The Space Congress® Proceedings

2016 (44th) The Journey: Further Exploration for Universal Opportunities

May 25th, 7:30 AM

Advancing the Theory and Practice of Engineering Project Management by addressing the issue of CPI Stability and Hidden Project Performance

Michael Staley

PE, PMP Dean of the School of Engineering, Design, & Construction, Seminole State College Doctoral Research, Center for PM Research

NASA 44th Space Congress

Advancing the Theory and Practice of Engineering Project Management

by addressing the issue of

CPI Stability and Hidden Project Performance.

Michael Staley, PE, PMP

24 May 2016

Overview

- **Literature Review**
  - Why EVM?
  - What is EVM?
  - Define the CPI Stability Issue
- **Research**
  - Propose a Solution
  - Illustrate with Case Study
- **Practice**
  - Application to Case Study
  - Identify Hidden Performance

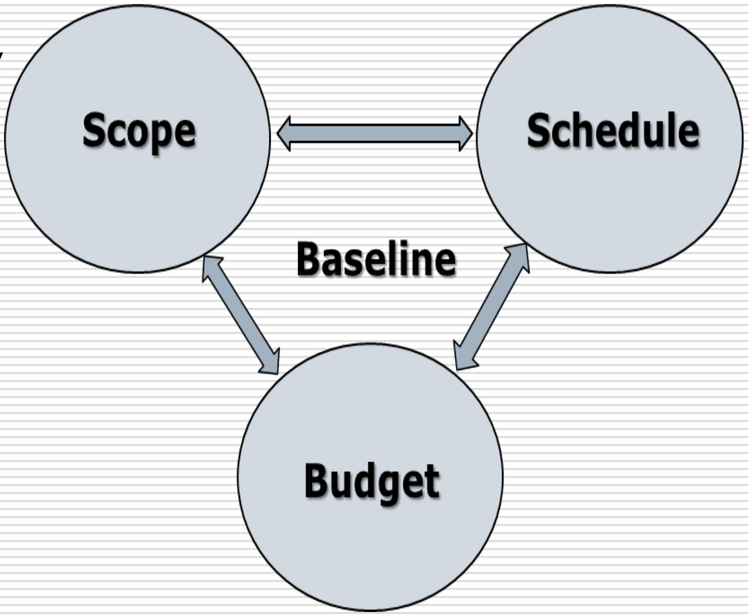
Literature Review:
Why EVM?

- **$12T** in projects globally
- **62% of all projects studied** use EVM
- U.S. **government requires** EVM on major projects…OMB, DoD, NASA, FAA, etc.
  - **69%** of projects using EVM are **voluntary** adopters
- **Usage** not just in U.S., but **globally**, e.g., UK, Australia, New Zealand, Japan, Hong Kong, Sweden, UAE, Saudi Arabia, India, Pakistan…

Song, Lingguang (April 2010) Earned Value Management: A Global and Cross-industry Perspective on Current EVM Practice", ISBN: 1935589067.

Literature Review:
What is EVM?

As defined by *PMBOK® Guide*, Earned Value Management is a "management methodology for integrating scope, schedule, and resources, and for objectively measuring project performance and progress…"



EVM requires an integrated baseline!

Project Management Institute. A Guide to the Project Management Body of Knowledge. 5th edition, 4th edition, 3rd edition, 2000 edition . Newton Square, Pennsylvania. USA

PMBOK is a registered mark of Project Management Institute, Inc.

Literature Review:
What is EVM?

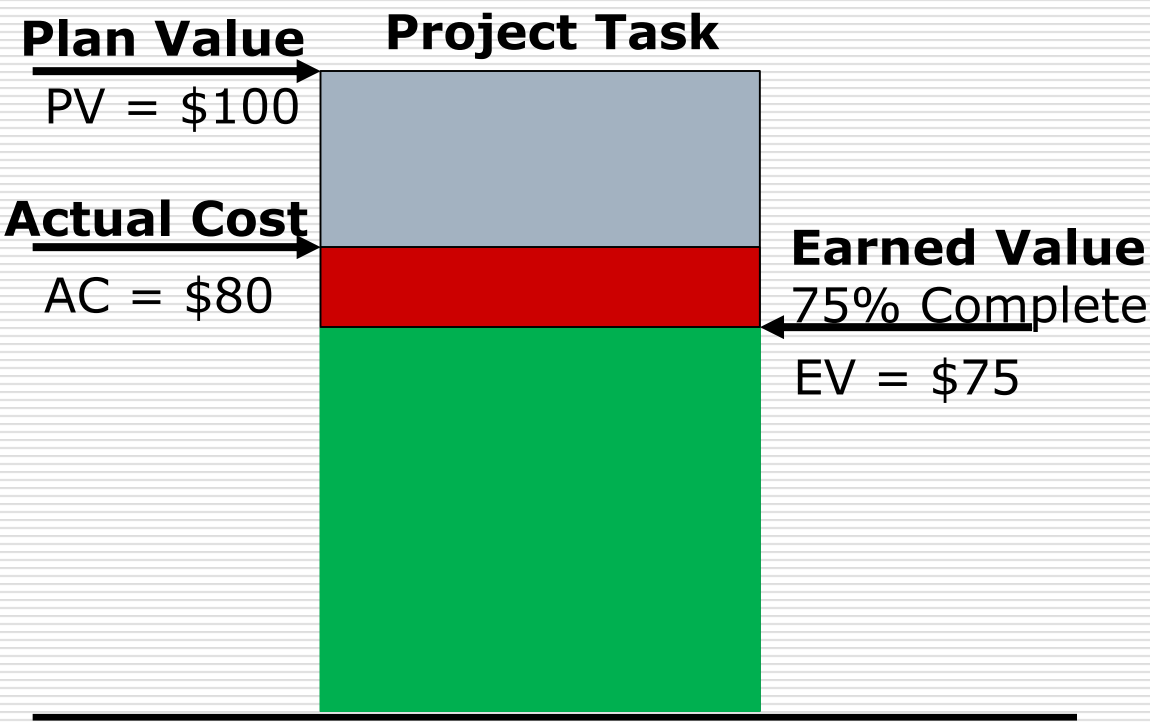
- Three key terms
  - **Earned Value (EV)** is
    "The value of work performed expressed in terms of the approved budget assigned to that work completed"
  - **Actual Cost (AC)** is
    "Total costs actually incurred and recorded in accomplishing work performed…"
  - **Planned Value (PV)** is
    "The authorized budget assigned to the scheduled work to be accomplished…"

Project Management Institute. A Guide to the Project Management Body of Knowledge. 5th edition, 4th edition, 3rd edition, 2000 edition . Newton Square, Pennsylvania. USA

Definitions are taken from the Glossary of the Project Management Institute, *A Guide to the Project Management Body of Knowledge, (PMBOK® Guide)* – Fifth Edition, Project Management Institute, Inc., 2013

Literature Review:
What is EVM?

