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Using Earned Value Data to Forecast the Duration and Cost of DoD Space Programs

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Air Force Cost Analysis Agency (AFCAA)

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Overview

1. Summary
2. Background
3. Methodology
4. Results
5. Conclusion

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Summary

- AFCAA studied the accuracy of various cost estimating models for updating the estimate at completion (EAC) for space contracts
- The Budgeted Cost of Work Performed (BCWP) based model was the most accurate
- The BCWP model assumed the underlying duration estimate was accurate
- Objective: Assess the accuracy of the duration method used in the AFCAA study and explore additional methods
- Duration Results: 2.9 to 5.2% overall improvement (mean absolute percent error - MAPE)
- Cost Results: 7.5% overall improvement (MAPE)

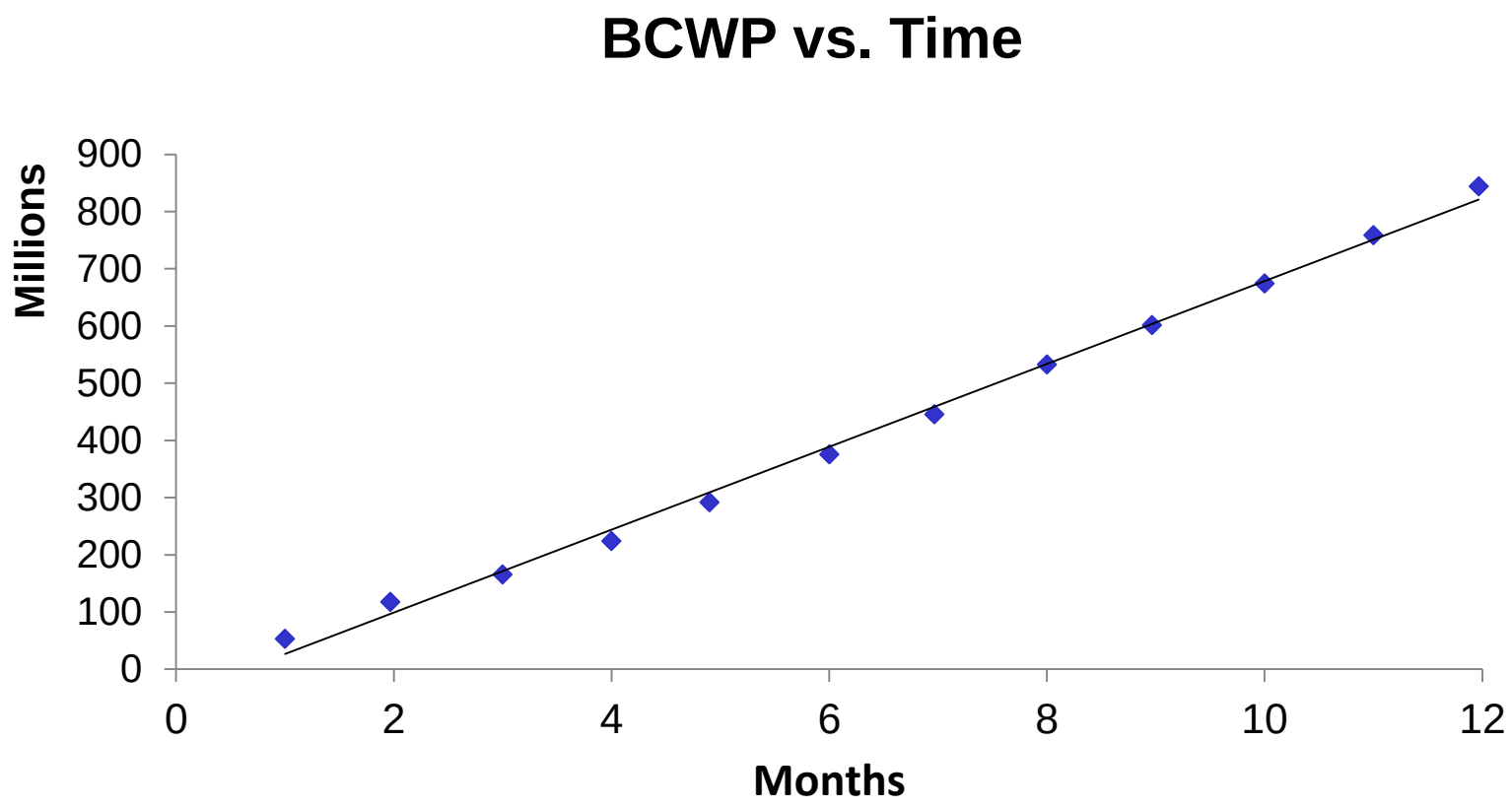
Background

- $EAC_{BCWP} = (Month_{Est\ Completion} - Month_{current}) * BCWP_{Burn\ Rate} + BCWP_{To\ Date}$

[# of months remaining * earned value/month + earned value to date]

- **Duration: the Critical Path Method (CPM) is used to determine the duration of a project (contract)**
  - Contractor Reported Estimated Completion Date (ECD)
  - “Status quo”

