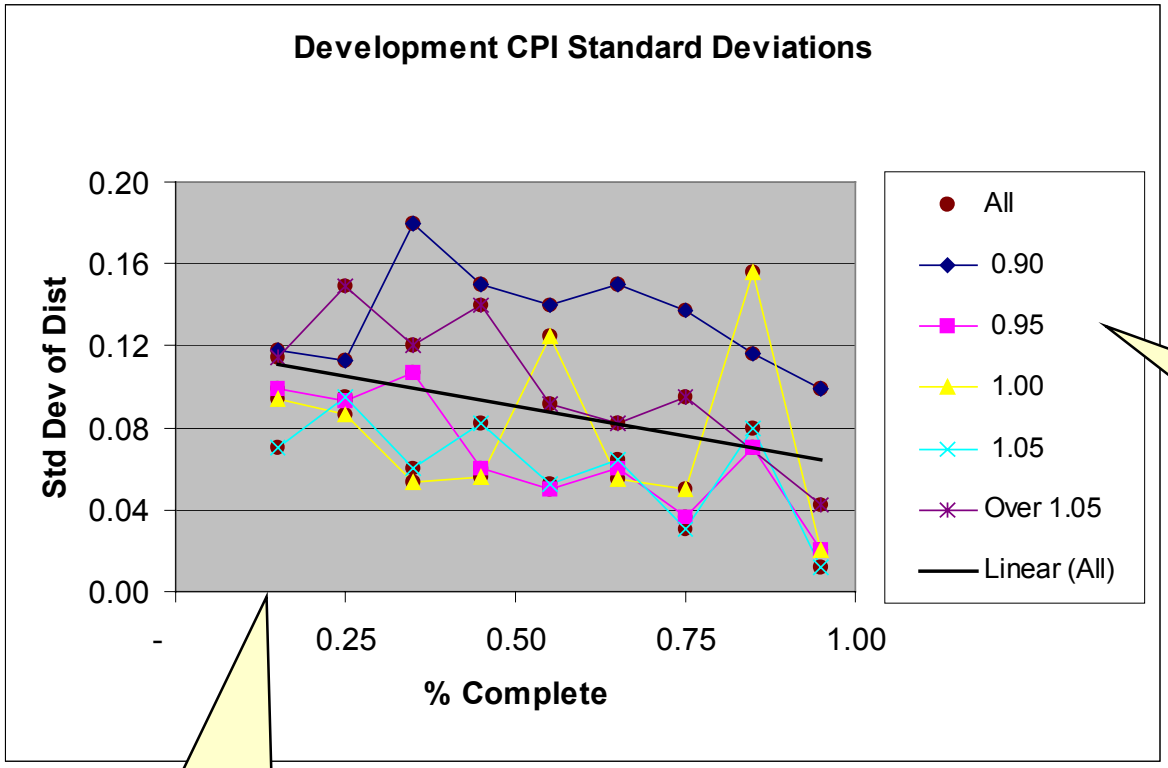
Standard Deviation of the Final CPI seems higher for extreme CPIs; however, this is likely a false trend

Std Dev with Cum CPI and % Complete – Development

- Plot of Standard Deviation vs. Cum CPI showed a potential x^2 pattern
- So, Standard Deviation was regressed against % Complete, Cum CPI, and (Cum CPI)^2
  - The regression model and all three variables were significant
- Despite significance, the x^2 pattern is believed to be a false trend
  - The quadratic pattern is not visually supported in scatter plots of the raw data[1]
    - The data in each bin appears homoskedastic with respect to Cum CPI
  - There is no obvious reason why very low and very high CPIs should have more variance
  - The apparent x^2 pattern is likely to be a result of the binning scheme
    - The lowest and highest CPI bins are unbounded (below 0.90 and above 1.05)
    - The unbounded bins often contain nearly one-third of the total data … so, we would expect for this bin to have more variance simply because it contains more data
- Recommend the use of a linear model with % Complete only
  - The Cum CPI data is poisoned by the binning scheme
  - There is no apparent relationship between Cum CPI and Standard Deviation in the scatter plots of the raw data[1]

1. Scatter plots provided in the appendices of Popp's paper

Standard Deviation and % Complete - Development



Warning: The % Complete axis is not a time axis, it is an initial condition axis

Data is grouped by Cum CPI

Std. Dev. declines as % Complete increases

Standard Deviation decreases as contracts mature

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Std Dev with % Complete – Development

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.370830489
R Square	0.137515252
Adjusted R Square	0.116979901
Standard Error	0.038640179
Observations	44

14% of the variation in Std. Dev is explained by the regression model

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.009998319	0.009998	6.696513	0.013209932
Residual	42	0.062708665	0.001493		
Total	43	0.072706984			

The regression model *is* statistically significant

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.11994237	0.013616984	8.808292	4.3E-11	0.092462174	0.14742257	0.092462174	0.147422565
% Midpt	-0.058636723	0.022659239	-2.58776	0.01321	-0.104364934	-0.0129085	-0.10436493	-0.01290851