Measure performance and progress



CV = EV – AC

CV = - $5

CPI = EV / AC

CPI = 0.9375

SV = EV – PV

SV = - $25

SPI = EV / PV

SPI = 0.75

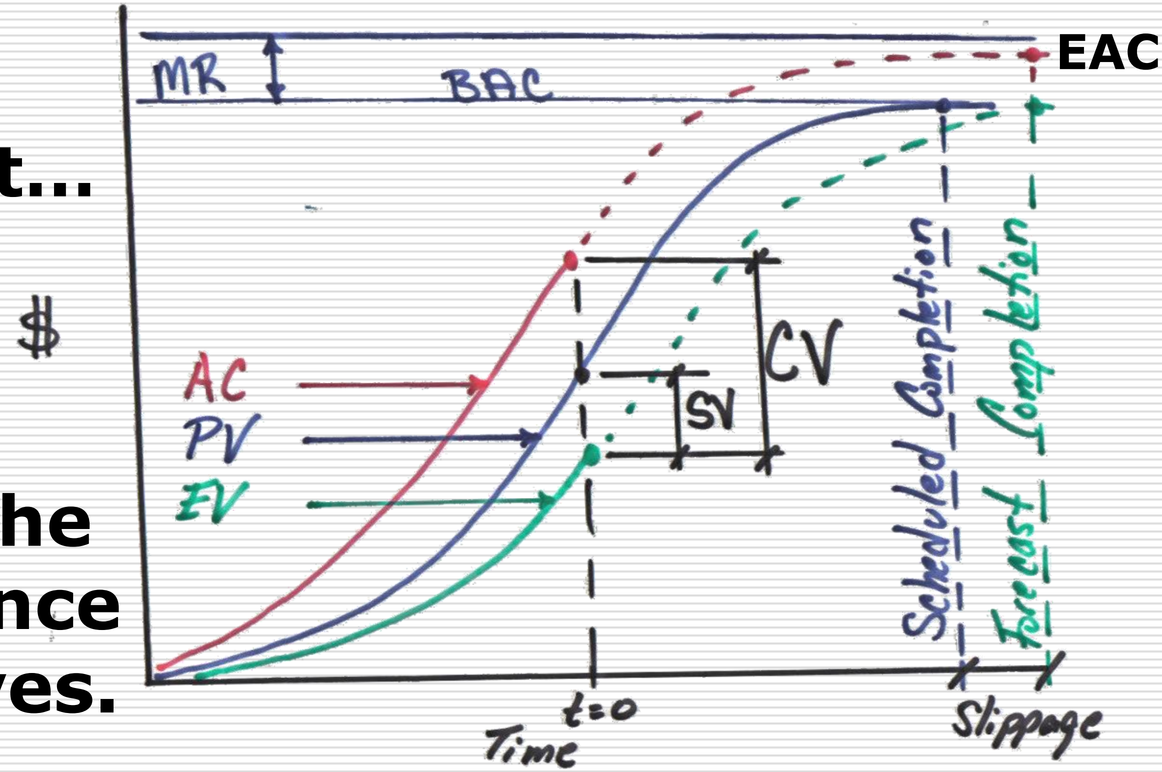
Definitions are taken from the Glossary of the Project Management Institute, *A Guide to the Project Management Body of Knowledge, (PMBOK® Guide)* – Fifth Edition, Project Management Institute, Inc., 2013

Literature Review:
What is EVM?

- **Forecast depends upon CPI Stability:**
  - EAC = AC + (BAC- EV)/CPI = BAC/CPI

S-Curves are whole-project... all tasks in aggregate.

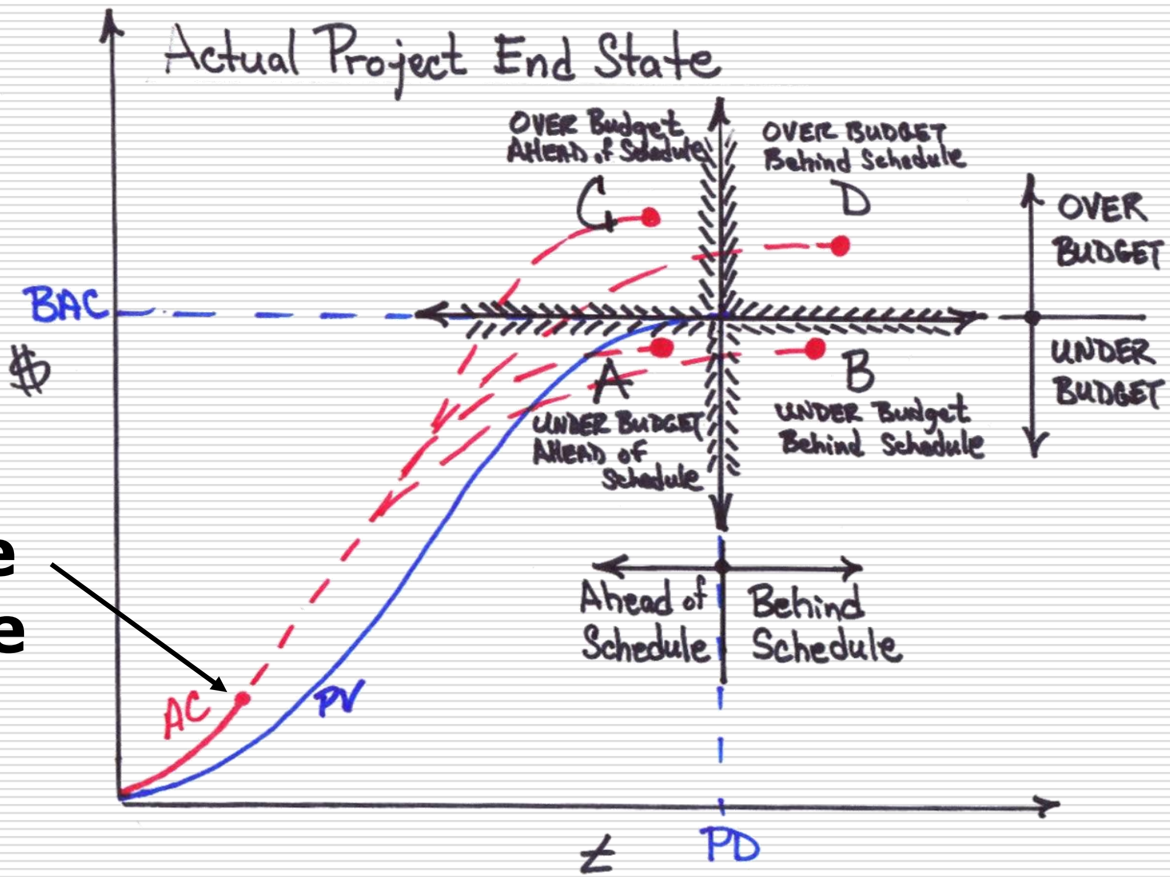
CV & SV are the vertical distance between curves.