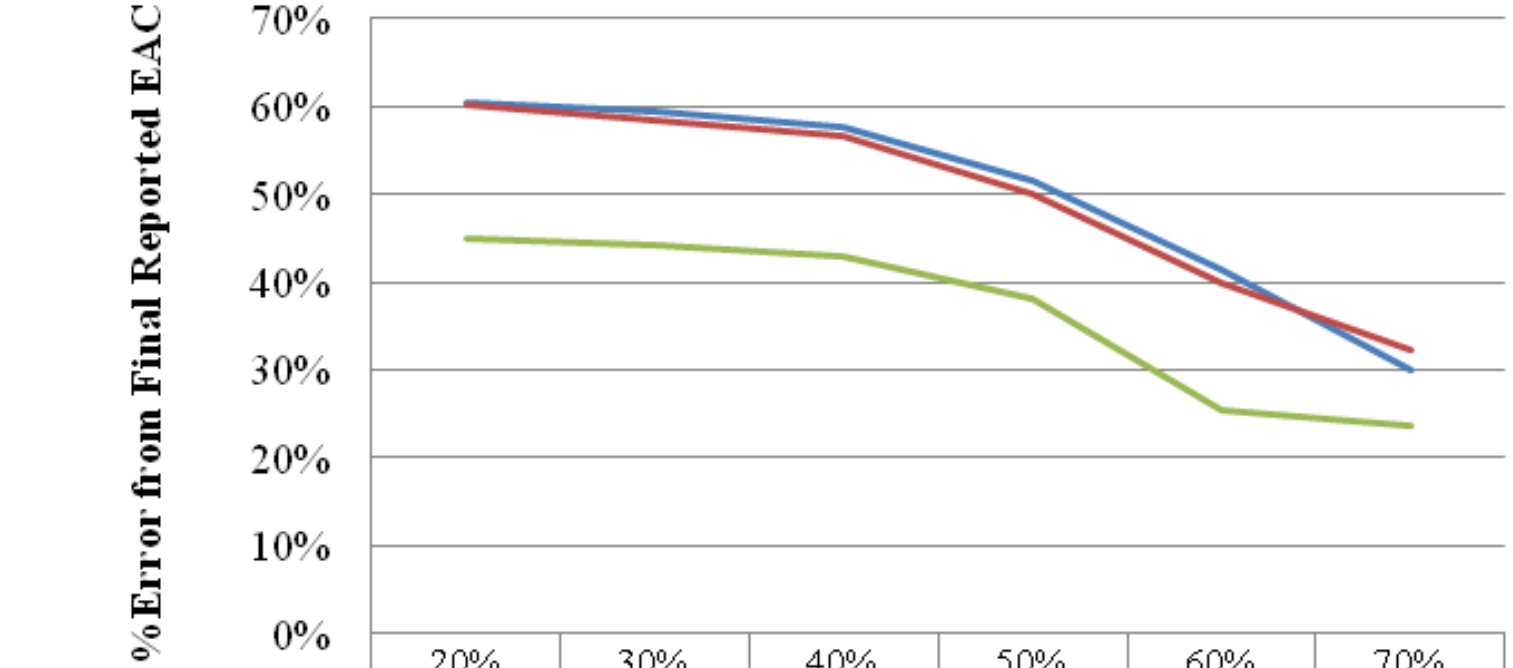
Background



$y = 72{,}401{,}283x - 45{,}653{,}892$

$R^2 = 0.996$

Background



	20%	30%	40%	50%	60%	70%
Reported	60%	59%	58%	52%	41%	30%
EAC Composite	60%	58%	57%	50%	40%	32%
BCWP Burn Rate	45%	44%	43%	38%	25%	24%

AFCAA Study (Keaton, 2014)

Why Improve Accuracy?

- **Improve the accuracy of the duration estimate in order to:**
  - Improve the accuracy of the cost estimate (earlier)
  - Detect schedule issues sooner (take corrective action)

- **Why is accuracy important?**
  - Underestimating – increased portfolio risk
  - Overestimating – opportunity cost
  - May not prevent further cost/schedule growth: earlier detection should lead to better decisions and more accurate budget inputs

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Data Source: EVM-Central Repository

Program	Data Points
Advanced Extremely High Frequency Satellite (AEHF)	148
Evolved Expendable Launch Vehicle (EELV)	12
Family of Beyond Line-of-Sight Terminals (FAB-T)	77
Military GPS User Equipment (MGUE)	31
Mobile User Objective System (MUOS) - Navy	55
Next Generation Operational Control System (GPS OCX)	21, 24, 61
NAVSTAR Global Positioning System (NAVSTAR GPS)	68, 70, 71
Space-Based Infrared System High Component (SBIRS High)	219
Wideband Global SATCOM (WGS)	43, 87

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Methodology

1. **Status Quo: reported duration (base case)**
2. **IMS: Earned Value Forecasting (EVM and Earned Schedule Index based) + Time Series Analysis**
3. **Linear Regression**
4. **Kalman filter Earned Value Method (KEVM)**
5. **IDE: Integrated Master Schedule Analysis (Independent Duration Estimate) + Time Series Analysis**

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Status Quo

- **Contractor Performance Report Planned Duration (CPR PD)**
- **Based on the critical path method**
- **The duration estimate is calculated with the:**
  - Contract Start Date
  - Estimated Completion Date (ECD)

Earned Value Forecasting

- **Time Estimate at Completion =**

  IMS Planned Duration/ Performance Factor

  (Henderson, 2004)
- **Planned Duration: CPM based from IMS**
- **PF: Index (from EV data)**
- **IMS models**

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Performance Factors

Name	Reported	Time Series
Baseline Execution Index	BEI	BEI (T.S.)
Schedule Performance Index	SPI	SPI (T.S.)
Cost Performance Index	CPI	CPI (T.S.)
Earned Schedule SPI	SPI(t)	SPI(t) (T.S.)
Schedule Cost Index	SPI*CPI	SPI (T.S.)*CPI (T.S.)
Schedule Cost Index (ES)	SPI(t)*CPI	SPI(t) (T.S.) *CPI (T.S.)
Enhanced Schedule Cost Index	BEI*CPI*SPI	BEI*CPI (T.S.)*SPI (T.S.)
Enhanced Schedule Cost Index (ES)	BEI*CPI*SPI(t)	BEI (T.S.)*CPI (T.S.)*SPI(t) (T.S.)
Enhanced CPI	BEI*CPI	BEI (T.S.)*CPI (T.S.)
Enhanced SPI	BEI*SPI	BEI (T.S.)*SPI (T.S.)
Enhanced SPI(t)	BEI*SPI(t)	BEI (T.S.)*SPI(t) (T.S.)

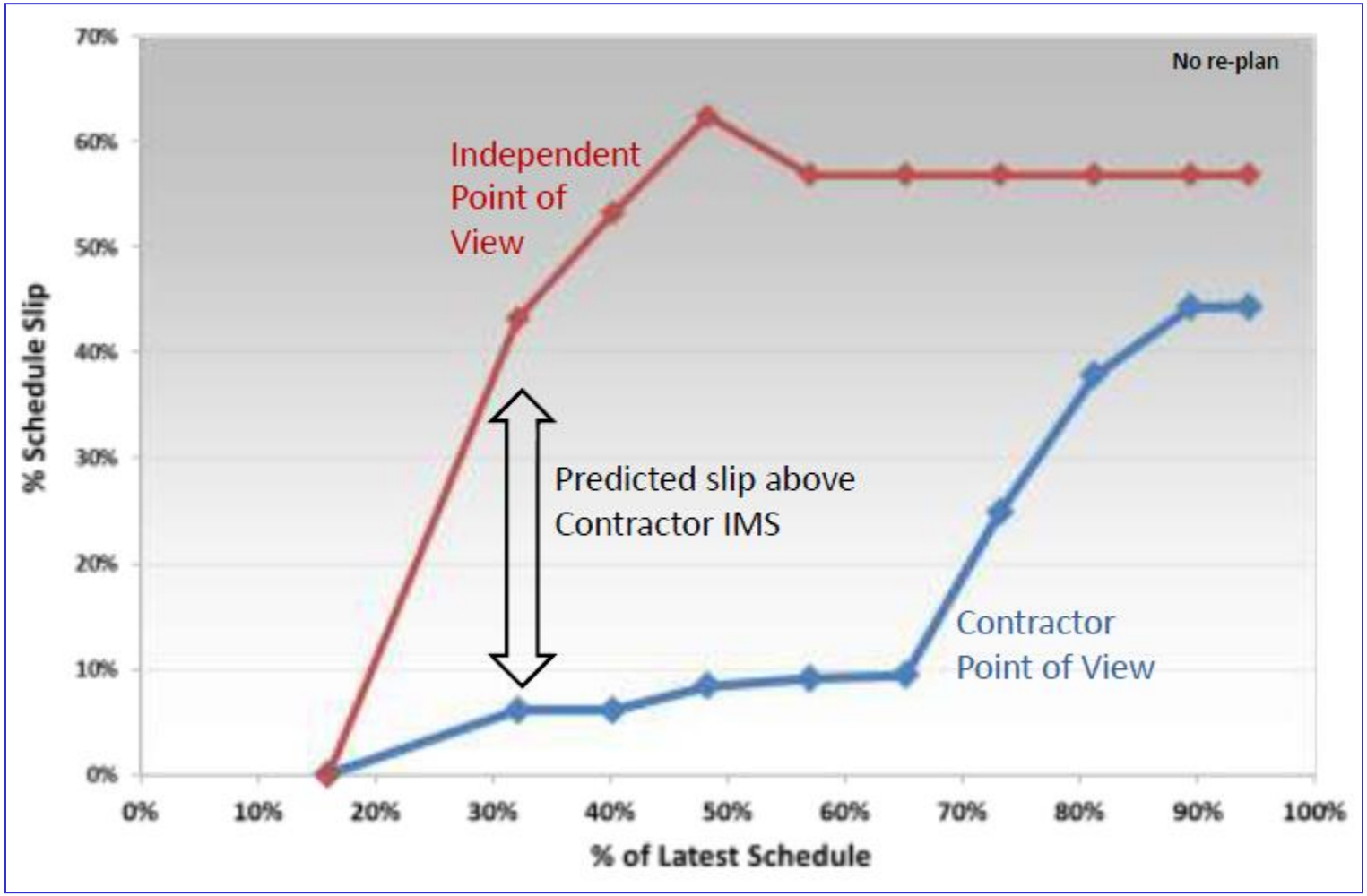
BEI = cumulative # of baseline tasks completed / cumulative # of baseline tasks scheduled for completion