Coefficient is statistically significant

As % Complete increases, the Std. Dev. decreases

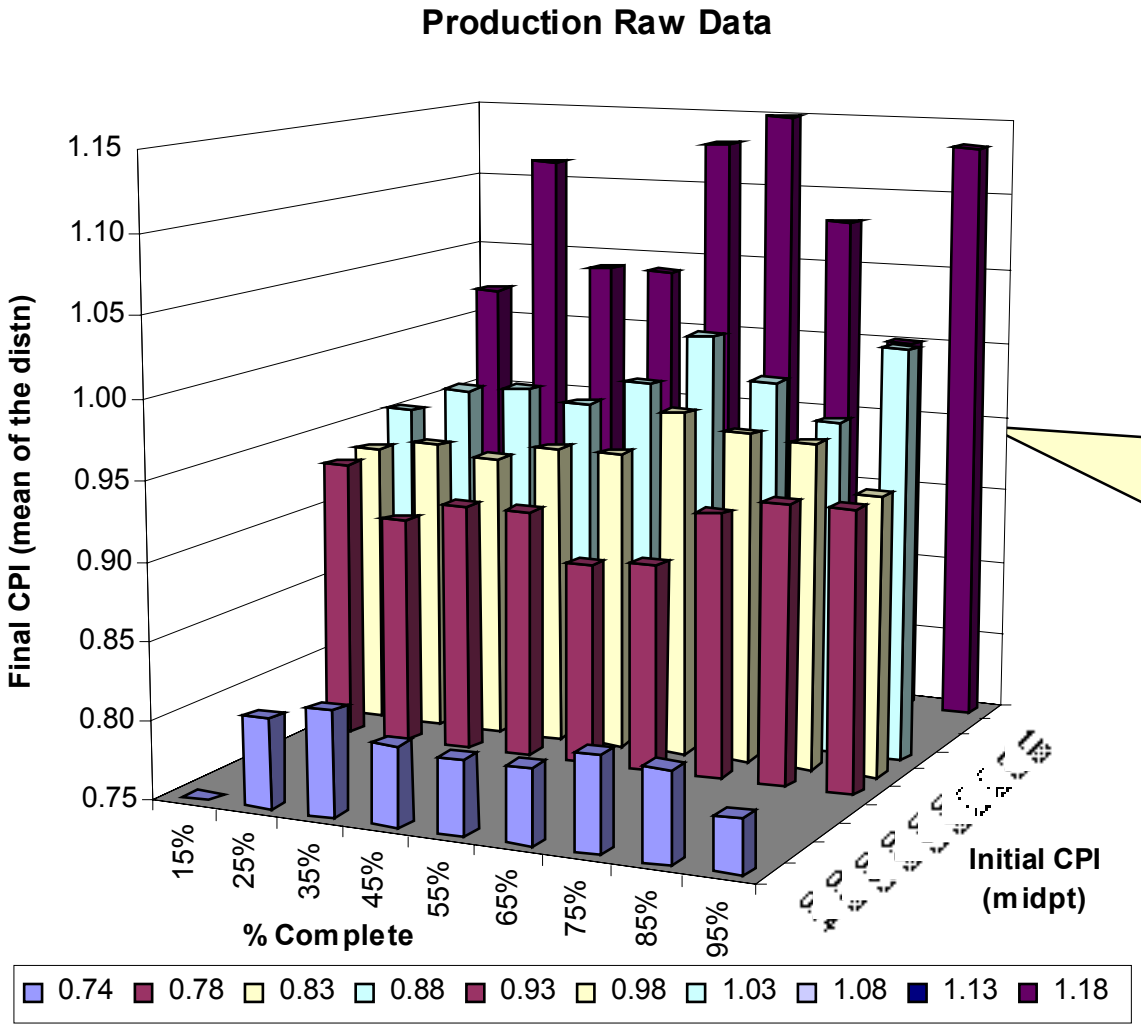
Std. Dev. = 0.120 – 0.059 * % Complete

What do we know about the Std. Dev? - Development

- **Programs have more variability if they have low Percent Complete**
  - **Your future is less certain early in the program**
- **There is no apparent relationship between Cum CPI and Standard Deviation in the raw data scatter plots**
  - **The false x^2 pattern in the binned data is likely caused by unbounded bins containing much of the data**

