Predicting Final CPI

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San Diego, CA

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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

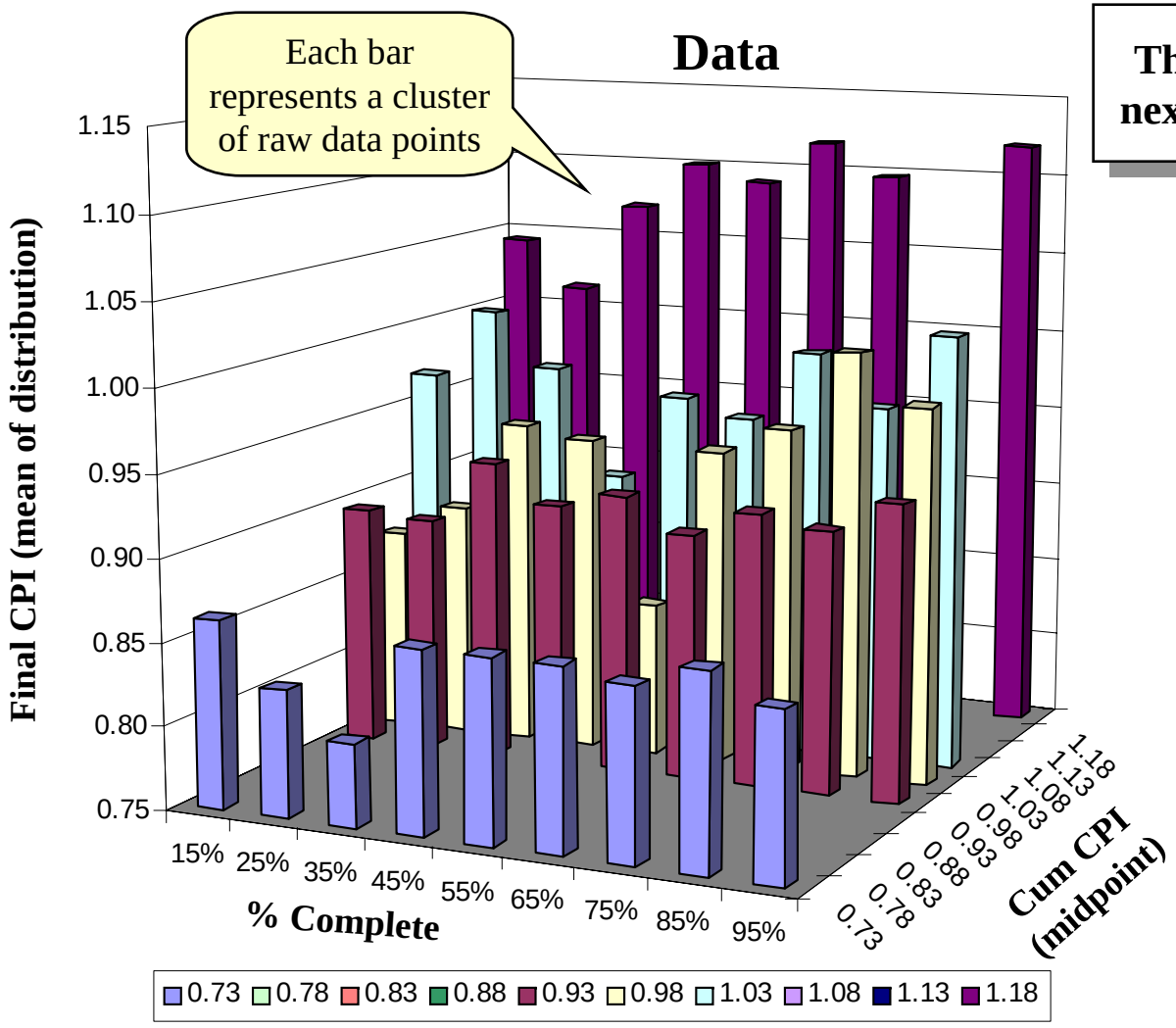
- **NAVAIR is in the midst of revising their EAC Toolkit**
  - **They are incorporating work by M. Popp on distributions of Final CPI given Cum CPI and % Complete**
- **NAVAIR lead cost risk analyst Steve Van Drew asked TASC to take a look at the data**
  - **Objective was to see if some quick work might 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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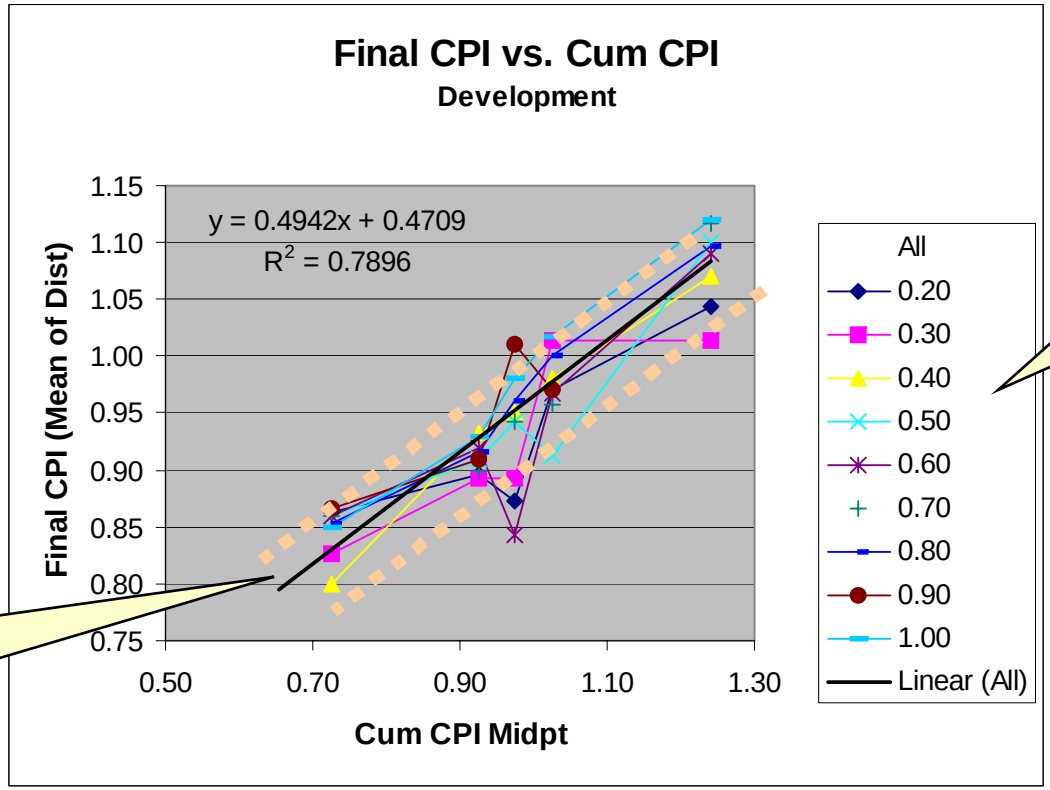
Final CPI and Cum CPI - Development