[used NASA's Schedule Test and Assessment Tool (STAT)]

Status Quo vs. Most Accurate IMS Model

Program	CPR PD (status quo)	[IMS PD / SPI(t) (T.S.) *BEI]	Delta
WGS-2	29.33%	30.90%	-1.57%
AEHF	25.66%	25.11%	0.55%
GPS OCX -1	20.41%	18.87%	1.54%
WGS-1	24.77%	22.86%	1.91%
NAVSTAR GPS-1	33.05%	30.52%	2.53%
SBIRS	24.63%	22.03%	2.60%
GPS OCX-2	25.71%	22.65%	3.06%
NAVSTAR GPS-2	32.89%	29.21%	3.69%
MUOS	19.23%	14.22%	5.01%
NAVSTAR GPS-3	23.76%	14.92%	8.84%

IMS Analysis – Independent Duration Estimate (IDE)



Lofgren (2014)

Independent Duration Estimate (IDE)

Schedule slip

- **Slip = Max (Current Finish – Baseline Finish – Total Slack)**
- **IDE = Schedule slip + baseline duration estimate**
- **Time Forecast = IDE/PF**

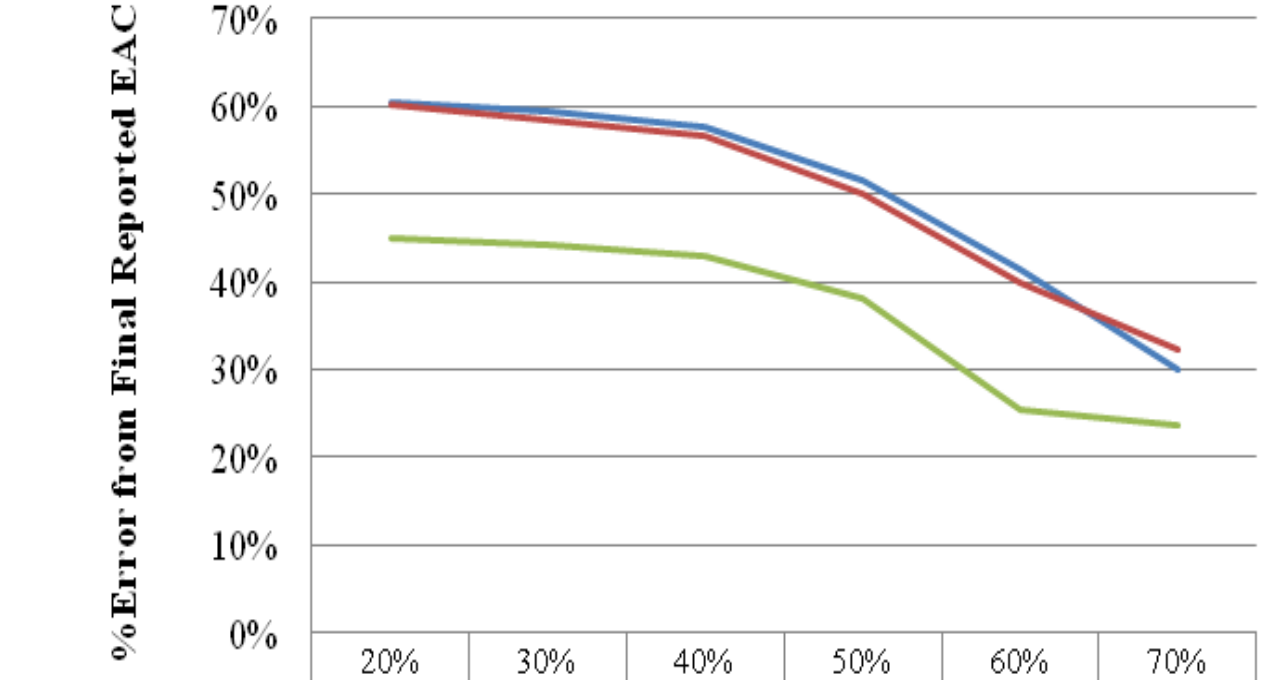
IDE Example

Task Name	Baseline Finish (IMS #1) (4/15/08)	Current Finish (IMS #2) (5/20/08)	Finish Variance (days)	Total Slack	Slip (days)	Slip (months)
Task 1	01/30/08	05/02/08	92	9	83	2.8
Task 2	06/02/08	06/02/08	0	-47	47	1.6
Task 3	05/16/08	07/02/08	46	-80	126	4.2
			MAX		126	4.2

Sensitivity Analysis: IDE

Program	CPR PD (status quo)	IDE/ SPI(t)	Delta
SBIRS	24.63%	24.49%	0.14%
WGS-1	24.77%	20.05%	4.72%
NAVSTAR GPS -2	32.89%	26.71%	6.18%
NAVSTAR GPS -1	33.05%	25.98%	7.07%
WGS-2	29.33%	21.65%	7.68%
NAVSTAR GPS-3	23.76%	13.25%	10.51%
MUOS	19.23%	8.29%	10.94%