Production Data

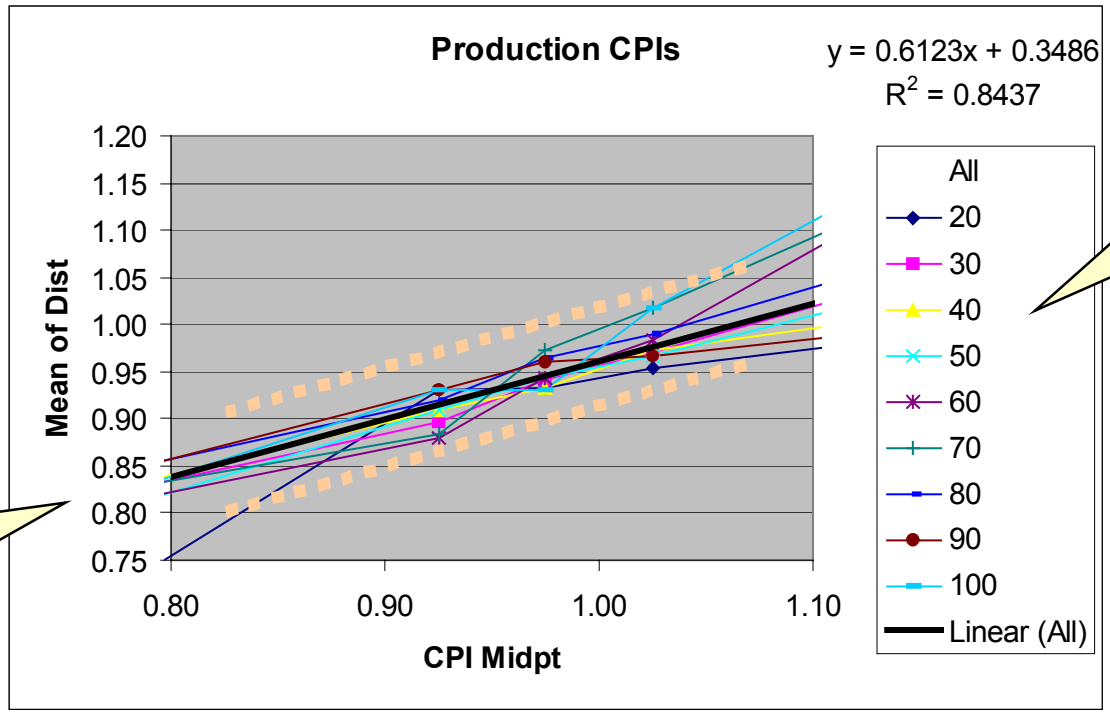
Data - Production



This is the data in 3-D, next we will see it in 2-D

Each bar represents a cluster of raw data points

Final CPI and Cum CPI - Production



Final CPI rises with Cum CPI

Data is grouped by % Complete

As in Development, Final CPI rises with Cum CPI, but the y intercept is low. The interpretation of this will require some discussion, which follows after a few slides…

Final CPI with Cum CPI and % Complete - Production

Final CPI vs. % Complete and Cum (Current) CPI

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.934778494
R Square	0.873810833
Adjusted R Square	0.867801826
Standard Error	0.036003676
Observations	45

87% of the variation in Final CPI is explained by the Cum CPI

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	0.376997378	0.188498689	145.4168215	1.32271E-19
Residual	42	0.054443116	0.001296265		
Total	44	0.431440494			

The regression model *is* statistically significant

s	*Coefficients*	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.302669429	0.038657924	7.829427913	9.69739E-10	0.224654555	0.380684303	0.224654555	0.380684303
Cum CPI Mdpt	0.622233453	0.036674835	16.96622356	2.08636E-20	0.548220616	0.69624629	0.548220616	0.69624629
% Comp Mdpt	0.066067211	0.020862696	3.166762815	0.002869681	0.023964572	0.108169851	0.023964572	0.108169851

As the Cum CPI increases, the Final CPI also increases

All variables are statistically significant

As % Complete increases, the Final CPI also increases

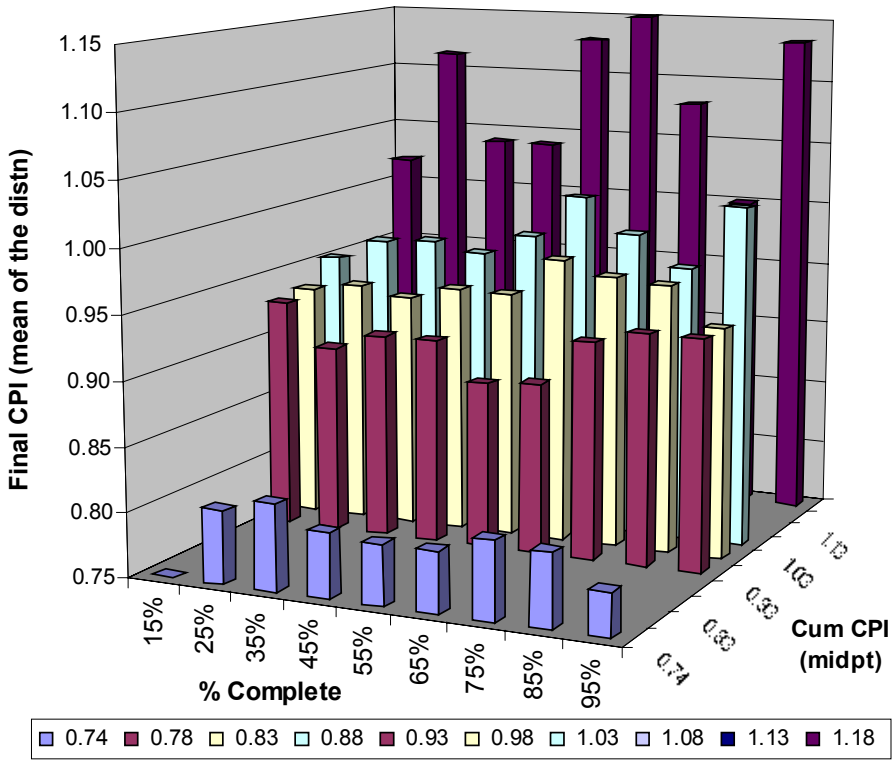
Final CPI = 0.303 + 0.066(% Complete) + 0.622(Cum CPI)