Definitions are taken from the Glossary of the Project Management Institute, *A Guide to the Project Management Body of Knowledge, (PMBOK® Guide)* – Fifth Edition, Project Management Institute, Inc., 2013

Literature Review:
What is EVM?

4. Determine Project Performance



Where will we end up?

Where we are now.

Literature Review:
CPI Stability

CPI Stability Rule

- CPI stabilizes by the time a project is 20% complete.
- Stability test for CPI
  - **CPI_{final} does not change by more than +/- .10 from $CPI_{20\%}$**
  - **CPI does not change by more than +/- 10% from 20% complete through project completion**

Henderson, Kym, O. Zwikael. "Does Project Performance Stability Exist ...a re-examination of CPI and evaluation of SPI(t) stability," *CrossTalk*, April 2008

Literature Review:
CPI Stability

CPI Stability Rule

- **Christensen and Payne (1992)**
  First empirical confirmation of CPI stability rule based upon 26 projects from USAF Systems Command Aeronautical Systems Division.
- **Fleming and Koppelmann (1999)**
  Generalized CPI stability rule to all projects
- **Christensen and Templin (2002)**
  Summarized findings…some projects improve
- **Adopted into EVM Standard (2004)**

CPI is stable!

Literature Review:
CPI Stability

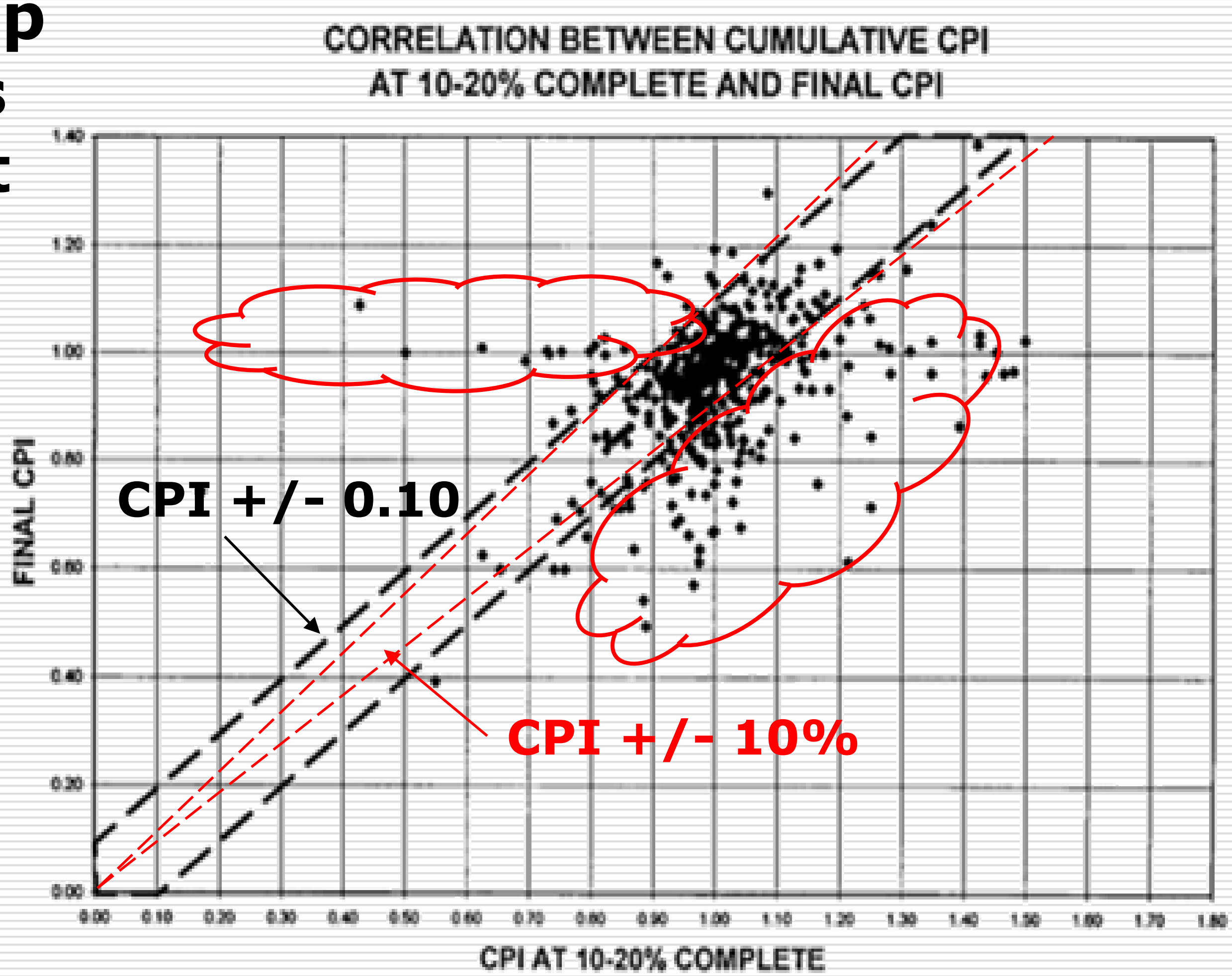
CPI Stability ~~Rule~~ Questions

- **Michael Popp (1995)**