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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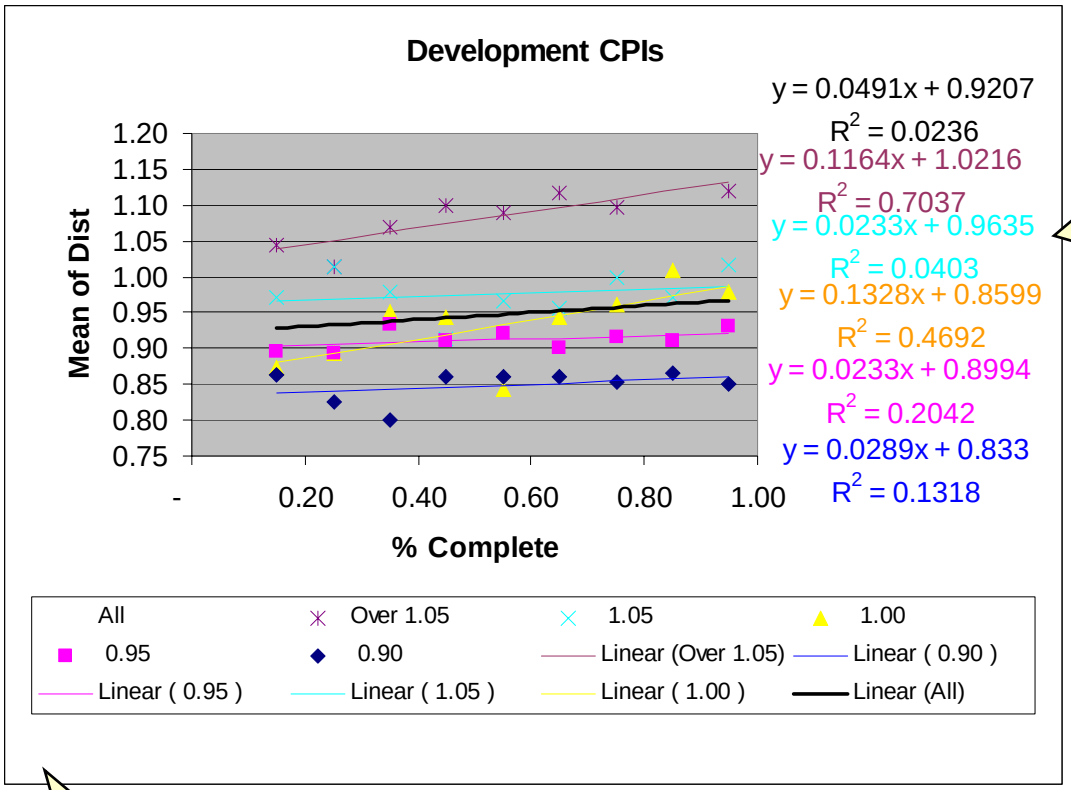
Final CPI and % Complete - Development



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)

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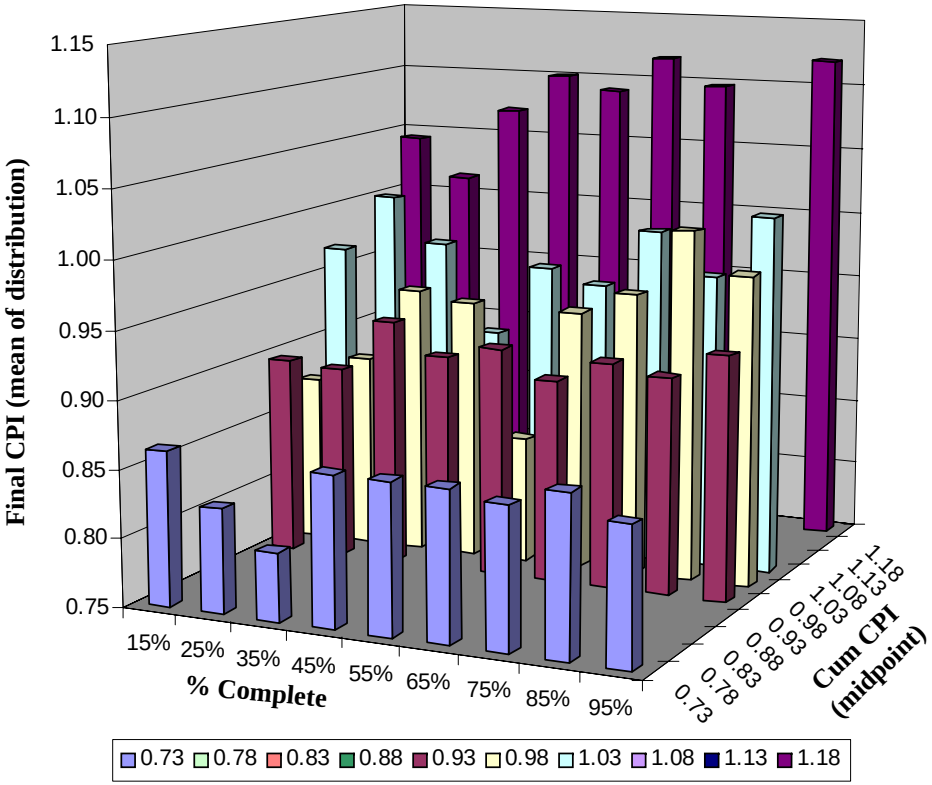
The Predictions - Development

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

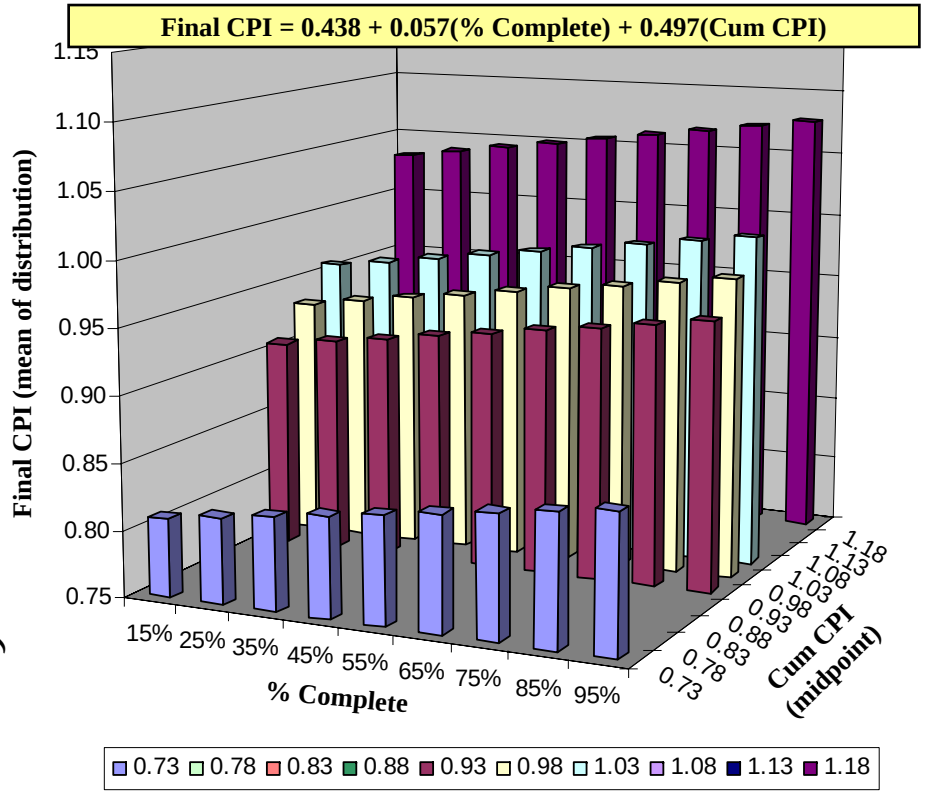
This is the model in 3-D, next we will see it in 2-D