The Predictions - Production

Warning: The % Complete axis is not a time axis, it is an initial condition axis

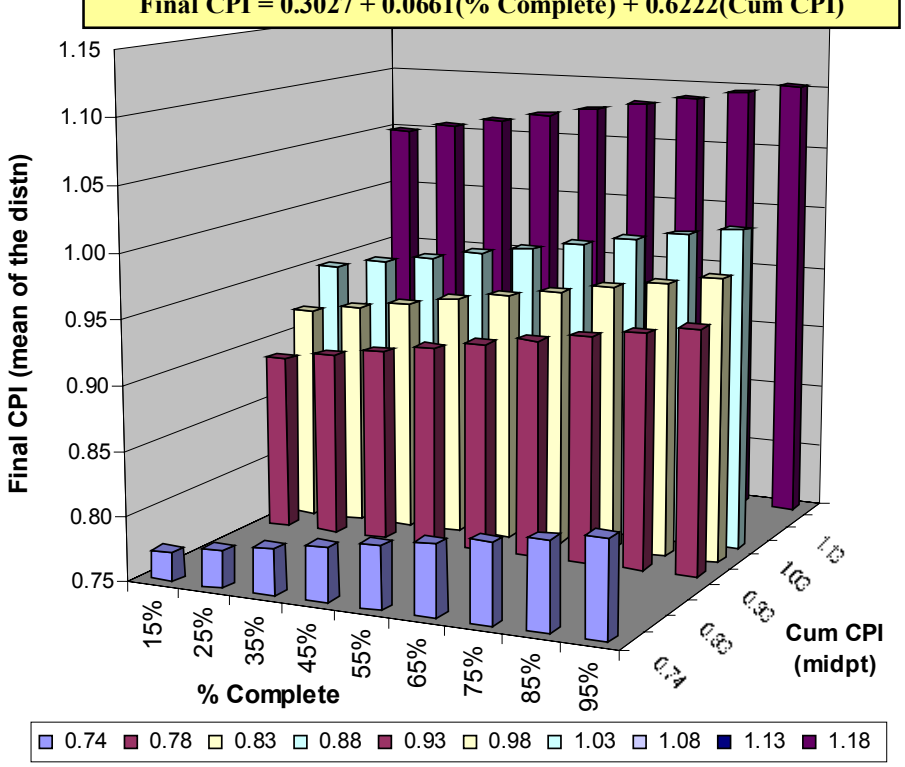
This is the model in 3-D, next we will see it in 2-D

Production Raw Data



Production Predictions - Linear

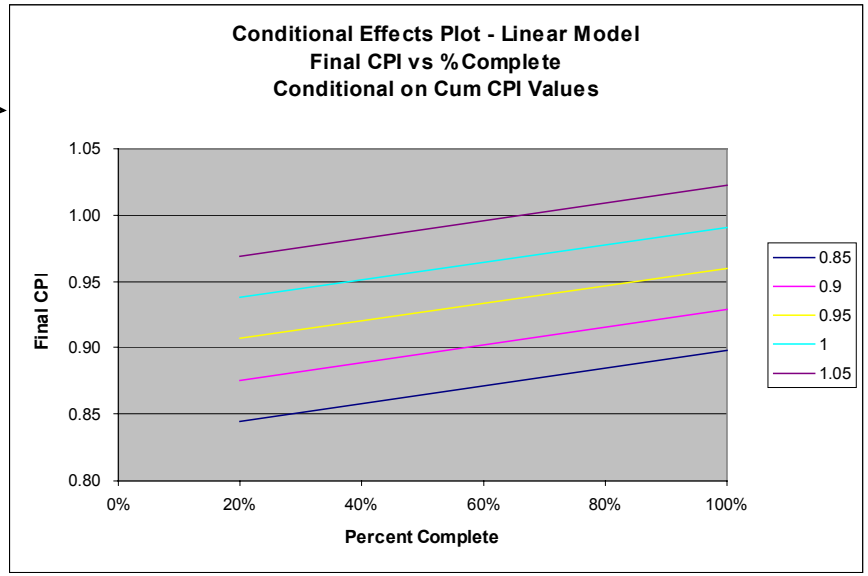
Final CPI = 0.3027 + 0.0661(% Complete) + 0.6222(Cum CPI)