  Plotted CPI_{20} vs CPI_{final} NAVAIR internal unclassified report.
- **David Christensen (1999 & 2002)**
  Using data from Michael Popp research, found that CPI stability could not be generalized.
- **Henderson & Zwikael (2008)**
  Analyzed 45 projects from 3 countries…87% Stable @20%
  Some projects did not stabilize until 70-80%.
- **Czarnigowska, Jaskowski & Biruk (2011)**
  Whole-project measures can be misleading"…poor performance may be compensated by good performance."

Is CPI stable?

Literature Review:
CPI Stability

Michael Popp chart shows a significant number of projects presenting unstable CPI's



Henderson, Kym, O. Zwikael. "Does Project Performance Stability Exist …a re-examination of CPI and evaluation of SPI(t) stability," *CrossTalk*, April 2008

Research: Proposed Solution

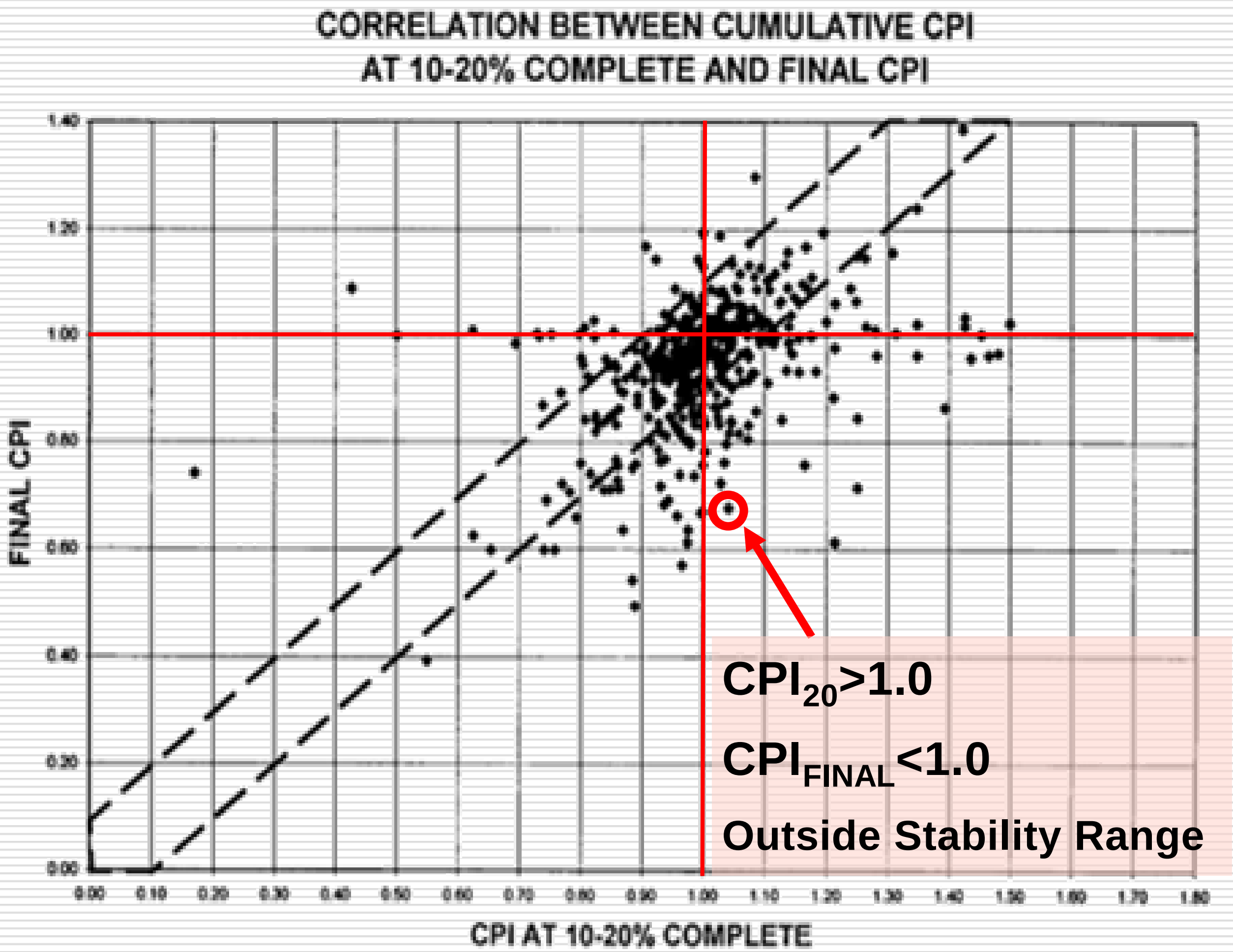
Working Hypothesis:

- **CPI is stable at the performance unit level.**
  - Performance Unit is a collection of resources working on the same task(s).
- **Each performance unit** within a project may have **different** cost and schedule **performance**, each requiring a unique management response.
- **Hidden Performance** - Good performing units hide poor performing units at the whole-project level.
- **We can develop alternative whole-project CPI formulae** based upon each unit's performance…better stability compliance.