Raw Data



Prediction Equation

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



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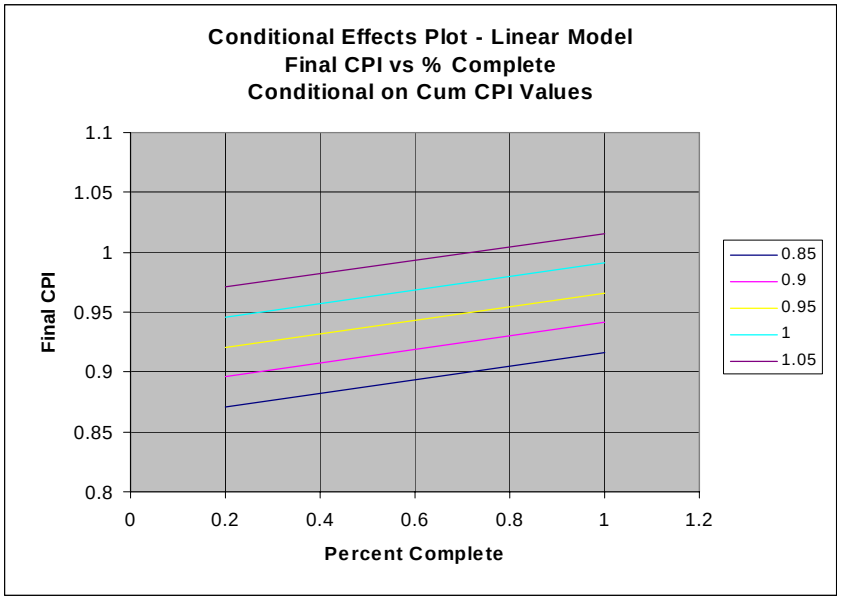
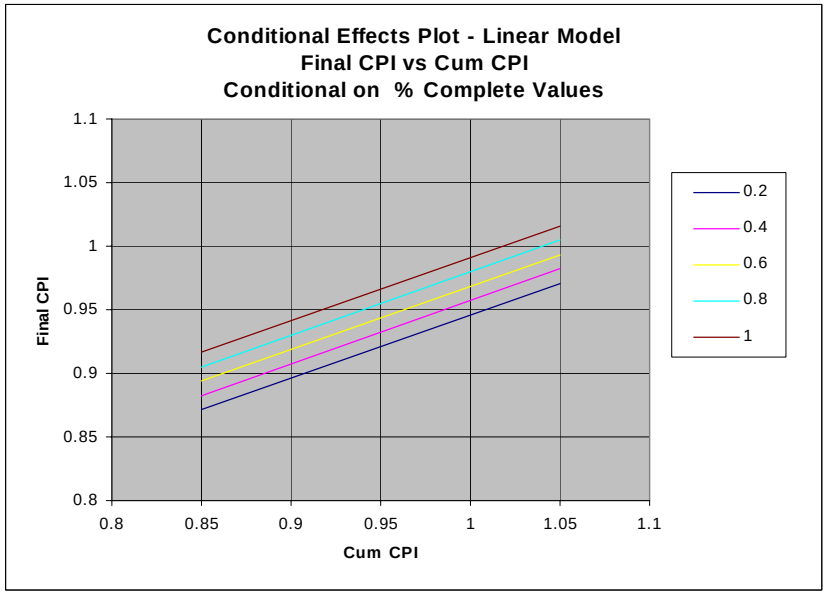
Conditional Effects Plots - Development

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

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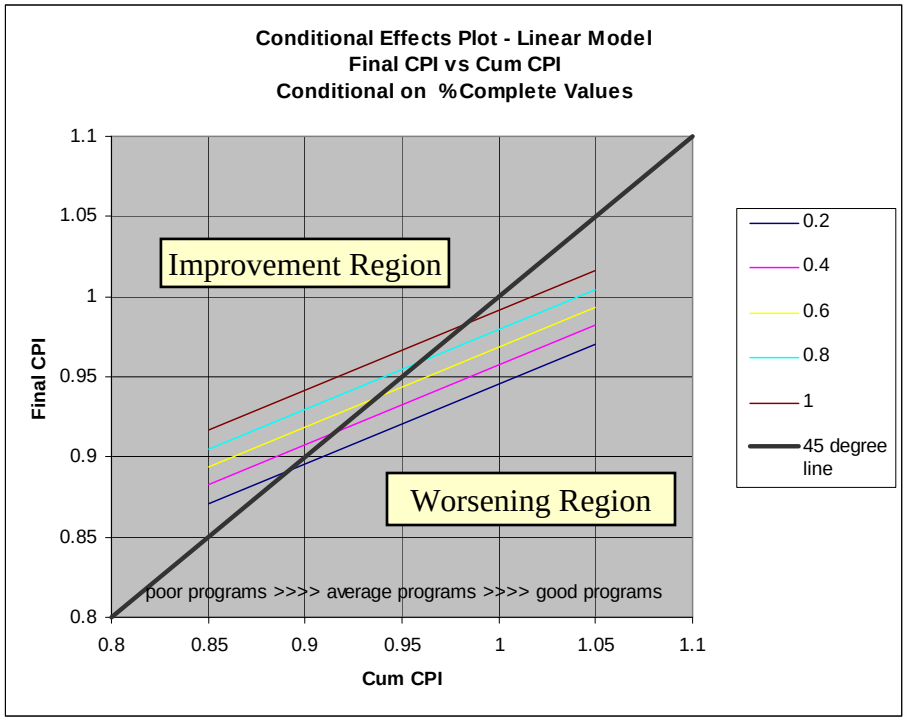
What do we know about the Final CPI? - Development