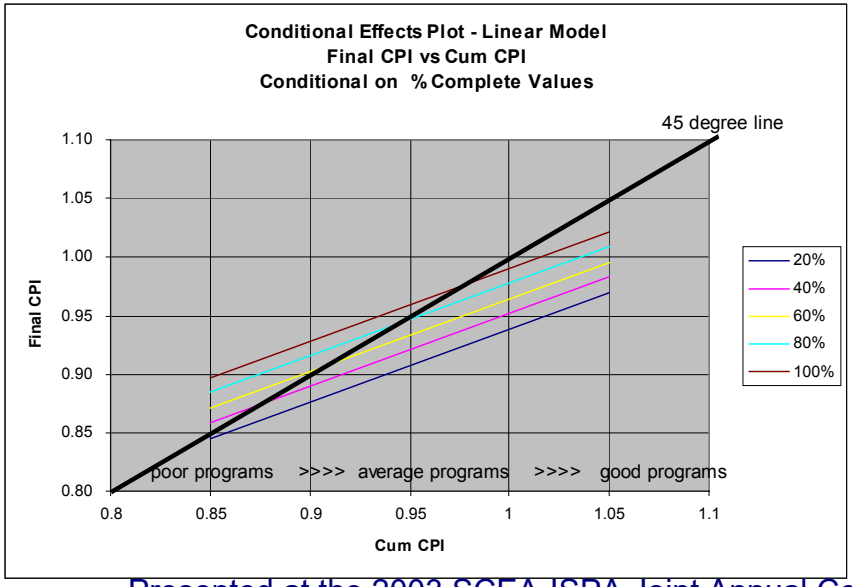
Conditional Effects Plots - Production

As Percent Complete rises, Final CPI rises gently

Curves of constant Cum CPI are separated



Warning: The %Complete axis is not a time axis, it is an initial condition axis



As Cum CPI rises, Final CPI rises less sharply than development

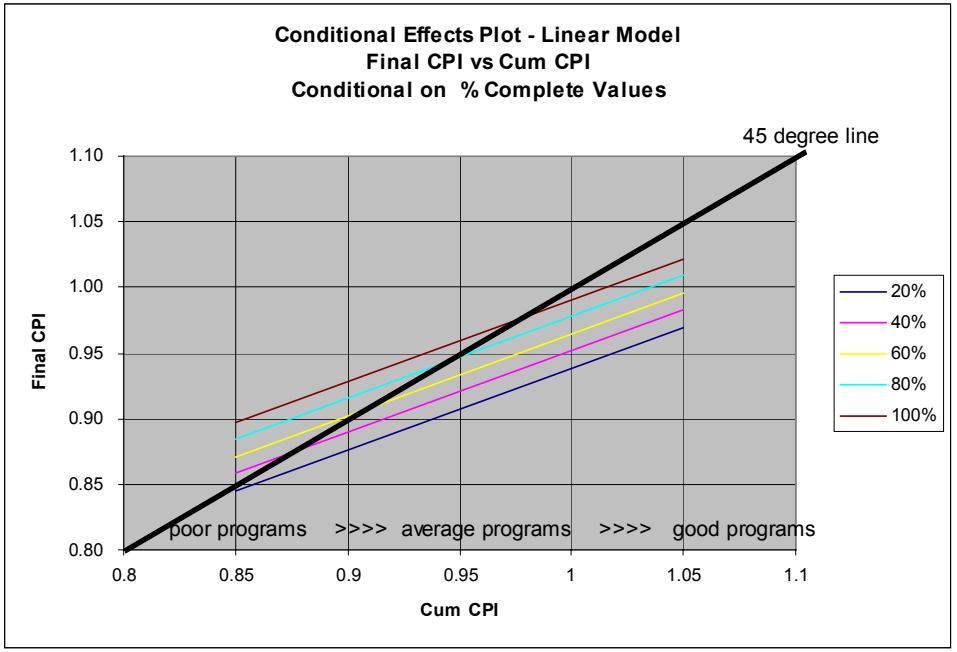
Curves of constant % Complete are slightly separated

What do we know about the Final CPI? - Production

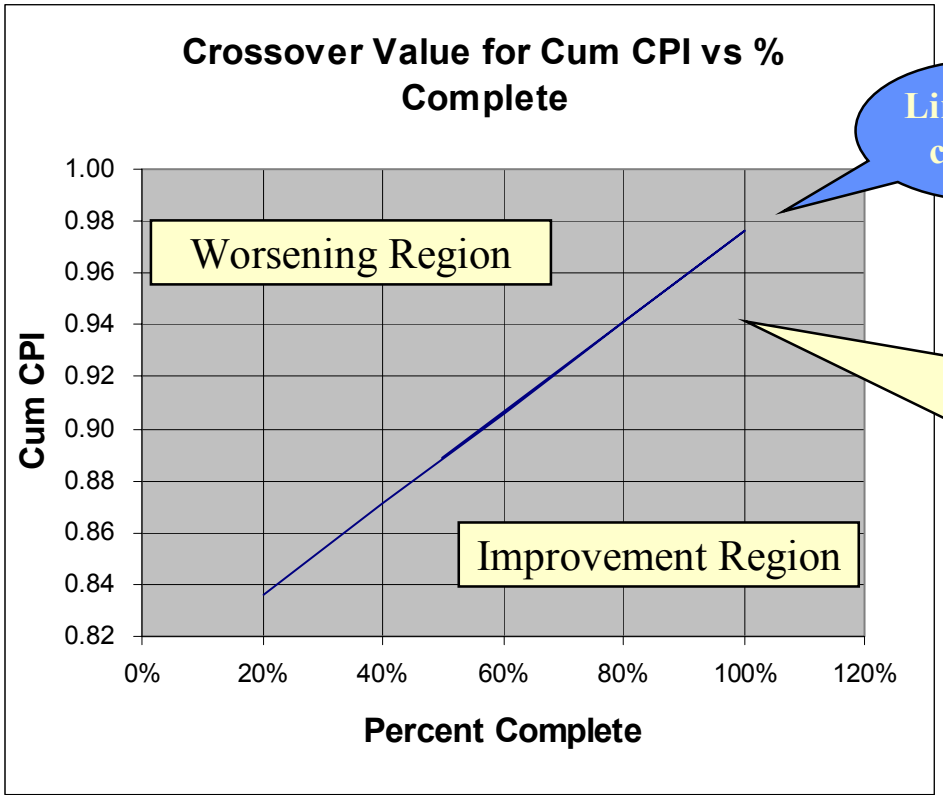
- **Final CPI rises with Cum CPI**
- **Final CPI rises slightly with % Complete**
- **Final CPI is *often* worse than Cum CPI**
  - **E.g., For production programs, Final CPI only gets better than Cum CPI if Cum CPI < 0.88 at 50% Complete**

Programs tend to get worse!