Revisit Original Study



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AFCAA Study (Keaton, 2014)

Cost Estimate Accuracy

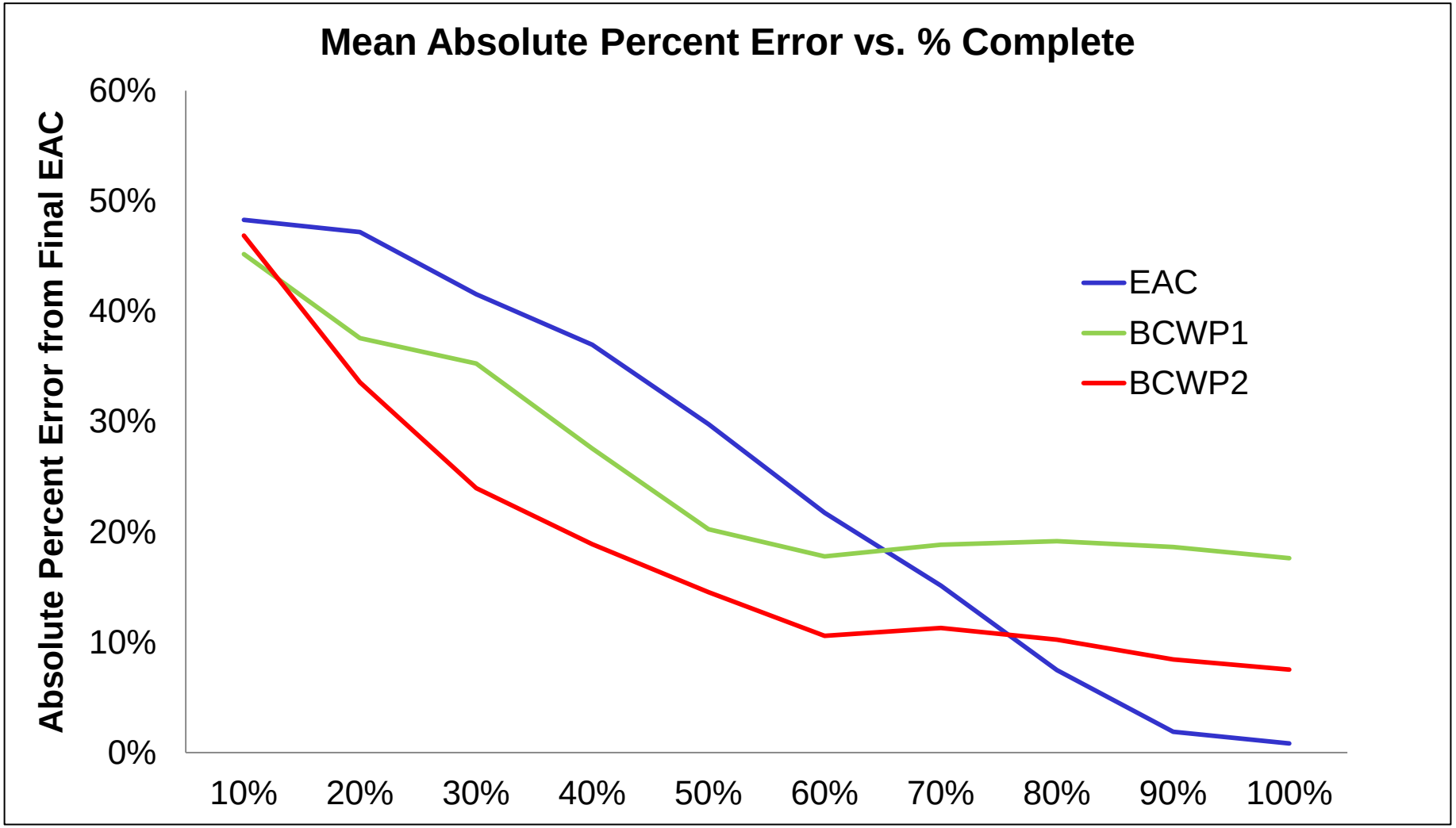
- **Applying duration estimates to BCWP model**
  - EAC Reported
  - BCWP 1: [CPR PD and actual time] (Keaton, 2014)
  - BCWP 2: [IMS PD / (SPI(t)*CPI) and actual time]
  - Simplicity, lack of data for other methods (IDE, BEI)
- **Added out of sample contracts:**
  - EELV (Evolved Expendable Launch Vehicle) (Production)
  - MGUE (Military GPS User Equipment) (RDT&E, Production)
  - FAB-T (Family of Beyond Line-of-Sight Terminals) (RDT&E)
  - MUOS (Mobile User Objective System) (RDT&E)
  - GPS OCX (Next Generation Control Segment) (Phase B) (RDT&E)

Cost Estimate Accuracy

Metric	EAC	BCWP1	BCWP2	EAC Delta	BCWP1 Delta
MAPE	25.3%	25.8%	**17.8%**	7.5%	8.0%
Median APE	28.0%	22.3%	**14.3%**	13.7%	8.1%
MAPE (0 to 70%)	33.3%	27.2%	**20.9%**	12.4%	6.1%
MAPE (20 to 70%)	28.6%	22.3%	**16.3%**	12.8%	7.4%