- **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**

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

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

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

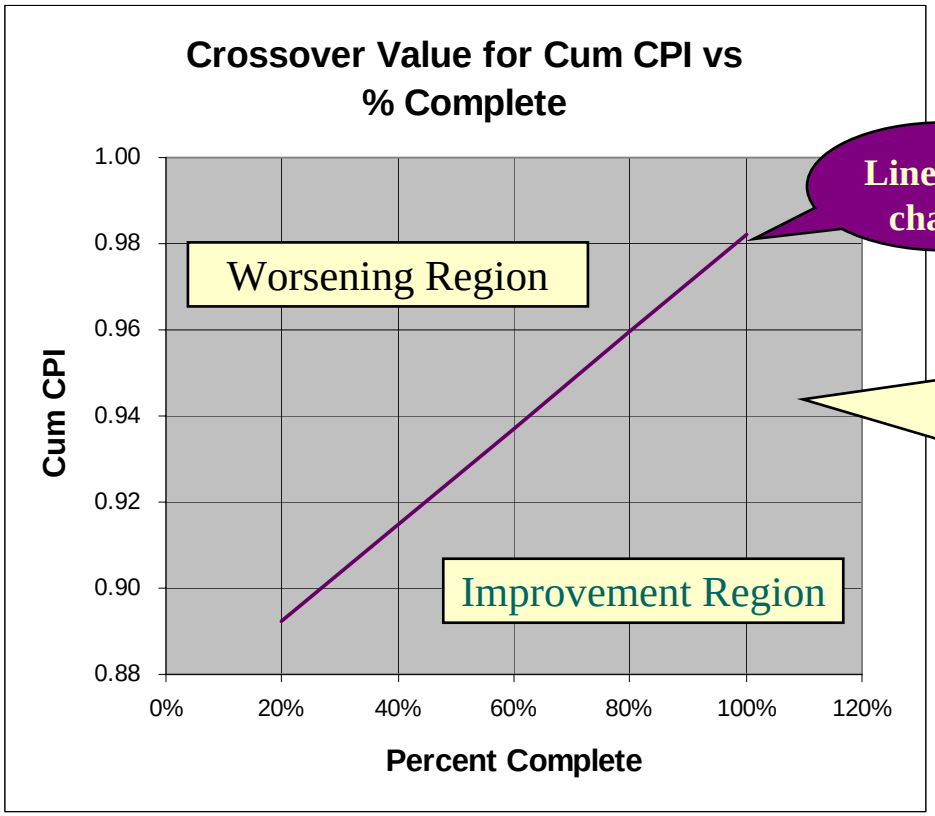
This is the "line of no change" on the next slide.

- **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

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"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**

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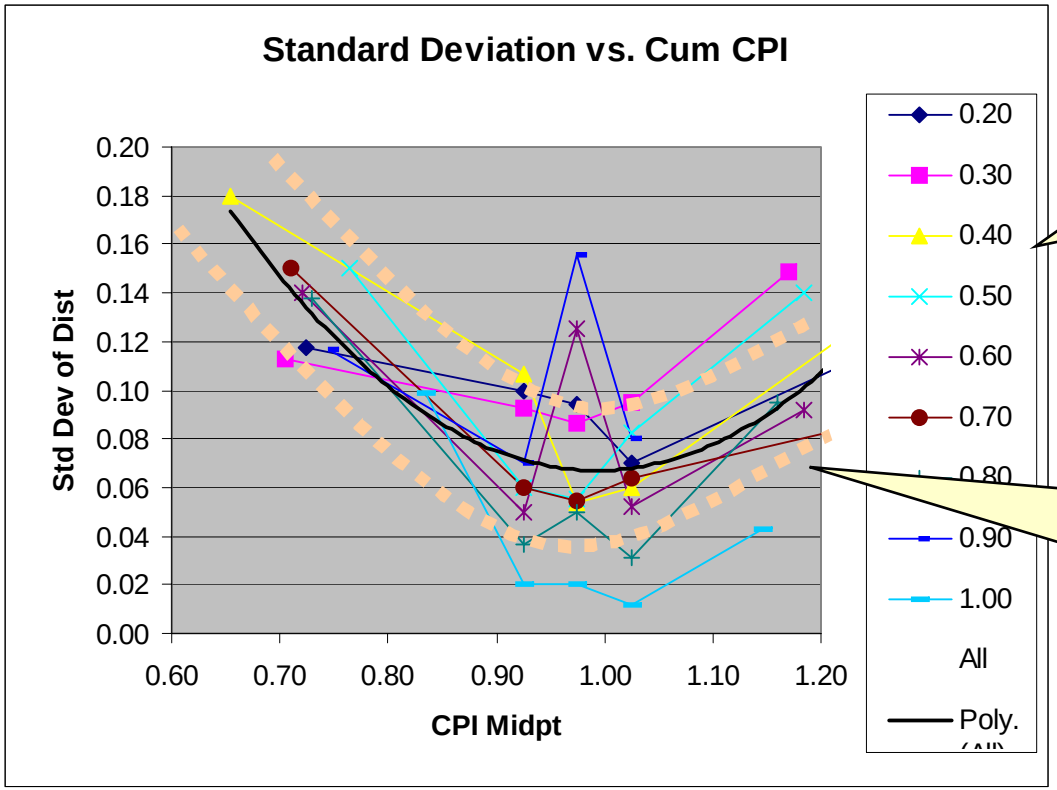
Standard Deviation of Final CPI vs. Cum CPI - Development



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

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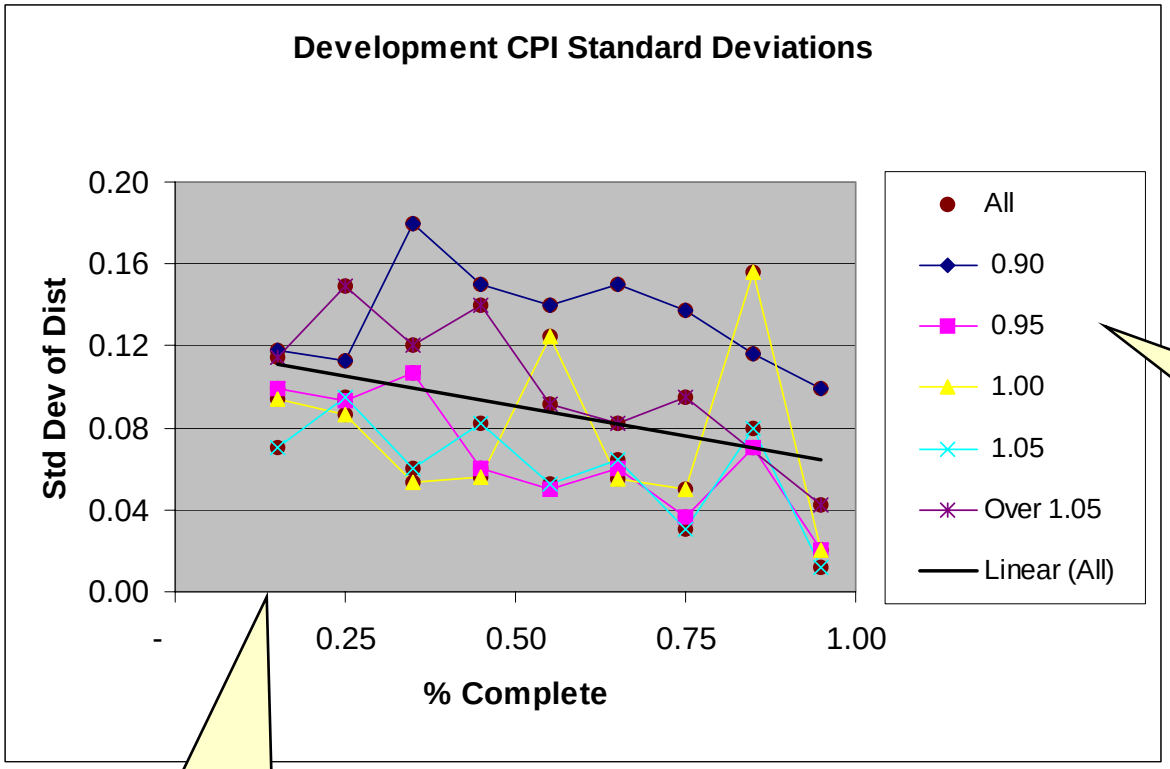
Std Dev with Cum CPI and % Complete – Development