- **Average to good programs do not get better**
- **Poor programs have a chance to improve**



"Crossover Point" for Cum CPI - Production



As Percent Complete rises, there is an increase in the *maximum value* for Cum CPI at which there is an expectation of improvement (the "crossover point")

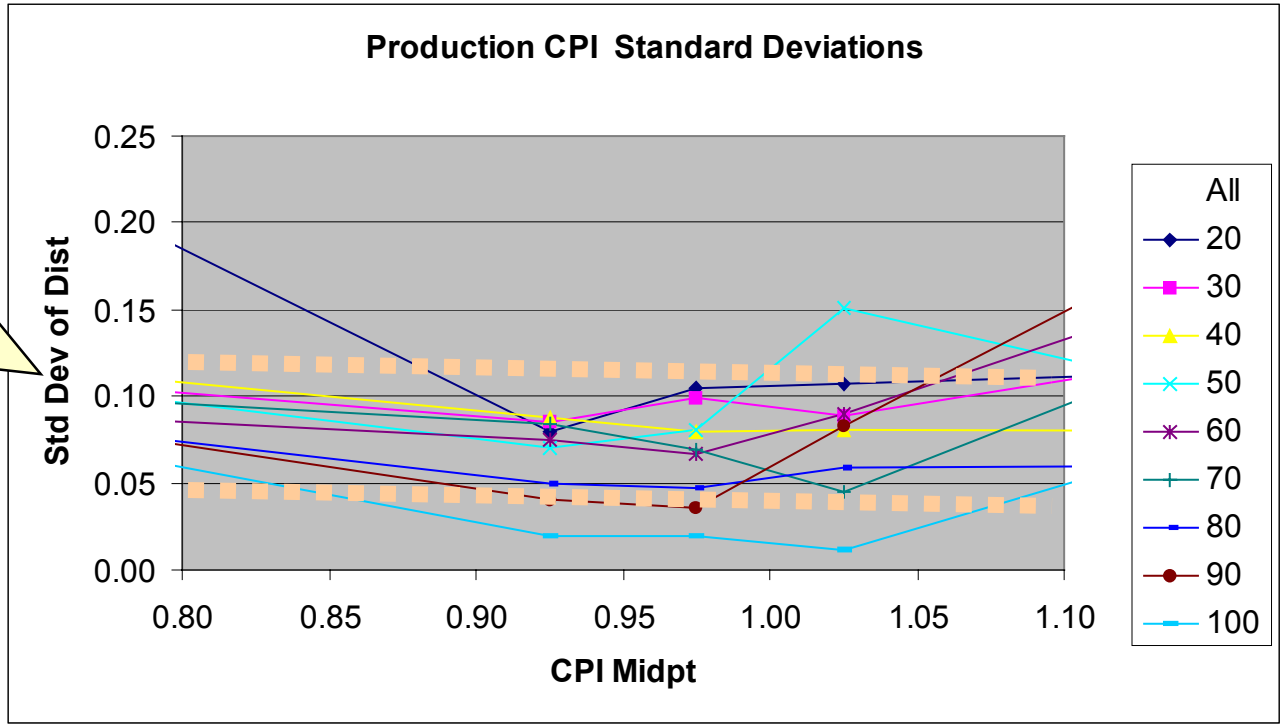
Warning: The % Complete axis is not a time axis, it is an initial condition axis

"Crossover Point" for Cum CPI – Production

- **Christensen, Abba and Christle:**
  - **The final cost variance will be worse than the cost variance at the 20% completion point**
    - **Testing for reasonableness -- after 20% complete, EAC reflects that a program will never get better**
    - **The EAC computed using the cumulative CPI is a reasonable lower bound to the final cost of a defense contract**
- **This study:**
  - **Average to good programs do not improve** ✓ **Consistent w/ Christensen**
  - **Poor programs have a chance to improve** ✗ **Close to Christensen, but with some exceptions**
    - **At 20%, programs with a cumulative CPI below 0.84 improve**
      - **High CPIs early on get worse (a CPI of 0.90 at 20% yields a final CPI of .88)**
      - **Low CPIs improve**
    - **At 80%, programs with a cumulative CPI below 0.94 improve**
      - **As the % Complete rises, the maximum ("crossover") point increases at which a program has a chance of improving**