MAPE – mean absolute percent error
APE - absolute percent error

Accuracy - All Contracts



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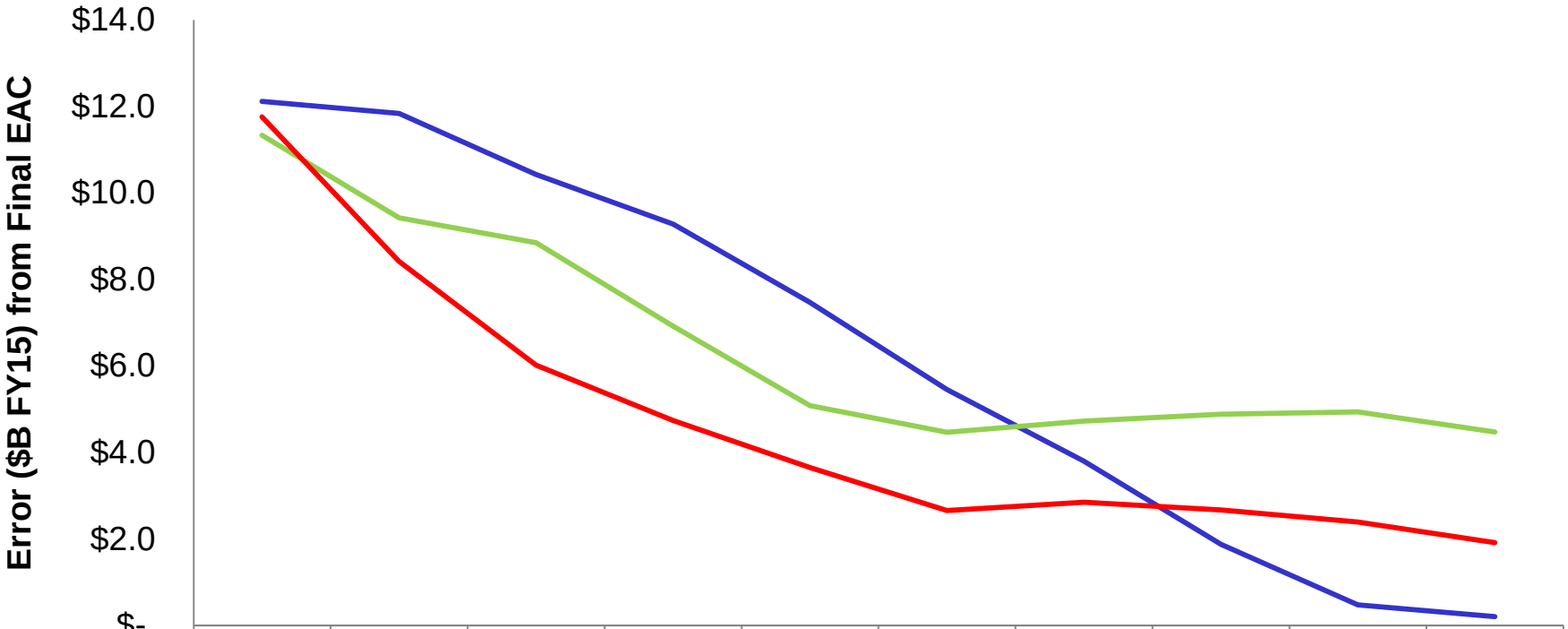
Dollars & Sense

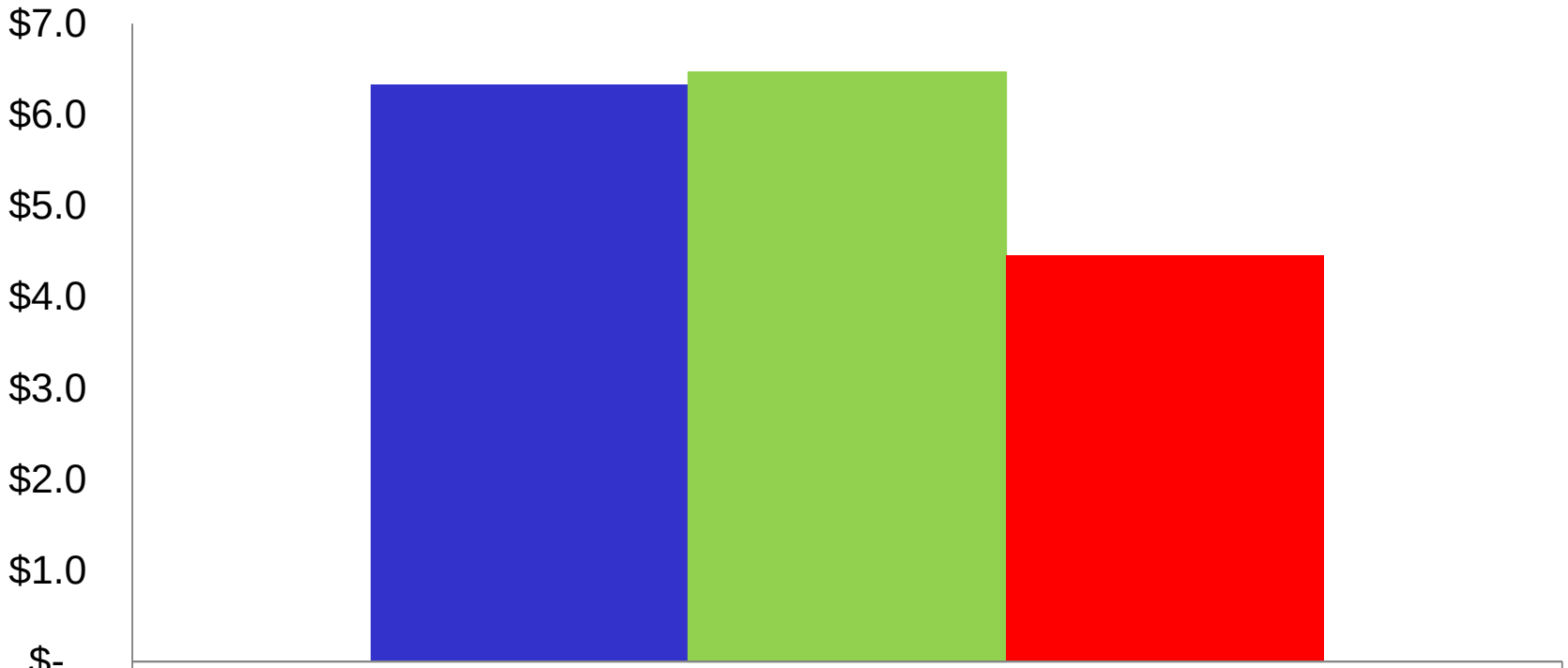
- **Get your Billions Back America!**
- **Not really… This next analysis is NOT Savings or Potential Realizable Savings**
- **% error converted to dollars based on the portfolio cost ($25.1B in FY15$)**
- **Comparison purposes over time**
- **Not cumulative**
- **[MAPEs*$25.1B = Estimating Error ($B)]**
- **[10% intervals]**

Cost Estimate Error ($)



	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
EAC	$12.1	$11.8	$10.4	$9.3	$7.5	$5.5	$3.8	$1.9	$0.5	$0.2
BCWP1	$11.3	$9.4	$8.8	$6.9	$5.1	$4.5	$4.7	$4.9	$4.9	$4.5
BCWP2	$11.8	$8.4	$6.0	$4.7	$3.6	$2.7	$2.9	$2.7	$2.4	$1.9

Average Estimate Error



	Average Error (in $B FY15)
EAC	$6.3
BCWP1	$6.5
BCWP2	$4.5

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Conclusions

- **Improved the accuracy of estimates:**
  - **Improved the accuracy of the cost estimate (EAC) [earlier]**
  - **More accurate inputs into the budget**
  - **Detect schedule issues sooner (take corrective action)**

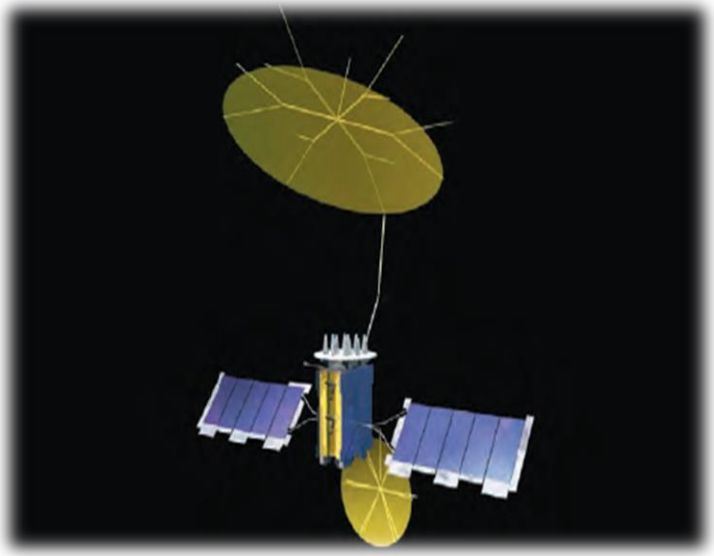
- **Why is accuracy important?**
  - **Underestimating – increased portfolio risk, a “tax” on other programs**
  - **Overestimating – opportunity cost**
  - **May not prevent further cost/schedule growth: earlier detection could lead to better decisions and resource allocation**

Limitations

- Small sample size (7, 10, & 15)
- Some contracts did not have data for calculating IDEs or BEIs
- More research is needed

Questions?