- **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

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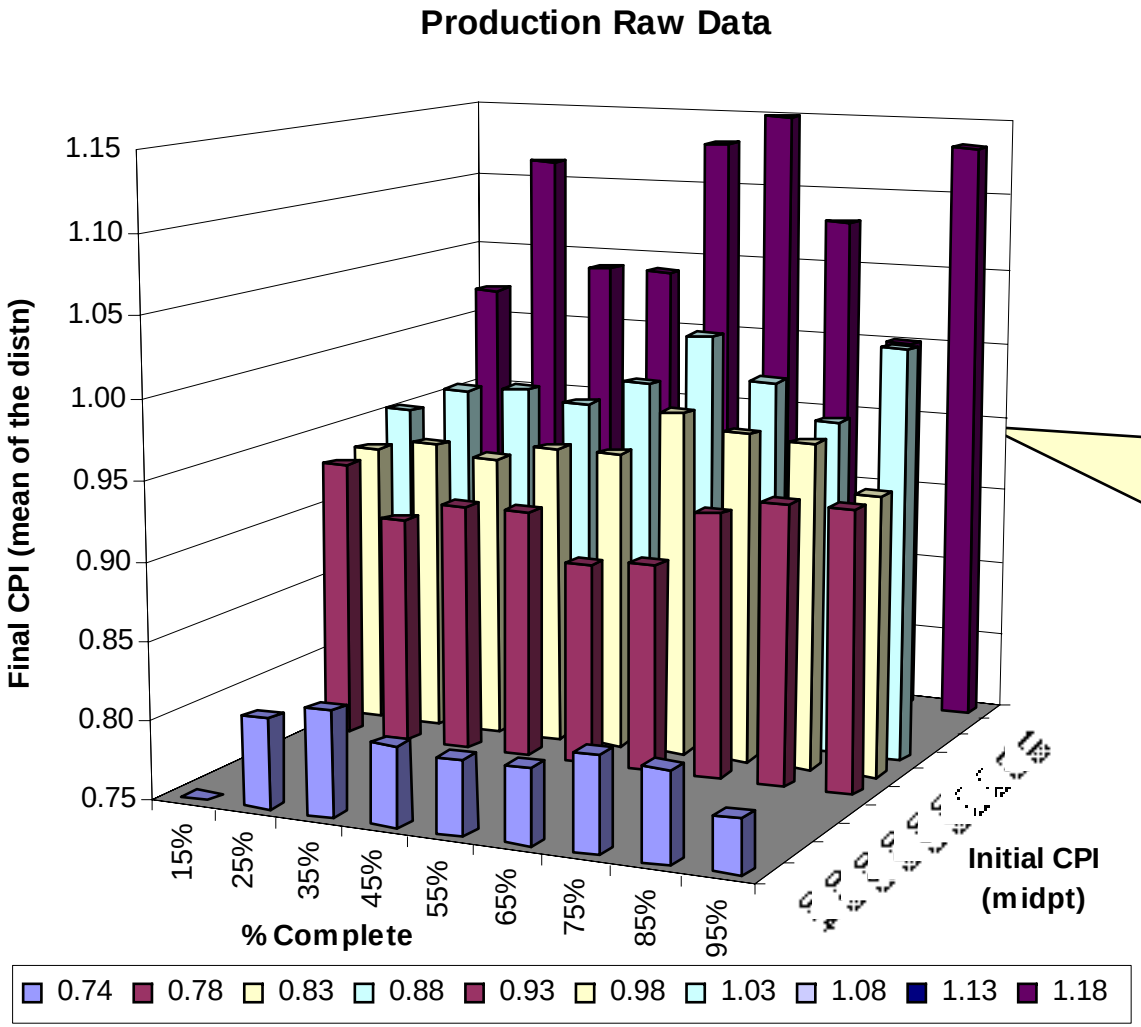
What do we know about the Std. Dev? - Development

- **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

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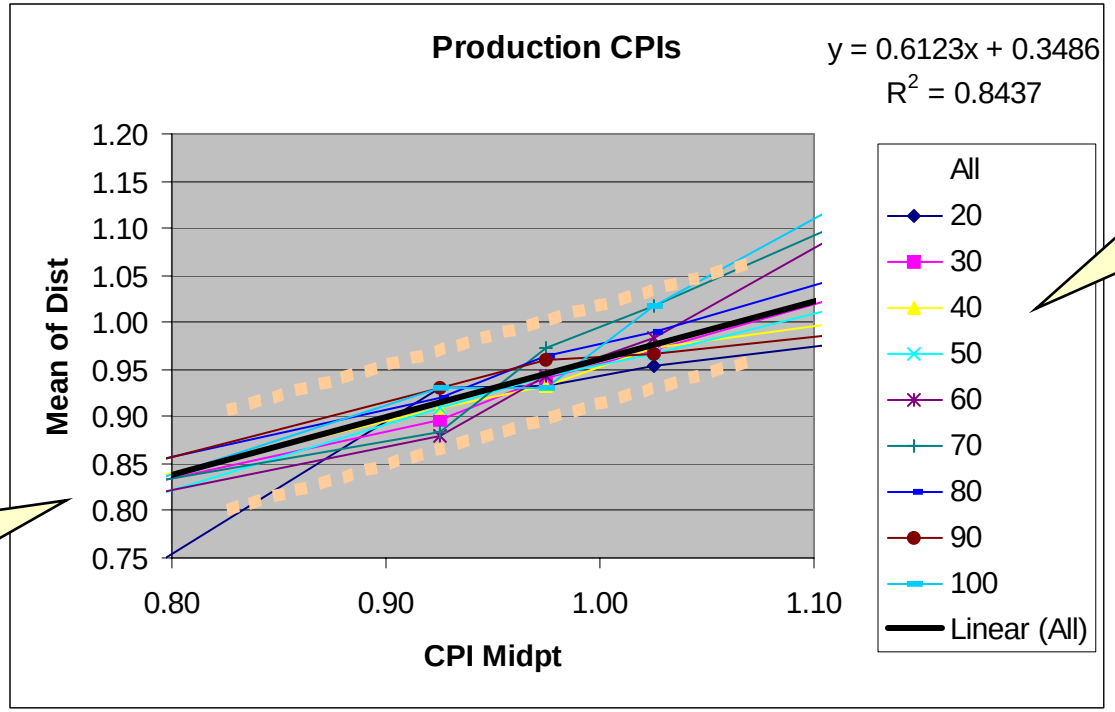
Final CPI and Cum CPI - Production



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…

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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)