Standard Deviation of Final CPI vs. Cum CPI - Production

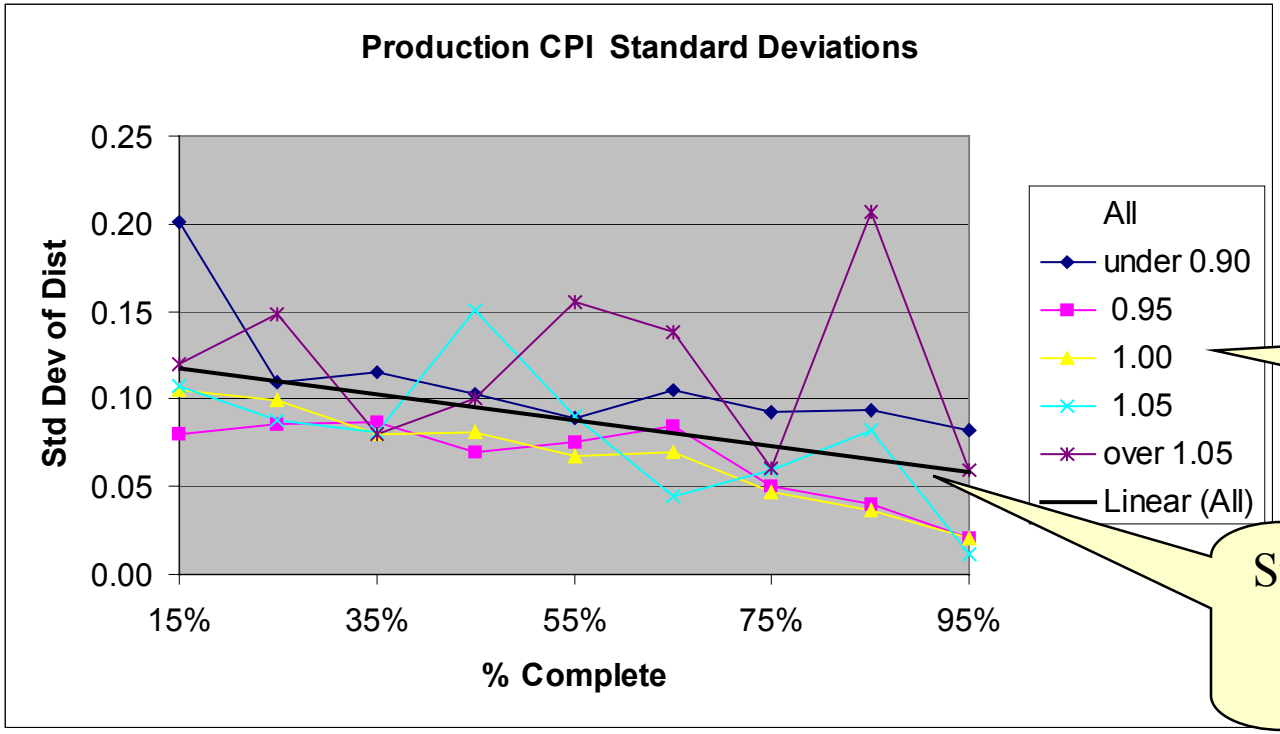
(Cum CPI)^2 tested as statistically significant in a quadratic regression … however, the slight x^2 effect is likely due to the binning scheme only



A linear function on % Complete is recommended … the Cum CPI data is poisoned by the binning scheme[1].

1. See slide 18 for details.

Standard Deviation of Final CPI vs. % Complete - Production



Warning: The % Complete axis is not a time axis, it is an initial condition axis

Data is grouped by Cum CPI

Std. Dev. declines as % Complete increases

The Production Standard Deviation decreases as contracts mature (as in development)

Std Dev with % Complete - Production

Standard Deviation of the Final CPI vs. % Complete

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.47221596
R Square	0.222987913
Adjusted R Square	0.204917864
Standard Error	0.036646896
Observations	45

22% of the variation in Std. Dev is explained by the regression model

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.016572819	0.016572819	12.34019445	0.00105634
Residual	43	0.057748783	0.001342995		
Total	44	0.074321602			

The regression model *is* statistically significant

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.129112774	0.012855465	10.04341499	7.56762E-13	0.103187275	0.155038273	0.103187275	0.155038273
% Comp Mdpt	-0.074325453	0.021158095	-3.51286129	0.00105634	-0.116994789	-0.03165612	-0.116994789	-0.031656117

As % Complete increases, the Std. Dev. decreases

% Complete and the intercept are statistically significant

Std. Dev. = 0.1291 - 0.0743*(% Complete)

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What do we know about the Std. Dev? - Production

- **Programs have more variability if they have low Percent Complete**
  - **Your future is less certain early in the program**
- **There is no apparent relationship between Cum CPI and Standard Deviation in the raw data scatter plots**
  - **The false x^2 pattern in the binned data is likely caused by unbounded bins containing much of the data**

Same conclusions as that of development programs.

Conclusions

- **Caveats:**
  - **Study not built on source data -- working with averages**
    - **Probably understating the variability of the data**
    - **Need to look at distributions and investigate skewness**
  - **Potential problems created by using binned data**
    - **The bin sizes could be causing erroneous signals (e. g., false x^2 pattern in Standard Deviation)**
    - **Points included/excluded could cause biases (use of highest % Complete in cases with multiple points in each bin)**
    - **Unknown number of points in each bin, so some points may be "over-represented"**
    - **Size effects unknown**
- **But: We can already predict Final CPI with considerable accuracy!**
  - **Production is much like Development – but not identical**
- **How can these results be used in real life? …**

EVM Tool

Predicting CPI and EAC

- **Predicting CPI**
  - **The primary objective of this study was to identify overall patterns and overarching principles in order to predict CPI**
  - **Concluded that CPI is a function of both Percent Complete and the Cum CPI**
- **What does the CPI tell us about the EAC?**
  - **CPI can be used to calculate EAC**
    - **This is only one of several methods to predict EAC**
  - **The next section will develop an EVM tool for predicting EAC based on the preceding research on CPI**
  - **Note: We are *not* recommending that CPI is the best method to predict EAC!**
    - **Other methods for predicting EAC (e.g., SPI, SPI x CPI, etc.) were not examined in Popp's paper or in this study**
    - **Recommend further study in this area**

Building the EVM Tool

- **Developed a tool to assist EVM analysts in predicting final EACs**
  - **Elements included are:**
    - **Calculation of Final CPI (Mean) based on inputs of Cum CPI and Percent Complete**
    - **Confidence Interval around the mean for lower and upper cost bounds**
    - **Final CPI and EAC corresponding to a desired percentile (e.g., what is the 80%-ile Final CPI?)**
    - **Percentile corresponding to a target Final CPI and EAC (e.g., what %-ile is a target Final CPI of 1.0?)**
- **Tool applies the equations derived earlier in this paper:**