- ??



Beep...Beep...Beep...

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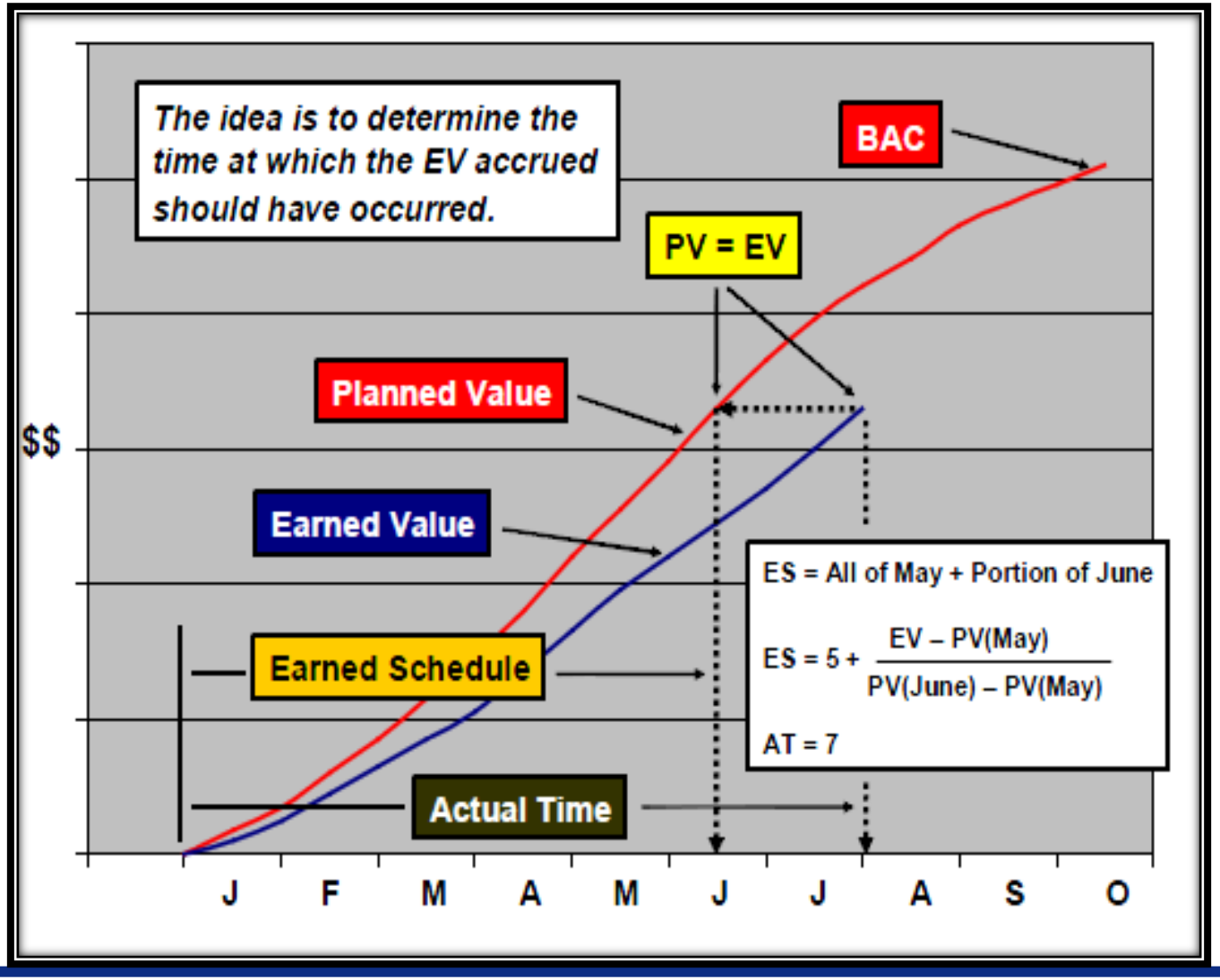
Backup Slides

Earned Schedule



Lipke, 2011

Linear Regression (Smoker)