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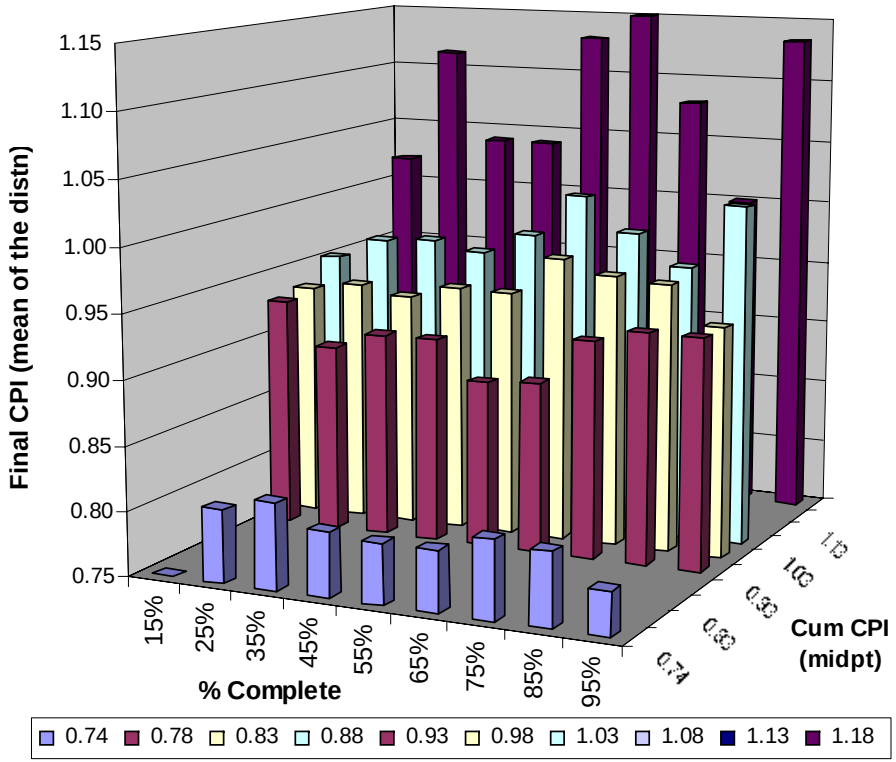
The Predictions - Production

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

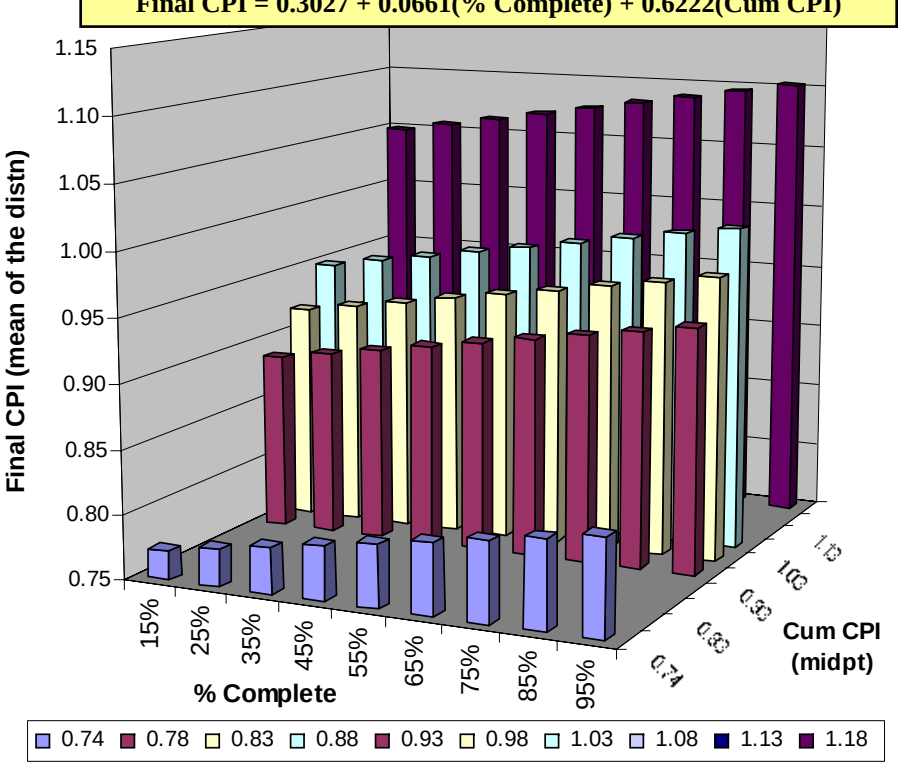
This is the model in 3-D, next we will see it in 2-D

Production Raw Data



Production Predictions - Linear

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



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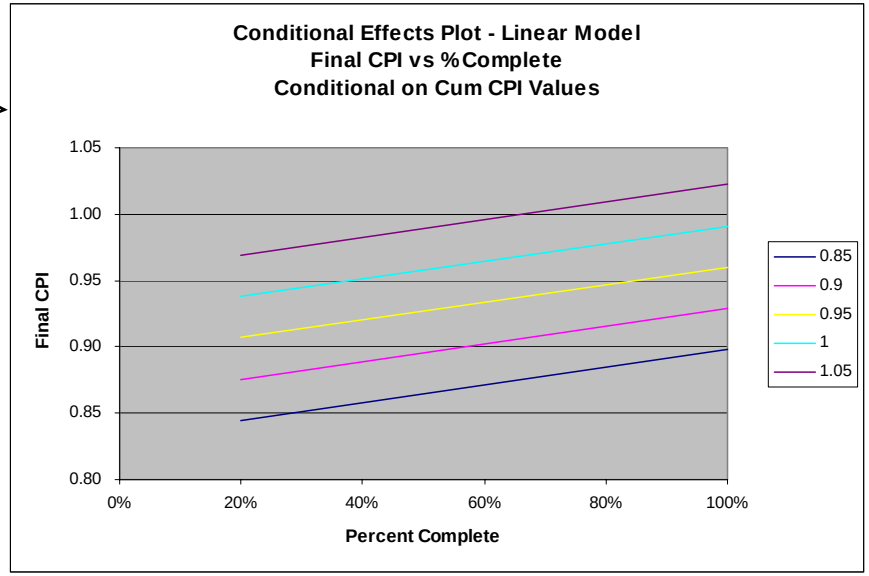
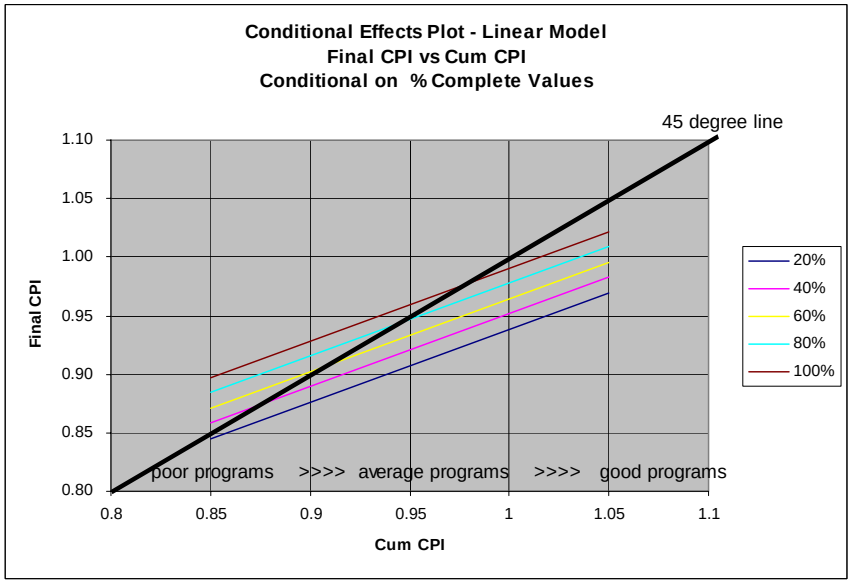
Conditional Effects Plots - Production