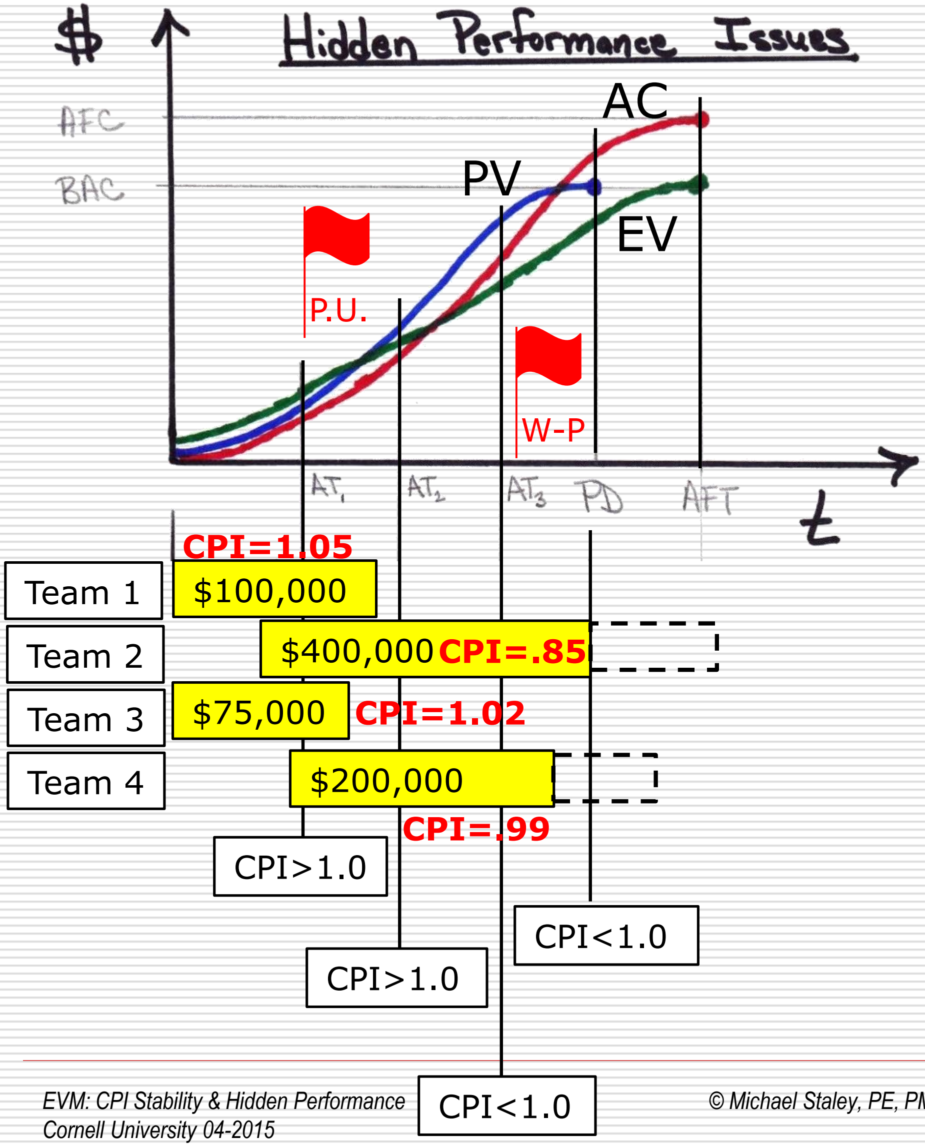
Research: Proposed Solution

Here we see a project that presents a CPI greater than 1.0 at 20% complete. However by the time the project finishes, the CPI has eroded to less than 1.0.

Henderson, Kym, O. Zwikael. "Does Project Performance Stability Exist …a re-examination of CPI and evaluation of SPI(t) stability," *CrossTalk*, April 2008



Research:
Proposed Solution



How can Stable Performance Unit CPI's present an unstable whole-project CPI?

Answer: The whole-project CPI is a weighted average…

Performance Unit CPI's can identify hidden performance issues in time to correct them!

Research:
Case Study

Mini Case Study A2D: You are the project manager of an A/E building design project. Task 1 is completed by the same team as Task 4.

Simple Baselines

WBS	ES	EF	Budget	1	2	3	4
Task 1	1	2	$100,000	35	65		
Task 2	2	3	$125,000		75	50	
Task 3	2	4	$145,000		20	60	65
Task 4	3	4	$75,000			25	50
Period PV				35	160	135	115
Cum PV				35	195	330	445

Project Status Report end of wk 2		
Task	**Status**	**Spent**
1	Complete	$97,750
2	65% Complete	$75,750
3	10% Complete	$19,850
4	Not Started	$0

Calculate the CV, CPI, SV, and SPI for the whole project.

Then calculate the same values for each of the performance units and compare the results.

Research:
Case Study

Mini Case Study A2D					
WBS	**BAC**	**EV**	**AC**	**CPI**	**EAC**
Task 1	$100,000	$100,000	$97,750	1.0230	97,750
Task 2	$125,000	$81,250	$75,750	1.0726	116,538
Task 3	$145,000	$14,500	$19,850	0.7305	198,500
Task 4	$75,000	$0	$0	1.0230	73,313
	445,000	**195,750**	**193,350**	**1.0124**	**486,101**

The whole-project CPI is > 1.0

EAC = BAC/CPI = 445,000/1.0124 = $439,546

Task 3's poor performance is masked by the good performance of the other units.

The sum of the performance unit EAC's is $486,101.

Research:
Case Study

Alternative Whole-Project CPI Formulae

- **CPI^1 = EV/AC** (Traditional CPI)
- **$CPI^2 = \sum ((BAC_{PU}/BAC_{total})X\ CPI_{PU})$**
  - Where CPI^2 is the sum of the performance unit CPI's weighted as a proportion of relative size
- **$CPI^3 = BAC_{total} / (\sum (BAC_{PU} / CPI_{PU}))$**
  - Where CPI^3 is an estimate of final CPI instead of a cumulative to date metric

Research:
Case Study

$$CPI = EV/AC$$

$$CPI_{final} = BAC/AFC,$$

where EV➔BAC and AC➔AFC

$$\left.\begin{array}{l} CPI_{EstFinal} = BAC/EAC \\ \text{where } EAC = BAC/CPI \end{array}\right\} \text{Whole Project}$$

$$\sum_{pu=a}^{z} EAC_{PU} = \left.\sum_{pu=a}^{z} \frac{BAC_{PU}}{CPI_{PU}}\right\} \text{Performance Unit}$$

$$\therefore CPI^{3} = \frac{BAC_{Total}}{\sum_{pu=a}^{z} \frac{BAC_{PU}}{CPI_{PU}}}$$