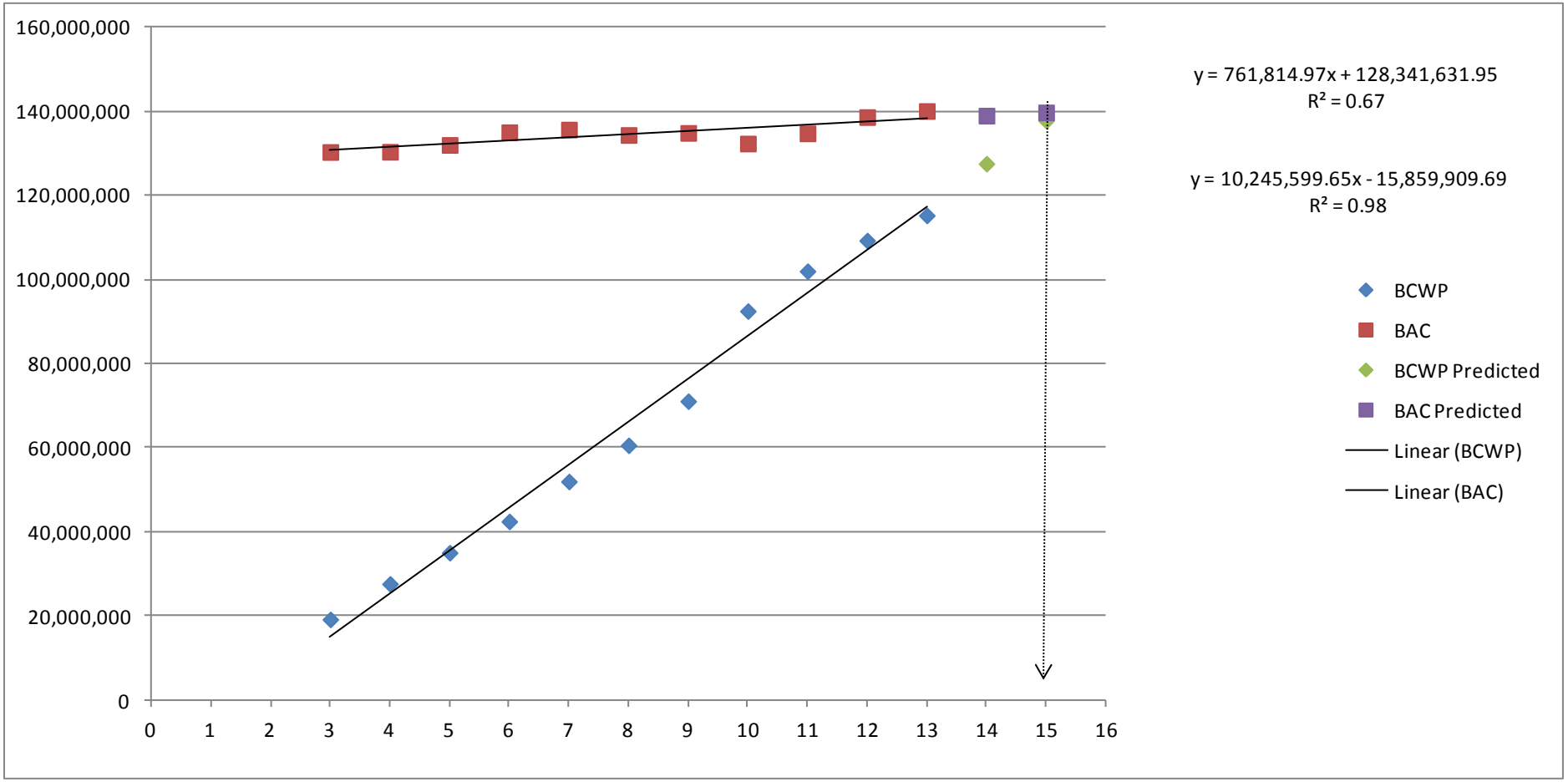
- **Regress BAC (Y) by Months (X)**
- **BCWP (Y) by Months (X)**
- **Set equations equal to each other**

(1) BCWP coefficient*Months + BCWP intercept =
BAC intercept + BAC coefficient*Months

(2) Months = $\frac{\text{BAC intercept – BCWP intercept}}{\text{(BCWP coefficient – BAC coefficient)}}$