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

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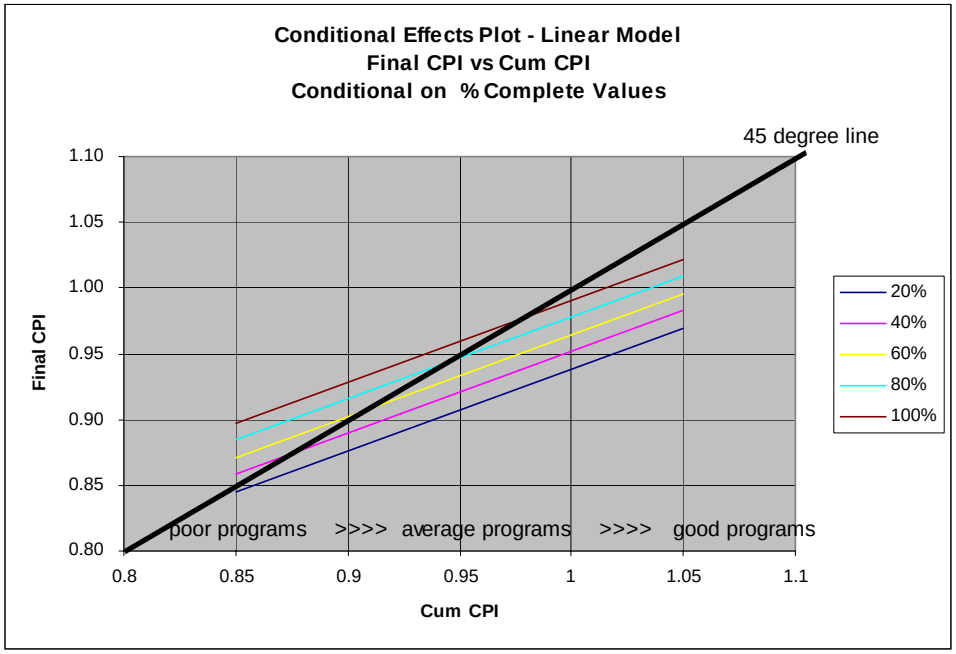
What do we know about the Final CPI? - Production

- **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**



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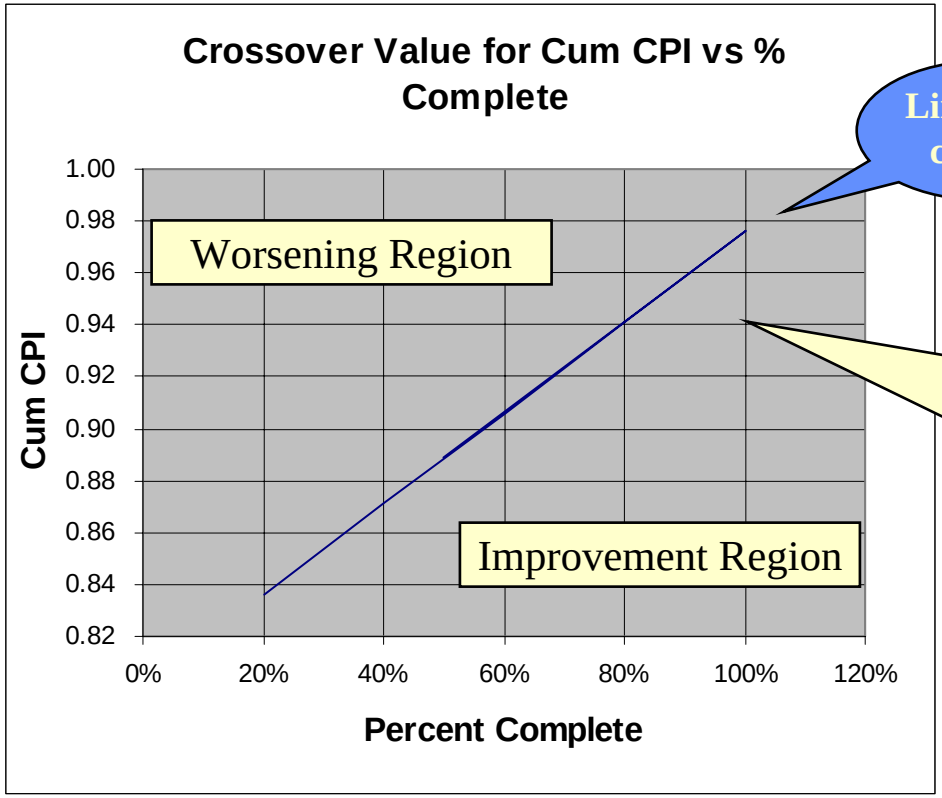
"Crossover Point" for Cum CPI - Production



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

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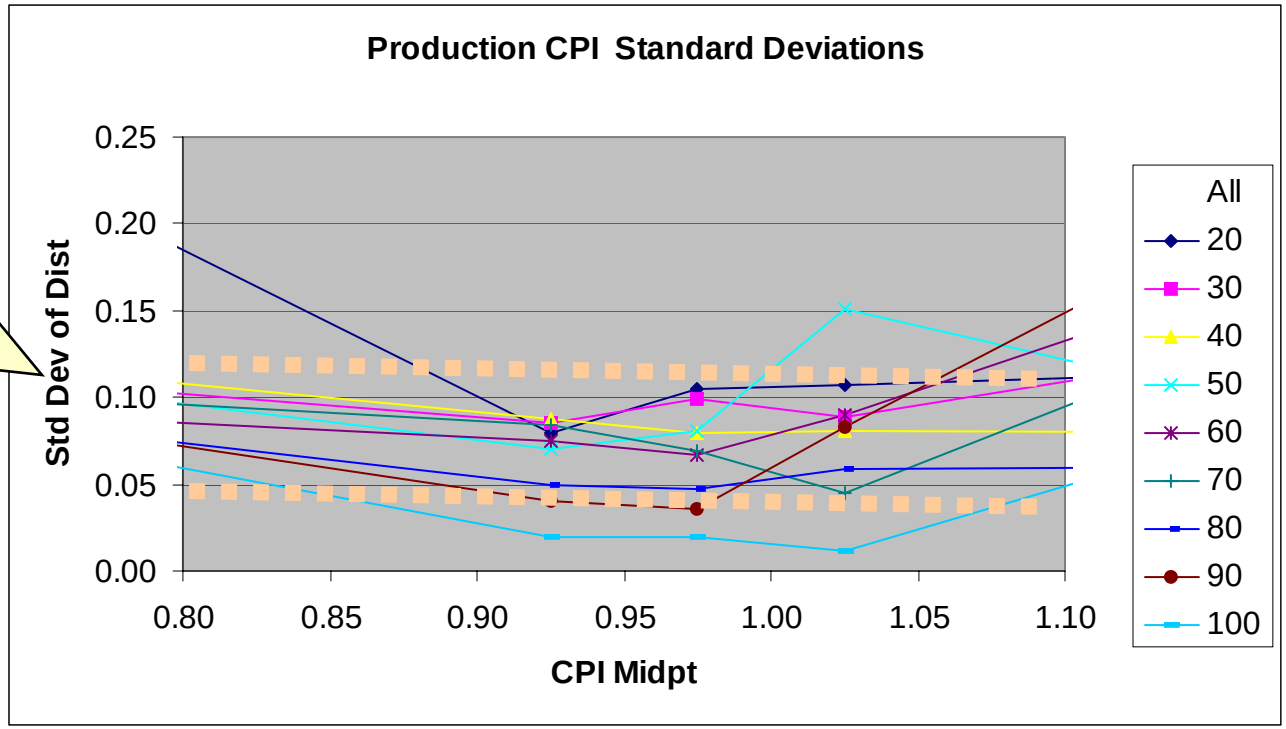
"Crossover Point" for Cum CPI – Production

- **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.