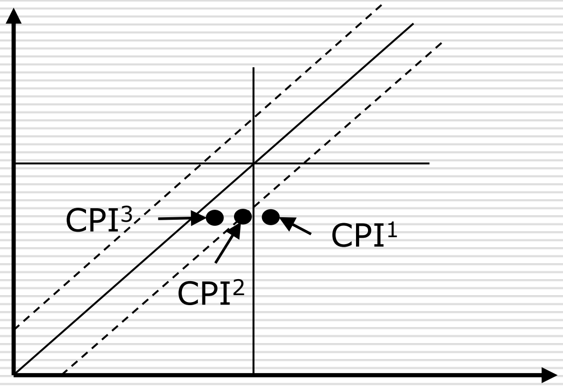
Research:
Case Study

Mini Case Study A2D					
WBS	**BAC**	**EV**	**AC**	**CPI**	**EAC**
Task 1	$100,000	$100,000	$97,750	1.0230	97,750
Task 2	$125,000	$81,250	$75,750	1.0726	116,538
Task 3	$145,000	$14,500	$19,850	0.7305	198,500
Task 4	$75,000	$0	$0	1.0230	73,313
	445,000	**195,750**	**193,350**	**1.0124**	**486,101**

$CPI^1 = 1.0124$

$CPI^2 = 0.9416$

$CPI^3 = 0.9155$



Practice:
Case Study

- **Aerospace Laboratory Case Study**
  - Multi-functional Propulsion Research Laboratory.
  - Unique environment where synergism among different advanced propulsion technologies can be exploited and used to expedite development.
  - Supports exploratory research and feasibility investigations of a wide range of high-payoff propulsion technologies.

Practice:
Case Study

- **Advanced Propulsion Research Technologies**, including
  - Beamed Energy (Laser)
  - Antimatter
  - Chemical Synthesis
  - Magnetohydrodynamics
  - Simulated Fission
  - High Power Plasma (Fusion)
  - Propulsion Physics
  - Solar Thermal

Practice:
Case Study

- **Facility Design Goals and Principles**
  - Stimulating Environment for Research
  - Building Flexibility for Changing Research
  - Sustainable Facility Design
  - Safe Laboratory Environment

Practice: Case Study

Work Breakdown Structure							SCHEDULE (Wks)		PROFESSIONAL LABOR					
Line	Level 1	Level 2	Level 3	Level 4	WBS [1]	WBS Code	Early Start	Early Finish	Project Manager	Sr. Engineer	Engineer	Tech	TOTALS Laborhours	TOTALS Dollars
									156.25	125.00	93.75	62.50		
					Construction Documents for $22,000,000 Plant	1			0.1	0.25	0.3	0.35		
					Architectural & Engineering	1.1								
					Architectural	1.1.1								
A					Schematic or Conceptual Des	1.1.1.1	1	4	80	200	240	280	800	77,500
C					Arch Design Development	1.1.1.2	5	7	150	375	450	525	1500	145,313
F					Arch 60% Construction Doc's	1.1.1.3	8	13	125	313	375	438	1250	121,094
J					Arch 90% Construction Doc's	1.1.1.4	14	17	125	313	375	438	1250	121,094
K					100% Construction Doc's	1.1.1.5	18	20	100	250	300	350	1000	96,875
					Structural, Mech, Elect, Plumb	1.1.2								
B					Engr Design Development	1.1.2.1	5	6	120	300	360	420	1200	116,250
E					Engr 60% Construction Doc's	1.1.2.2	8	10	300	750	900	1050	3000	290,625
H					Engr 90% Construction Doc's	1.1.2.3	14	16	300	750	900	1050	3000	290,625
K					100% Construction Doc's	1.1.1.5	18	20	150	375	450	525	1500	145,313
					Industrial Engineering (IE)	1.2								
					Plant Layout, Equipment, Process	1.2.1								
D					IE Design Development	1.2.1.1	5	6	75	188	225	263	750	72,656
G					IE 60% Construction Doc's	1.2.1.2	8	11	125	313	375	438	1250	121,094
I					IE 90% Construction Doc's	1.2.1.3	14	17	100	250	300	350	1000	96,875
K					100% Construction Doc's	1.1.1.5	18	20	75	188	225	263	750	72,656
									1825	4563	5475	6388	18250	
									285156	570313	513281	399219		1,767,969