BAC – Budget at Completion
BCWP – Budgeted Cost of Work Performed

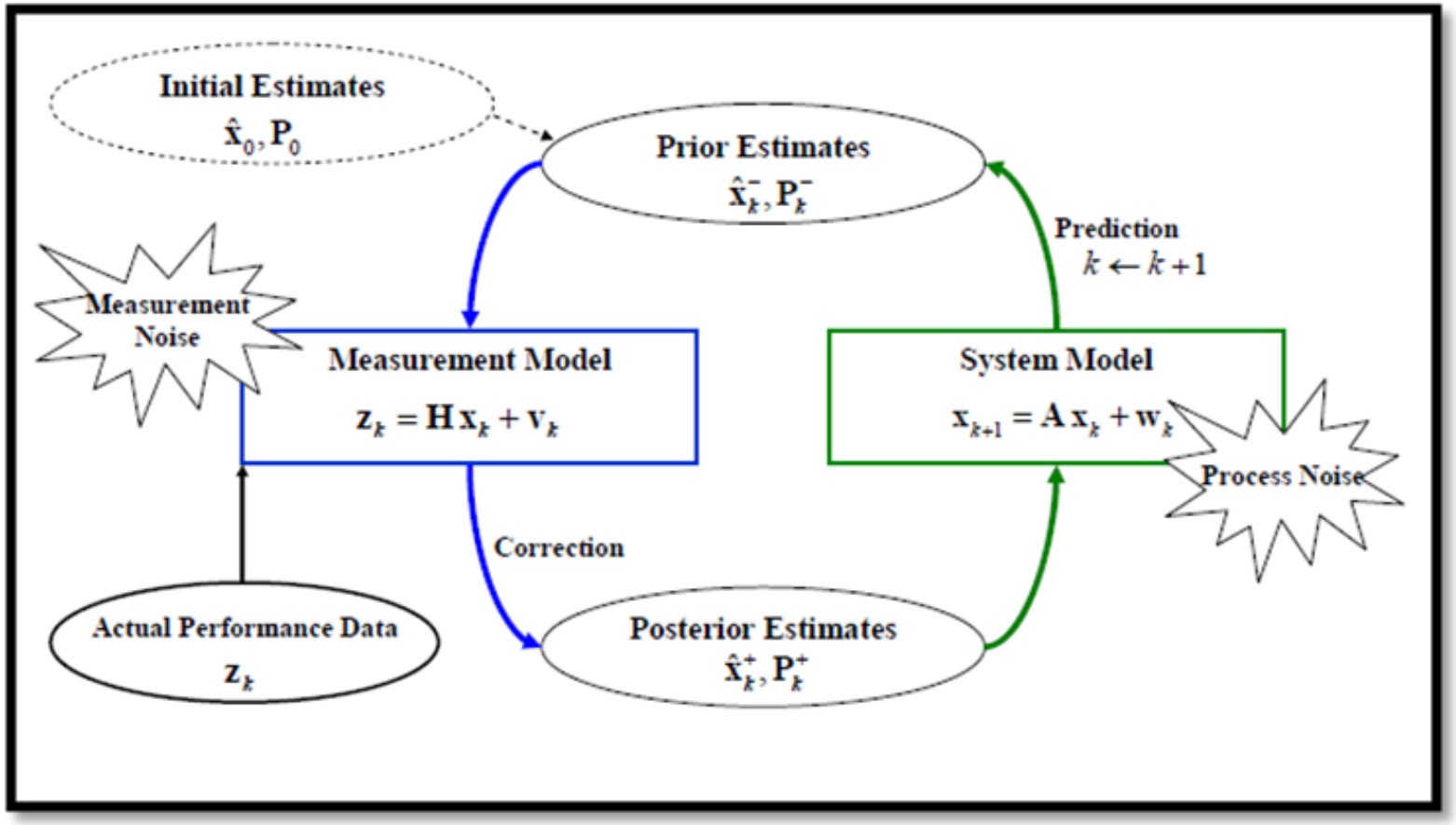
Linear Regression



761,814.97x + 128,341,631.95 = 10,245,599.65x - 15,859,909.69

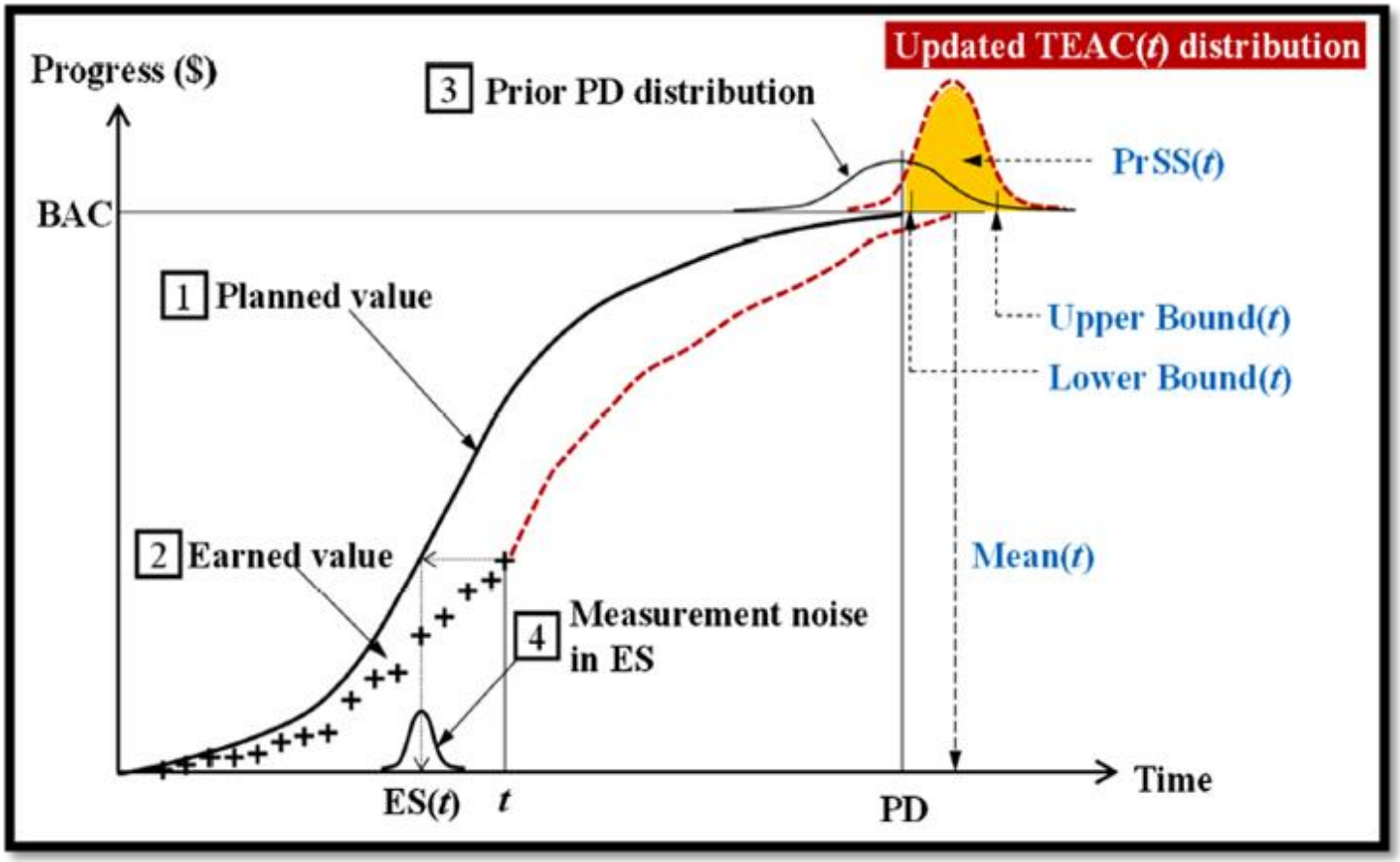
Months = 15.2

Kalman filter Earned Value Method (KEVM)



Recursive learning cycle of the Kalman filter (Kim, 2013)
x = state variables, P = error covariance variables

Kalman filter Earned Value Method (KEVM)



(Kim and Reinschmidt, 2011)

Kalman filter Earned Value Method (KEVM)

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Project Duration Forecasting using the KEVM

Input Cells

Output Cells

Project Name:

The probability between the upper and lower bounds: 90%

Progress Curves			KEVM			
			TEAC (Time Estimate at Completion)			
Time	PV	EV	Mean	LB	UB	PrSS
0	0	0	12.00	11.01	12.99	50.0%
1	29	14	12.04	10.78	13.29	52.0%
2	86	60	12.14	10.89	13.39	57.2%
3	171	130	12.33	11.11	13.55	67.2%
4	286	230	12.59	11.42	13.75	79.6%
5	429					
6	600					
7	771					
8	914					
9	1,029					
10	1,114					
11	1,171					
12	1,200					
13						
14						
15						

KEVM Outputs

The array formula in the cells "E9:H24"
'= {=KEVMLite($C$9:$C$24,$D$9:$D24,$F$4)}

Copyright 2013 BC Kim. Last updated on August 1,2013.

Contract	Final Duration MAPE		Final EAC MAPE		
	CPR PD	SPI(t)* CPI	EAC	BCWP	BCWP
GPS MUE-3	22.70%	**21.00%**	31.60%	22.70%	**8.70%**
AEHF*	25.70%	**23.20%**	23.70%	16.30%	**11.70%**
FAB-T	8.30%	**3.60%**	25.90%	21.30%	**12.20%**
GPS OCX-1	20.40%	**19.90%**	13.90%	13.10%	**12.40%**
EELV	**5.70%**	9.00%	23.70%	16.10%	**14.40%**
GPS OCX-2	22.70%	**22.00%**	15.80%	17.90%	**15.00%**
WGS-1	24.80%	**20.80%**	17.60%	52.20%	**17.00%**
WGS-2	**29.30%**	36.20%	**2.70%**	32.00%	17.20%
MGUE*	42.10%	**27.90%**	28.00%	30.80%	**18.10%**
MUOS-2	**8.60%**	9.60%	22.50%	19.60%	**18.50%**
GPS MUE-1	33.00%	**25.00%**	35.60%	26.90%	**19.90%**
GPS OCX B*	23.10%	**16.30%**	37.30%	27.60%	**20.20%**
GPS MUE-2	32.80%	**28.50%**	37.90%	24.80%	**22.00%**
MUOS-1	**20.30%**	34.40%	**24.20%**	35.10%	28.80%
SBIRS*	24.70%	**24.20%**	38.80%	**30.20%**	30.40%

*Not 100% complete

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Literature Review

- **1991 Cancellation of A-12 Avenger ignited EVM research**
- **David Christensen – EAC (1993 & more)**
- **Walt Lipke – Earned Schedule and SPI(t) (2003 & more)**
- **Kym Henderson – EAC and Time EAC with SPI(t) (2004) (shorter contracts and non DoD)**
- **Forecasting: Methods and Applications (Makridakis, Wheelwright, & Hyndman) (1998)**
- **Roy Smoker - Regression (2011)**
- **B.C. Kim - Kalman Filter Forecasting Method (2007)**
- **Eric Lofgren – Improving the schedule estimate with the IMS (2014)**