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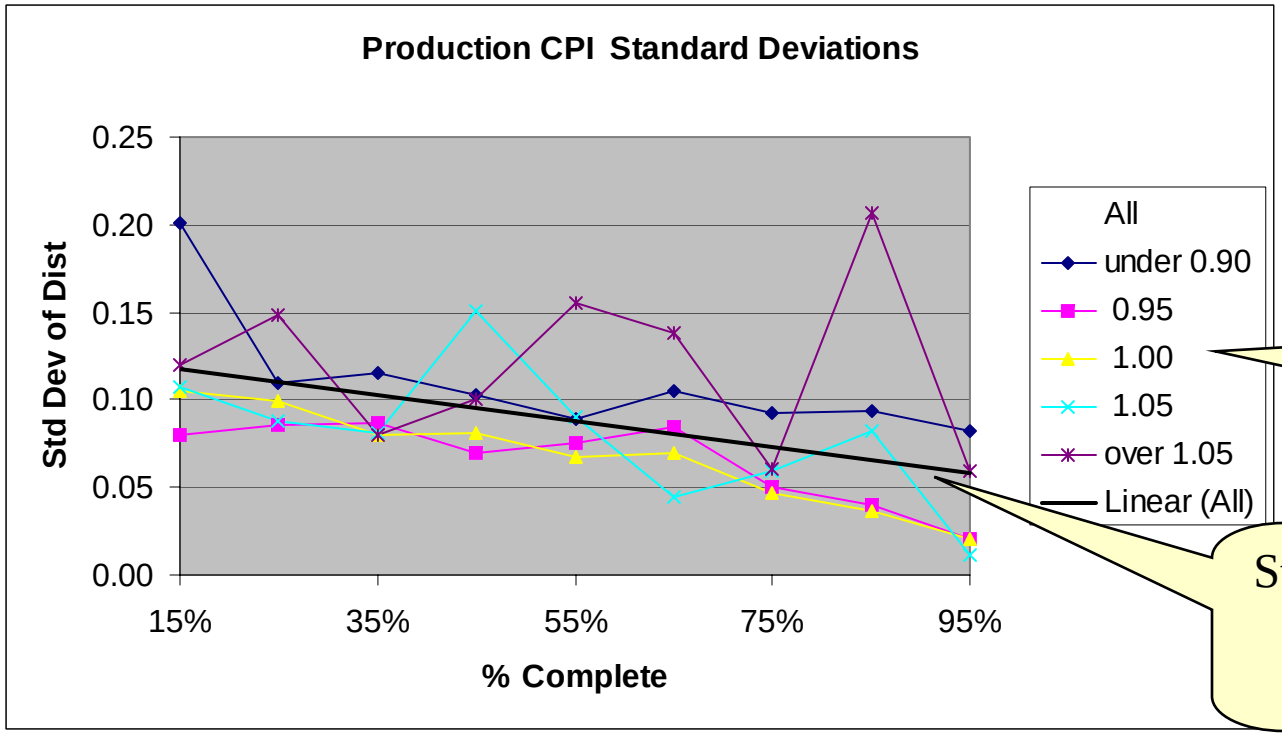
Standard Deviation of Final CPI vs. % Complete - Production



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)

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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%

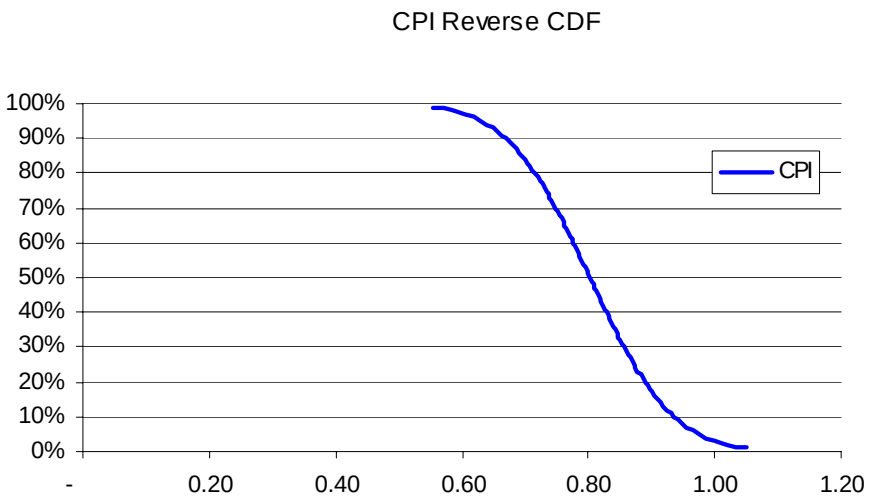
ETC

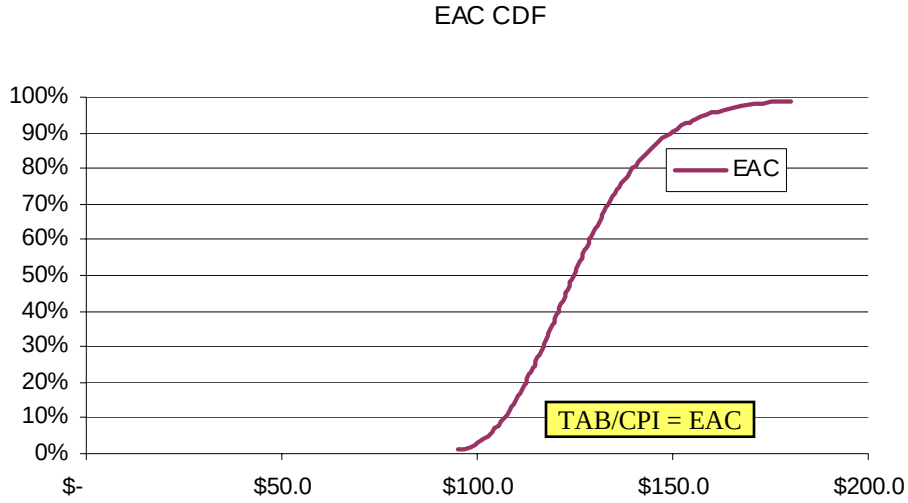
	CPI	ETC	% Probability
Upper cost bound:	0.73	91.57	84%
50th Percentile:	**0.90**	**76.59**	**50%**
Lower cost bound:	1.06	64.67	16%

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





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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!**