Practice:
Case Study

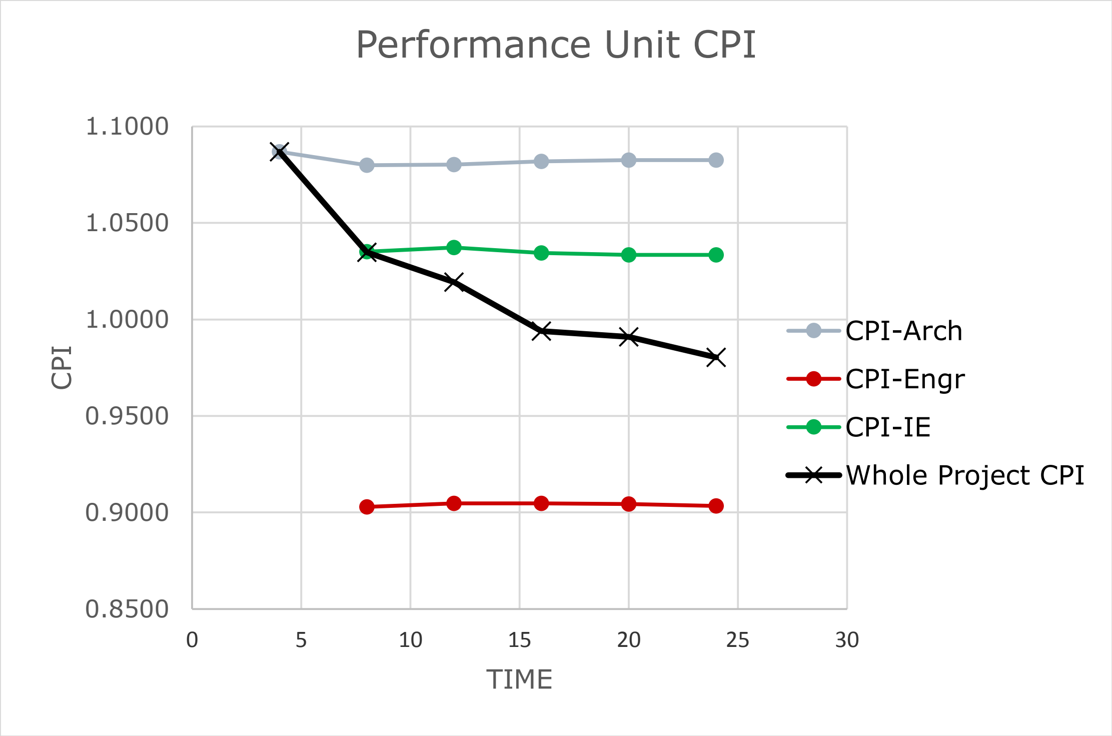
Aerospace Laboratory Case Study

	Whole-Project CPI			Performance Unit CPI		
Wk	CPI	CPI 2	CPI 3	CPI A	CPI E	CPI IE
4	1.0870			1.0870		
8	1.0347	0.9863	0.9797	1.0799	0.9029	1.0351
12	1.0193	0.9877	0.9811	1.0802	0.9047	1.0373
16	0.9940	0.9877	0.9811	1.0820	0.9048	1.0344
20	0.9909	0.9876	0.9809	1.0826	0.9044	1.0335
24	0.9804	0.9871	0.9804	1.0826	0.9034	1.0335

1 2

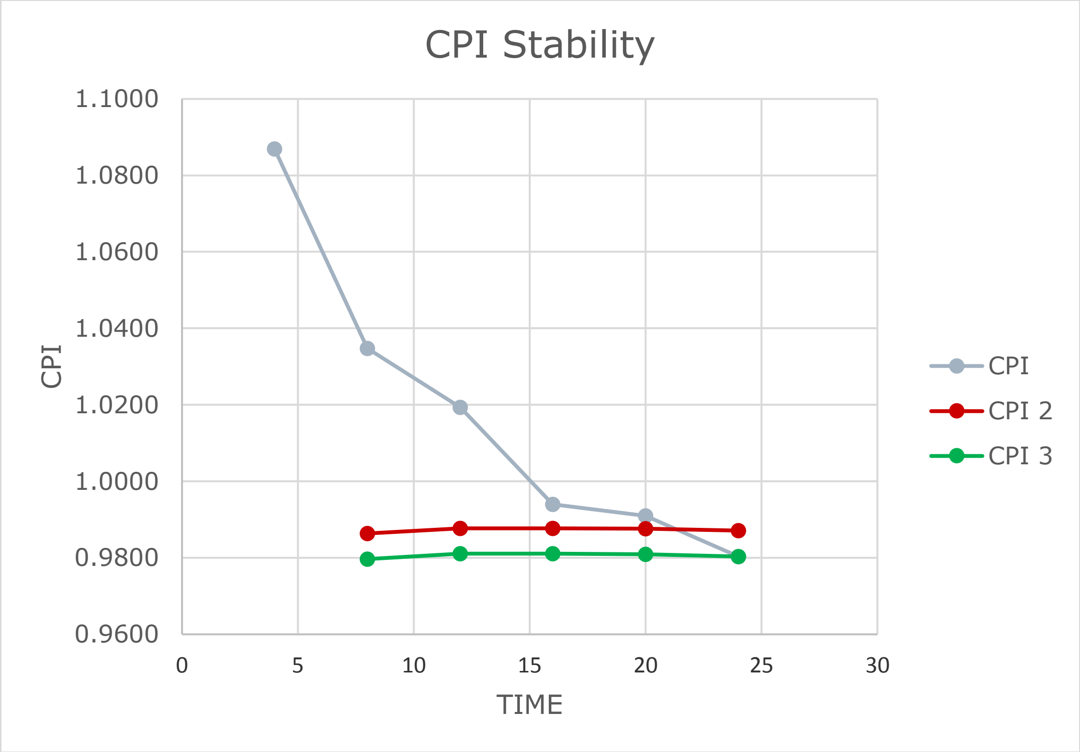
1. **CPI[1] does not drop below 1.0 until month 4 of 5. CPI[2] and CPI[3] reveals poor performance in month 2.**
2. **Performance Unit analysis reveals which unit is performing poorly.**

Practice:
Case Study



- ✓ **Performance Unit CPI's are stable**
- ✓ **Each performance unit has a different CPI**
- ✓ **Good performance is hiding poor performance**

Practice:
Identify Hidden Performance



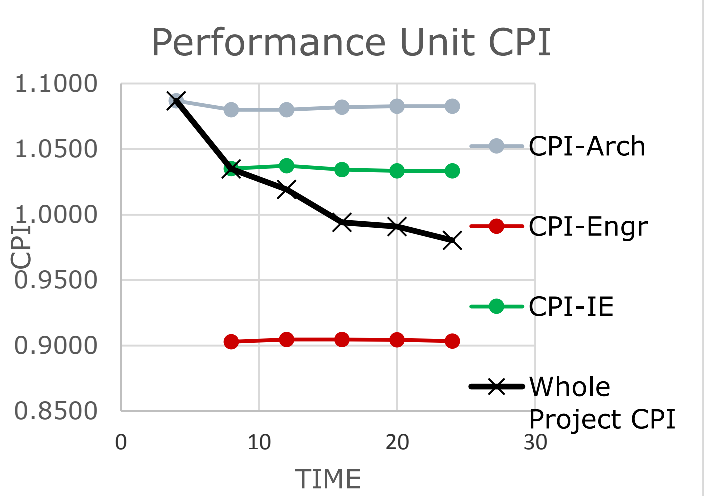
Alternate Whole-Project CPI's are stable