Development Programs:

Final CPI = 0.438 + 0.057(% Complete) + 0.497(Cum CPI)

Std. Dev. = 0.12 – 0.06 * % Complete

Production Programs:

Final CPI = 0.6743 - 1.1791(Cum CPI) + 0.6186(Cum CPI)^2 - .0686(% Complete)

Std. Dev. = 0.1291 - 0.0743*(% Complete)

EVM Tool

Cum CPI	**0.80**	**input**
% Complete	**40%**	**input**
Development/Production	**Dev**	**input**
TAB (in $M)	**$ 100.0**	**input**
Final CPI:	0.86	**result**
Std. Dev.:	0.10	**result**
CV:	11%	**result**
If a confidence interval is desired other than +/- one standard deviation indicate here:	*68.3%*	**default +/- 1 std dev is 68.3%**

Probability of achieving CPI		
Target Final CPI:	**1.00**	**input**
% Probability:	8%	**result**
% Probability:	**80%**	**input**
Target Final CPI:	0.78	**result**

Probability of achieving EAC		
Target EAC:	**$ 117.0**	**input**
% Probability:	51%	**result**
% Probability:	**90%**	**input**
Target EAC:	$ 128.9	**result**

EAC

	CPI	EAC	% Probability
Upper cost bound:	0.76	131.57	84%
50th Percentile:	**0.86**	**116.59**	**50%**
Lower cost bound:	0.96	104.67	16%

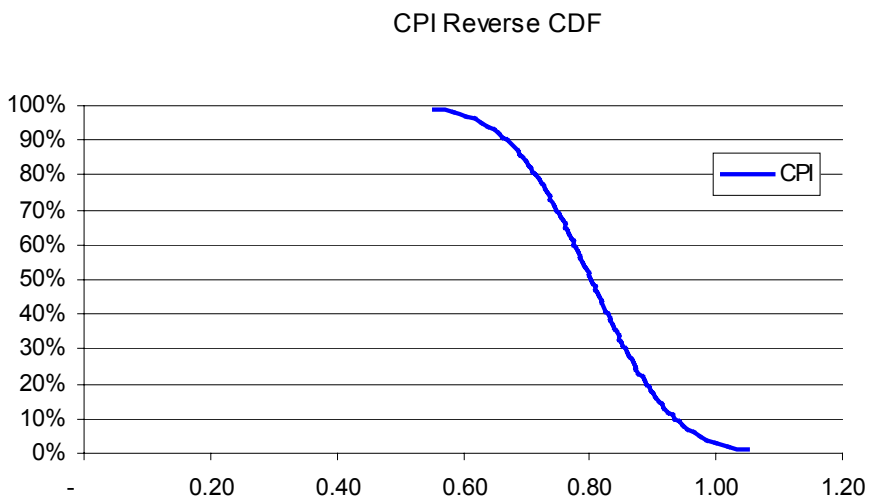
ETC

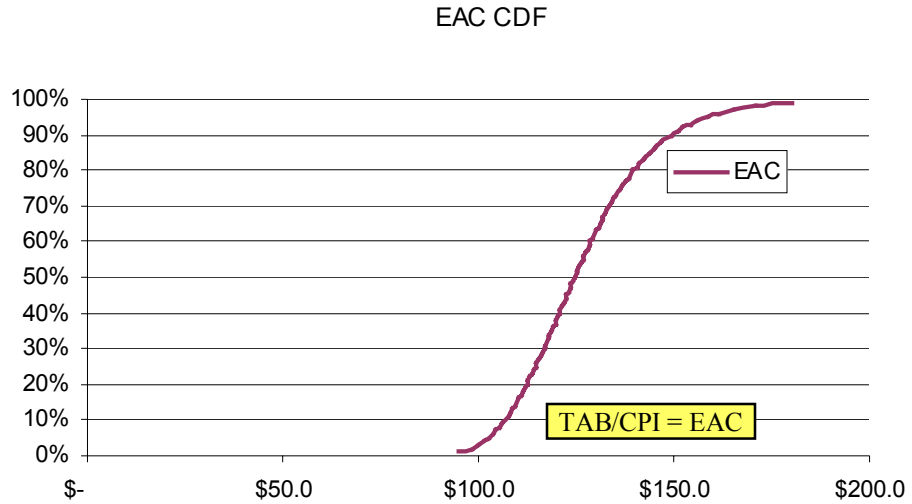
	CPI	ETC	% Probability
Upper cost bound:	0.73	91.57	84%
50th Percentile:	**0.90**	**76.59**	**50%**
Lower cost bound:	1.06	64.67	16%

Distributions of the CPI and EAC

- **Built into the EVM tool are distributions for the CPI and thus the EAC as a function of the CPI**
- **CPI – *t* distribution with a sample mean and standard deviation**
- **EAC – constant divided by a *t* distribution yields a slightly skewed distribution**

Example: Cum CPI = 0.80, % Complete = 40%, Dev. program, TAB = $100.0M





The Road Ahead

- **Future work**
  - **Conduct analysis with original source data**
    - **Initial study provides good direction, want to investigate further**
  - **Eliminate the previously noted data issues**
  - **Check the size effect**
  - **Look at other metrics like SPI/CPI combinations**
- **The outlook is bright … this is very promising!**