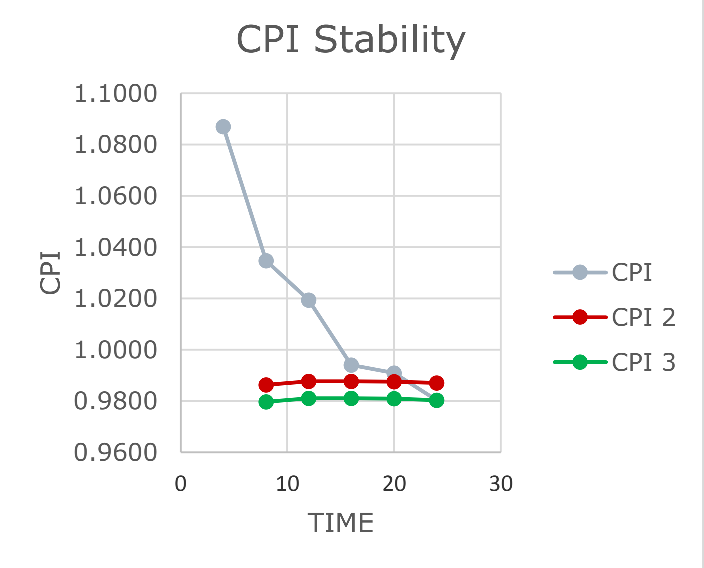
CPI^3 produces best fit

Conclusion:

Working Hypothesis:

- ✓ **CPI is stable at the performance unit level.**
  - Performance Unit is a collection of resources working on the same task(s).
- ✓ **Each performance unit** within a project may have **different** cost and schedule **performance**, each requiring a unique management response.
- ✓ **Hidden Performance** - Good performing units hide poor performing units at the whole-project level.
- ✓ **We can develop alternative whole-project CPI formulae** based upon each unit's performance…better stability compliance.

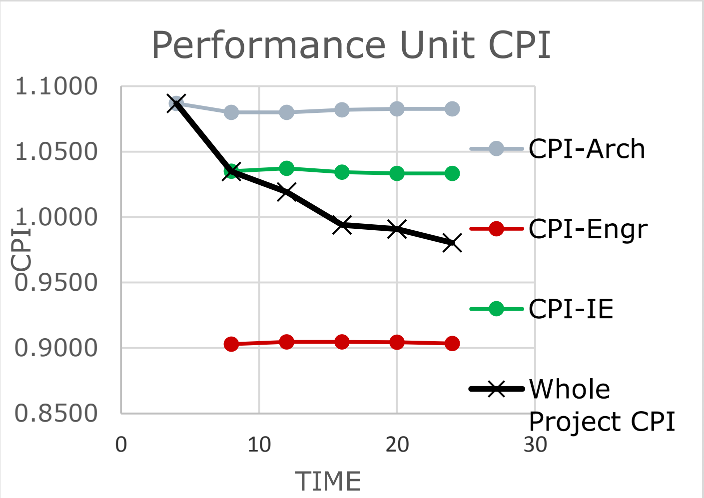


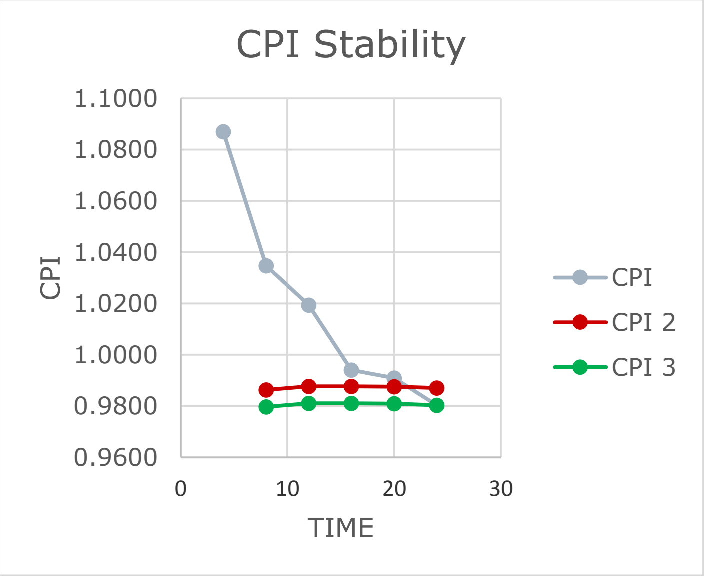


Conclusion:

Take Aways:

- ✓ **Use Limit States to identify project performance issues and management responses**
- ✓ **Each performance unit** within a project may have **different** cost and schedule **performance**, each requiring a unique management response.
- ✓ **Hidden Performance** - Good performing units hide poor performing units at the whole-project level.
- ✓ **Drill down to the performance unit analysis level to identify hidden performance issues**.





Bibliography

Christensen, DS, Antolini, RC, McKinney, JW. A Review of Estimate at Completion Research. Journal of Cost Analysis and Management. Spring 1995 P. 41-65.

Christensen, DS, Templin, C. EAC Evaluation Methods: Do They Still Work? Acquisition Review Quarterly. Spring 2002. P 105-116.

Czarnigowska, Agata, Jaskowski, Piortr, Biruk, Slawomir. (2011) Project Performance Reporting and Prediction: Extensioins of Earned Value Management. International Journal of Business and Management Studies. Vol 3 No. 1 2011

Fleming, Quentin and Koppelman, Joel. (1994) The Essence and Evolution of Earned Value. AACE International Transactions.

Henderson, Kym, O. Zwikael. "Does Project Performance Stability Exist …a re-examination of CPI and evaluation of SPI(t) stability," *CrossTalk*, April 2008

Kwak, Young Hoon and Anbari, Frank. History, practices and future of earned value management in government: Perspectives from NASA. Project Management Journal Volume 43, Issue 1 Pg 77-90 Feb 2012.

Lipke, Walt. Further Study of the Normality of CPI and SPI(t). The Measurable News. 2012 Issue 2

Lipke, Walt. Statistical Process Control of Project Performance.   The Journal of Defense Software Engineering. March 2002

Lipke, Walt and Vaughn, Jeff. Statistical Process Control Meets Earned Value. The Journal of Defense Software Engineering. June 2000

Project Management Institute. A Guide to the Project Management Body of Knowledge. 5th edition, 4th edition, 3rd edition, 2000 edition . Newton Square, Pennsylvania. USA

Project Management Institute. Practice Standard for Earned Value Management. Project Management Institute 2004

Song, Lingguang (April 2010) Earned Value Management: A Global and Cross-industry Perspective on Current EVM Practice", ISBN: 1935589067.